# JOURNAL OF SCIENCE

## PART B: ART, HUMANITIES, DESIGN AND PLANNING

**Year** | Yıl : 2025 **Volume** | Cilt : 13 **Issue** | Sayı : 2

Published Date: 30 / 06 / 2025

e-ISSN: 2147-9534

GAZİ UNIVERSITY FACULTY OF ARCHITECTURE
GAZİ ÜNİVERSİTESİ MİMARLIK FAKÜLTESİ

e-ISSN: 2147-9534

Gazi University

# Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

**Year** I Yıl : 2025 **Volume** I Cilt : 13 **Issue** I Sayı : 2

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Journal of Science
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e-ISSN: 2147-9534

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# User Experience and Design Performance in Turkish Basketball Arenas: A Qualitative Post-Occupancy Evaluation (POE) Approach

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**Article Info**

*Received: 17/03/2025*
*Accepted: 27/03/2025*

**Keywords**

*User Experience,*
*Design Performance,*
*Basketball Arenas,*
*Post-Occupancy Evaluation.*

**Abstract**

Despite the global popularity of large-scale basketball arenas, research on their design performance and user experience, particularly in regional contexts, remains limited. This qualitative Post-Occupancy Evaluation (POE) study explores the interplay between design, user experience, and facility management practices in three prominent Turkish basketball arenas. Utilizing on-site observations, document analysis, and interviews with facility managers, the research uncovers how design choices impact user experiences and operational efficiency. The findings reveal recurring challenges related to HVAC systems, natural ventilation, multi-purpose adaptability, and wayfinding. Additionally, the study highlights the influence of management structures on arena performance and the critical role of incorporating user feedback. By integrating facility managers' perspectives, this research offers valuable lessons and recommendations for creating future arenas that enhance both spectator satisfaction and operational efficiency.

## 1. INTRODUCTION

Large-scale sports arenas are increasingly prominent features of contemporary urban landscapes, serving as hubs for sporting events, cultural gatherings, and tourism [1]. Their design and management pose unique challenges for architects and facility managers, who must balance complex functional requirements with creating engaging and comfortable user experiences while ensuring long-term sustainability [2]. A systematic approach to evaluating building performance is essential to foster a continuous cycle of learning and refinement in the design process. This is especially crucial in arenas where user satisfaction is paramount and directly influenced by design choices impacting comfort, accessibility, safety, and overall enjoyment.

Post-Occupancy Evaluation (POE), a systematic method for assessing building performance in use, has become a vital tool for identifying successes and shortcomings in design and informing future improvements [3]. POE aims not only to document performance but also to contribute to the knowledge base of building performance, identifying gaps between intended outcomes and users' actual needs and expectations [4]. The seminal work of Preiser, Rabinowitz, and White [4] established a framework for understanding the complex building-occupant relationship, which has been further explored through diverse methodologies, including quantitative surveys, qualitative interviews, observational studies, and environmental monitoring [6]. These methods provide valuable insights into building performance's technical, functional, and behavioural aspects, leading to improved design, construction, and operation. Building performance evaluation pioneers Leaman and Bordass stress the importance of a holistic approach that integrates design and management throughout the building lifecycle [7, 8, 9].

Despite its recognized value, POE remains underutilized in the context of sports facilities, with research predominantly focusing on more common building types [10]. This limited attention restricts opportunities to learn from past projects and hinders the development of more effective, user-centered,

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and sustainable arenas [11]. Building upon a previous quantitative POE study of Turkish basketball arenas [12], which highlighted the need for standardized assessments of experiential quantitative performance, this paper focuses on three prominent large-scale basketball arenas in Turkey—Ankara Sports Hall, Ülker Sports and Event Hall, and Sinan Erdem Sports Hall—to investigate the interplay between design, user experience, and facility management practices.

Large-scale basketball arenas pose unique challenges that warrant a focused POE approach. These venues cater to diverse user groups with distinct needs and expectations [13], often hosting a variety of events beyond basketball, requiring adaptable and flexible design and management. User satisfaction is intertwined not only with design but also with effective facility management practices that contribute to a positive experience [7]. Additionally, the environmental impact of these large-scale venues necessitates sustainable design and management practices to mitigate negative consequences on energy consumption, resource use, and local biodiversity [14].

This study employs a qualitative POE approach, utilizing on-site observations, document analysis, and semi-structured interviews with facility managers. The collected data will be analysed using thematic analysis and coding to reveal key themes, patterns, and relationships between design choices, user experience, and facility management practices. By uncovering both successes and shortcomings in existing arenas, this research aims to provide valuable insights and actionable recommendations for architects, facility managers, and policymakers involved in creating future sports venues that enhance spectator experience and operational efficiency.

## 2. POST-OCCUPANCY EVALUATION OF ARENA DESIGN AND USER EXPERIENCE

Post-Occupancy Evaluation (POE) is a systematic process of assessing building performance in use, involving the collection of occupant and stakeholder feedback, and the analysis of data to identify areas for improvement [3]. Since emerging in the 1960s, POE has evolved significantly, with an increasing emphasis on standardized methodologies, robust data collection techniques, and integrating user feedback into the design process [15]. This reflects the growing recognition that buildings are complex systems whose success depends not only on technical aspects but also on meeting user needs and expectations [16].

POE methodologies can be broadly categorized as quantitative, qualitative, and mixed methods:

- Quantitative POE focuses on gathering numerical data, often using standardized occupant surveys, building performance measurements (e.g., temperature, lighting, acoustics), and statistical analysis. This approach excels in providing objective performance measures and enabling comparisons between buildings or design options [16, 17].
- Qualitative POE emphasizes in-depth understanding of user experiences through methods like semi-structured interviews, observations, focus groups, and thematic analysis. This approach provides rich insights into occupant perceptions, preferences, and behaviors.
- Mixed-methods POE combines quantitative and qualitative methods for a more comprehensive and nuanced evaluation, integrating diverse data sources for a holistic understanding of building performance and user experience.

The choice of POE methodology depends on research questions, context, resources, and desired detail. POE plays a crucial role in sustainable building design and operation [15, 16]. It identifies performance gaps, highlighting discrepancies between design intent and actual performance informs design decisions, enabling more informed choices prioritizing comfort, functionality, and sustainability [19]. Finally, POE helps optimize building operations, leading to greater energy efficiency, reduced maintenance costs, and enhanced well-being [20]. Despite its value, POE remains underutilized in sports facilities [10], limiting opportunities to learn from past projects and hindering the development of more effective, user-centered, and sustainable arenas [11].

Evaluating building performance in sports facilities requires a comprehensive approach that considers user satisfaction, thermal comfort, ventilation and air quality, acoustics, and energy efficiency. User satisfaction is paramount in arenas, encompassing comfort, enjoyment of the event, ease of circulation, quality of amenities, and the overall atmosphere. Maintaining comfortable temperatures is also essential, given their large size and dynamic occupancy levels [21, 22]. Adequate ventilation and air quality are crucial for spectator health, particularly during crowded events [23].

Attending a basketball game is a multi-sensory experience encompassing the thrill of competition, social atmosphere, and comfort of the venue [24]. Spectator experience is shaped by comfort and amenities, atmosphere and excitement, connection to the game, social interaction, and safety and security. Comfortable seating, adequate legroom, good sightlines, and convenient access to amenities are essential and contribute to user satisfaction like other building types [18]. The arena's design and operation should foster excitement through dynamic lighting, high-quality sound, engaging displays, and well-designed social spaces [25]. Spectators crave a strong connection to the game, influenced by seating proximity, sightlines, and acoustics. Basketball games are social events, and arenas should encourage interaction through design. Finally, a sense of safety and security is paramount, achieved through clear exits, visible security measures, and well-maintained facilities.

POE provides a valuable tool for evaluating spectator experience in basketball arenas, capturing both quantitative and qualitative aspects of user satisfaction, informing design decisions for new arenas and improving the management and operation of existing venues.

## 3. METHOD

**Research Design and Qualitative POE Approach:** Despite a growing body of literature on sports venue design and management, there remains a significant gap in understanding the specific performance of large-scale basketball arenas, particularly regarding user experience in diverse regional contexts. This study addresses this gap by employing a focused qualitative POE approach to investigate the design and utilization of three prominent basketball arenas in Turkey. The study seeks to unravel the complex interplay between design choices, user experience, and facility management practices, ultimately aiming to inform the development of more effective and user-centered arenas in the future.

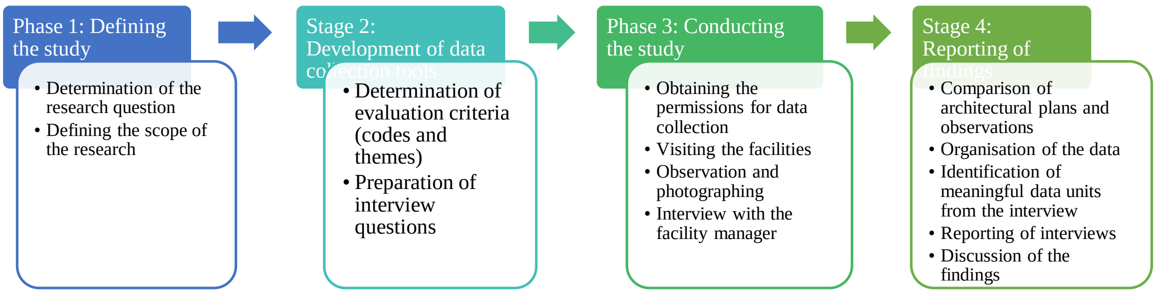


***Figure 1.*** *Research Methodology: An Overview of the Study's Key Stages*

**Selection of Case Studies:** To ensure a comprehensive analysis of the diverse factors influencing large-scale basketball arena design, use, and management in Turkey, three prominent arenas were purposefully selected as case studies: Ankara Sports Hall, Ülker Sports and Event Hall, and Sinan Erdem Sports Hall. These arenas represent a spectrum of design approaches, user demographics, and operational contexts, providing a rich foundation for understanding the complexities of this building typology within the Turkish context. Drawing on the principles of user-centered design commonly employed in product and service development, this study adapted the "Voice of Customer" technique to the architectural realm. This approach involved gathering insights from multiple data sources, including on-site observations, document analysis, and in-depth interviews, with a particular emphasis on capturing the expert opinions and experiences of facility managers, who serve as key stakeholders in shaping the user experience within these venues.

***Table 1.*** *Overview of Case Study Arenas: Key Characteristics and Information*

| Ülker Sports and Event Hall | Sinan Erdem Sports Hall | Ankara Sports Hall |
|---|---|---|
|  |  |  |
| Year of construction: 2008<br>Location: Istanbul, Turkey<br>Capacity: 16500 persons<br>Architect: Omerler Architecture<br>Project payer: Fenerbahçe SK<br>Purposes of use: Basic sports activities such as basketball, volleyball, ice hockey, boxing, concerts and congresses. | Year of constructio:n 2010<br>Location: Istanbul, Turkey<br>Capacity: 15000 people<br>Architect: Nuhoglu Construction<br>Project taxpayer: Istanbul Metropolitan Municipality<br>Purposes of use: Basic sports activities such as basketball, volleyball, ice hockey, boxing, concerts and congresses. | Year of construction: 2010<br>Location: Ankara, Turkey<br>Capacity: 10000 persons<br>Architect: Yazgan Design Architecture<br>Project payer: Ministry of Youth and Sports<br>Purposes of use: Basic sports activities such as basketball, volleyball, ice hockey, boxing, concerts and congresses. |

**Data Collection and Analysis:** A multi-method approach, incorporating on-site observations, document analysis, and semi-structured interviews with facility managers, was employed to gain a holistic understanding of the interplay between design, user experience, and facility management in the arenas. This triangulation of data sources enhanced the validity and reliability of the findings.

Direct observations during event and non-events provided a user-centered perspective on how the physical layout supported user flow and accessibility, while also revealing user behaviours and potential issues related to wayfinding, comfort, safety, and satisfaction [26]. Document analysis, encompassing architectural plans, facility reports, operational manuals, and maintenance records, offered a deeper understanding of the design intent, usage patterns, operational practices, and potential recurring problems [27]. Lastly, semi-structured interviews with facility managers, as key stakeholders in arena management [33], elicited their insights on design effectiveness, management challenges, user satisfaction, and recommendations for improvement. These interviews highlighted the factors shaping arena performance from a practical, operational perspective.

To extract meaningful insights from this data, a rigorous analysis process was undertaken. The collected qualitative data were systematically analysed using thematic analysis, a widely used method for identifying patterns and themes within qualitative data [28]. This involved coding the data, grouping similar codes into overarching themes, and analysing the relationships between those themes to understand the complex interplay of factors shaping arena performance. The data were interpreted using a framework adapted from the literature on building performance evaluation, focusing on technical, functional, and behavioural aspects. This comprehensive approach provided a rich understanding of the successes and challenges experienced within each arena. By comparing the findings across the three venues, the study gleaned valuable insights regarding best practices in design, management, and community integration for large-scale basketball facilities.

## 4. FINDINGS

This section presents the key findings from the qualitative POE of the three Turkish basketball arenas, organized by case study and analysed within the framework of technical, functional, and behavioural aspects.

### 4.1. Ülker Sports and Event Hall

Ülker Sports and Event Hall, designed by Ömerler Architecture, has been operational since 2012, boasting a capacity of 12,687 spectators. Located in Istanbul's Ataşehir district, the arena serves as the home court for Fenerbahçe Basketball Club, also hosting concerts, corporate gatherings, and theatrical performances. The ground floor is strategically designed to facilitate efficient and controlled circulation for diverse user groups. Separate entrances for press, teams, trucks, FIBA representatives, VIP guests, and spectators effectively segregate traffic flow, minimizing congestion and enhancing security. This separation is maintained through designated corridors and circulation paths, allowing different user groups to navigate the facility efficiently.

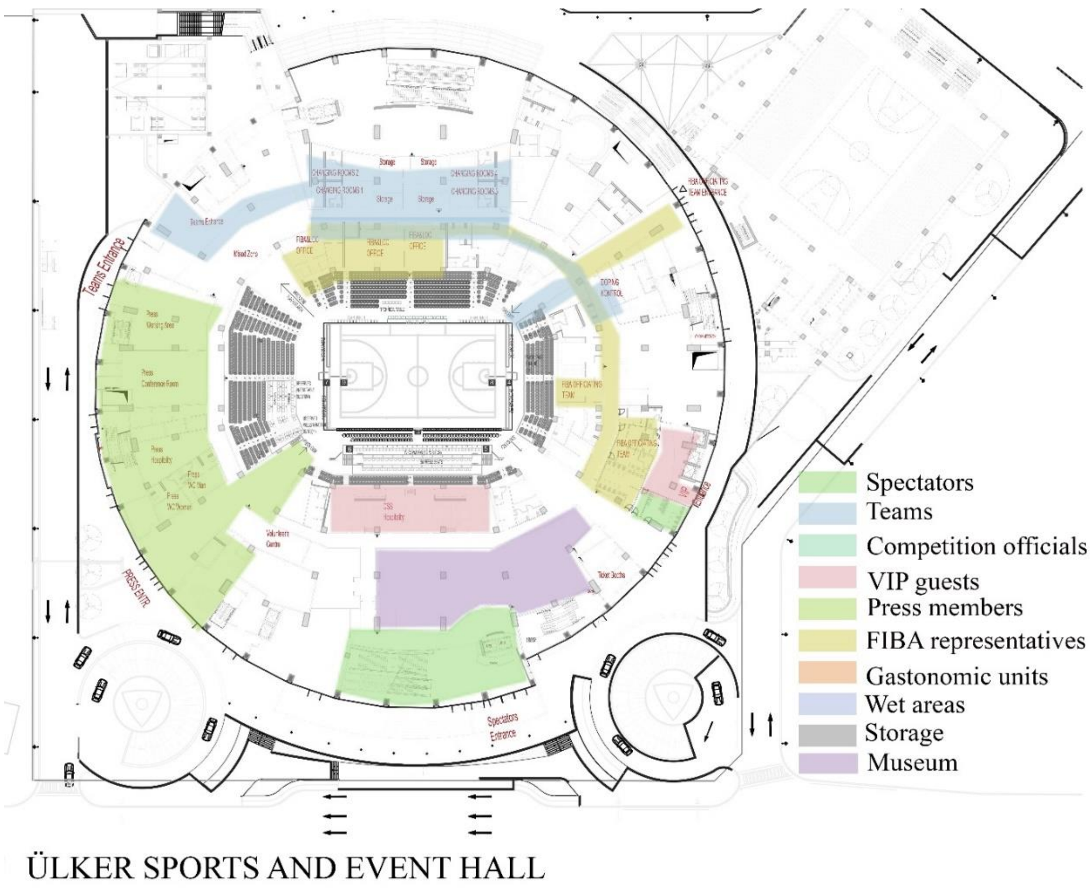


***Figure 2.*** *Spatial Organization of Ülker Sports and Event Hall (+0.00 Level): Highlighting User-Specific Zones*

Spectators enter a spacious, well-lit foyer leading directly to grand staircases ascending to the upper seating levels, promoting a clear and intuitive path that minimizes confusion and fosters a sense of anticipation. Meanwhile, press members, teams, and VIPs are guided along separate corridors to their designated areas, each equipped with specific amenities and workspaces. This spatial segregation enhances security and privacy, promoting a more streamlined flow for all users.

The Fenerbahçe Basketball Club Museum on the ground floor adds another layer of engagement for fans and visitors. Situated near the spectator entrance but distinctly separate from event traffic, its spacious layout and well-designed exhibits offer an immersive experience, allowing exploration of the club's history. The museum serves as an independent attraction, even during non-event periods, solidifying the arena's role as a cultural hub

The ground floor's design demonstrably prioritizes clarity, efficiency, and comfort, contributing to a positive user experience. Separate entrances, designated corridors, wide spaces, strategically placed elevators, and accessible restrooms minimize congestion and promote inclusivity. Prominent signage, clear wayfinding graphics, and strategic lighting further enhance intuitive navigation, while convenient access to amenities like concessions, restrooms, and the museum adds to the overall enjoyment of a visit. By carefully considering the diverse needs of user groups, Ülker Sports and Event Hall achieves a balance between functionality, efficiency, and user experience.

From a technical perspective, Ülker Sports and Event Hall exhibits a mix of strengths and areas needing improvement. While the electrical, lighting, and furnishing systems are generally up-to-date, challenges related to thermal comfort and natural ventilation persist. Maintaining consistent temperatures within the seating bowl, particularly during high occupancy, proves difficult, with spectators reporting discomfort from overheating in summer and underheating in winter. This suggests potential shortcomings in the HVAC system's capacity or distribution efficiency, echoing findings from other studies on the complexities of thermal comfort in large-scale venues with fluctuating occupancy [29]. Furthermore, the lack of natural ventilation in the main hall and offices raises concerns about indoor air quality, especially during crowded events, potentially impacting user well-being.

Observations also revealed inconsistent lighting levels in certain areas, particularly lower-than-recommended illumination in concourses, potentially impacting pedestrian safety and comfort [30], the reliance on traditional metal halide lamps for court lighting contributes to high energy consumption, presenting an opportunity for retrofitting with more efficient LED systems [31]. The absence of visible renewable energy technologies further limits the arena's sustainability profile.

***Figure 3.*** *Interior View of Ülker Sports and Event Hall: The Main Court and Seating Bowl*

Functionally, the arena is effectively utilized for various events, with basketball competitions comprising the majority of its use. The inclusion of sponsor areas and concessions contributes to revenue generation and enhances the spectator experience [25]. However, the integration of commercial units with external access, while providing additional income, could benefit from improved visibility and accessibility to attract customers. The well-designed museum, separate from main spectator areas, offers a valuable cultural and historical experience for fans and visitors (Figures 4, 5, and 6).


***Figure 4****. Sponsor Area within Ülker Sports and Event Hall: Integrating Branding and Spectator Amenities*

***Figure 5.*** *Commercial Units with External Access at Ülker Sports and Event Hall: Balancing Revenue Generation and User Flow*

***Figure 6.*** *Fenerbahçe Basketball Club Museum within Ülker Sports and Event Hall: Providing a Cultural and Historical Experience*

The arena showcases commendable design flexibility and adaptability, accommodating events with diverse needs and attendance levels through a variety of meeting room configurations and efficient use of space. Features like retractable seating, movable partitions, and flexible stage setups allow for diverse uses. Even dividing walls are utilized for displaying exhibitions, showcasing a sophisticated integration of art and design (Figures 7 and 8).

Ülker Sports and Event Hall demonstrates a strong commitment to intuitive and efficient circulation, contributing to a positive user experience. The facility manager reported no significant wayfinding issues, suggesting that the arena's planned design and clear signage effectively guide users throughout the facility. This positive assessment is supported by observations of smooth spectator flow during events, with minimal congestion or confusion in key areas like entrances, concourses, and staircases. Strategic placement of prominent signage featuring clear wayfinding graphics and directional arrows enhances the ease of navigation.

Distinctive architectural elements further enhance wayfinding by serving as landmarks, aiding user orientation. The central atrium, with its soaring ceiling and abundant natural light, provides a central point of reference. Similarly, the strategically placed museum acts as a visual anchor within the concourse area. Color-coded zones for different user groups further simplify navigation, allowing quick identification of designated areas. Additionally, the intuitive spatial organization, with its clear hierarchy of spaces and logical connections, minimizes disorientation and allows users to develop a mental map of the facility easily. The ability to evacuate the arena in approximately 15 minutes reinforces the effectiveness of the circulation paths and the strategic placement of exits, demonstrating a commitment to spectator safety in potential emergency situations.

While the arena does not currently utilize formal building assessment certifications, a commitment to performance evaluation is evident. Comprehensive evaluations were conducted between 2012 and 2016, suggesting a proactive approach to assessment and improvement. Although not currently ongoing, the facility actively incorporates user feedback, primarily complaints received via email or telephone, into its management practices. This responsiveness highlights a user-centered approach to arena operation and a dedication to enhancing the spectator experience. However, implementing a more systematic and ongoing POE program that incorporates diverse user feedback mechanisms and objective performance data could provide a more comprehensive understanding of the arena’s strengths and weaknesses, ultimately leading to further improvements in design and operation.

***Figure 7.*** *Installations on Dividing Walls within Ülker Sports and Event Hall: Integrating Art and Design*

***Figure 8.*** *Meeting Room and Press Area at Ülker Sports and Event Hall: Accommodating Diverse User Needs*

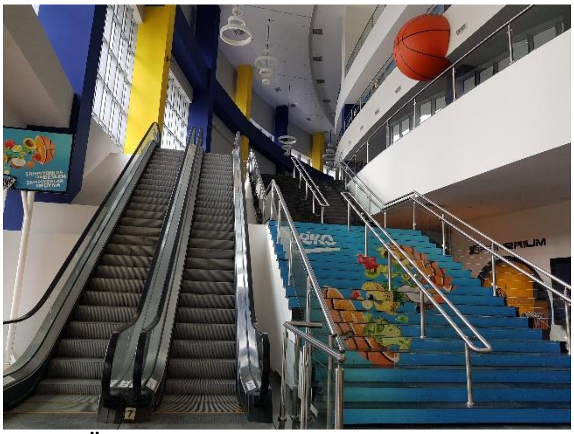

***Figure 9***. *Spectator Staircase at Ülker Sports and Event Hall: Assessing Circulation and Wayfinding Ankara Sports Hall*

### 4.2. Ankara Sports Hall

Ankara Sports Hall, completed in 2010 and operated by the Turkish Basketball Federation, has a capacity of 10,000 spectators. This multipurpose venue hosts diverse events, including basketball, volleyball, ice hockey, boxing, concerts, and congresses, with a unique design that allows for transformation into an ice hockey rink, enhancing its adaptability. The arena employs a system of segregated entrances and circulation routes for different user groups, similar to Ülker Sports and Event Hall, aiming to optimize flow and minimize potential conflicts. Spectators enter at ground level and access the seating bowl via designated staircases, while VIPs, press members, athletes, and service vehicles are guided along separate paths. The ground floor houses the "CSS Lounge" for VIP guests, offering dedicated amenities and direct access to seating areas. The east facade is reserved for press members and FIBA officials, providing dedicated workspaces and observation points. Management offices are also situated on the ground floor, facilitating operational oversight. A designated lorry entrance ensures efficient delivery and setup for events, directly accessing the court area (Figure 10).

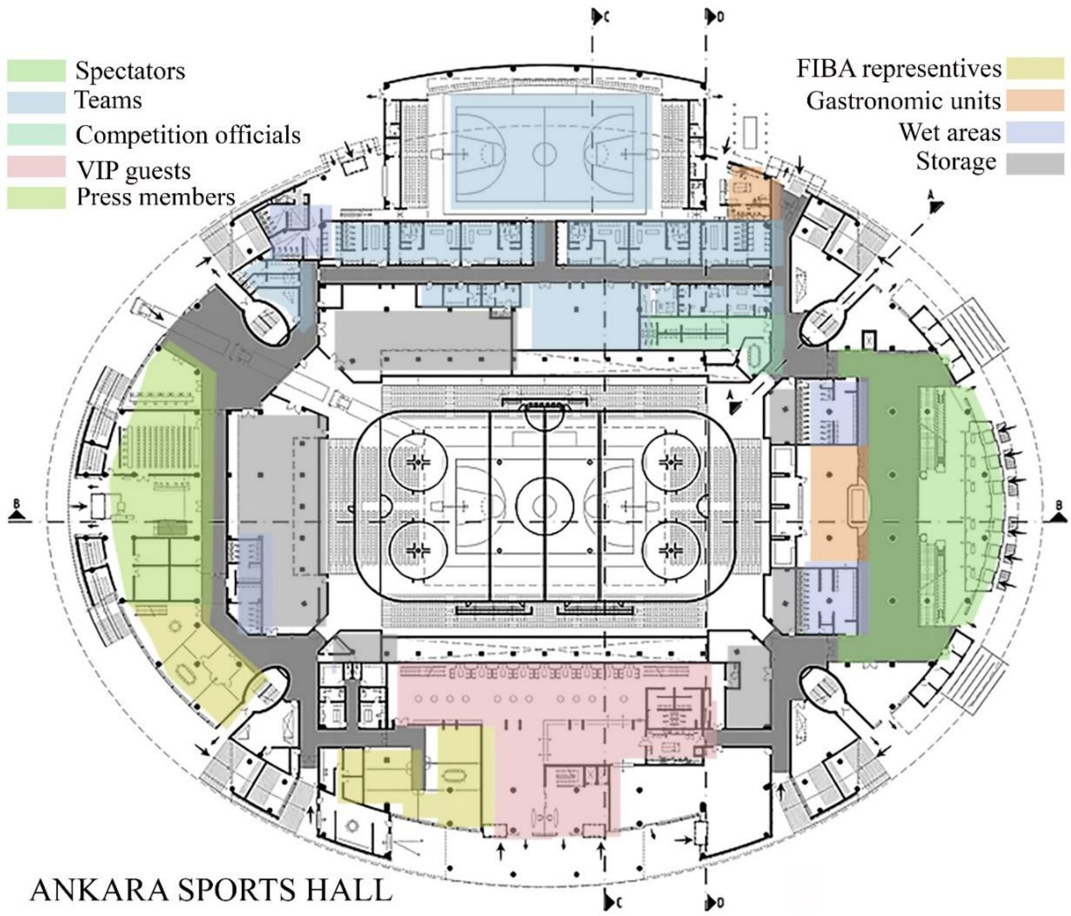


***Figure 10.*** *Spatial Organization of Ankara Sports Hall (+0.00 Level): Illustrating User-Specific Circulation Paths and Functional Zones*

Despite these design features aimed at optimizing user flow and functionality, Ankara Sports Hall faces several technical, functional, and evaluation challenges. Persistent issues with thermal comfort were reported, particularly during summer and winter events, with the facility manager indicating that the HVAC systems struggle to maintain consistent temperatures within the main hall and offices, suggesting potential capacity limitations in handling fluctuating occupancy levels [23]. The lack of natural ventilation in the hall further compounds this challenge, impacting office areas where staff experience discomfort due to poor air quality and lack of fresh air, raising concerns about indoor air quality and the potential for high $CO_2$ levels during events, which could negatively impact user health and well-being [32].

The multi-purpose design necessitates different lighting levels for various events, but the existing lighting infrastructure lacks flexibility, forcing reliance on temporary lighting solutions. This approach creates logistical challenges and raises concerns about energy efficiency and cost-effectiveness. The outdated software controlling the LED lighting system further hinders optimal performance and adaptability.

Additionally, the sound system's limited coverage, concentrated in the center of the hall, results in uneven audio quality for spectators in certain areas.

While the facility manager expressed satisfaction with the furnishings' quantity and quality, he highlighted concerns about the structural integrity of the seating steps, noting their susceptibility to bending, buckling, and even collapse under heavy use during events, raising concerns about spectator safety and long-term durability. This issue emphasizes the need for more robust design or higher-quality materials to withstand frequent use and large crowds.

***Figure 11.*** *Interior View of Ankara Sports Hall: Showcasing the Main Court and Transformable Playing Surface*

Functionally, the arena effectively serves its multi-purpose role but faces challenges regarding its transformation into an ice hockey rink. The facility manager cited high maintenance costs and potential disruptions as concerns, highlighting limitations in design flexibility for accommodating evolving needs. The arena features concessions within the foyer, offering food and beverages to spectators, and ten lodges, two of which can be combined, provide amenities for VIP guests (Figures 12 and 13).


***Figure 12.*** *Food and Beverage Concessions at Ankara Sports Hall: Assessing Placement and Adaptability for Various Events*

***Figure 13.*** *Lodges at Ankara Sports Hall: Analysing Flexibility in Configuration and Usage*

Despite these challenges, Ankara Sports Hall exhibits effective circulation and wayfinding systems, with clear signage and an intuitive layout ensuring smooth spectator flow during events. The strategic door placement allows for quick evacuation, demonstrating a commitment to safety (Figure 14). However, the lack of formal building performance evaluation, including certifications and user surveys, represents a missed opportunity to learn from user experiences, identify areas for improvement, and inform future design and management decisions.

***Figure 14.*** *Spectator Entrance and Foyer at Ankara Sports Hall: Highlighting Clarity of Circulation and Wayfinding*

### 4.3. Sinan Erdem Sports Hall

Construction of Sinan Erdem Sports Hall began in 1993 in Istanbul. The arena, consisting of a ground floor and two upper levels, accommodates 15,000 spectators and has served as a major venue for basketball competitions, concerts, party congresses, school graduations, and other indoor events. Designed to host the 2010 FIBA World Basketball Championship, the arena features extensive press areas, though these are not fully utilized for current events.

Sinan Erdem Sports Hall utilizes a hierarchical system of entrances and circulation paths, aiming to manage diverse user groups. Spectators enter at ground level and are directed to upper levels via staircases, while dedicated entrances provide access for basketball teams, VIPs, VVIPs, press, and management personnel. This system, however, exhibits significant weaknesses impacting user experience and operational efficiency. The sheer size of the building, combined with a lack of clear wayfinding cues and a complex circulation system, creates challenges for user navigation. Spectators reported difficulties in orienting themselves and locating their designated seating areas, leading to confusion and frustration, particularly during high-traffic periods. The steep staircases at the main spectator entrance further hinder accessibility and create a sense of disorientation upon entry. This complex and inefficient circulation system also impacts operational efficiency, as staff members struggle to navigate the building quickly and effectively, potentially delaying event setup, maintenance activities, and emergency response.

The east entrance leads to a dedicated zone for basketball teams, equipped with locker rooms, a first aid room, and a doping control room. A lorry entrance with direct court access facilitates efficient event logistics. The management entrance opens to administrative units, while VIPs and VVIPs are admitted through separate entrances, with VVIPs enjoying access to dedicated rest areas and VIPs utilizing the press entrance to reach the CSS Lounge. The absence of a dedicated training hall for athletes represents a notable functional limitation (Figure 15).

While the facility manager at Sinan Erdem Sports Hall reported achieving thermal comfort through the arena's HVAC systems, he acknowledged the substantial operational costs associated with maintaining these systems in such a large facility. This observation underscores the ongoing challenge of balancing user comfort with energy efficiency and cost-effectiveness in large-scale sports venues while the mechanical ventilation systems effectively provide ventilation comfort, their operational and maintenance costs are significant. The absence of natural air circulation in the lounge areas raises concerns about air quality and user comfort, potentially contributing to a stuffy and less pleasant environment. Carlucci et al.

highlight that over-reliance on mechanical ventilation in sports halls, especially if not optimally designed and maintained, can lead to increased energy consumption and inadequate air quality [32]. Occasional lighting malfunctions resulting in reduced illuminance levels suggest potential issues with the lighting system's reliability or maintenance practices. Ensuring consistent and adequate lighting is critical for user safety, visual comfort, and optimal task performance in sports venues.

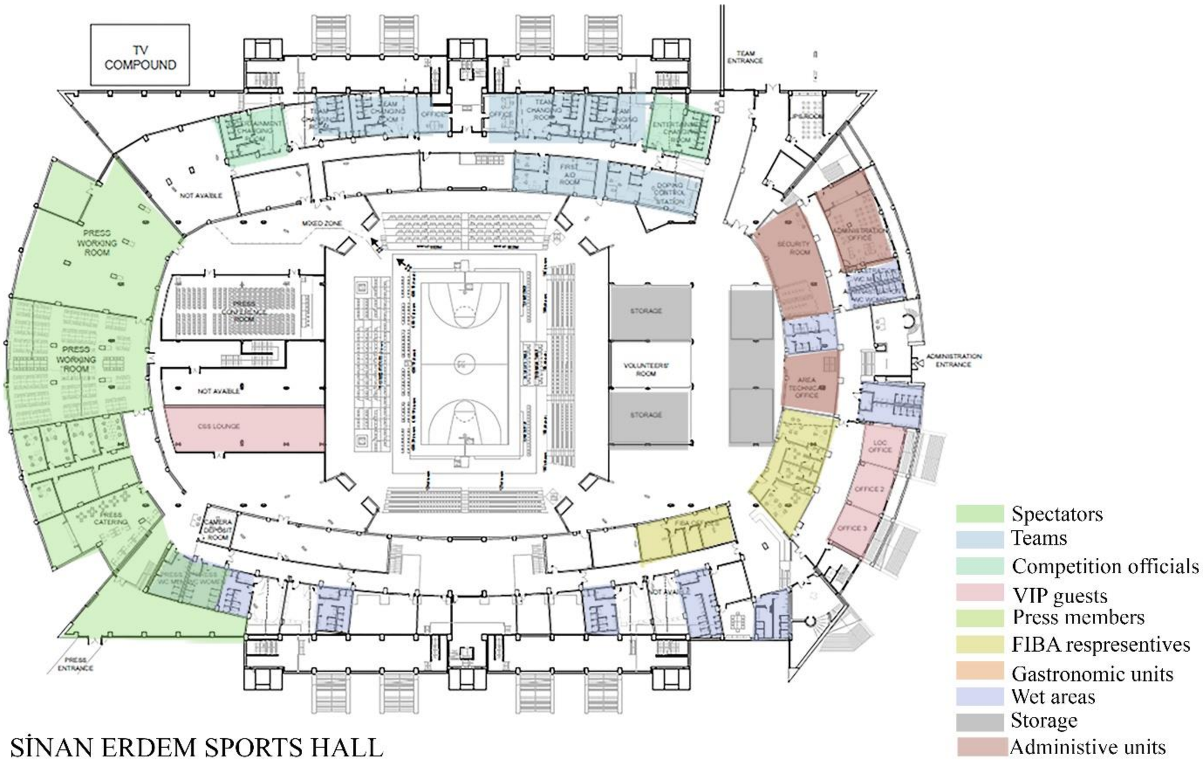


**Figure 15.** *Ground Level Usage of Sinan Erdem Sports Hall: Depicting User Zones and Circulation Patterns*

***Figure 16****. Interior View of Sinan Erdem Sports Hall: Showcasing the Main Court and Seating Bowl*

Sinan Erdem Sports Hall is actively used for various events, with basketball competitions being the most frequent. The facility manager confirmed the adequacy of furnishings and equipment, indicating no significant deficiencies. Food and beverage concessions within the foyer area cater to spectators, but their placement and design could be improved to minimize congestion and enhance accessibility during peak event times (Figure 17). The haphazard placement of exhibition elements within a corridor, rather than a dedicated museum or display area, represents a missed opportunity to create a more engaging and informative experience for visitors (Figure 18). Integrating gastronomic areas and exhibition spaces more thoughtfully into the design process, rather than distributing them along circulation routes, could have enhanced their functionality and accessibility, ultimately improving user experience.

***Figure 17.*** *Food and Beverage Concession Area at Sinan Erdem Sports Hall: Analysing Placement and Impact on User Flow*

***Figure 18.*** *Exhibition Area at Sinan Erdem Sports Hall: Assessing Functionality and User Engagement*

A significant observation regarding Sinan Erdem Sports Hall is the presence of large, uncontrolled voids within the facility that are not actively utilized. These voids not only represent an inefficient use of space but are also potential sources of significant heat loss, impacting energy efficiency and operational costs. Additionally, the ad hoc creation of office spaces using dividers within the foyer area suggests a lack of foresight in the original design to accommodate administrative needs (Figure 19). This observation, along with the temporary relocation of the Turkish Basketball Federation's headquarters to the arena, highlights the need for more adaptable and flexible design solutions in sports venues to accommodate evolving needs and future changes in use.

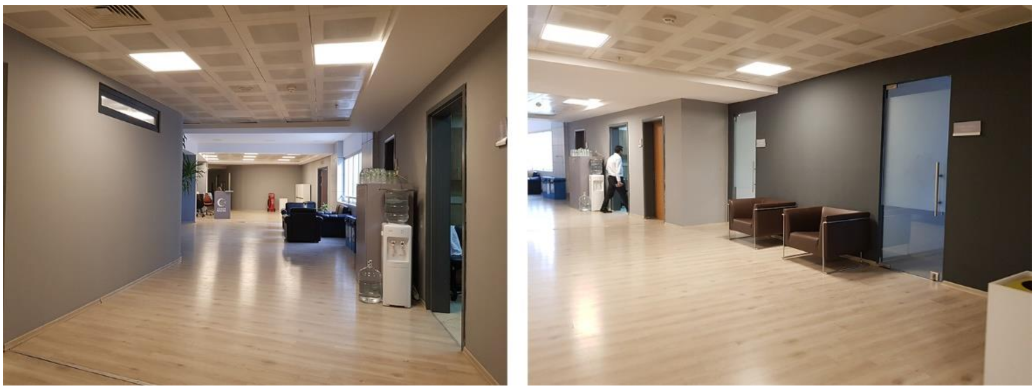

***Figure 19.*** *Administrative Offices at Sinan Erdem Sports Hall: Highlighting Adaptations and Spatial Inefficiencies*

The facility manager stated that the arena's electrical systems, furnishings, and overall spatial organization facilitated easy orientation, with no major wayfinding issues reported. However, the reported evacuation time of 35 minutes for a fully occupied arena raises concerns about the efficiency of circulation paths and exit capacity. finding suggests a potential need for further analysis and optimization of the arena's egress systems to ensure spectator safety in emergency situations.

Although Sinan Erdem Sports Hall does not currently utilize formal building assessment certifications, the facility management team has undertaken efforts to collect user feedback. Complaints received from users have identified specific problems related to accessibility, particularly with disabled lifts and toilets, highlighting areas requiring immediate attention and improvement. However, a more systematic and comprehensive POE approach, incorporating diverse user feedback mechanisms and objective performance data, would provide a more holistic understanding of the arena's strengths and weaknesses, guiding more effective improvements in design and operation.

## 5. DISCUSSION AND RECOMMENDATIONS

This section synthesizes the findings from the qualitative POE of the three Turkish basketball arenas, highlighting successes and shortcomings in their technical, functional, and behavioural aspects. Based on these lessons, actionable recommendations are presented to guide the design and operation of future arenas in Turkey.

The case studies emphasize the crucial role of a user-centered approach in achieving optimal arena performance. Ülker Sports and Event Hall, despite technical challenges, demonstrates a strong commitment to user feedback and continuous improvement. Its well-planned design prioritizes intuitive circulation, clear wayfinding, and convenient access to amenities, creating a positive and engaging experience for diverse user groups. Ankara Sports Hall, while successfully accommodating various events, exhibits significant technical shortcomings related to HVAC performance, natural ventilation, and lighting flexibility. The proactive efforts of the facility manager to mitigate these issues underscore the importance of resourcefulness in addressing design limitations, but the absence of systematic user feedback collection and the high costs of transforming the arena into an ice hockey rink emphasize the need for a more integrated and user-centered design and management approach. Sinan Erdem Sports Hall, despite being deemed satisfactory by the facility manager, reveals spatial inefficiencies, potential safety concerns related to evacuation time, and limited adaptability in accommodating evolving needs. The underutilization of press areas, prolonged evacuation time, and ad hoc creation of office spaces highlight opportunities for improvement. The high operational costs of mechanical systems further emphasize the need for energy-efficient design solutions and incorporating natural ventilation strategies.

These case studies provide valuable lessons for shaping future basketball arenas. Future arenas should prioritize investments in modern, efficient, and adaptable HVAC systems with zoning capabilities to ensure consistent thermal comfort [23]. Integrating natural ventilation strategies, particularly in areas with prolonged occupancy, will enhance indoor air quality and contribute to energy efficiency. Flexible and adaptable lighting systems, utilizing a combination of natural and artificial sources, prioritizing energy-efficient LED technology, and incorporating smart controls, are essential [31].

Beyond technical considerations, thorough user research is essential to understanding the diverse needs of various user groups, ensuring spaces are designed for both functionality and enjoyment [26]. Adaptability for multi-purpose use should be prioritized, employing modular and convertible design elements to maximize flexibility. Circulation patterns should be clear and intuitive, minimizing congestion and maximizing accessibility for all users. Comprehensive wayfinding signage, strategic landmarks, and logical spatial organization enhance navigability and user comfort. Robust technology infrastructure allows for seamless adaptation to diverse event formats.

Crucially, future arena development must embrace proactive and adaptive management that prioritizes user feedback and performance evaluation [33]. Implementing formal building performance evaluation programs that incorporate both objective performance data and subjective user feedback is essential. Diverse feedback mechanisms, such as surveys, online platforms, and focus groups, will capture a wider range of user perspectives. Fostering open communication channels between facility managers, stakeholders, and design professionals will enhance knowledge sharing and collaborative problem-solving, ultimately leading to the development of more effective, user-centered, and sustainable basketball arenas.

## 6. CONCLUSION

This research offers both theoretical and practical insights into the design and management of large-scale basketball arenas. By employing a qualitative POE approach, the study illuminates the intricate relationships between design choices, user experience, and facility management practices in three prominent Turkish arenas. The findings reveal that user satisfaction transcends mere technical performance, as it is significantly influenced by the interplay between design, operational practices, and facility managers' responsiveness to user feedback.

The identified challenges related to HVAC systems, natural ventilation, adaptability, and wayfinding underscore the need for a holistic and user-centered approach to arena design and management. This research emphasizes the importance of:

- **Prioritizing user comfort and well-being:** Investing in well-designed and efficient HVAC systems, incorporating natural ventilation strategies, ensuring adequate lighting and acoustics, and providing accessible spaces.
- **Designing for flexibility and adaptability:** Accommodating a variety of events and user needs through modular and convertible design elements to maximize spatial flexibility.
- Integrating technology effectively: Utilizing smart building systems, energy-efficient lighting controls, and advanced sound and video technologies to enhance functionality, user experience, and sustainability.
- **Establishing robust feedback mechanisms:** Implementing ongoing performance evaluation programs that incorporate both objective performance data and subjective user feedback to enable continuous improvement.

While the study’s focus on three Turkish arenas may limit the generalizability of the findings, the qualitative nature of the research provides rich insights that lay a foundation for further exploration. Future research can expand the scope to include a wider range of arenas and incorporate quantitative data collection methods, such as user surveys and environmental monitoring, to further validate and generalize findings. Investigating the economic impact of design choices and the influence of specific elements on fan behaviour and crowd management would also provide valuable insights for future arena development.
Despite its limitations, this research contributes to the growing body of knowledge regarding best practices for designing and operating large-scale sports venues. By emphasizing user experience, sustainability, and continuous improvement, this study encourages a shift toward a more holistic and user-centered approach to arena design and management, ultimately leading to the development of more successful, impactful, and sustainable sports venues worldwide.

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Research Article GU J Sci, Part B, 13(2): 155-171 (2025)

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PART B: ARTS, HUMANITIES, DESIGN AND PLANNING

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# The Impact of Building Envelope Design on Sustainable Architecture

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**Article Info**

*Received: 21/02/2025*
*Accepted: 22/05/2025*

**Keywords**

*Sustainability, Building Materials, Building Envelope Design, Biomaterials, Sustainable Architecture*

**Abstract**

The building envelope plays a crucial role in shaping the identity of buildings by interacting with users, stimulating ideas and arousing curiosity. Since the earliest times, people have been working to produce materials to improve the building envelope. As a result of these studies, environmental pollution and carbon emissions have grown so much since the Industrial Revolution that the need for an environmentally friendly approach has emerged worldwide. Sustainable material innovation is an important focus in the eco-friendly design process. Sustainable architecture has developed under the influence of lifestyles, geographical conditions, social and physical needs, and economic reasons. In addition, the materials that emerged for the purpose of discovering environmentally friendly building design also have a great impact on building envelope design. With the opportunities provided by new materials, there has been a great change in building designs. The aim of this research is to investigate the effects of materials used in sustainable building designs by examining international examples of the historical evolution of materials. The process from the materials used in the early ages to the present day has been examined in detail. In addition, the research explores the effects of nanotechnological materials on the design of the building envelope and highlights their potential to improve energy efficiency, durability, and environmental performance in line with future sustainability goals. In this context, the methods followed on the subject are determined and possible solutions for the future evolution of the material are discussed.

## 1. INTORDUCTION

Architecture, which is the most concrete reflection of human history, has always been a dynamic expression of cultural and technological developments throughout civilization. Not only does it serve as a record of human progress, but it also embodies the evolving relationship between humans and their environment. The concept of sustainability has become a critical approach in architectural design that aims to minimize environmental impacts through conscious choices in materials, energy use, spatial development, and ecosystem protection. This is particularly important, considering that buildings are responsible for around 39% of global CO2 emissions and account for 36% of total energy consumption worldwide [1]. In response to these challenges, sustainable architecture emphasizes energy efficiency and ecological conservation in the built environment.

This study focuses on examining the evolution of building envelope systems from past to present, analyzing the impact of facade materials, and evaluating the systems that are expected to shape the future of sustainable architecture. Improving building envelope design plays a crucial role in reducing both construction costs and the effects of the climate crisis. By improving the material-envelope relationship, it is possible to achieve more energy-efficient and environmentally friendly building designs.

The building envelope acts as the primary interface between a structure and its users, influencing perceptions and forming an integral part of the building's identity.[2] Therefore, this research aims to investigate the role of sustainable facade materials in creating environmentally sound designs and to offer

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insights into how these materials can contribute to the production of innovative and resource-efficient facades.

**The main questions of this study are:**

- "Do the materials used have a decisive influence on the design of the building envelope?"
- "To what extent can the carbon footprint of a building be reduced by using sustainable building envelope materials?"
- "How does building envelope design affect a building's energy consumption (heating, cooling, lighting)"?
- "What are sustainable building envelope design approaches in different climate regions"?

The aim of this research is to investigate the impact of sustainable materials on building envelope design by examining different facade systems. By focusing on these aspects, the study seeks to understand how the use of eco-friendly materials can contribute to reducing a building's carbon footprint and lead to more sustainable and energy-efficient designs.

## 2.METHOD

This study examines the development of building envelope materials, starting with the historical evolution of these materials. The research examines the envelope materials that have influenced the design of buildings throughout history, revealing the effect of the historical evolution of the material on building construction methods. In the research, it examines the development of building materials by dividing them into four main groups: before the Industrial Revolution, building envelope designs after the Industrial Revolution, developments in sustainable building envelope design with today's technology, and the building envelope of the future with technology, and investigates how the materials used in facades have changed over time.

Technological innovations and advances have played an important role in shaping the design of building envelopes. This research also analyzes the impact of these technological advances on the structure and design of the building envelope.

In addition, the study reviews current sustainable building technologies and the role of these innovations in reducing the environmental impact of buildings. The literature on sustainable technologies is analyzed to understand the evolution of these materials and their potential use in future building designs.

Finally, the collected data is tabulated and analyzed to provide insights into trends and advances in building envelope materials (Figure 1).

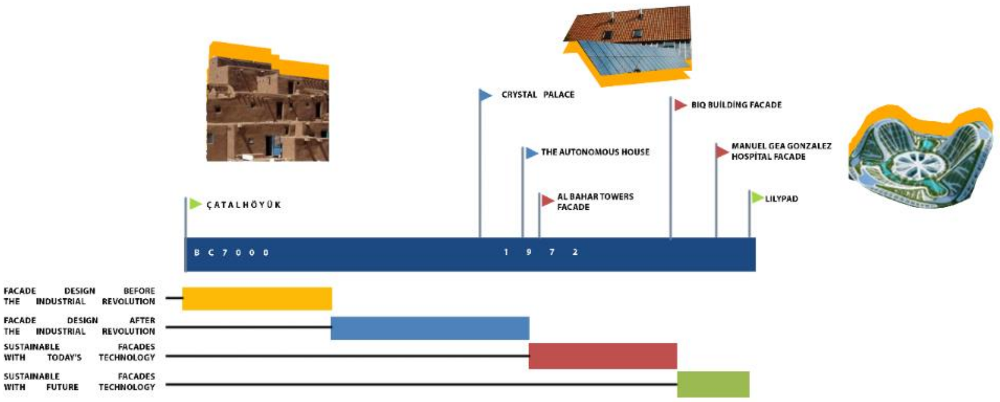



***Figure 1.*** *Facade progress diagram (Prepared by the author)*

**Research Methodology**

1. Determination of current international standards for sustainability technologies through a comprehensive literature review.
2. Investigation of the historical development of building envelope materials.
3. Comparison of selected cases by tabulating them after detailed examination and analysis.

## 3. RESEARCH FINDINGS

Since ancient times, architecture has been the art of creating spaces that reflect the cultural, economic, social, technological and intellectual realities of societies [3]. In this section, the evolution of facades that serve as expressions of buildings and the materials used in their construction are examined. Starting with the concept of building envelopes, the historical development of materials, including facade designs both before and after the Industrial Revolution, is traced.

The technological developments that come with the development of materials are also taken into account and the focus is on how these innovations affect building envelope design. The effects of these technological developments on the design of building facades are analyzed in detail.

### 3. 1. Building Envelope Concept:

The building envelope design, which separates the indoor and outdoor environments within the building, protects the users from the negative effects of external climatic conditions and ensures the creation and maintenance of the necessary comfort conditions in the interior. In terms of physical environmental control, building envelope design aims to establish and maintain a certain balance in the indoor environment in line with the needs of the users. For this purpose, the building envelope is a balancing component between indoor and outdoor environments [4].

The building envelope of a building is the first point of contact between the building and the people. Therefore, it plays a major role in determining the relationship between people and buildings. When considered as external reflections of buildings, buildings reveal the cultural, social, economic and technological reality of society.

### 3.2. Historical Development of Building Coating Material:

There is no way to interpret facades as just the outer building envelope of a building. It is a very important element in determining the privacy between the original users of the building and the people outside and the physiological needs of the users.

A place since ancient times. It is known that starting from 7000 BC, people took the first step towards sustainable materials by combining clay, soil and straw and drying them in the sun and started using adobe bricks. The concept of sustainability has developed greatly with the innovations in materials entering architecture with the increasing energy problem that started with the Industrial Revolution. As the development of materials from adobe to smart facades progresses, the design of the building envelope has changed and developed many times thanks to the possibilities brought by these materials. Throughout history, man can learn a lot about the living conditions of that society by studying the facade designs and materials of each period.

### 3.3. Pre-Industrial Revolution Building Cladding Design:

In prehistoric times, the facades of people's buildings were not part of the design process, but the final product. However, when people evaluate the materials that make up the facades of buildings, it is easy to see that they are trying to improve the materials that nature offers them.

When the Neolithic settlement of Çatalhöyük is examined, it is seen that the main materials used are adobe, reed and wood. The columns of the buildings are made of wood, and the ceilings are made of compacted clay and reed. People who entered the adjacent buildings through the roof did not leave any openings in the facades in order to protect themselves from the attacks of enemies and wild animals.

In Egyptian architecture, solid, massive and magnificent structures were built, focusing on the other world, consisting of geometric forms built with mathematical precision, as if to convince people of immortality. Egyptian architecture underwent only minor changes over the course of 2,700 years over thirty-one dynasties. The purpose of architecture, including Egyptian culture and institutions, is continuity and order; This constant effort against time, death, and decay has transformed architecture into an activity dedicated to serving tradition. [5]

Egyptian Architecture consists of simple and regular geometric forms and linear designs. They created the first examples of prefabrication with stones brought from distant countries.

Although Greek architecture differed in each province and period, the structures did not deviate much from the schemes established in the archaic era, except for minor changes. Unlike the Egyptians, the Greek civilization built structures close to the human scale. The Greeks, who were in search of balance and symmetry, often used stone in their structures. Greek architecture is the embodiment of the effort to find the ideal balance between extremes, that is, the middle, in stone. In architectural understanding, this translates into a balance between vertical load-bearing elements (columns) and horizontally load-bearing elements (eaves beams), and between movement and immobility. [5]

Order and symmetry, repetition and rhythm are the main features of Greek structures consisting of straight lines. The use of two different layouts in the same monument from the end of the 5th century and the invention of the Corinthian capital show the effort to enrich the structures. Since the rulers of Anatolia and Egypt were the ones who built the most buildings after the 4th century, the buildings began to be built much larger and ornate, and the simplicity characteristic of Greek architecture was lost. [6] Unlike other civilizations, in Greek and Roman architecture, the dimensions of preformed stone building elements were applied not for technical reasons or cost-cutting concerns, but rather with a desire to achieve a certain aesthetic harmony in the proportions between the different parts of the structures.

Gothic architecture, which originated in France in the 12th century, spread to various countries in Europe and continued to exist until the end of the 16th century. Gothic architecture, which emerged with the influence of the clergy who wanted to establish authority over the people, is mostly seen in churches in Europe. Since the general purpose is to glorify God, elaborate decorations, ribbed vaults, and pointed arches are often seen in pointed cathedrals that rise into the sky.

With the Gothic architecture based on the load transfer system, the walls ceased to carry loads and the use of stained glass began to emerge to create a mystical atmosphere in the building with the opening of high windows. Just like the stone, brick or cement coatings of the buildings built by the Greeks and Romans with the column-lintel system, the stained glass windows between the arches supported by the columns in medieval cathedrals are examples of curtain walls that have existed anonymously for centuries[7].

When a general evaluation is made, the architectural styles before the Age of Enlightenment lasted for centuries and there was no need to search for new construction techniques on the existing materials used. The change that occurs when the development of structures is followed is not the product of technological pursuits, but of formal pursuits. (Figure 2)

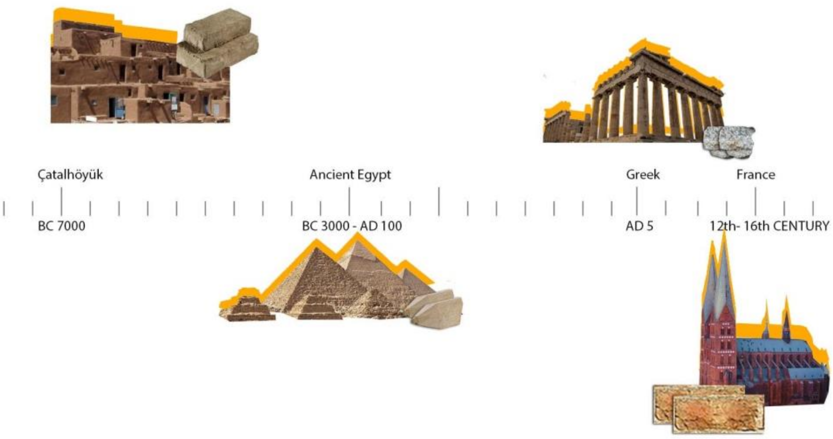



***Figure 2.*** *Facade Design Before the Industrial Revolution (Prepared by the Author)*

### 3.4. Post-Industrial Revolution Envelope Design :

The Industrial Revolution, which is a continuation of the Enlightenment movement that started in the 17th century and led to great changes in the social structure in the 19th century, has shown itself in the field of architecture as well as in every field. In the late 18th century, during the Age of Reason, people understood what style meant and began to become aware of different styles. Horace Walpole Strawberry's Summer House on the Hill was one of the first signs that people consciously chose the style of their buildings as they would wallpaper [8].

In the 19th century, new types of structures were needed due to the migration from villages to cities due to production and consumption. There was a housing deficit due to the wars, and this deficit could not be met by traditional construction methods. Advances in materials and techniques have industrialized and brought construction and factory production to the forefront. Until the 19th century, sufficient progress was not made in natural materials such as wood, stone and terracotta, and structures were built as much as the materials allowed. With modernization and the development of technology, new materials appeared. Iron, glass and, towards the end of the 19th century, concrete became the building elements of the new age.

The Crystal Palace building is the symbol of this new era. For the first time in history, the building was built with prefabricated structural parts. Thanks to this new system introduced by the British, not only the construction times were shortened, but also the costs were reduced.

Crystal Palas shook up the architectural patterns based on the understanding of composition based on the perfect harmony of the part with the other parts and the whole, and instead brought a brand new understanding that reveals the continuous repetition of a modular building unit, the possibilities of combination and displacement without trying to embellish it with a narrative. [9] However, new building materials were only used in engineering structures such as bridges and factories.

The artist tried to give his low-cost products an expensive look with ornaments, as the bourgeoisie, which is the new rich class that emerged in the social sphere as a result of the Industrial Revolution, lived in the cities and owned capital, and increasingly demanded objects in which historical styles and decorations were used, which they saw as a symbol of wealth and status. This caused 19th-century design to hide behind the past and past styles. [10]. From the 19th century onwards, architects repeated traditional architectural styles rather than exploiting the innovative opportunities brought by new building materials; Architects, who showed a refreshing approach with names such as New Gothic, New Renaissance, New Baroque, New Rococo and New Classicism, later changed their approach. Towards the end of the 19th century, there was a backlash against this neo-classical approach.

Art historian Heinrich Wölflin, in his 1888 article, observes that 'architecture expresses the attitude of the age towards life'. Twentieth-century architecture had to express its uniqueness by celebrating electric lighting, radio communications, automobiles, and airplanes. The dawning century was to be the century of the machine, speed, and motion, and the architecture of the new age would certainly reveal this mechanization. [5]

Unlike the 19th century, when the 20th century was entered, a modern architectural understanding emerged by making use of the possibilities of the machine. The main idea of these newly formed modernist movements was that architecture should use the tools of the age according to its characteristics, and they built their buildings with this principle.

The emergence of the Art Nouveau movement, born in Brussels at the end of the 19th century, is associated with the problems of industrialization and growing economies. Although the Art Nouveau movement did not simplify art, it argued that architecture should be separated from traditional forms and a unique understanding should be brought to designs. Influenced by Japanese art such as the Arts and Crafts movement, Art Nouveau aimed to bring dynamism to architecture with curviline-floral motifs.

All the movements that emerged from the arts and handicrafts, Art Nouveau and Art Deco to postmodernism that developed against the eclectic attitude at the end of the 19th century are examined under the title of modern architecture. [11]

One of these movements is the Futurism movement that emerged in Italy in 1909. In the Futurism movement (using materials based on glass, iron and plastic), architects aimed to create a simple architecture that would receive light and reject horizontal and vertical lines and cubic forms.

From the beginning of the 20th century to the present, many works in the field of architecture have been classified under the name of Expressionism. But this movement also includes Futurism, Purism, etc. It has been laid down in some manifestos. Expressionism should not be considered as a collective movement of artists who agree with each other, but as a classification that can be made according to the qualitative values of interesting and original works that emerge as a result of the unique behaviors of some individual architects. [12]

In the 1970s, architects began to react to the Rational Architecture movement, which has dominated the understanding of building since the beginning of the 20th century, and thus Post-Modernism emerged. Since these years, structures inspired by machines and expressing themselves stylistically have emerged. In the 80s, the 'High Tech' trend emerged with the reflection of technological developments on the structure. High-tech buildings, which adopt an expressionist approach, create structures like large machines by reflecting vertical circulation elements and installation channels to the outside. Norman Foster, Richard Rogers and Renzo Piano are the pioneers of this movement.

Architects of the De Constructivism movement, born in 1988, rejected all these approaches and began to look for contradictory forms.

Deconstructivist architecture [13], a system of thought that intervenes, disintegrates and robs the pure form but does not deny its existence, seeks to emphasize the current indifference of society by increasing the tension between structural elements [14].

Today, contrary to the individualist attitude mentioned above, there is a pluralistic approach in architecture. Architects transcended the mere expression of their ideas and the social context in which they operated, as seen in movements such as Deconstructivism, and instead embraced a principle that integrated sustainability into the built environment. This shift has been driven by the pressing challenges of the 21st century, including ecosystem degradation and the depletion of natural resources – issues that were formally recognized at the First World Environment Conference in 1972. (Figure 3)

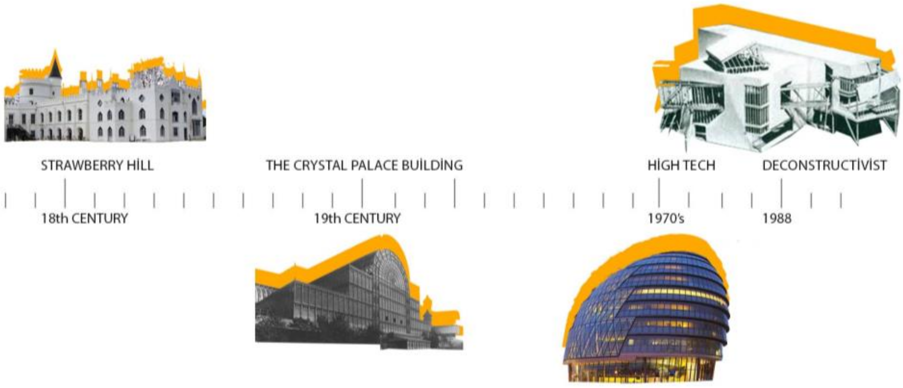



***Figure 3.*** *Facade Design After the Industrial Revolution (Prepared by the Author*)

### 3.5. Technological Advances in Sustainable Building Envelope Design

Since the first years of construction, people's primary expectations from building materials have been safety and air conditioning. As a result of the research, it has been determined that by understanding the relationship between facades and energy, different gains can be obtained not only by providing indoor comfort, but also by evaluating the facades and temperature gains. (Table- 1) [12] With the need for raw materials and the climate change crisis that started with the Industrial Revolution, the term sustainability, which was used at the World Environment Conference in 1972, has entered other disciplines as well as the field of architecture. The idea that precautions should be taken against structures that are thought to be largely responsible for the carbon footprint has become widespread all over the world over time.

Kim and Rigdon (1998) divide the principles of sustainable architecture into three groups: efficient use of resources, life cycle design, and improvement of human quality and aesthetics of life. While the efficient use of resources, reducing the use of non-renewable energy, which starts with the production of building materials and continues throughout the building life cycle, is defined as an important principle, life cycle design is considered as the stages of design, construction, operation, maintenance and demolition. It states that improving the quality of human life aims to increase and improve people's living standards, the quality of the cultural, social and physical environment, as well as to protect human health and comfort [15].

Initially focused on improving insulation, architects and engineers later developed effective systems using renewable energy sources. Techniques in which energy is used efficiently are constantly developed in direct proportion to the advancement of technology. The idea of living in harmony with nature rather than dominating it is becoming more and more common in the built environment.

### 3.6. Developments in Sustainable Building Envelope Design with Today's Technology

Built by Brenda and Robert Vale in 1975, the "Autonomous Home" is considered one of the first applications made with ecological concerns. It aims at low energy use by adopting a holistic approach from building and material production to interior arrangement. The idea of ecological design, the first example of which is a residential design, was developed in 1991 under the six principles developed for ecological design in the book "Green Architecture".

William McDonough defined the Hannover Principles for sustainable design in 1992. These principles are accepted by those who practice architecture based on ecological values and provide a starting point for architects to develop their approach principles.

1. Emphasizing the integration of human rights and nature in healthy, supportive, diverse and sustainable designs.

2. Identify interdependence. Human design elements interact with and depend on the natural world at every scale.
3. Respect the relationship between spirit and matter.
4. Take responsibility for design decisions related to human well-being, natural systems, and the interoperability of their realities.
5. Creating objects that have long-term value and are safe for future generations.
6. Eliminating the concept of waste. Improving and evaluating the entire life cycle of products and processes, addressing the status of waste-free natural systems.
7. Rely on the natural flow of energy. Like living soil, humanistic designs must derive their creative power from the constant gain of sun. Combine energy efficiently and safely for convenient use.
8. Understands the limitations of design. Endless inhumane creation and design is not the answer to all problems. Creators and planners must practice humility in nature. See nature as a model and mentor rather than a nuisance to be avoided or controlled.
9. Seek continuous improvement through knowledge sharing. Re-establish the holistic relationship between natural processes and human activity, and promote direct and open communication between colleagues, bosses, producers and users involved in long-term, sustainable conditions linked to moral responsibility. [18] Today, many studies are being done to reduce the carbon footprint of buildings. It has been discovered that sustainability can only be achieved with smart facade designs that are independent of the interior systems of buildings.

Smart facades are generally defined as "an active and precise intermediary between the external environment and the interior of the building, providing optimal interior comfort with minimal energy consumption" [16]

One of the most important factors that create smart facades is that the materials used are smart. With proper design adjustments, double-skin facades can optimize natural ventilation and daylight while significantly reducing thermal loads. [17] Smart materials can be divided into three groups; Smart Materials That Change Properties, Smart Materials That Change Energy, and Smart Materials That Change Matter [16] (Table 1)

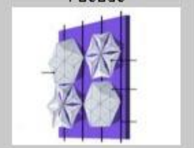
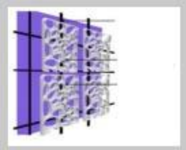
***Table 1.*** *Advantages, disadvantages and applications of smart materials. [5]*

| Name of Smart Material | Advantages | Disadvantages | Applications |
|---|---|---|---|
| Piezoelectric | • High frequency response<br>• Generate electrical signal on application of mechanical force<br>• Structure is simple | • Working stroke is limited to several or ten micrometers limits its application in or as actuators<br>• Wear and heat generation<br>• Difficult to manufacture<br>• Inchworm piezoelectric has complex structure | • Used in electronics devices such as transducers and sensors<br>• Used at high temperature due to their high curie temperature<br>• Micro positioning accuracy<br>• Power gen in auto<br>• Tyre pressure sensor<br>• Knock sensor<br>• Piezo fuel injectors |
| Magnetostrictive | • Higher energy density<br>• Intrinsic robustness | • Magnetostrictive materials increases the complexity of the system<br>• The accuracy of experimental reproduction is not enough | • Tuned vibration absorber<br>• Damper<br>• Engine mounting<br>• sensors<br>• Energy harvesting |
| Shape memory alloy | • They have elastic behavior<br>• High fatigue failure Life<br>• High damping capacities<br>• High strength<br>• Corrosion resistant | • Expensive<br>• Temperature sensitive<br>• High cycle fatigue<br>• Complicated design and high weight | • Biocompatible<br>• Aerospace<br>• Robotics<br>• Clothing and fashion industries |
| Electro-rheological fluid | • More stable system performance<br>• Simple controller design<br>• Act as power amplifier | • High Density<br>• Fluid become thick after prolonged use need replacement | • Vibration dampers, Shock absorber<br>• Clutches<br>• Hydraulic valves |
| Magneto-rheological fluid | • Very little remnant magnetization<br>• Higher permeability<br>• Higher saturation magnetization | • High quality fluids are expensive<br>• Settling of ferro particles can be problematic | • Vibration absorber<br>• The deposition of iron particles<br>• Sealing problems<br>• Environmental contamination |
| Optical fibers | • Higher bandwidth support<br>• High carrying capacity<br>• Immunity to electromagnetic interference and tapping<br>• Flexible<br>• Optical fiber cables take up less space<br>• Resistance to corrosive materials | • More expansive transmitter and receiver equipments<br>• It cannot carry electrical power to operate terminal devices<br>• Not suitable at higher optical powers<br>• Installation is costly | • Advanced intrusion detection security systems<br>• Optical chemical sensors and optical biosensors<br>• Used to transmit power using a photovoltaic cell, as light guides in medical and other applications<br>• Structural health monitoring, Spectroscopy, Imaging optics |

With technological developments, technological materials used in buildings reduce energy consumption by making use of insulation, while buildings can now produce their energy with the use of facade materials.

Designed with this approach, Al Bahar Towers in Abu Dhabi meets 5% of the building's total energy needs thanks to photovoltaic cells placed on the roof of the building. High-glazed curtain wall systems increase solar heat gains during the summer months, leading to higher cooling demands. [18]
Together with the shading system, the building reduces CO2 emissions by 1,750 tons per year. In another example in Hamburg, Arup built the first "bioreactor facade ". Glass panels containing moss were installed on the sun-facing facades of the building. These panels made of moss meet all the energy needs of the building and reduce carbon emissions by 6 tons per year. The Manuel Gea Gonzalez Hospital in Mexico City was designed not only as a finishing material for the facade of the building, but also as a system capable of cleaning the surrounding air. (Table 2)

***Table 2.*** *Evaluation of Examples in the World According to Sustainability Criteria [14] (Editor: Author.)*

| | Al Bahar Towers Facade  | BIQ Building Facade  | Hospital Facade  |
|---|---|---|---|
| Design Suitable for the Environment and Climate | Shading indoor comfort conditions | Shading indoor comfort conditions | Shading indoor comfort conditions |
| Conservation of Energy | Reducing the need for a cooling system with 80% shading, and reducing the need for artificial light with its ability to be turned on and off. | Meeting all the energy needs of the building with the algae inside the glass panels | – |
| Use of New and Renewable Energy Sources | The electrical needs of the shading system are provided by photovoltaic panels placed on the roof. | Use of biomass-renewable energy source | – |
| Waste Management | – | Reducing carbon emissions | - Reducing the building's carbon emissions<br>-Cleaning air pollution caused by fossil fuel consumption and reducing damage to the environment |
| Use of Recycled Materials | – | Glass panels used on the facade | – |

As innovations in smart material exchange continue, architects continue to work on what elements they can improve. Yazgan Architecture, which most recently designed a 'smart column' system for the Heper Factory in 2020, predicts that this module, which is used for operations such as cameras, lighting, etc., can be developed in the future by combining it with nanotechnology and using algae to make carbon emulsions.

John MacLane Johansen (b.1916-d.2012), which he defined as "nano-architecture", which grows and multiplies from a seed like a plant in nature, and produces spaces in line with the needs of the user with the programming of the designer, was discussed. In the light of the data obtained, it has been seen that futuristic architectural designs are related to biomimetic concepts beyond the morphological approach and Johansen's architectural approaches that imitate the functioning of nature at the molecular level are worth discussing with today's paradigms. [19].

### 3.7 Creating Envelopes with Future Technology

Biomimicry was first invented by Janine M. Benyus, a science observer from Montana. This concept, which comes from the roots bios (life) and mimesis (imitation), also means "imitation of nature". [19].
Facade designs, which started to protect people from natural conditions, have come to the point of protecting and adapting to the ecological balance over time. With the concept of sustainability coming to the fore and the execution of studies in this field, efforts to build structures in harmony with nature have emerged. At this point, architects envisaged being a part of imitating this ecosystem as a way of being in harmony with the ecosystem in nature. In this context, the first examples have started to be given in the field of "Biomimetic Architecture", which is one of the two most important terms of the future.

The Lilypad project is an eco-friendly floating city that is expected to be home to 50,000 people. The project, designed by Vincent Callebaut, will be presented at the "Oceans 2008" conference. The project, which envisages zero carbon emissions, will be able to produce all the energy people need with titanium dioxide facades.
In the Lilypad project, it is seen that another term encountered in the architecture of the future is "nano-materials."

***Figure 4.*** *Images from the Lilypad project* [20]

In addition to nanotechnology, developments in other branches of science such as software, robotics and genetics will take architecture to a different dimension from its current patterns. With the software applied to nanomaterials, even the texture of the building will be able to switch between the solid, liquid and gaseous states of the material at any time, and sometimes opaque and sometimes transparent facades can be obtained. In short, everything that is important in architecture today will lose its meaning and humanity will meet a completely different and completely organic architecture [21].

### 4. DISCUSSION

In the research, the structures that have changed the strategy of building with the materials used throughout history were examined. In this section, these structures, which left their mark in the periods mentioned in the article, are compared in the context of the sustainability criteria in the table below (Table 3)

***Table 3** Comparison of the Examined Buildings in the Context of Sustainability Criteria*

| | Çatalhöyük | The Crystal Palace | Autonomous House | Al Bahar Towers Front | BIQ Bina Cephesi | Facade of Manuel Gea Gonzalez Hospital | Lotus leaf |
|---|---|---|---|---|---|---|---|
| Fit by design Environment and Climate | -Climatic adaptation<br>-Local Building Materials<br>- Topographic harmony | -Light Transmission<br>- Location of the Building | -Heat Insulation<br>-Use of Solar Energy<br>-Water Management | Shading interior comfort conditions | Shading interior comfort conditions | Shading interior comfort conditions | -Surfaces covered with green plants<br>-Zero Carbon Emissions<br>-Ecological balance<br>-Refresh Knows Energy Sources<br>-Use of Ecological Technology |
| Protection Energy | Natural heating and lighting. | Natural Lighting | -Use of Solar Energy<br>-Thermal insulation<br>-Natural Heating and Cooling<br>-Waste Management and Recycling | It reduces the need for artificial lighting that can be turned on and off. | All of the building's energy needs are met by algae inside the glass panels | - | -Natural Lighting and Ventilation |
| New & Available<br>Renewable Energy Sources | Biomass | - | -Wind Energy | The need for electricity is provided by photovoltaic panels placed on the roof. | -Use of renewable energy sources | - | -Solar Energy,<br>-Wind Energy,<br>-Tidal Energy,<br>-Biomass Energy,<br>-Water Treatment with Solar and Wind Energy |
| Waste Management | Flammable Wastes | - | -Compost Tuvalet<br>-Recycling<br>-Zero Waste Target<br>-Natural Waste Management<br>- Environmentally | - | Reduction of emissions | -Cleaning up air pollution caused by fossil fuel consumption and reducing damage to the environment Reduction of the | -Waste Reduction and Resource Utilization<br>-Waste Water Management |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Safe Waste Disposal | | | building's carbon emissions | |
| Use Recycled Material | -Metal items<br>-Natural Ingredients. | - | -Recycled Building Materials<br>-Recyclable Interior Decoration Materials<br>-Recycled Water and Electrical Appliances | - | Glass panels used on the facade | - | -Product Recycling<br>-Innovation and Technology |

In the Neolithic settlements of Çatalhöyük, concepts such as complex energy systems, the use of recycled materials or waste management were not used as they are today. However, people living in this period generally used simple methods to protect natural resources, and even if these methods did not aim at sustainability, it was possible to meet basic needs and make life easier with energy resources obtained from local sources. The design of the houses was made to adapt to the variable climate of Central Anatolia. In addition, there were stoves inside the houses for protection during the winter months. In the construction of the houses, materials that are abundant in the region were preferred. The design of the houses is planned in such a way as to make the most of sunlight. Natural materials such as plant fibers, leather, and bone can be recycled or recycled for the reuse of waste. For example, an animal's skin can be used to make clothes or bags, and bones can be used to make tools. Çatalhöyük residents can recycle metal items by reshaping them. For example, an old metal container or tool can be melted down and cast to be reused for another purpose. Therefore, recycled material can be used to build a structure or repair an existing structure. Using passive design strategies for the construction of settlements, the design of the houses is planned to make the most of the sunlight. [22]

The environment and climate in which the Crystal Palace is located is one of the important factors considered in its design. London, where the building is located, has a typical temperate oceanic climate, which means that the weather is generally mild and rainy. The design was made with these environmental and climatic factors in mind. The Crystal Palace is covered in glass panels that allow plenty of natural light to enter the interiors. A large area, such as Hyde Park, where the building is located, ensures the preservation of the natural environment and the best use of the landscape. A structure with large glass surfaces, such as the Crystal Palace, allows natural light to enter the interiors. The building has no known initiatives in terms of Use of New and Renewable Energy Sources, Waste Management, Use of Recycled Materials.

The Autonomous House project includes design principles suitable for environmental and climatic conditions. Completed in 1993, the house aims to make the most of environmental elements. . Using a giant greenhouse to keep the house warm in the English winter provides effective heating in cold climatic conditions. A giant greenhouse is used to heat the house by trapping solar heat, and triple-glazed windows reduce heat loss. Electricity is generated by using solar panels in homes. Heat loss is minimized by the use of triple glazing. Electricity is supplied by photovoltaic arrays, and the surplus is fed into the national grid. The water is used by collecting rainwater and treating wastewater through a composting toilet. Meeting the need for water by collecting rainwater stands out as an environmentally friendly water management strategy. Domestic wastewater is treated and recycled through a composting toilet. This prevents the waste of water and other resources and reduces energy-related side effects. In some cases, wind turbines can also be used. These turbines convert wind energy into electricity and meet the energy needs of the home. The use of recycled materials in house construction is encouraged. Recycled materials are used as insulation material in the house. Recyclable materials were preferred in furniture, carpets, flooring and other decorative materials used in the house. Water and electrical appliances used at home are produced from recycled materials.

Al Bahar Towers aims to reduce the need for a cooling system and the use of artificial light by providing 80% shading to ensure indoor comfort conditions. The electricity requirement of the shading system is provided by photovoltaic panels placed on the roof. Shading interior comfort conditions Panels that can be opened and closed reduce the need for artificial lighting. The need for electricity is provided by photovoltaic panels placed on the roof.

BIQ Building aims to meet all the energy needs of the building with algae inside the glass panels to provide indoor comfort conditions. This includes the use of algae, which is a renewable energy source with biomass. In addition, it is aimed to reduce carbon emissions. The glass panels used on the facade are used for this system. Shading interior comfort conditions are provided at a high level. All of the building's energy needs are met by algae inside the glass panels Reduction of emissions

The Manuel Gea Gonzalez Hospital Facade aims to clean up air pollution caused by fossil fuel consumption and reduce damage to the environment. It also aims to reduce the building's carbon emissions. Cleaning up air pollution caused by fossil fuel consumption and reducing environmental damage are among the goals of the building

Lilypad is built with energy-efficient design principles. Energy consumption is minimized by using technologies such as insulation materials, energy-efficient lighting and heating systems. Thus, the energy used is used efficiently. Natural Lighting and Ventilation are at the forefront in the project, which has Solar Energy, Wind Energy, Tidal Energy, Biomass Energy, Solar and Wind Energy and Water Treatment systems. During the design phase of the project, strategies are determined to minimize waste generation. This is achieved by focusing on material selection, production processes and consumption habits. Proper treatment and recycling of wastewater is one of the waste management strategies of the project. Material Selectioncan encourage the use of recycled materials. For example, during a construction or renovation project, waste materials can be collected and sent to recycling facilities. The use of ecological technology is at the forefront of the project shaped by nanotechnology.

## 5. CONCLUSION

It aims to contribute to the literature by providing enlightening information on how this structure has changed over time, depending on the characteristics of facade designs, and how technological breakthroughs have shaped the evolution of sustainable facades. The study of different architectural styles and their parts through financial analysis, how interests, technical developments and social requirements make facade design open to change.

The contemporary transformation of technologies such as iron, glass and concrete, traditionally distributed in adobe, stone and wood, is largely one of the main consequences of the distribution triggered by the Industrial Revolution. Although the natural characteristics of the environment and an environmentally friendly approach were obtained in the early days of humanity, the material possibilities were limited Just as human beings obtained the first composite materials such as adobe, soil and straw by combining and drying them, developments for the sustainability of facade design materials continue. Carbon emissions from construction have risen to high levels due to the distribution of fabricated production materials all over the world, which started with the Industrial Revolution.

On the other hand, these developments have facilitated the construction of larger and more complex structures and made possible the existence of creative facades.

The study of environmentally friendly facade solutions highlights how important their prevalence has become for modern architectural applications. Architects: Use state-of-the-art technologies to reduce temperatures and increase occupant comfort. This technology can range from active systems, such as photovoltaic panels and algae-based bioreactors, to passive design methods, such as enhanced flexibility.

In addition, hardware technologies (especially biomimicry and nanomaterials) offer an interesting perspective on their properties, their ability to adapt to the nature of architecture, and how their differences can be mimicked. The Lilypad project is an exemplary example that integrates ecological conditions with products produced to build sustainable living spaces. The idea aims to achieve zero carbon emissions and uses titanium dioxide fronts.

These developments have the potential to reduce vulnerability, it is also useful to be able to choose whether it is more ecological and economical to do so. In order for sustainable facade solutions to be inclusive and equitable, issues such as cost, accessibility and scalability need to be taken into account.

The study concludes by highlighting the complex components that exist between sustainable building materials, technological innovation, and facade design. By tracing the trajectory of facades and analyzing their current and current condition, architects can embrace the potential of transforming technologies and draw inspiration from the past to create buildings that balance the environment with human solutions.

The concept of facade has not only been a part of the design process of the building from the first moment people started to build, but also revealed the cultural, social, economic and technological reality of the society. From this point of view, the materials used in the facade design are as important as the design language used.

The concept of sustainability, which entered our lives with the need for raw materials that started with the Industrial Revolution and the climate crisis, has entered every field of technology as well as construction technology. It is an undeniable fact that great innovations are needed to ensure the use and application of sustainable materials.

In the second part, the historical development of the facade was examined and it was seen that people started to develop the material from the Neolithic age. The adobe material used at that time is the biggest example of this. Until the 19th century, people continued to produce new materials, and with the use of these materials, not only new technologies, but also new architectural styles were formed.

The Crystal Palace with prefabricated building parts. This new system shortened construction times and reduced costs.

Although the industrialization in the construction sector, which comes with this new system, accelerates the construction time of the buildings, it has increased the carbon footprint of the buildings and made the construction sector one of the main elements of the climate crisis. The term sustainability, which was used at the World Environment Conference in 1972, has entered the field of architecture as well as other disciplines. The idea that precautions should be taken against structures that are thought to be largely responsible for the carbon footprint has become widespread all over the world over time.

Technological advances on sustainable fronts are examined. Smart facade systems used in today's technologies continue to develop and transform. Al Bahar Towers reduces 1750 tons of $CO_2$ emissions per year thanks to bioreactor facade systems and algae.

The Lilypad project, which is one of the first examples in the field of biomimetic architecture, is considered one of the first examples of this.

In this study, the effect of the material on the facade design and how the concept of sustainability is included in the architectural process are examined. Structures built with today's technology and technologies envisaged in the future are evaluated.

On the scale of Turkey, determining national standards will be a long and costly process. It is not easy for companies operating in the field of smart facade systems to switch to such an application at once. Companies may need to invest and change their production approach. But such a change will be very profitable in the long run, it will not only make a great contribution to the country's economy, but also be a solution to the climate crisis.

Such a change can be realized through legal regulations and credit and incentive systems to be given to commercial companies. More important than the economic dimension is that architects and all units operating in the construction sector realize how important and necessary this issue is and are convinced.

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Research Article GU J Sci, Part B, 13(2): 173-191 (2025)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

http://dergipark.gov.tr/gujsb

# Literature Research for Architectural Design Model Proposal of Technology Development Zones in Türkiye

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**Article Info**

*Received: 24/04/2025*
*Accepted: 02/06/2025*

**Keywords**

*Technology Development Zones,*
*Architecture,*
*Architectural Design,*
*Design Criteria,*

**Abstract**

Technology Development Zones (TDZs) have become significant drivers of innovation and economic development by fostering collaboration between universities, industry, and research centers. However, despite their increasing importance, the architectural design parameters that influence the spatial quality and functionality of TDZs have not been sufficiently examined in the literature. This study aims to address this gap by evaluating the development, conceptual foundations, and design criteria of TDZs, with a specific focus on their architectural dimensions in Türkiye. The research adopts a comprehensive literature review methodology, analyzing international and national models, legal frameworks, and evaluation methods related to TDZs. The first stage of the study examines the historical background, emergence, and key components of TDZs, as well as their evolution worldwide and in Türkiye. The second stage focuses on identifying and categorizing the architectural design parameters and approaches relevant to TDZs, including functionality, flexibility, sustainability, aesthetics, and social context. The findings reveal that while the economic and managerial aspects of TDZs are well-documented, architectural considerations remain underexplored. International evaluation models such as AMIEM emphasize the importance of collaborative environments and adaptable physical spaces. In Türkiye, the lack of architectural standards for TDZs presents challenges for achieving spatial quality and homogeneity. This study highlights the need for holistic architectural approaches in TDZ planning, offering a foundation for further research and practical improvements in the design of innovation ecosystems.

## 1. INTRODUCTION

In recent decades, the rapid development of science and technology has brought about fundamental changes in the practice of societies and economies around the world. These changes are evident, for example, in the establishment of novel environments known as Technology Development Zones (TDZs) designed to stimulate R&D, enhance innovation and promote close collaboration among universities, industries and research institutions. TDZ is used to mean suitably designed deterministic areas stimulating business knowledge, technology and entrepreneurship.

TDZs have emerged as critical infrastructures supporting innovation and economic growth by facilitating collaboration among universities, industries, and research institutions. While their economic and managerial roles have been extensively discussed in the literature, the architectural design parameters that shape the spatial quality, adaptability, and functionality of TDZs remain significantly underexplored—particularly within the context of Türkiye. This underrepresentation presents a key problem for both academic discourse and practical implementation in the planning and design of innovation ecosystems.

The primary aim of this study is to address this gap by examining the conceptual evolution, physical planning principles, and architectural design strategies relevant to TDZs, with a specific focus on their development and application in Türkiye. By situating TDZs within a broader architectural discourse, the research seeks to contribute to a more holistic understanding of how built environments can support innovation-driven ecosystems.

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The scope of the study encompasses international and national TDZ models, legal and institutional frameworks, and existing evaluation mechanisms. The research adopts a two-phase methodology. In the first phase, it explores the historical trajectory and key components of TDZs, along with their emergence and transformation both globally and within Türkiye. In the second phase, the study identifies and classifies core architectural design parameters that are integral to TDZ performance but often overlooked in practice.

Findings indicate that although the economic and governance-related dimensions of TDZs are well-documented, the architectural qualities of these environments lack systematic evaluation. For instance, international models such as the AMIEM framework emphasize the significance of collaborative environments and spatial adaptability in fostering innovation. In contrast, the absence of well-defined architectural standards in Türkiye hinders the achievement of spatial quality, consistency, and user-centered design in TDZ developments.

In this regard, the study underlines the necessity of integrating comprehensive architectural approaches into TDZ planning processes. It offers both a theoretical foundation and practical implications for advancing the design of innovation spaces that are responsive, inclusive, and conducive to multidisciplinary interaction.

## 2. TECHNOLOGY AND TDZ

Given the observation, we shall divide the literature review of this study into two sections. This part presents the features that have contributed to the appearance of TDZs, the events that followed, the conceptual components, the evaluation methods, the consequent stages of development, and the legal basis in our country. The second part explores design, architectural design, key architectural parameters, and the conceptual and physical aspects of related architectural approaches.

### 2.1. Technological Development and Its Interactions with Human Life

Throughout human history, intellectual and technological advances have radically transformed lifestyles and production styles. This process, which began with the discovery of fire, evolved from hunter-gatherer to settled life, from physical labor to machine power, and finally, with digitalization, to life-based on artificial intelligence.

Until the 18th century, people relied on natural resources like muscle power and water for agriculture-based production. As needs grew, traditional methods became inadequate. The Industrial Revolution began in mid-18th century England with steam power’s integration into production and transportation, shifting from workshops to factories. This boosted production and capital, increasing international interaction and knowledge [1]. Higher production capacity led to rural-to-urban migration, the growth of collective settlements, and the rise of the working class, triggering urbanization and changing cities’ architectural needs. The invention of electricity in the late 19th century and the achievements of the 1st Industrial Revolution initiated the 2nd Industrial Revolution. During this period, machine technology accelerated production, transportation, and communication; electrical energy increased product variety, reduced costs, and raised living standards. At the same time, the working class became stronger, and social effects began to be felt on a global scale [2].

Industry 3.0 began in the 1950s with the integration of digital technologies into production; flexible and efficient production was made possible with developments such as transistors, computers, CNC machines, and ERP systems. This digitalization formed the basis of Industry 4.0. Industry 4.0 refers to smart factories equipped with the Internet of things, big data, smart sensors, and autonomous systems, and creates radical transformations in both production and daily life. The basic building blocks of the Industrial Revolution and their effects on human life are summarized in Table 1.

***Table 1.*** *Schematic Summary of Industrial Revolutions*

| Industrial Era | Definition | Main Tech | Features | Effects on People's Lifestyles |
|---|---|---|---|---|
| Industry 1.0 (late 18th century) | Mechanical Production | Steam & water power | Beginning of mechanization, increase in efficiency | Migration from rural to cities, factory work, workforce is physical and tiring |
| Industry 2.0 (late 19th century) | Mass production | Electrical assembly line | Mass production, increased division of labor, efficiency | Lower cost and standardized products, regulation of working hours, working class |
| Industry 3.0 (20th century) | Automation | Computers and robots | Automation systems, digitalization, flexibility in production | Improvement in working conditions, access to information technologies, growth in the service sector |
| Industry 4.0 (21st century) | Smart Production | IoT, artificial intelligence, big data | Smart factories, autonomous systems, data analytics | Digital work environments, remote working, personalized products |

### 2.2. Technology Development Zones

Technology Development Zones (TDZs) are special areas established by universities, research centers, and industry cooperation to support R&D, technology transfer, and innovative initiatives. These zones encourage innovation while also contributing to the economy by strengthening university-industry cooperation.

The origin of technology development zones dates back to the United States in the 1950s. The first example is the Stanford Research Park (1951), which is considered the starting point of technology development zones [3]. Stanford University aimed to support the economic development of the region and to create a bridge between the university and industry by leasing large areas of land in the region to technology companies. This model pioneered the birth of Silicon Valley and became an example for many countries around the world.

Research Triangle Park (RTP) in the USA is one of the first concrete examples of TDZs established in the 1950s to transform the industrial structure of North Carolina. It aimed to attract knowledge-based industries thanks to its proximity to universities such as Duke, North Carolina State, and UNC. It focused not only on industry but also on qualified manpower, quality of life, and cultural opportunities, emphasizing intellectual capital and creating a model that inspired the creative class theory [4].

*"To many observers, the RTP strategy had been a success. By 1970, the New York Times reported approvingly that RTP now had 7,000 employees, almost all white, and an annual payroll of about $70 million, and noted that revenues in the three counties had increased by 28 percent, or $1,000, during the 1960s."* [4].

From the 1970s onwards, the success of TDZs in the USA inspired similar initiatives in Europe and Asia. Examples such as Cambridge Science Park in England and Tsukuba Science City in Japan were implemented; the first successful model in Europe was Sophia-Antipolis in France [5]. In the 1980s, Japan developed the concept of "technopolis", and countries such as Taiwan, South Korea and Turkey also turned to technology park investments [6]. In 1984, IASP was established to bring together the professionals who manage these structures. IASP defines technology development zones as follows [7]:

*"A science park is an organization managed by specialized professionals whose main aim is to increase the wealth of its community by promoting the culture of innovation and the competitiveness of its associated businesses and knowledge-based institutions. To enable these goals to be met, a Science Park stimulates and manages the flow of knowledge and technology amongst universities, R&D institutions, companies and markets; it facilitates the creation and growth of innovation-based companies through incubation and spin-off processes; and provides other value-added services together with high quality space and facilities. The expressions "technology park", "technopole", "research park" and "science*

*park" encompass a broad concept and are interchangeable within this definition. The acronym STP (science and technology park) is used to refer to all of these expressions."*

Studies on the establishment dates of technoparks reveal that there was a 48% increase in the 1990s and this number has been increasing rapidly since the 2000s [8]. During this period, the aim of TDZs is to support technology transfer, strengthen R&D activities and increase national innovation capacities.

As the integration of technological innovations into industry increased from the 1990s onwards, TDZs became widespread worldwide and gained importance in areas such as software, biotechnology and advanced engineering. In the 2000s, the Industry 4.0 process was initiated; information-based production came to the fore, and TDZs became structures that supported university-industry collaboration and innovative initiatives as part of this process.

The main purpose of TDZs, creating an R&D and innovation environment, is important in terms of developing resilience against economic vulnerabilities and supporting sustainable development [9]. Research shows that R&D has positive effects on long-term growth [10], innovation, human capital development and environmentally friendly solutions [11]. Therefore, creating an ecosystem that encourages R&D investments, and innovation is considered critical for countries' development and social problems [12].

With the increasing importance of TDZs, academic research has also begun on these structures. However, studies directly focusing on TDZs in the context of architecture are quite limited. Most of the research in the literature focuses on the fields of economics, law and business development; from an architectural perspective, only indirect and superficial relationships are established [13]. In the bibliometric analysis study conducted by Böyükaslan and Özkara [13] with the keywords "technopark", "technocity", "technology development zones", the researchers reached the results in Table 2. When the Table is examined, no studies were found in the context of architecture, except for the limited and superficial relations of the topics of temporal and spatial distribution and site selection criteria with the field of architecture in the academic studies conducted on TDZs until 2019.

***Table 2.*** *Bibliometric analysis of academic studies on TDZs in the ULAKBİM database as of 2018* [13]

| Subject of Study | Frequency |
|---|---|
| University-Industry-Public Cooperation | 5 |
| Management Effectiveness, Problems, Solution Suggestions | 4 |
| Innovation Impact | 3 |
| Tax Advantages | 3 |
| Impact on Employment | 3 |
| Benefits and Importance of Technoparks | 3 |
| Impact on National and Regional Innovation Systems | 3 |
| The Impact of Innovative Companies | 3 |
| Institutional Transformation, Transition to Information Society | 2 |
| Technology Transfer, Technology Transfer Collaboration | 2 |
| Contribution to Patent Production | 2 |
| Investment Needs, Investment Impact | 2 |
| Economic Impact | 1 |
| Technopark-University Collaboration | 1 |
| Temporal and Spatial Distribution | 1 |
| Innovation Performance | 1 |
| Establishment Location Selection Criteria | 1 |
| Absorptive Capacity | 1 |

### 2.3. Technology Development Zones in Türkiye

In Türkiye, technoparks are defined as follows in the Technology Development Zones Law No. 4691:

*"Technology Development Zone: A site where high/advanced technology or new technology-oriented companies produce/develop technology or software by utilizing the facilities of a specific university or high technology institute or R&D center or institute, operate to transform a technological invention into a commercial product, method or service, and contribute to the development of the region in this way, within or near the same university, high technology institute or R&D center or institute area; where academic, economic and social structures are integrated or a technopark with these features…"*

Based on the definition, it is understood that the concept of TDZ covers concepts that appear in literature with different names, such as science park, science and technology park, technology park, technopark, research park, innovation area and technopolis.

The first step to support R&D and innovation in Türkiye was taken with the 1984-1989 Five-Year Development Plan, and then policies for technoparks were developed. [14]. The first steps towards TDZ were taken with the establishment of KOSGEB in 1990 and the commencement of operations of TÜBİTAK-MAM in 1992. [15]; With the law numbered 4691 enacted in 2001, TDZs gained legal ground and began to be supported with various incentives. [16, 17]. Technology development zones have become not only R&D centers but also structures that support entrepreneurship and local economic growth. Countries like Türkiye, as part of regional development strategies, provide incentives and tax advantages to new initiatives. Developing through university, private sector and public cooperation, these zones are key actors in innovation-based development.

As of October 2024, there are a total of 104 Technology Development Zones in Turkey. 91 of the 104 Technology Development Zones continue their activities, while 13 of them have not yet become operational due to ongoing infrastructure work [18]

TDZs are important spatial ecosystems for the discipline of architecture due to their multi-faceted and interactive structures. These structures, which also include the physical infrastructure of innovative environments, are open to evaluation in terms of architectural design. However, in the existing literature, studies that address TDZs with a focus on architecture are quite limited; for example, although Erenler's study focuses on physical planning, it leaves the architectural dimension incomplete [19].

***Table 3.*** *Parameters for examining the physical planning principles of technoparks*

| Category | Parametric | Definition |
|---|---|---|
| Site Selection Criteria | Regional Economic Structuring | Economic potential and infrastructure adequacy |
| | Transportation Facilities | Proximity to transportation networks |
| | Proximity to Universities and Research Institutions | The situation of benefiting from the knowledge and research opportunities of universities |
| Planning Principles | Intensity | Area usage rates and building density rates |
| | Construction Process in Stages | Phased construction process |
| Characteristics of Physical Areas | Managing Company Locations | Central areas for management and organization |
| | Service Areas | Social infrastructures such as dining halls, cafeterias, and health services |
| | Recreational Areas | Rest and green areas to meet the social needs of employees |
| | Residential Areas | Housing areas for guest workers |
| | Transportation Network | Transport infrastructure such as pedestrian paths, cycle paths and parking lots |

| | | |
|---|---|---|
| Technological and Economic Context | R&D Areas | High-tech production and research centers |
| | Relations with Local Industry | Development of local economic structure and industrial modernization |
| | Technological Adaptation | Technology transfer units |
| Social and Environmental Parameters | Landscape and Environmental Design | Sustainable environmental planning and green space arrangements |
| | Quality of Life | High standards of work and living |

Another study conducted on the axis of architecture and TDZ reveals analyses regarding the measurement of user satisfaction levels of TDZ buildings based on various architectural criteria [20]. However, in this study, since the subject is handled with a focus on the evaluation of existing structures, the architectural reflections of the conceptual infrastructure of the TDZ phenomenon and the design criteria regarding its requirements are not addressed.

There is no specific legislation regarding the architectural design of TDZs in Türkiye. Decisions such as site selection, design and construction are generally determined by the founding committee and the management company. Projects are evaluated only in terms of compliance with legal regulations; criteria such as design quality, sustainability and functionality are not considered. For this reason, a homogeneous and qualified structure cannot be achieved in architectural terms in TDZs.

As a result of considering the TDZ structures in an architectural context, the following evaluations can be made regarding the subject within the scope of this study:

1. Researching the criteria for TDZ design and making suggestions regarding design parameters can provide resources for academic studies and legal regulations to increase the quality of TDZs in our country.
2. The aim is to minimize the qualitative differences between TDZs and to spread the high-quality TDZ ecosystem throughout the country, thus supporting the establishment of a homogeneous system.
3. TDZ areas and structures that will be built in accordance with architectural design parameters will increase employee productivity and help use resources efficiently.

### 2.4. TDZs' Evaluation Models

Technology Development Zones consist of versatile components that support knowledge production, technology transfer and innovation; architectural design, functional infrastructure and sustainable innovation ecosystem constitute the basic elements of this structure [21].

In the literature, TDZ evaluation is carried out using models and tools based on certain parameters. Among the main models used in the evaluation of TGBs, the Cabral-Dahab Model offers ten parameters for the provision of qualified R&D personnel [22]. The Estrategigram proposes a seven-part structure and a positive and negative axis rating system that supports the strategic development of technology parks [21]. The CERNE model provides a systematic approach for process organization and maturity level assessment [23].

The AMIEM model, developed by Amaral, seeks to bridge the gap where existing models have focused too strictly upon a single axis and may not be comprehensive enough. It is based on twelve detailed case studies undertaken in Brazil, Uruguay, Italy and France [23] and is an extended version of Da Poian's model.

***Table 4.*** *AMIEM Evaluation Factors Table* [21]

| | |
|---|---|
| **Timeframe** | Maturation process of innovation environments (usually 15-20 years) |
| **Government Support** | Infrastructure, financing, tax breaks and incentives, etc. |
| **Local Community Involvement** | Participation of entrepreneurs, media and local representatives, regional integration of the innovation environment |
| **University and Research Centers Involvement** | Universities and R&D institutions, collaborations and patents |
| **Funding and Promotion Agency Support** | Venture capital, private and public funds |
| **Presence of Leading Companies** | Presence of leading companies and academic institutions |
| **Physical Space and Location** | Infrastructure, transportation, communications and cost-effective office spaces, etc. |
| **Management and Operational Management** | Dynamic, creative and accessible management, advertising, service provision and development support |
| **Leadership** | Competent and committed leadership units, collaboration with leaders, society and stakeholders. |
| **Promotion and Advertising** | Promotional activities, courses, seminars and visits |
| **Quality of Life and Work Environment** | High quality living and working environment, center of attraction |

As per the AMIEM evaluation model, we can group the main factors that TDZ should contain respectively as follows: University-industry-government collaboration, Physical space and infrastructure, Government supports and policies, Leading companies and industrial partners, Community and social participation, Financial supports, Management and operational infrastructure, Technological infrastructure and digital systems.

**University-Industry-Public Collaboration**

In the literature, which framed the development of TDZs within the scope of the Triple Helix model functional and administrative components have been emphasized. This university-industry-public-cooperation-based model is one of the important underpinning structures and the basis for the sustainability of the knowledge-based economy in our society. In this model, the university contributes to knowledge production, the industry to technology commercialization and the government to the provision of the regulatory framework [21]. It may be suggested that in this context, the TDZ architecture includes units such as joint work areas, R&D laboratories and training centers that will support multi-faceted interaction.

**Physical Space and Location**

TDZ's sustainability and effective operation depend on the availability of advanced infrastructure and versatile physical spaces. AMIEM model - physical spaces being a manifestation of this, must be flexible and have scope to accommodate the needs of users. One of the main features TDZ are built on physical resources, that is, the physical factors such as buildings, offices, meeting rooms and scientific equipment that are provided to companies [21, 24]. There are two primary roles that physical infrastructure plays in TDZs. For the first, provide clustering space for firms; this structure allows firms to cluster together to reduce cost and access specialized resources. It also promotes the establishment of networks between knowledge-generating organizations and industry. The second function is to help newly established firms, in particular, overcome resource deficiencies by providing common areas and equipment. These shared resources also offer complementary advantages with sustainable income potential [24]

**Government Support**

Government support and policies are an important component in the development of TGBs, encouraging long-term development through tax advantages, public investments and infrastructure support. This support is valuable not only economically but also in terms of stability. In terms of architecture, this support can be thought of as administrative and legal units that will manage cooperation with legal mechanisms and office spaces that will coordinate incentive practices [21].

**Leading Companies and Industrial Partners**

Leading companies support the innovation ecosystem by promoting knowledge sharing and collaboration in TDZs. This component can be reflected in spatial solutions such as modular offices, production workshops and collaboration areas [21].

**Community and Social Participation**

Community and social participation support sustainability by strengthening internal and external interactions in TDZs [21]. This component should be architecturally supported by investor offices, technology transfer units, and meeting areas.

**Financial Supports**

Financial support is critical to the sustainability of TDZs and ensures the continuity of resources required for R&D projects [21]. This component should be architecturally supported with investor offices, technology transfer units and meeting areas.

**Management and Operational Infrastructure**

In TDZs, management and infrastructure are required for effectiveness [21]. This management can be met at the architectural level with flexible and multifunctional administrative offices, management centers and logistics areas.

**Technological Infrastructure and Digital Systems**

In TDZs, technological infrastructure increases efficiency with digital systems such as fast internet and data management. This structure can find architectural counterparts with spaces that support the digital infrastructure and provide security.

When the functional and sustainable essences of TDZ components are evaluated, it is important to consider the architectural design of TDZs with a holistic understanding. TDZ architecture can be considered as a multi-dimensional building design that supports social, economic and environmental sustainability as well as innovation.

## 3. DESIGN AND ARCHITECTURAL DESIGN

The design process has been addressed using various approaches in different disciplines. Design refers to decisions made under conditions that are not clear and certain [25]. Design is a process that not only analyzes the current situation but also imagines and realizes potential future solutions [26]. Design is a cognitive process in which the human mind is actively involved. In this process, mental activities such as analysis, synthesis, imagination and evaluation come together [27]. The design process is based on past experiences, theoretical knowledge and practical applications. This knowledge is used to develop new and original solutions [28]. Design deals with both clear and vague ideas, with both systematic and chaotic ways of thinking, and with both imagination and mathematical calculations [29].

### 3.1. Design Models

Unlike traditional sequential models, multidimensional thinking structures developed in the information age offer more comprehensive solutions. Especially in the preliminary design phase, intuitive decisions with limited information are insufficient; therefore, the use of multi-criteria analysis methods is important for sustainable and optimum design solutions [30].

The Integrated Thinking Model is the most comprehensive model that enables designers to produce innovative and flexible solutions to complex problems by combining basic, logical and creative thinking approaches [31]. The Integrated Thinking Model consists of three components: Basic thinking includes the problem definition and solution development process based on the designer's knowledge and experience. Logical thinking is the scientific analysis of data, and methodical evaluation of solution alternatives. Intuition, imagination and creativity to generate innovative ideas underpin creative thinking. The first stage of Integrated Thinking Model is to analyze the design problem and gather information. This work is conducted in a holistic manner, however, considering context, needs of users and cultural aspects. An information-based design consists of the steps of problem definition, alternative generation, as well as solution evaluation and decision making. Merging logical and creative thinking, the theoretical and practical dimensions of the model allow for the emergence of new solutions in the architectural design process [31].

### 3.2. Architectural Design

Architectural Design is a multi-dimensional process oriented at space and form, and it is also program oriented. The process has layers: layers of technical knowledge, aesthetic feeling and social need and it spans both information based decisions through to creative ones [32]. The architectural design process is a knowledge-based planning process that focuses on producing better solutions by analyzing existing conditions. Each design produces a subjective solution that is specific to the context, user and designer [33]. In recent years the architectural design criteria have gone beyond traditional criteria and into new dimensions like sustainability, flexibility, accessibility and technology. The purpose of this study is to provide a comprehensive view with TDZs by intersection that architecture discipline and all what part of components followed in design process.

**Function**

The concept of function in architecture came to the fore in the modernist period with Louis Sullivan’s “form follows function” principle; it revealed the understanding that form should be derived from function [34]. However, this approach was criticized by Reyner Banham on the grounds that it led to the limitation of architectural meaning and was evaluated as a superficial slogan [35]. According to Michl, the function is divided into two parts: planned and real; this distinction reveals that the design can transform over time in line with the needs of the user [36]. Hillier and McLeod emphasize that function should be flexible and redefinable not only in physical but also in social and cultural contexts [37, 38].

In modern architecture, the function is defined by focusing on social needs and placing the architect in a position of authority independent of the user. This approach led to architecture gaining a political dimension. New approaches developed from the 1950s onwards emphasized that function could not be considered independent of context and user; they argued that flexible and creative solutions suitable for every situation should be developed [39]. Function is not a hard rule in architecture, it is seen to be a fluid and re-interpretable element that varies depending on context. This is the method that postulates critical and innovative architecture being, which is always intertwined with social, cultural and political specifications [40].

The functional capacity of a structure relies on criteria such as user requirements, spatial organization, accessibility and flexibility. The functionality in the architectural design of technoparks gives a strong need for situational, user-centered and flexible designs. Designing with an understanding of other specialties would be to design for sustainability through adaptability to differing needs — one that acknowledges specialized spatial needs.

**Flexibility**

Flexibility is a spatial and structural strategy that allows structures to adapt to time, users and functions [41]. Hertzberger [42] talked about flexibility in terms of providing opportunities for multi-purpose usage; Friedman [43] discussed growth and division strategies (in response to changing needs). An approach in architectural design flexibly is to develop more durable and user-friendly facilities, not just functionally but also with social, cultural and economic dimensions.

Flexibility in architectural design is a multidimensional strategy that aims to adapt structures to changing user needs and functions over time. Within the scope of this study, the basic design approaches that provide flexibility can be summarized below:

1. Mobility: It enables the space to be rearranged according to temporary needs, thanks to portable equipment and structural elements [44].
2. Modularity: Creating repeatable units with a grid layout speeds up the production process, reduces costs and increases portability [44, 45].
3. Combinability and Divisibility: With the polyvalence approach, structures can be rearranged for different functions; movable walls and sliding panels support this strategy [42] [46].
4. Neutral Areas: Spaces that are not tied to a specific function can be opened to different uses with the harmony of service and served areas. The "shell and core" approach is an example in this context [47].
5. Additive and Removable: The ability of structures to expand horizontally and vertically is explained through primary and secondary systems within the framework of Habraken's Open Structure approach [48].
6. Multi-Purpose Use: With the principle of functional ambiguity, a space can be adapted to different functions through open plan and mobile equipment. User participation is an important factor that increases the success of flexibility [49].
7. Different Plan Types: Pre-planning different space organizations that will respond to various user profiles within the same structure provides scenario-based flexibility, albeit limited [45].

These strategies are parallel to each other in terms of the design of sustainable, user-oriented, and transformable spaces, especially with their dynamism, such as TDZ.

**Aesthetic**

Aesthetics is related to the basic psychological needs of the individual and should not be considered as a luxury alone but as a need that increases the quality of life [50, 51]. In architecture, aesthetics encompasses the sensory and psychological effects of space as well as physical elements [52]. While the aesthetic experience is enriched by visual, tactile and kinesthetic perceptions, it is also deepened by cultural and symbolic contexts [53, 54]. Elements, such as material, form and light, shape this experience. Aesthetics and functionality are complementary elements and should be addressed with a holistic approach in the design process. As in Gehry's Guggenheim Bilbao example, aesthetic superiority should be balanced with functional deficiencies [52].

Aesthetics is directly related to the psychological needs of the individual and is an integral part of both sensory and functional experiences in architecture [50, 51]. Aesthetic experience is not only based on physical form; it is also based on emotional, cultural and social interactions established with the space [52] [52, 53]. In the architectural design of TDZs, aesthetics should be evaluated in terms of geometry, light and color, tactile perception, and volumetric arrangement as parameters affecting the user experience as well as visual identity.

Geometric Perception:
Building form and order affect aesthetic satisfaction. Curvilinear forms produce more positive emotional responses; linear geometries evoke a sense of order and power [55] [56]. In virtual reality and EEG-supported studies, it has been observed that curvilinear forms receive higher scores in aesthetic and emotional evaluations [57].

Light, Color and Material Interaction:
Light is the basis of color perception. The quality of natural and artificial lighting determines the atmosphere of the space[58, 59]. Warm colors create a sense of closeness and energy, while cold colors create a sense of spaciousness and calm. However, color cannot be considered independently of light and material; shiny surfaces reflect colors more vividly, while matte surfaces reflect them more deeply [60] [61]. While natural materials provide warmth and intimacy, artificial materials emphasize modernity. Color-material-light harmony has a direct impact on user psychology and spatial perception.

Aesthetics and Functionality Balance:
Aesthetics should not only be evaluated as visual satisfaction; it should be evaluated together with the usability of the space. Integrating aesthetic values without compromising functionality increases the design quality in multifunctional structures such as TGB. Gehry's Guggenheim Bilbao example emphasizes the importance of this balance [52]. These components are important design parameters that increase the aesthetic quality in TDZs and strengthen the identity of the structure and user interaction.

**Sustainability**

Incorporating natural environmental components and climatic data into architectural design is fundamental to achieving sustainability goals related to ecology, human well-being, resource conservation, and economic efficiency [62]. Sustainability is a holistic approach developed against global problems such as resource depletion, environmental pollution, climate change and social inequality. Instead of waste accumulation and resource waste caused by the linear economy, a circular economy should be adopted; renewable energy use and carbon emission reduction should be prioritized. While social sustainability requires social justice and participation, economic sustainability should be supported by innovation and responsible resource use [63]. Ecological balance, continuity of natural processes and effective use of renewable resources form the basis of sustainability [64]. Local resource use, recycling and long-term planning are important in this context. Sustainability in architectural design provides both environmental and social benefits by integrating with strategies such as life cycle analysis, circular economy, adaptive management, ecological restoration and community participation. Sustainability in architecture stands out as an approach that considers environmental, social and economic balances with resource management, life cycle-based design and quality of life-oriented solutions [65].

***Table 5.*** *Parameters of the concept of sustainable architecture* [65]

| Principle | Evaluation Parameters |
|---|---|
| **Resource Management Policy** | Effective Use of Energy |
| | Effective Use of Water |
| | Effective Use of Material |
| | Effective Use of Building Areas |
| **Life Cycle Design Principle** | Pre-production Period |
| | Construction Period |
| | Post-Production Period |
| **Design Principle for Quality of Life** | Protection of Natural Conditions |
| | Urban Design and Land Planning |
| | Design for Human Health and Comfort |

### Social and Cultural Context

Architecture is not just the production of physical environments; it is also closely connected to social and cultural contexts. Social norms, traditions, and cultural values shape spaces and their relationships with users. Emphasizing contextuality and locality, as opposed to modernism’s universalism, promotes spaces with distinct identities. “Critical regionalism” supports a sense of belonging by reinterpreting local architectural values in contemporary ways.

Space should be considered as a phenomenon where individuals establish their identities and social ties; cultural heritage, traditional lifestyles and local rituals should be integrated into the design process. While the concept of “non-place” brought by globalization points to the production of spaces without identity and disconnected from context; the context-oriented design supports user experience and social sustainability [66, 67].

Contextual analyses should not be limited to the physical environment but should also include social, cultural, and economic parameters [68]. Physical reflections of the social and cultural context include open spaces interacting with the landscape, spaces that enable socialization, and the use of historical and cultural elements with contemporary interpretations at the material, plan, and form levels. With this approach, architecture not only produces structures but also becomes a social tool that shapes lifestyles.

### Economic Feasibility

The construction industry today is under pressure to develop more efficient and cost-effective solutions due to the increasing population, sustainability goals and economic constraints. The resource wastage, low productivity and high costs caused by traditional methods have necessitated the adoption of modern construction methods (MMC) such as prefabrication, modular systems and hybrid structures. MMC can reduce construction time by up to 50% with factory-produced structural elements, while also reducing waste production and energy consumption [69-71]. For example, projects such as the La Trobe Tower, which was completed 30% faster, demonstrate the potential of this method[72]. However, high initial costs, lack of regulation and industry resistance limit the widespread use of MMC [73].

Life Cycle Cost Analysis (LCCA), used together with Building Information Modeling (BIM), which was developed for the purpose of more accurate management of construction processes in terms of cost and performance, enables the planning of costs that will occur throughout the entire life of buildings. This method optimizes investment, operation and maintenance costs starting from the design phase; while also improving visualization and decision support processes [74].
Another digital technology that increases field efficiency, the Internet of Things (IoT), speeds up processes and reduces maintenance costs by monitoring material and equipment management with real-time data. However, inadequate data-sharing infrastructure, security vulnerabilities, and installation costs make implementation difficult for small-scale businesses [75, 76]. Additive manufacturing (AM), on the other hand, attracts attention with its fast production and low material usage. This technology, which can reduce wall production time by up to half [77], offers potential, especially in the production of complex forms, but is still in the development phase due to material incompatibility, lack of standards and limitations in large-scale applications [78]. All these approaches play a transformative role in the construction sector's achievement of cost, speed and sustainability goals.

### Technology and Innovation

Architecture has been transformed with technology and innovation throughout history; today, these elements have become even more critical in line with environmental problems and energy efficiency targets. Smart materials, dynamic façade systems and smart building technologies transform architecture into a versatile design area by establishing a bridge between functionality and sustainability. Smart materials increase energy efficiency and improve building performance thanks to their structures, which are sensitive to environmental stimuli [79]. These materials, developed in mechanical, optical, self-healing, energy-generating, coating and composite types, provide durability and environmental compatibility. Dynamic façade systems offer solutions that respond to environmental data in order to increase thermal and visual comfort, provide natural ventilation and reduce energy consumption [80, 81]. Kinetic structures and façade elements designed with smart materials and biomimetic applications increase the functional and aesthetic performance of façades. Smart building systems, on the other hand, offer solutions in multidimensional areas such as energy management, comfort, security and digitalization. While the components cover functional frameworks such as technology, health, flexibility and ecology, they work in integration with systems such as HVAC, lighting, energy and security, improving the sustainability of buildings and user experience [82]. This integration transforms the concept of smart buildings into an indispensable architectural strategy for reducing environmental impacts and improving the quality of life.

**Privacy and Security**

Privacy and security in the design of workspaces have a decisive effect on employees' psychological comfort, productivity and interaction level. Open-plan office arrangements, in particular, create significant problems that reduce satisfaction due to a lack of visual and auditory privacy [83]. In a research by Kim and de Dear [84], it was statistically demonstrated that lack of visual privacy negatively affects satisfaction (-0.46) and lack of auditory privacy also produces significantly negative results (-0.20). Privacy is addressed in three dimensions: visual, auditory and physical. Glass partitions and semi-permeable panels are recommended for visual privacy, acoustic panels and individual work cabins for auditory privacy, and closed meeting areas and private interview units are recommended for physical privacy [85]. Integrating privacy into design is considered as a holistic strategy that increases not only individual comfort but also collaboration and productivity.

In today's workplaces, security is addressed holistically, not only physically, but also with digital protection, access control, and human-centered design approaches [83] [85] . Multi-layered access control provided by systems such as card access and biometric verification enables both physical security and monitoring of access records. Closed-circuit camera systems, motion detection sensors, and artificial intelligence-supported monitoring technologies support in-building security; data encryption and multi-factor authentication provide protection against cyber threats. Emergency evacuation systems and guidance for fire and disaster scenarios also reinforce the sustainability of security.

Cybersecurity applications have gained a critical place in digitalized business processes. These approaches, supported by firewalls, network monitoring systems, and data encryption techniques, are strengthened with training for employees. Security systems do not only provide physical protection; they also contribute to employee productivity by increasing the sense of psychological security.

Privacy and security stand out as complementary design criteria, especially in open-plan office layouts. The protection of visual, auditory and physical privacy is supported by acoustic solutions, modular furniture and individual areas. Leading office applications exemplify these approaches: Google invests in individual focus areas, Amazon in biometric access systems, and WeWork in flexible and privacy-focused spaces [83]. These examples show that the balanced integration of privacy and security is a fundamental design strategy for sustainability and efficiency in the workplace.

## 4. DISCUSSION

In line with the criteria addressed by literature sources, it is seen that architectural design processes are not limited to traditional criteria such as aesthetics or functionality but are shaped in line with multi-dimensional approaches. In this context, the basic criteria to be considered in design include functionality, flexibility, aesthetics, sustainability, social and cultural context, economic feasibility and security parameters. It can be said that considering these criteria with a holistic approach forms the basis of contemporary and sustainable architectural design understanding.

***Table 6.*** *Parameters and approaches of the concept of TDZ architecture (Produced by author)*

| Design Parameter | Architectural Approach |
|---|---|
| **Functionality** | "Form Follows Function", Flexible Design, Adaptability to Social Context |
| **Flexibility** | Modularity, Neutral Areas, Different Plan Types, Addition and Removal, Mobility, Combinability, Multi-Purpose Use |
| **Aesthetic** | Visual Approach, Sensory Approach, Symbol and Meaning, Function-Aesthetic Balance, Historical and Cultural Context |
| **Accessibility** | Parking, Transportation, Access, Accessibility |
| **Sustainability** | Resource Management, Life Cycle Design, Design for Quality of Life |
| **Technology and Innovation** | Intelligent Material Use, Dynamic and Interactive Building Components, Intelligent Building Systems, |
| **User Experience and Social Life** | Design for People, Design with Society and Environment, Design with Cultural Elements, etc. |
| **Security and Privacy** | Visual Privacy Design, Auditory Privacy Design, Disaster and Accident Safety Design, Infrastructure and Digital Security Systems Design |
| **Feasibility and Cost (Economic Feasibility)** | Modern Methods of Construction (MMC), Building Information Modeling (BIM) and (LCCA), Use of Internet of Things (IOT), Additive Manufacturing |

## 5.CONCLUSION

This study has shown that Technology Development Zones (TDZs) have become an integral part of innovation strategies, with their evolution shaped by ongoing advancements in technology, shifts in policy, and changing economic priorities. Although TDZs were initially established to foster collaboration between universities and industry, their purpose has broadened over time, making them key drivers for research, entrepreneurship, and the growth of knowledge-based economies.

While there is considerable research focused on the economic and managerial aspects of TDZs, the architectural and spatial qualities of these environments remain underexplored. International models reviewed in this study, including AMIEM—Amaral's evaluation model for TDZs—highlight the importance of adaptable and well-designed spaces that can accommodate a diverse range of activities and user needs. In Türkiye, the lack of unified architectural standards for TDZs continues to present challenges in achieving consistency and quality across different sites.

Overall, the findings suggest that a holistic approach to the architectural design of TDZs—one that considers factors such as functionality, flexibility, sustainability, and aesthetics—can play a critical role in enhancing both innovation capacity and user experience. Continued research on the architectural dimension of TDZs could provide valuable guidance for policymakers, designers, and all stakeholders aiming to improve these dynamic environments in the future.

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Review Article GU J Sci, Part B, 13(2): 193-199 (2025)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

http://dergipark.gov.tr/gujsb

# A Multi-Layered Examination of the Conceptual Role of Knowledge in Architectural Design

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**Article Info**

*Received: 17/05/2025*
*Accepted: 10/06/2025*

**Keywords**

*Design process,*
*Conceptualization,*
*Knowledge*

**Abstract**

The architectural design process embodies many uncertainties from the very first stage. Therefore, various studies have been conducted in different contexts. Within the scope of this study, it is aimed to examine the role of knowledge in the architectural design process in the context of conceptualization. In this context, the role of conceptualization in the architectural design process is mentioned in the context of knowledge. The act of design starts with the acquisition of knowledge. This knowledge is internalized when the acquired knowledge is interpreted and shaped according to the design problem. The information that is interpreted and used affects both the schemes produced in the first stage of design and the final product produced in line with the schemes. The acquired information is processed by making choices and associated with each other. After this process, which is called the information processing stage, new information is obtained by transforming the information. Concepts are produced by associating the information acquired in the design process and pre-existing information. Concepts are important in terms of expressing thoughts and diversifying ideas. Conceptualization continues from the first stage of design until the final product is produced. As a result, architectural design, conceptual process and information constitute three layers that are integrated with each other at every stage. This multi-layered system consists of a dynamic and interactive structure. In this study, the ways in which information is handled in the architectural design process and its role in the conceptual process are discussed in order to address the place and importance of the subject in design education.

## 1. INTRODUCTION

The architectural design process is a multi-layered phenomenon and this process can be difficult for designers to make sense of. In this study, it is aimed to make an examination in which the role of knowledge is examined in this complex process. In this process, which is discussed in the context of conceptualization, studies defending the view that design is not only intuitive but also a learnable action and can be explained through reason and science have been used.

Christian de Portzamparc (2010) [1], while explaining the process by which words become concepts, asks 'Can one think without language? The limits of language are directly proportional to the limits of the world of meaning. Therefore, the more words designers are guided to design thinking, the wider their imagination becomes. Conceptualization contributes to the architectural design process from a cognitive and pedagogical perspective, supporting a deep understanding of the process and the permanence of learning.

Since the early 20th century, knowledge has become an important research topic in different disciplines. Knowledge, types of knowledge, modes of transmission of knowledge, differences between types of knowledge have been focused on. In the field of architecture, the focus has been on design knowledge, types of design knowledge, and modes of transmission. Oxman (2004) stated that one of the most important forms of design knowledge is conceptual knowledge [2]. Conceptual knowledge is the basic material of design thinking and is very important for the development of design education.

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Architectural design, conceptual process and information constitute three layers that are integrated with each other at every stage. This multi-layered system consists of a dynamic and interactive structure. In this study, which was conducted to address the place and importance of the subject in design education, the ways in which information is handled in the architectural design process were examined and its role in the conceptual process was discussed.

## 2. COMPONENTS OF DESIGN KNOWLEDGE

Knowledge is in the totality of one's cognition system: Knowledge can exist with cognition systems. Objects, facts and events in the environment are perceived, interpreted using cognitive resources in memory, analyzed and synthesized, structured, and problems are solved with this knowledge when needed [3]. The knowledge process is generally defined as the relationship between a knowing subject and a known object, and different conceptions of knowledge theory have emerged throughout history. The conceptions that emphasize the object are called realistic (realism, materialism, naturalism), while the conceptions that emphasize the subject are called idealistic (idealism, rationalism, subjectivism) [4].

When we look at knowledge in the context of memory process, it is seen that they are used interchangeably. With reference to Ülgen (2004), 'declarative and procedural memory' [5] was used to explain declarative and procedural knowledge, and 'episodic and semantic memory' was used to explain episodic and semantic knowledge [6]. Neves and Anderson (1981), on the other hand, used the word knowledge, not memory, when analyzing knowledge based on the memory process. Under the name of 'Theory of Knowledge Compilation', he mentions three types of knowledge [7], [8]. One of these is encoded knowledge in a network of meaning, the second is procedural, and the third is compositional (integrating knowledge). In terms of process, these three types of knowledge are gradually realized in memory and complement each other. These three stages should be considered as a whole for the acquisition of knowledge. Similarly, Marx (1969) categorized knowledge as recall and recognition, reconstruction and reproduction [3]. Table 1 summarizes how different types of knowledge are addressed in different scientific disciplines.

***Table 1.*** *Types of Information (Çam,2025 adapted from a doctoral thesis), [9]*

<table>
<tr><th>Source</th><th colspan="4">Types of Information</th></tr>
<tr><td>Marx (1969)</td><td>recall and recognation</td><td colspan="2">reconstraction</td><td>reproduction</td></tr>
<tr><td>Kant (1994)</td><td colspan="2">information obtained through the senses</td><td colspan="2">information provided by the available data</td></tr>
<tr><td>Klatzky (1980)</td><td colspan="2">declarative</td><td colspan="2">procedural memory</td></tr>
<tr><td>Tulving (1983)</td><td colspan="2">episodic</td><td colspan="2">semantic</td></tr>
<tr><td>Glover (1990)</td><td>encoded information</td><td colspan="2">transactional information</td><td>composition (integrating knowledge)</td></tr>
<tr><td>Brew and Boud (1995)</td><td colspan="2">personally identifiable information</td><td colspan="2">person-dependent information</td></tr>
<tr><td rowspan="3">Uluoğlu (2000)</td><td colspan="2">reflective knowledge</td><td colspan="2">Used in understanding facts</td></tr>
<tr><td colspan="2">operative knowledge</td><td colspan="2">Focuses on how things are</td></tr>
<tr><td colspan="2">contemplative knowledge</td><td colspan="2">Encourages deep thinking</td></tr>
</table>

| | | |
|---|---|---|
| | directive knowledge | Leads to the next step |
| | associative knowledge | Helps to concretise thoughts through association |
| Akın, 1986 (transmitting Canbay Türkyılmaz, 2010) | descriptive information | processor information |

Schön (1985) states that participants who experience the architectural design studio develop a design language in which they use descriptive and procedural knowledge together [10]. Describing the current state of the design and revealing the design decisions it contains refers to descriptive knowledge. Defining the transition from one design decision to another and the method followed in this process refers to procedural knowledge. Due to its transferable characteristic, procedural knowledge gives the student the ability to generalize and abstract in design. Schön (1985) states that individuals who have acquired good procedural knowledge of the design process can easily adapt this knowledge to other open-ended problem solutions [10].

Dorst and Dijkhuis (1995) discussed two paradigms for design methodology in their study, representing two different ways of looking at the world: positivism and structuralism [11]. The rational problem-solving paradigm and action-reflection paradigms are summarized in Figure 1.

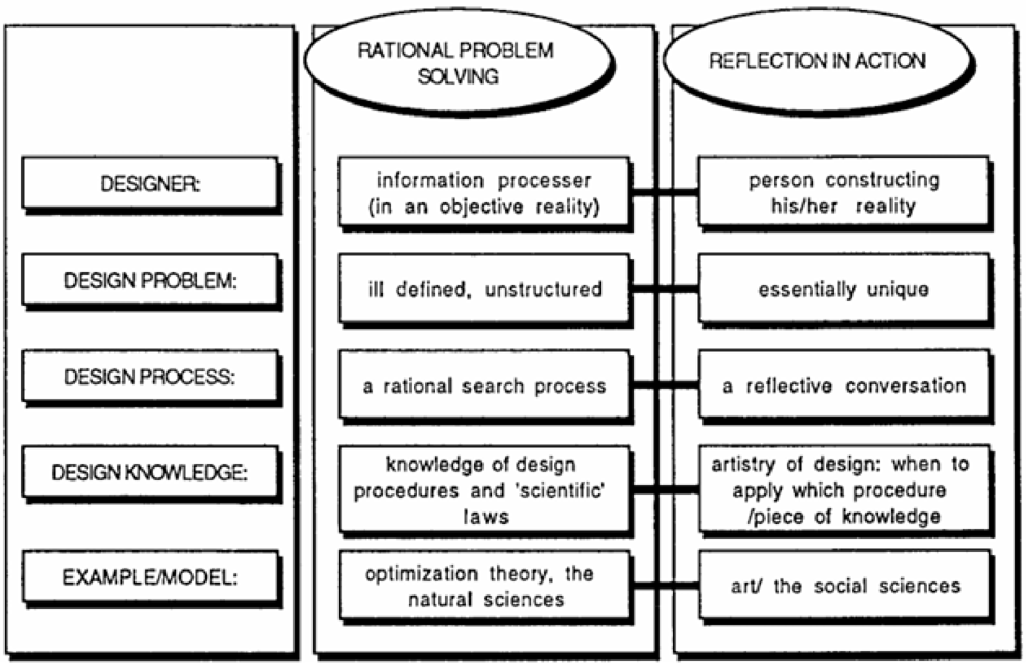


***Figure 1.*** *The rational problem solving paradigm and the reflection-in-action paradigms summarized [11]*

Based on the definitions of knowledge, it is indisputably accepted that there is an inseparable link between knowledge and the design process due to the nature of architecture. Designers use different knowledge and information sets at every step of their design process. This knowledge consists of designers' past experiences, preferences and perceptions, as well as the experiences validated throughout the process and the sharing of related disciplinary practices, depending on the view that knowledge is gained through experience. In a classification made accordingly, the subjective sources of design knowledge are personal judgments, wishes and emotions. The objective sources of knowledge, on the other hand, consist of experimental facts, valid rules, classifications obtained through scientific methods that increase the estimation power of the person, as well as the facts produced by the designer's own cognitive filter. The design process starts with the revision of the existing information contained in the objects, objectives and methods that form links with each other in the design process and the new information acquired with these subjective and objective sources of information and eventually turns into a product. For this reason, design knowledge is defined as a 'dynamic phenomenon' that enables the change of layers that develop throughout the design process [12].

## 3. THE FUNCTION OF KNOWLEDGE IN THE CONCEPTUAL PROCESS

In the memory of individuals, there is a network of meanings as a structural form. The individual develops new words in this form by interacting with stimuli from the environment. It creates a schema form on any subject. The individual develops new meanings to this form in the interaction process and perceives the field as a whole. There is a concept form and the individual classifies his/her knowledge with this form [13].

Gagne (1984) mentioned three different ways of generating, schematizing and conceptualizing knowledge [14]. The first of these is the placement of previously learned information on the relevant information (acquisition - accreations). The second is making sense of the new in the light of what has been learned before (Tuning). The third is the reconstruction of knowledge (reconstruction). With conceptualization, new information is encoded, formatted and stored in long-term memory, helping to retrieve this information after time has passed.

Due to the nature of architecture, knowledge and the design process are inextricably linked. Knowledge and knowledge sets are used in every step of the design process. While analyzing this process in which theoretical and practical design knowledge is acquired and this knowledge is transformed into a design model with creative interpretations, knowledge can be handled under the main headings of knowledge acquisition, knowledge processing and knowledge transformation. In this way, information sets consisting of the information selected as input from the infinite information space are produced and the ways of association and organization of these information sets are determined [9]. As shown in Figure 2, information clusters produced within the infinite information space are organized, linked, and transformed to obtain different information sets.

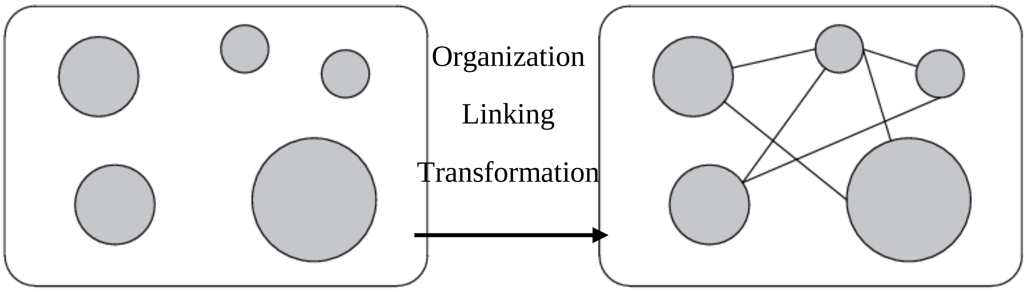


***Figure 2***. *Knowledge Sets and the Ways Knowledge Sets are Related*

Paker (2001) has considered knowledge, which is one of the inseparable basic components of the act of designing, in the dimensions of 'designer's cognitive interpretation/mental process and 'representation and expression of interpretation' [15]. The design process is the act of establishing interactive connections between these three dimensions, depending on the designer's cognitive style. There are two critical points in the context of knowledge in the architectural design process. The first one is the stage where designers decide which information or information sets from the infinite general information space they will accept as design information and take them as inputs to the design. The second stage is the stage where the selected information is processed and associated with each other in the process. The ways in which information and information sets are related within the infinite information space are shown in Figure 3.

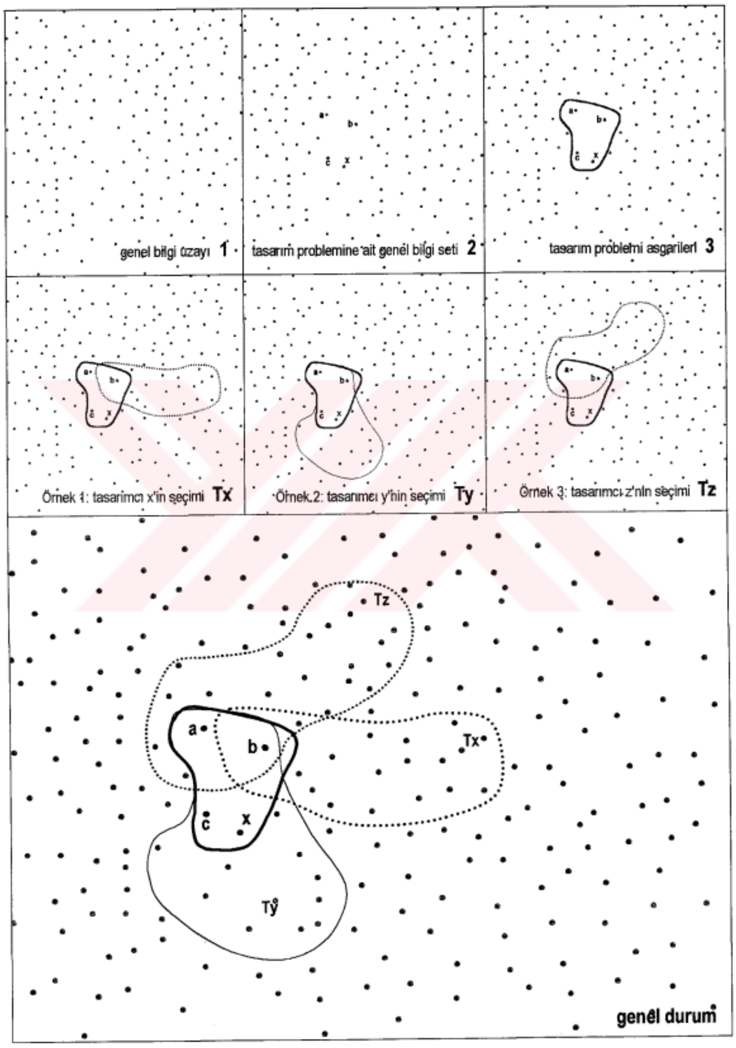


***Figure 3***. *Knowledge Sets and the Ways Knowledge Sets are Related [15]*

In his research, Gardner evaluates the child's mental development by dividing it into qualitatively different stages while reaching the logical and conceptual maturity stage [16]. As a result of the evaluation of the child's cognitive expressions and graphics in the first stage of mental development, he examined the metaphorical language used between the visual reality and the perspectival expressions used in the drawings and stated that the same rules applied by drawing are applied in the management of mental operations and tried to obtain data on the development of logical thinking. According to Golomb (1993), who conducted a similar research, one of the data obtained is that the graphic expressions made by the child can be considered as a printout of his/her mental image and conceptual structure [17]. At this point, a similarity can be drawn between this method, which deals with the study of the child's mental development, and the development process of a student's ability to describe the thought process at the beginning of architectural design education. In the first stage of his/her education, the student transfers his/her thoughts into graphic expressions with the symbols already present in his/her memory, while with the knowledge and experience he/she gains during his/her education, he/she can reach the ability to use more advanced and complex symbols.

## 4. MULTILAYERED KNOWLEDGE-CONCEPT-DESIGN

This knowledge is internalized by interpreting and shaping the acquired knowledge according to the design problem. The information interpreted and used affects both the schemes produced in the first stage of design and the final product produced in line with the schemes. The acquired information is processed by making choices and associated with each other. After this process, which is called the information processing stage, new information is obtained by transforming the information [9].

In the design process, concepts are produced by associating the acquired knowledge and pre-existing knowledge. Concepts are important in terms of expressing thoughts and diversifying ideas. The more concepts and information sets are produced, the diversity of the design, the readability of the process and the integrity of the transformation of abstract ideas into concrete products are enriched in direct proportion. Conceptualization continues from the first stage of design until the final product is produced.

The forms of association of information sets produced with concepts are organized and transformed into design products. In order to transform the objectives in the form of abstract and conceptual definitions into a design, it is necessary to apply a design language that transforms abstract concepts into architectural concepts [18]. Starting from the first stage of the design process, designers produce their knowledge based on different approaches according to their own problem definitions. Thus, a design space consisting of different information sets is formed. Each designer creates his/her own design space.

As a result, the architectural design process is a dynamic phenomenon formed by the interrelation of knowledge, conceptualization and design process. In the first layer, the knowledge layer, information is acquired, problems are defined, and the foundations of the design process are formed. In the conceptualization layer, concepts are developed and knowledge sets are produced as a result of the information acquired. With the transfer to design layer, formal decisions are taken by determining the forms of association of these information clusters. Ideas are concretized. These three layers are in a cyclical relationship that allows for feedback.

## 5. CONCLUSION

It should include the conclusion of the article. Due to the nature of architecture, there is an inseparable link between knowledge and the design process. Designers use different information and information sets at every step of their design process. The diversity and organization of this information is directly related to the way the designer conceptualizes the abstract ideas produced throughout the process. The fact that the design process proceeds in an integrated manner with conceptualization enables meaningful learning to take place by linking the existing knowledge of designers with the knowledge sets they produce. In addition, it also supports designers to adapt to different problems and gain multiple perspectives.

In the knowledge-based conceptual process understanding in architectural design, information clusters are created with the information selected as input from the infinite information space, and the ways of relating and organizing these clusters are determined. In this way, unique results shaped by the experiences of each designer can be obtained. This approach contributes to formulating problems and generating alternative solutions to different design problems.

As a result, information has been handled in various contexts in different disciplines. In this study, the way it is handled in the architectural design process is examined and its role in the conceptual process is discussed. The information obtained in the design process and the way of conceptualizing and expressing the information sets produced contribute to the concretization of abstract ideas in the minds of students in architectural design education. This design approach is thought to contribute to the process of developing new thinking strategies by integrating it into different design problems in different design disciplines.

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Research Article GU J Sci, Part B, 13(2): 201-216 (2025)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

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# Historical Transformation of Cultural Heritage Conservation Policies in Turkey with Special Reference to Çemberlitaş Hamam (1951-2004)

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**Article Info**

*Received: 30/04/2025*
*Accepted: 12/06/2025*

**Keywords**

*Çemberlitaş Hamam, Traditional Turkish bath, Cultural heritage conservation in Turkey, Archival research.*

**Abstract**

Among the traditional Turkish baths built in Istanbul during the Ottoman period, Çemberlitaş Hamam is an important example of cultural heritage in the country and internationally, with its location, scale, architecture and historical context. This study discusses the architectural features of Çemberlitaş Hamam, its historical development until the 1950s, and its physical and functional transformation. Since 1951 and the establishment of the High Council for the Historical Real Estate and Monuments, the change in this cultural heritage has been determined in line with the council's decisions regarding Çemberlitaş Hamam and evaluated in this context. Thus, this article is aimed at revealing the historical transformation of cultural heritage conservation policies in Turkey with a special focus on the Çemberlitaş Hamam.

## 1. INTRODUCTION

Many traditional Turkish baths were built in the province, which became the capital of the Ottoman Empire with the conquest of Istanbul, for reasons such as the importance given by the Ottoman people to cleanliness, good income and being built as charitable works. In the Republican Period, many public baths lost their functional and economic value due to changes in living habits and the addition of private bathroom spaces in homes. Consequently, many of these buildings were destroyed by urban plans, ruined or used for different purposes, losing their original function. Although Çemberlitaş Hamam has undergone many repairs and alterations since its construction, it is one of the best-preserved examples of Turkish baths that has maintained its spatial integrity and historical identity as it continues its original function. Today, it serves many visitors due to its location in a region where tourism and trade are intense.

While this study contextualizes the historical process of Çemberlitaş Hamam from the Ottoman period to the Republic, the main focus is examining the conservation policies for cultural property in Turkey through the conservation council decisions taken since 1951, with emphasis on Çemberlitaş Hamam. In this context, the evaluations were based on national legislation as well as international principles and regulations, and the council decisions were analyzed in a holistic manner in line with these principles.

## 2. LOCATION AND ARCHITECTURE OF ÇEMBERLİTAŞ HAMAM

Çemberlitaş Hamam is on Vezirhan Street, Molla Fenari Neighborhood, Fatih District, Istanbul Province (Figure 1). The bath, which is close to the square where the Roman Çemberlitaş Column is located, which gives its name to the bath and neighborhood, has a façade on Divanyolu Street, which has been the city's main street in every period [1]. The bath is surrounded by many cultural properties belonging to different periods. This has obscured other parts of the bath from the outside, except for the masses of the dressing room (Figure 2).

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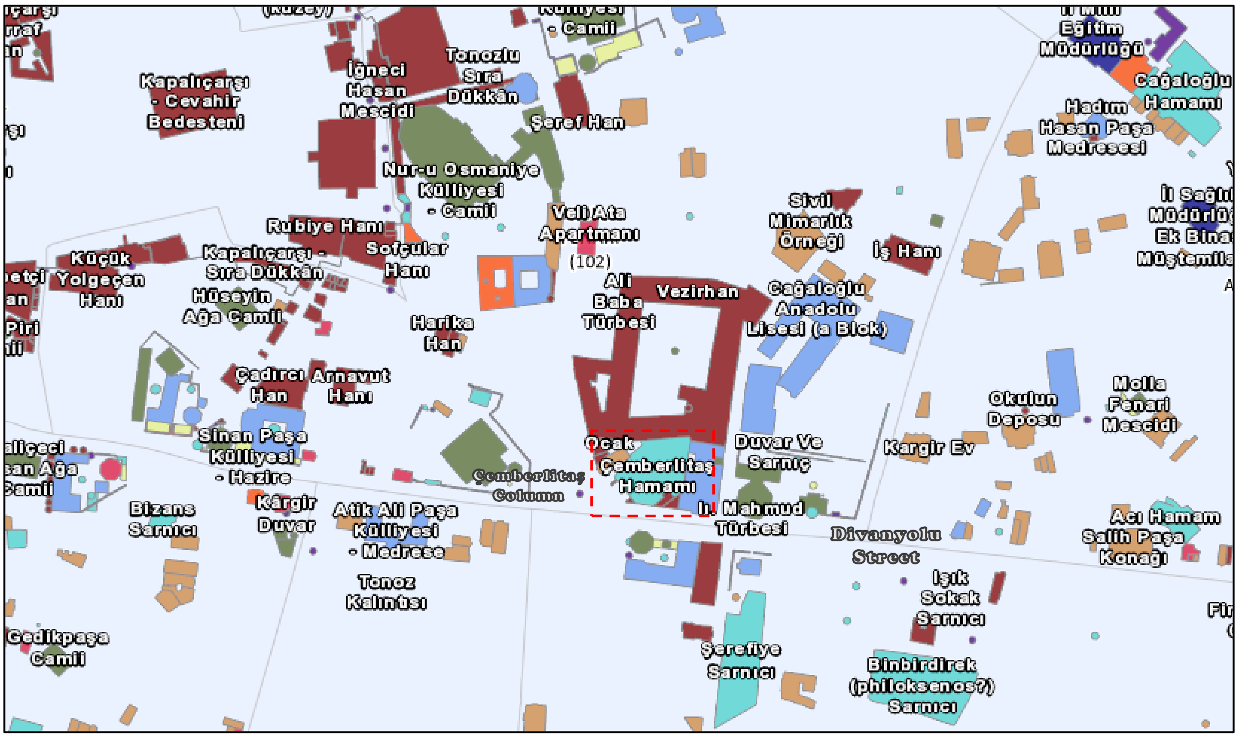

***Figure 1.*** *Çemberlitaş Hamam and its surroundings today* [2]

***Figure 2.*** *Çemberlitaş Hamam entrance façade on Vezirhan Street* (2021)

Çemberlitaş Hamam is a double bath built almost symmetrically with men's and women's sections (Figure 3). The entrance to the men's bath is on Vezirhan Street. The seventeenth-century Köprülü Waterways map shows there used to be a portico (revak) along the entrance façade of the men's bath (Figure 4).

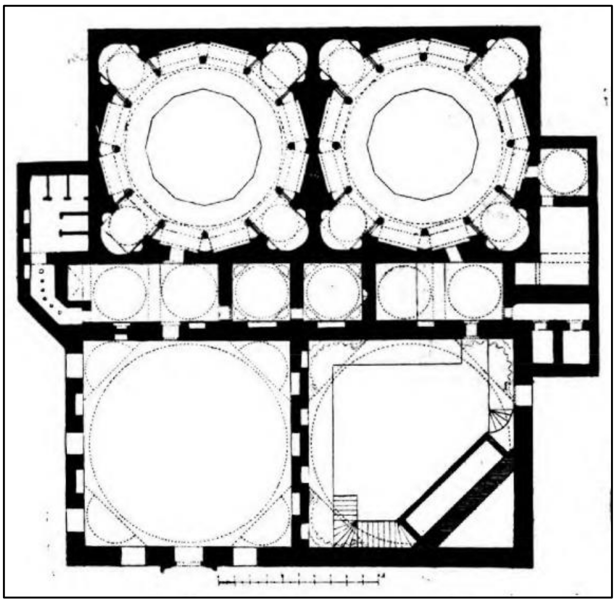

***Figure 3.*** *Çemberlitaş Hamam plan scheme* [3]

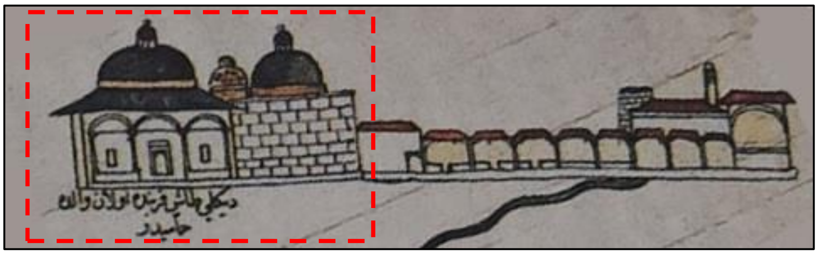

***Figure 4.*** *Çemberlitaş Hamam on the Köprülü Waterways map* [4]

The square-planned dressing room (soyunmalık), which is entered through a crown door with a flat arched door and an inscription on it, is covered with a dome resting on trumpets. In the center of the dome is a circular skylight covered with a light lantern. The rectangular warm room (ılıklık) is covered with two domes resting on pendentives. One of the narrow sides of the space leads to the shaving room (usturalık), which is covered with a dome resting on tromps, and the other leads to the latrine (hela) attached to the outside of the bath mass. The hot room (sıcaklık), which Cichocki describes as "the heart of the bath", has a plan scheme that is not encountered in traditional Turkish baths [5]. The dome in the center of the externally square-planned space is carried by arches resting on twelve columns. Under this dome is a large, heated stone (göbektaşı) in the form of dodecagon. At the corners of the space, four private cells (halvet) are covered with a dome. The spaces between the columns in front of these halvets are covered with triangular pedimented marble walls with couplets carved on them (Figure 5). The creation of a large and spacious temperate space by leaving the upper part of these walls open is an innovation that Mimar Sinan brought to Turkish baths [6]. Except for the column intervals where the transition to this space is provided, bathing benches (seki) and water basins (kurna) are in the intervals.

***Figure 5.*** *Men's bath sıcaklık* (2022)

### 2.1. Architectural Evolution of the Çemberlitaş Hamam

The Çemberlitaş Hamam has undergone a series of architectural transformations since its construction, shaped by urban planning decisions, contemporary functional needs, and changing conservation policies. Following the Hocapaşa Fire of 1865, as part of the area's redevelopment, the widening of Divanyolu Street led to the partial demolition of the women's soyunmalık mass, which was subsequently enclosed with a new façade.

During the Republican era, particularly after the establishment of the High Council for the Historical Real Estate and Monuments in 1951, structural interventions such as the addition of reinforced concrete mezzanine levels, passage openings and a basement floor significantly altered the bath's spatial configuration. After the enactment of Law No. 2863 on the Conservation of Cultural and Natural Properties in 1983, council decisions began to emphasize the preservation of the bath's original function. However, interventions implemented during this period, including reinforced concrete floors and new passage openings, introduced additional layers to the architectural narrative of the hamam. Details of these transformations are discussed in Section 5.

## 3. HISTORY OF ÇEMBERLİTAŞ HAMAM

Çemberlitaş Hamam was built in 1584 by Nurbanu Sultan, the mother of Sultan Murad III, to generate income for the Atik Valide Mosque and Complex in Üsküdar and other charitable organizations [1]. In Tuhfetü'l Mimarin, one of the sources that includes information about Mimar Sinan and his buildings, this bath is listed as Valide Sultan Bath in Dikilitaş [7]. It is also referred to as Valide-i Atik, Gül, Third Sultan Murad Bath [8].

Çemberlitaş Hamam, which belonged to the Atik Valide Sultan Foundation, was operated from the time it was built until 1708 through a single lease method called "icare-i vahide". In this leasing method, the maintenance and repair of the bath and waterways were determined, and the costs for implementation were covered by the foundation. In 1708, with the double lease method called "icareteyn", some of the bath's remit, which was rented for a long period, were transferred to the tenant who had the right of use, referred to as "mutasarrıf" in the documents. Thus, the mutasarrıf was held responsible for the bath's maintenance and repair [9]. In an archival document from 1880, Hacı Ahmed, Mehmet Cemil Efendi and Ayşe Feride Hanım, the mutasarrıfs of the bath, requested repairs from the foundation treasury because the waterways needed repair. The document stated the repair and renovation of the waterways inside the bath, starting from the entrance door to the ashtray, belonged to the bath trustees and the rest belonged to the foundation [10]. Çemberlitaş Hamam was operated under the icareteyn method for many years and changed hands many times. In a 1899 document, it was stated that a non-Muslim person, who was one of the mutasarrıf of the bath, "katiyen ferağ" (absolutely gave it away) to an Italian citizen [11]. In two documents from 1908, the names of Memnûne and Cenab Hanım were mentioned as bath shareholders [12].

During the Ottoman period, many wooden residential buildings, mosques and madrasahs were around Çemberlitaş, but many fires in the region damaged these structures [13]. In 1865, the area was affected by the Hocapaşa fire (Figure 6), the biggest fire in the history of Istanbul, and was reorganized by the Islahat-ı Turuk Commission, which was established in 1869. With the idea of opening the area around the Çemberlitaş Column, houses and other structures left behind from the fire were demolished, and Divanyolu Street was widened by nineteen meters [14]. With this widening work, the corner of the square-planned women's soyunmalık mass of the Çemberlitaş Hamam and part of its dome were cut off and covered with a façade [1] (Figure 7), reflecting the architectural understanding of that period. It can be seen in the photographs of the period that two shops were added in front of the new façade facing Divanyolu Street (Figure 8). These additions made a recess in the women's bath's soyunmalık space up to the level of the beginning of the trumpet and this recess was organized as a resting area for distinguished visitors, accessed by a wooden staircase [3].

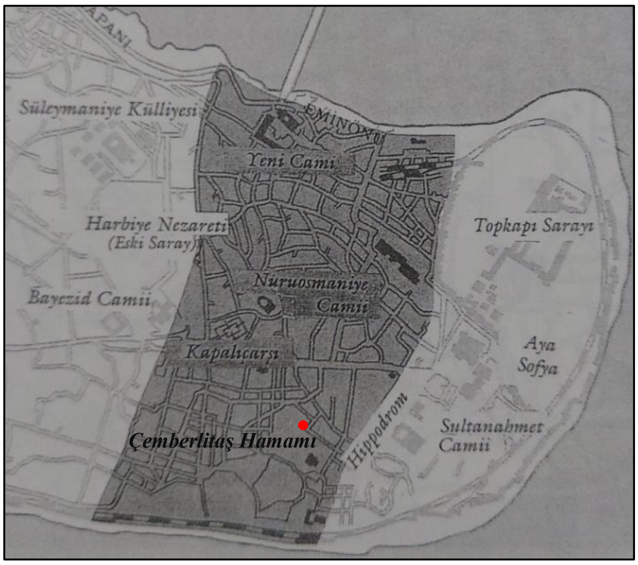


***Figure 6.*** *The location of Çemberlitaş Hamam in the area affected by the Hocapaşa fire of 1865* [14]

***Figure 7.*** *Çemberlitaş Hamam women's soyunmalık façade* (2021)

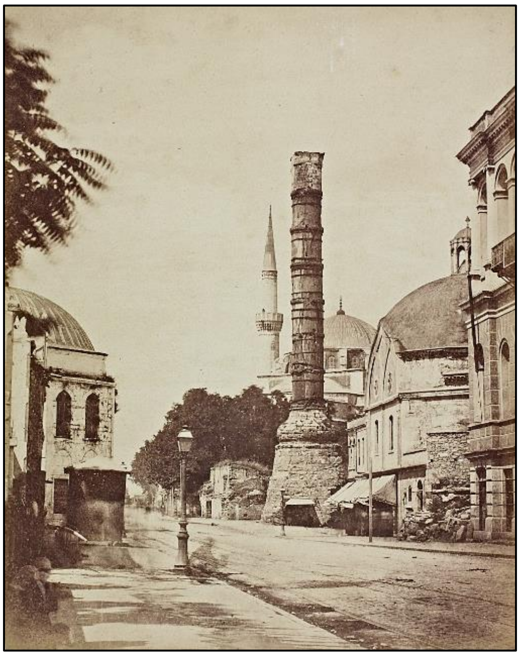

***Figure 8.*** *Women's soyunmalık façade of Çemberlitaş Hamam in 1894* [15]

The Austrian art historian Heinrich Glück conducted research on Turkish art in Istanbul in 1916-17 and examined the Turkish baths there [16]. Glück stated that Çemberlitaş Hamam was used as a military tephirhane (a place for purification of germs with mist) during these years, so passage openings were added between the women's and men's sıcaklık and ılıklık, and a modern heating system was installed in the women's ılıklık [3].

Although the expenses of the bath foundation, which was operated under the icareteyn method for many years during the Ottoman Period, were reduced, the transfer of foundation properties to the administration of the General Directorate of Foundations in the Republican Period led to the transition of income-generating cultural assets, especially baths, to private ownership [5]. The bath, which was transferred to private ownership at an unknown date, changed hands several times [17]. In a 1940 document from the Istanbul Archeology Museums General Directorate of Istanbul Archaeology, which lists the privately owned baths registered as Asarı Atika, the name of Çemberlitaş Hamamı is mentioned [18]. It is understood from newspaper advertisements and sources from this period that the bath was used with its original function during these years. A newspaper advertisement dated 11.9.1938 stated that repairs were made to the bathhouse, the boiler was replaced, a bath and shower were added, and it was closed for a month and a half due to these interventions [19]. K. A. Aru, in his 1941 work titled Turkish Baths Etude, stated the women's bath was not in use [20]. In a 1944 newspaper advertisement, it was stated the bath was for sale [21]; in the Istanbul Encyclopedia, it was stated the bath changed hands in the same year and was used as a men's bath, while the women's bath was not used [22].

## 4. METHOD

The literature review and archival documents show that Çemberlitaş Hamam maintained its original function during the Ottoman Period, and after a brief change of function in the early 20th century, it returned to its original function in the Republican Period. In this study, archival research was conducted on the Çemberlitaş Hamam file at the Istanbul Regional Council for the Conservation of Cultural Property (KVKBK) No. IV, including council decisions and written and visual documents. In line with these documents, the conservation process for the bath is divided into two groups and the decisions are evaluated in the text with chronological and analytical approaches.

The first group starts with decisions taken by the GEEAYK, which was established on 02.07.1951, regarding the hamam. These decisions cover the period until the promulgation of the Historic Artefacts Act No. 1710 dated 25.04.1973, the first conservation law of the Republic. The use of the Ottoman-era law on the conservation of cultural properties, the level of technical staff and financial impossibilities were reflected in the decisions and practices taken in this process [23]. The GEEAYK, which made decisions for the conservation of historical artefacts, did not consider financial resources in this regard since it was a scientific institution. The fact that responsibility for the protection of privately owned cultural assets remained with the property owner led to the obsolescence, dilapidation or destruction of many cultural assets in this situation [24]. The second group begins with the abolition of the Historic Artefacts Act on 21.07.1983 and its replacement by the Law on the Conservation of Cultural and Natural Property No. 2863. The purpose of this law was "...to define movable and immovable cultural and natural property to be protected, regulate proceedings and activities, describe the establishment and duties of the organization that shall set principles and take implementation decisions in this field". With this law, the GEEAYK was abolished, and the powers and duties, such as determination, registration and decision-making regarding cultural and natural properties, were transferred to the Regional Conservation Councils within the framework of the principal decisions of the High Council for Conservation (Regional Conservation Councils were referred to as Conservation Councils between 1987 and 2004) [25]. Council decisions and practices belonging to both groups are discussed comparatively in the context of Çemberlitaş Hamam and evaluations are made in the context of the historical transformation of the approach to the conservation of cultural properties in Turkey.

## 5. EXAMINATION OF ÇEMBERLİTAŞ HAMAM IN THE CONTEXT OF CULTURAL HERITAGE CONSERVATION DECISIONS IN THE REPUBLICAN ERA

Çemberlitaş Hammam was registered as a "historic artefact" by GEEAYK decision no. 343 dated January 24, 1955 and no. 654 dated May 18, 1957 [26]. In the decision of the Istanbul Regional Council of Immovable Cultural and Natural Properties No. 4075 dated September 25, 1987, the phrase "a first-degree valuable art structure in terms of Turkish Architectural History" was included and this document was accepted as the decision determining the bath's registration and conservation group. Çemberlitaş Hamam is within the Historic Peninsula Urban and Historical Conservation Area defined by decision no. 6848 dated July 12, 1995, of the Istanbul Council for the Conservation of Cultural and Natural Property (KTVKK) No. I.

### 5.1. Group 1 Decisions

With a petition sent to GEEAYK in 1965, it was reported that the women's baths' soyunmalık had been vandalized to convert it into a shop. After the on-site investigations made from this petition, it was determined the space's original floor, which was previously used as a warehouse, would be removed and columns, two floors and stairs were added on reinforced concrete foundations. One of these floors was in the form of a mezzanine with a circular space in the middle, the other was arranged on the same level with the shops on Divanyolu Street (Figure 9) and a basement floor was created (Figure 10). With the removal of the walls between the shops and soyunmalık, a connection was established between these spaces. In GEEAYK decision no. 3156 dated June 4, 1966, it was decided that these interventions, which caused the destruction of the space's original elements in question and permanent change, were not objectionable, but it was decided to stop them and submit their projects to the council. In GEEAYK decisions no. 3578 dated July 30, 1967 and no. 4410 January 12, 1969, it was decided that the reinforced concrete mezzanine added to this space could be used without any partition. Although the decision also stated the interventions in the space were by the project submitted to the council, the additional basement floor was not included. This situation showed that inspections were not carried out sufficiently or the issue was ignored. A newspaper article dated 1968 reported that, with these alterations carried out in the women's soyunmalık space of Çemberlitaş Hamam, this section started to be used as a restaurant [27].

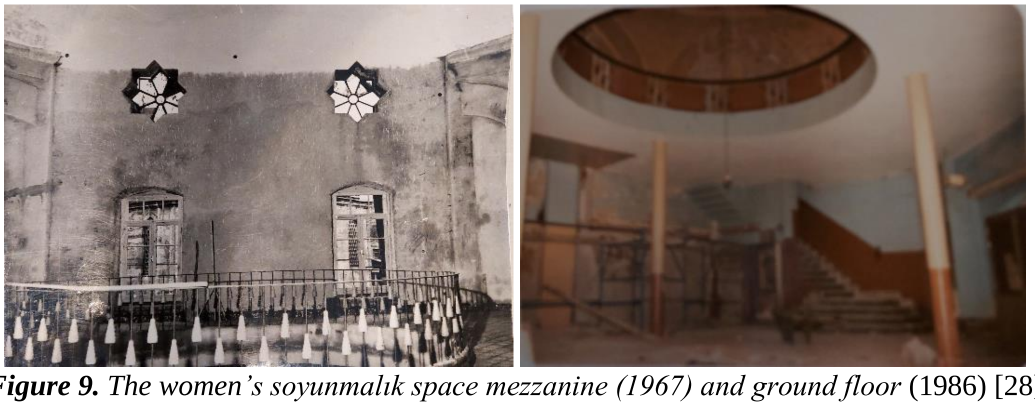

***Figure 9.*** *The women's soyunmalık space mezzanine (1967) and ground floor* (1986) [28]

***Figure 10.*** *The basement floor added to the women's soyunmalık* (1967) [28]

The project, report and photographs prepared by the owners of the men’s section, which served as a single bath with its original function, were submitted to GEEAYK in 1968 as part of the restoration request. It was stated the interventions included arrangement of this section’s entrance, removal of the dilapidated wooden cabinet (şirvan) in the soyunmalık and its replacement with a three-story building with a basement, renovation of the hela and tıraşlık to meet the requirements of modern life, repair of the dilapidated hypocaust brick piers of the sıcaklık, and renovation of parts of the surface coatings in need of repair. In GEEAYK decision no. 5383 dated 10.5.1970, the restoration proposal project was deemed inappropriate and a measured drawing of the section requiring intervention was requested. In the decision, it was stated that, of the interventions planned to be made, only the structure to be added to the men’s soyunmalık was deemed appropriate, provided it did not exceed two storys, and it was decided to send a new project in this direction. In GEEAYK decision no. 6449 dated May 13, 1972, regarding the restoration project prepared after this decision, the addition in question was deemed appropriate. In the decision, it was decided to preserve the original coatings and elements of the men’s bath, complete the deficiencies, add a passage opening between the men’s and women’s sıcaklık due to the desire to use the women’s sıcaklık space, and remove the two-story reinforced concrete annex (Figure 11) added in front of the men’s bath entrance without council permission. Photographs from 1969 show the alterations planned for the men’s soyunmalık were started before this council decision (Figure 12). In this decision, which does not cover the entire bath, the reinforced concrete construction of the two floors added to the soyunmalık and acceptance of opening a passage to allow the sıcaklıks to be used together was an intervention that damaged the bath structurally. Although it contained more information on preservation and repair than previous decisions, by specifying the surface coatings and architectural elements to be preserved and completed, it did not mention the practical details.

***Figure 11.*** *Reinforced concrete addition in front of the entrance of Çemberlitaş Hamam* (1969) [28]

***Figure 12.*** *Çemberlitaş Hamam men’s soyunmalık (1969)* [28]

### 5.2. Group 2 Decisions

On November 14, 1986, the owners of Çemberlitaş Hamam submitted their application for the restoration of the men’s section, which served its original function, as a touristic center for exhibition, display and sales purposes, and the restoration project prepared for this subject to the Istanbul Regional Council Directorate of Immovable Cultural and Natural Heritage on January 8, 1987. Decision no. 4075 dated September 25, 1987, of the Istanbul Regional Council of Immovable Cultural and Natural Properties stated,

> ...That the Çemberlitaş Hamam is a work of great historical value, that it is a work of art of the first degree in terms of the history of Turkish architecture with features that are not found in any other baths in the Ottoman Period Turkish bath architecture, apart from all these, the importance of this building in the history of the city has increased since it is located on the main street of the city and in the middle of a region where important works of history and art are concentrated, and that it is not deemed appropriate to allocate such a work to works other than its main function to turn it into an exhibition-exhibition-sales center, in the face of this situation, it was decided that the fact that this valuable work of architecture is located in a touristic area increases the interest in Turkish baths, and that its restoration and use as a bath in accordance with its original function is deemed necessary in terms of the history of Istanbul; however, in this restoration, it was decided that it would be appropriate for the beauty of the work and the city to demolish and organize the shops that mask the work from the outside according to a project[1] [29].

When looking at the bath buildings that were restored in these years with a commercial function, it was seen that they were irreversibly subjected to many interventions. Therefore, with this decision, the architectural integrity, historical value and identity of Çemberlitaş Hamam were preserved and brought to the present day.

On April 25, 1989, the project, which included alterations to partially open the women's bath to use in its original function, was sent to council for approval. In the project, it was stated the other spaces of the women's bath would be used in their original function since the soyunmalık was being used as a shop, and the entrance from the men's bath would lead to the ılıklık and part of this space would be used as a dressing area. In decision no. 1249 dated August 23, 1989, of the Istanbul KTVKK No. I, it was stated the men's and women's baths should be arranged separately by the traditional Turkish bath layout and it was requested to close the passage opening between the sıcaklık spaces. However, it was stated the entrance to the women's bath could be provided from the back of the men's soyunmalık, which was not by this layout. It was also decided to remove the men's bath third floor changing room and the additions in front of the entrance façade, but they were not implemented. The lack of a measured drawing was ignored in this council decision, taken with the proposed project submitted to council.

Approximately four years after decision no. 1249, on June 7, 1993, the measured drawing of the bath, which was submitted to council, was accepted with decision no. 4661 dated June 11, 1993, by the Istanbul KTVKK No. I, it was decided to submit the application project of the bath to the council. From the photographs sent with these measured drawings, it is understood the women's section of the bath was opened for use (Figure 13).

***Figure 13.*** *A signboard showing the transition to the women's bath* (1993) [28]

[1] Author's translation of decision no. 4075**,** issued on September 25, 1987, by the Istanbul Regional Council of Immovable Cultural and Natural Properties. The document is held in the Istanbul KVKBK No. IV Archive.

On July 1, 1993, in the restoration project submitted to council, the entrance of the women’s bath was arranged as specified in decision no. 1249; from the corner of the men’s soyunmalık, a passage was given to the women’s bath, a part of the ground floor was reserved for women by making arrangements in the men’s soyunmalık space, the additional passage between the men’s and women’s sıcaklık was closed with two doors, and the additions to the entrance façade of the bath were removed except for those with property problems. The additional shops previously located on parcels 180 and 181 in front of the women’s soyunmalık were not included in this project (Figure 14). In decision no. 4737 dated July 13, 1993, of the Istanbul KTVKK No. I, the importance of this cultural asset was emphasized; it was stated the bath should be handled and restored as a whole and the project was accepted for use of the women’s bath with the aforementioned transition for a temporary period until the women’s soyunmalık space was included in the project and integrity was ensured. Today, as stated in this decision, the women’s bath is used as a whole, in its original function. However, the addition of an opening to provide access to the women’s bath is a negative structural intervention to this cultural asset built in the masonry technique. The fact the restoration project in question includes different transitions from the oldest dated drawing of the baths by Glück (Figure 3) shows there were different interventions in this direction. In addition, the fact the women’s bath is still accessed from the men’s bath, as accepted in this decision, is contrary to the notion of privacy that guides the design of the traditional Turkish bath.

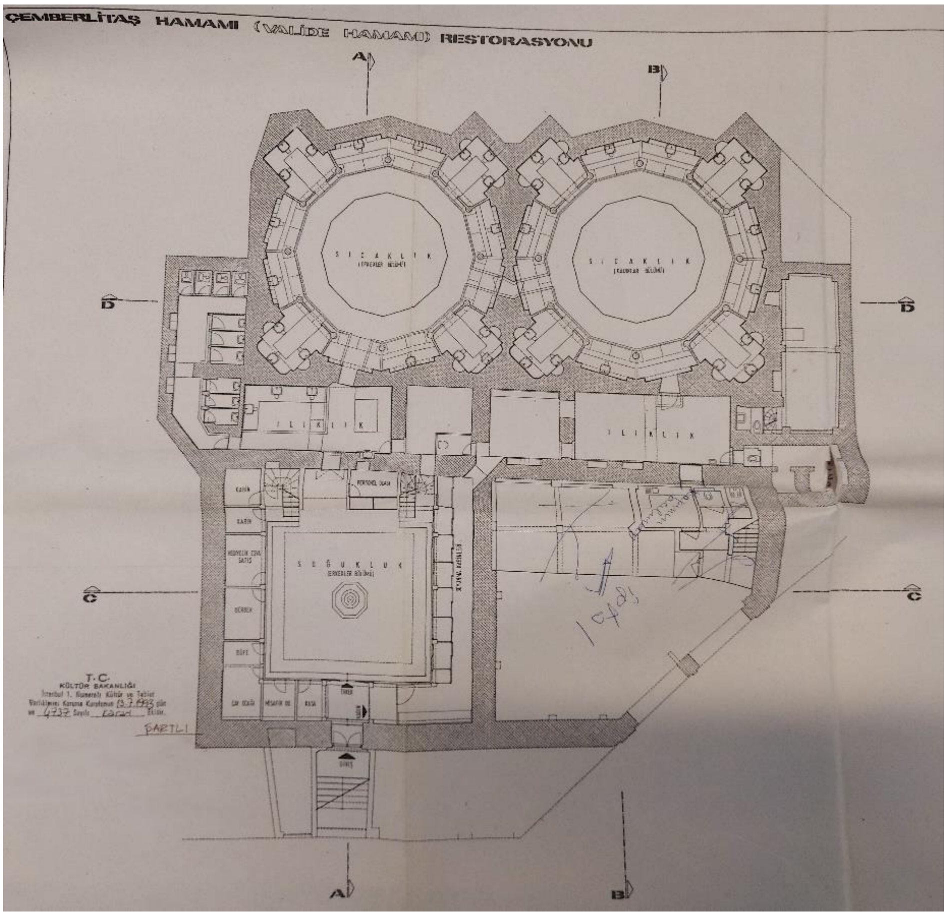


***Figure 14.*** *Restoration Project Plan for Çemberlitaş Hamam* [28]

Following decision no. 4737, the Eminönü District Municipality sent a letter to council requesting the temporary period specified in the decision and whether the women’s baths can be used as a shop. In response, in decision no. 5263 of the Istanbul KTVKK No. I dated January 12, 1994, it was decided that the bath can be used in this way for one year from the date of decision no. 4737 by implementing the application according to the bath’s approved project; at the end of this period, the space in question would be included in the bath’s function and integrity would be ensured.

After decision no. 5263, the owner of the bath sent a letter to council stating it was not possible to include the women's soyunmalık in the original bath function due to financial reasons at the time and parcels 180 and 181 within this space were under different ownership. As a result of this application, in decision no. 5326 dated February 2, 1994, of Istanbul KTVKK No. I, it was decided the bath could be used for three years from the date of the license to be granted by the municipality by the project approved in decision no. 4737, and after this date, the women's soyunmalık should be included in the bathhouse as a whole, considering the historical and architectural value of the bathhouse.

On January 13, 1999, the preliminary project for the inclusion of the women's soyunmalık in the original function was submitted to council. Parcels 180 and 181 on the Divanyolu Street façade of this space were not included in the project due to their different ownership. In decision no. 12065 dated July 26, 2000, of Istanbul KTVKK No. I, it was decided the arrangements for the sıcaklıks in the restoration project approved by council decision no. 4737 would be valid as they were and the project for alteration of the soyunmalıks would be appropriate. Following this decision, since the Fire Brigade Directorate stated a fire escape should be determined by regulations, a revision project was prepared and an exit from the women's baths to Divanyolu Street was added. This project was approved by decision no. 13227 of the İstanbul KTVKK No. I dated 3.10.2001, subject to council decisions no. 4737 and no. 12065 (Figure 15).

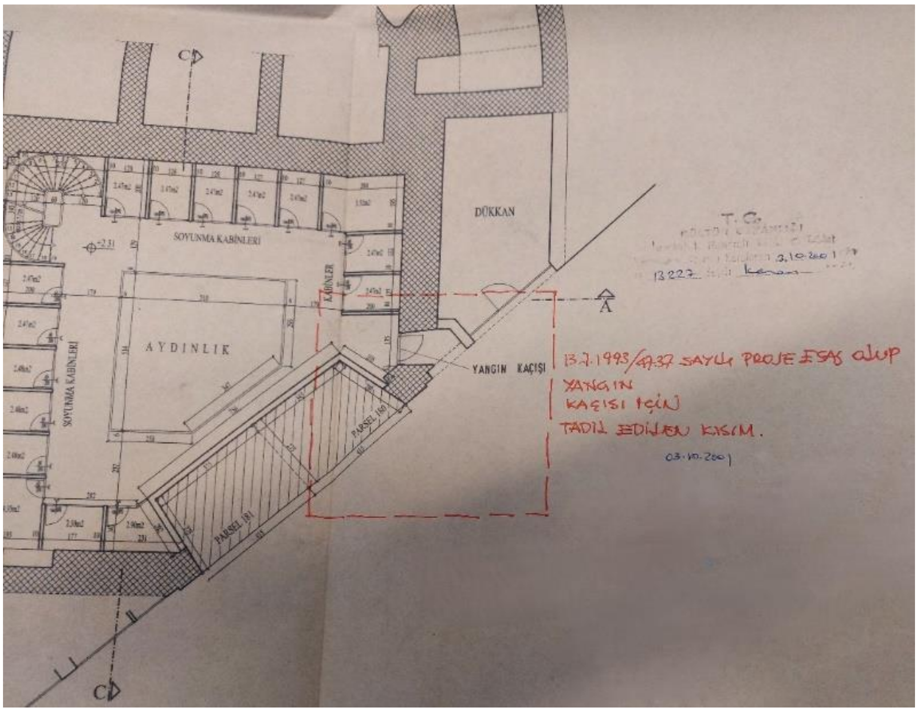


***Figure 15.*** *Revision project showing a fire escape* [28]

In line with decision no. 12065, the men's soyunmalık was rearranged and the transition to the women's bath was provided with a short passage (Figure 16), while the opening added to the corner of the men's soyunmalık in line with decision no. 4737 was closed. The reinforced concrete gallery floor with circular cavities was removed from the women's soyunmalık and a two-story reinforced concrete gallery floor similar to the men's soyunmalık was added, the floor level was rearranged, the floor was covered with marble, and an ornamental pool was added in the middle of the space (Figure 17). In Glück's plan (Figure 3), the original benches and wooden şirvan in this space [3] were not included in the restoration project and implementation. The transition from this space to the ılıklık was achieved by reopening the original passage that was previously closed. In the restoration project attached to decision no. 4737 (Figure 14) and in the photographs from 1993 (Figure 18), it was seen there are original latrines in the men's bath. Despite GEEAYK decision no. 6449 dated 1972, stipulating preservation of the originality of the existing latrines and that decisions no. 12065 and no. 13227 did not include any regulation on this section, the latrines were renovated and shower sections were added.

***Figure 16.*** *Transition from the men’s soyunmalık to the women’s bath* (2021)

***Figure 17.*** *Women’s soyunmalık space* (2022)

***Figure 18.*** *The original latrines of the men’s hamam, which do not exist today* (1993) [28]

The two shops (located on parcels 180 and 181) added to the women’s soyunmalık of Çemberlitaş Hamam in the 19th century were removed in the 1960s because the space was to be used for commercial purposes. After being used in this way for many years, these shops were added again with the project attached to decision no. 13227. A lawsuit was filed against the Ministry of Culture in 2003 for the annulment of this decision. Decision no. 14848 dated 16.4.2003 of the Istanbul KTVKK No. I upheld the validity of decision no. 13227 and the project because these parcels were registered independently at the Eminönü Land Registry Directorate, and there was visual evidence of their existence at the beginning of the 20th century. However, the implementation of this decision was contrary to the purpose of restoring and preserving the bathhouse as a whole, as stated in decision no. 4737 of 1993. Furthermore, this decision showed the restrictive effects of ownership problems on the conservation of cultural assets.

Decision no. 14379 of KTVKK Istanbul No. I dated 4.11.2002 regarding the signboard requested to be placed at the entrance of Çemberlitaş Hamam also covers this hamam and surrounding buildings. For the issue to be taken into consideration, it was decided to remove the additions that harmed the characteristics and quality of this cultural property in the buildings around the bath and to submit a proposal for a uniform signboard and the sketch showing the places where they will be placed to council.

## 6. DISCUSSION

The period between 1951 and 1983, when Group 1 decisions on Çemberlitaş Hamam were taken, began with registration of this cultural property as a “historic artefact in need of preservation” by GEEAYK in 1955 and 1957. In the decision taken in 1966 concerning unauthorized alterations carried out during the 1960s for the commercial use of the women’s soyunmalık space, it was concluded that the addition of a reinforced concrete mezzanine floor did not pose any objection and it was decided the corresponding alteration project would be submitted. The submitted project was approved by decisions in 1967 and 1969. Although the original floor was removed and a basement floor was added, as well as alterations made to other spaces of this section, these interventions were not included in the project and the decisions in question. This situation showed that changes were made outside the scope of the interventions specified in the documents. The absence of any deterrent penalty for those who carried out such interventions, which destroy original elements and cause permanent damage, paved the way for indiscriminate interventions in Çemberlitaş Hamam and other cultural properties, damaging the historical value of cultural assets and shortening their lifespan.

In 1968, the project prepared in line with the restoration requests of the owners of the baths for the men’s section was sent to the High Council, and the decision taken in 1970 requested the preparation of a measured drawing of this section. With this decision, many permanent interventions planned to be made in this part of the bath were not accepted, showing council’s sensitivity for protection of the bath. However, it was decided the new project would be prepared on the condition that the structure to be added to the soyunmalık instead of the şirvan would not exceed two floors and would be submitted to the High Council. When the project prepared in line with this decision was accepted with the decision taken in 1972, the two-story addition, which still exists today, was built with a reinforced concrete system and a passage opening was added between the women’s and men’s sıcaklıks. In contrast to these interventions, which structurally damaged the bath to meet functional needs, the rest of the decision focused on preservation of the original elements and balance was achieved to preserve the bath’s historical value. While these developments indicate progress in national conservation policy, they fall short of international regulations such as the Venice Charter (1964) [4], which emphasizes the principles of minimal intervention, authenticity, and reversibility in the conservation of cultural heritage.

The first decision belonging to the second group, which covers the decisions of the conservation council on Çemberlitaş Hamam from the adoption of Law No. 2863 in 1983 until 2004, determined the bath’s registration and conservation group. This decision, which was taken in 1987 after the restoration project for the conversion of the men’s section used as a bath into a bazaar function was submitted to the regional council, emphasized the importance of the bath in terms of historical, architectural and urban history; it was stated that its restoration was necessary to maintain its use as a bath and aimed to increase public interest in this value. In this restoration, it was stated the additions around the bath should be removed for the aesthetic value of the city and this cultural asset. This decision, which constitutes a significant document for the conservation of the hamam, aligns with several fundamental principles outlined in international conservation charters. The emphasis on maintaining the original function is in line with

Article 4 of the Carta del Restauro (1931), the removal of surrounding additions is in line with Article 6 of the Venice Charter (1964), and the aim of raising social awareness is parallel to the principle of local participation in the Amsterdam Declaration (1975) [4].

In 1989, the project for the use of the women's bath with its original function except for the soyunmalık was submitted to council and in the decision taken in the same year, the principles about the functioning and usage methods of the bath were determined and it was decided to remove the additions on the entrance façade. Although the project was not officially approved, the interventions specified in the decision were implemented; separate spaces were created for male and female users, a passage was provided from the men's soyunmalık space to the women's bath, and this section was opened for use. In 1993, the measured drawing of Çemberlitaş Hamam was submitted to council and the restoration project was sent after council's decision was accepted; arrangements were made according to the decision taken in 1989. The decision was taken in 1993 to temporarily use the bath as specified in the project, provided the women's soyunmalık was included in the original function and integrity was ensured. In 1999, the alteration project was submitted to council. With the council decision taken in 2000, the arrangements for the soyunmalık spaces in this project were found to be appropriate. With this decision, reinforced concrete floors were added to the women's soyunmalık and no change was made in the layout where the passage to both sections was provided from a single place. With the addition of shops in the women's soyunmalık space, the integrity objective stipulated in the decision of 1993 could not be realized. It was understood that the interventions were not limited to the decisions taken, such as removal of the original latrines, which were emphasized to be preserved in a decision in the first period. The fact the decisions for implementation were taken without a restitution project and details were not included has damaged the cultural property's historical identity.

## 7. CONCLUSION

The first period between 1951 and 1983 revealed that the conservation process for Çemberlitaş Hamam was insufficient in terms of a sustainable and holistic conservation approach, document-based decision-making and control mechanisms. Although council decisions taken during this period occasionally expressed principles to protect the building's historical identity and architectural features, the interventions reflected in practice often contradicted these principles. The fact that practices that harm the originality of the building, such as removal of the original flooring in the women's soyunmalık and the addition of a basement floor, were not sufficiently covered in council decisions showed the interventions were not inspected or recorded in detail. Furthermore, the lack of sanctions for such interventions encouraged violation of conservation principles, threatening the historical identity of not only Çemberlitaş Hamam but also other cultural assets.

The second period, which began after the 1983 enactment of Law No. 2863 on the Conservation of Cultural and Natural Properties, showed a more institutionalized and systematic approach was adopted in the conservation processes for Çemberlitaş Hamam. The decisions taken in this period provided a framework in which the building's historical, architectural and urban identity values were emphasized and restoration proposals were evaluated to ensure continuity of the original function. In particular, the decisions taken to remove the annexes around the bath and include the women's section in the functional integrity reveal the existence of an approach to preserve the building's original function and identity. However, some interventions implemented in this period without project approval, the lack of detailed restitution studies and the weakness of a holistic restoration approach in implementation decisions indicated the conservation process was not functioning at an ideal level. Nevertheless, it can be said that a more conscious conservation approach was adopted compared to the first period and this process was an important transformation phase in the conservation of cultural properties.

Çemberlitaş Hamam needs to develop solutions for interventions that are contrary to the architecture, traditions and functioning of the traditional Turkish bath, such as the entrance for men and women from a single location and the presence of additions contrary to its original architecture. In addition, to not repeat mistakes made in the past, the cultural property should be kept under constant supervision by the relevant institutions.

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Research Article GU J Sci, Part B, 13(2): 217-225 (2025)

Gazi University

**Journal of Science**

PART B: ART, HUMANITIES, DESIGN AND PLANNING

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# Adaptive Reuse as Potential Spaces: Shopping Malls – The Case of Ankara

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**Article Info**

*Received: 12/05/2025*
*Accepted: 15/06/2025*

**Keywords**

*Adaptive Reuse,*
*Shopping Centers,*
*Sustainable Architecture*

**Abstract**

It is considered that shopping malls (SMs) will become obsolete in the future due to various reasons, primarily the development of technology and the shift in shopping habits towards online shopping. In this case, the reuse of these structures, which have not yet completed their useful life, by converting them holds many economic, social, and environmental potentials. The purpose of this research is to determine the SM with the highest potential to be reintegrated into urban life with adaptive reuse (AR) strategies instead of demolition in the event that Ankara's SM s become idle in the future. Semi-structured qualitative interviews were conducted with 25 different experts operating in Ankara on AR and SM issues through the SM cards created for SM s in Ankara (29 SM cards in total); as a result of these interviews and literature review, the framework of the subject was drawn; subject titles and sub-titles (themes) were created; and the most suitable SM was identified with the highest potential for transformation. The study reveals that urban memory plays a pivotal role in evaluating reuse potential, with community attachment to historical structures significantly influencing project viability. Findings indicate mixed-use conversions consistently outperform single-function adaptations, offering greater economic and social benefits through diversified programming. Centrally located malls with historical significance emerge as prime candidates for adaptive reuse, given their inherent advantages in accessibility and cultural value. Crucially, the research underscores architectural expertise as the cornerstone of successful adaptive reuse, requiring careful balance between preservation and innovation.

## 1. INTRODUCTION

The concept of environmental consciousness and sustainability began to significantly permeate society, the economy, and the field of architecture following the 1979 oil crisis. Alongside technical aspects such as resource conservation, energy efficiency, and waste management, approaches began to emerge that addressed the built environment through educational, cultural, and social dimensions. The concepts and practices of “green buildings” and “sustainable architecture” have started to be considered not only in the design of new buildings but also in the process of enhancing the functionality of existing structures [13]. [14]. The three pillars of sustainability are defined by the “3Rs”: reduce, reuse, and recycle. A key subcomponent of these principles, “reuse,” emerges in architecture as the concept of “adaptive reuse” (AR). Through the application of AR design principles, existing buildings can be refunctionalized to meet contemporary needs while preserving various values and avoiding demolition.

In addition to its environmental benefits, adaptive reuse contributes to the reduction of economic costs [1],[2]. By enabling efficient use of economic resources, it plays a strategic role in achieving sustainability goals. Revitalizing abandoned or underused buildings provides long-term benefits both economically and environmentally, while also contributing to the preservation of cultural heritage.

Economic analyses by Kincaid [1] and Christensen [2] demonstrate that AR projects offer cost advantages in both the short and long term. Moreover, AR ensures the protection of buildings’ historical and cultural values within their urban contexts. In this regard, it serves as a strategic approach that transfers the heritage of the past to future generations and provides a holistic perspective on urban

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transformation processes [3],[4]. The use of classical buildings for new functions during the Renaissance and the conversion of religious buildings into industrial or military facilities after the French Revolution indicate the historical roots of AR [5],[6]. As stated by Giresun and Tönük [7], the renewal of vacant buildings through AR is not only a technical necessity for ensuring the sustainability of the existing building stock, but also a cultural and social imperative. Thus, AR should be considered as a comprehensive strategy. As emphasized by Underhill [3] and Arnheim [4], it is crucial to implement architectural interventions that meet the demands of contemporary life while preserving the original texture of historical buildings during AR processes.

As demonstrated by researchers such as Powell [8] and Robert [9], historical examples of buildings being repurposed to meet different needs also serve as sources of inspiration for contemporary practices. Approaches advanced by Plevoets & Van Cleempoel [10] and Robert [9] highlight AR's contribution to socio-cultural sustainability and underline its potential as a mechanism for social transformation.

In the contemporary era, digital transformation, globalization, and shifting consumption habits have profoundly reshaped the retail sector and, consequently, the construction industry. The rapid rise of online (e-) commerce has diminished the functionality of physical retail spaces, causing shopping malls (SMs) to fall into disuse. For instance, in the United States, new SM projects are no longer being developed, and existing idle malls are being refunctionalized through AR [11]. In Turkey, it is reported that at least 3 million square meters of mall space face the risk of becoming obsolete [12]. In this context, AR emerges as a beneficial approach for reintegrating these disused areas into urban life and incorporating them into urban transformation processes.

Scharoun [11] notes that through AR, SMs can be redefined with new cultural, social, and economic functions, thereby extending the lifespan of buildings and enhancing their contribution to urban vitality. In Turkey, existing mall spaces hold the potential to be aligned with both environmental and economic sustainability principles [12]. In a rapidly urbanizing city such as Ankara, the adaptive reuse of existing SMs is of great significance. While new construction projects associated with urbanization processes often lead to environmental degradation and loss, AR enables the preservation of various values in existing structures while addressing contemporary demands.

This study aims to examine how existing SMs in a city like Ankara—where rapid urbanization is highly evident—can be refunctionalized through AR, while addressing the environmental, economic, cultural, and social dimensions of this transformation through a holistic approach. Implementing AR strategies in evaluating the current mall stock is expected to contribute to urban transformation processes with a scientific basis and offer innovative solutions within the scope of sustainable architectural practices. In this regard, the theoretical frameworks and practical examples discussed in this study aim to demonstrate how sustainable urban living can be supported through the adaptation of existing SMs. The results obtained will shed light on both the academic literature and practical applications in the field.

## 2. METHOD

The central hypothesis of this research is that abandoned or underutilized shopping malls (SMs) can be transformed into functional and beneficial structures through the principles of adaptive reuse (AR). Shaped by the philosophy of sustainability, rational architectural design approaches and AR practices make it possible to convert shopping malls—symbols of consumer culture—into urban and even green public spaces.

To test this hypothesis, 29 "SM cards" were created by compiling plans, sections, urban context data, and technical information related to shopping malls in Ankara. Based on these cards, semi-structured interviews were conducted with 25 participants, consisting of experienced architects and urban planners based in Ankara.

In the first phase of the interviews, participants were asked to share their views on the advantages and disadvantages of AR compared to the demolition–reconstruction approach. In the second phase, they were asked to select five malls from the SM cards and rank them according to their transformation potential (with scores of 5, 4, 3, 2, and 1 assigned based on order of selection). In the final phase, participants were requested to fill out forms suggesting possible architectural programs for the top three malls they had selected.

All interviews were audio-recorded and archived to be used in subsequent stages of the analysis.

## 3. RESULTS AND DISCUSSION

The findings and discussion are addressed in two sections. The first section presents and discusses the participants' views on the subcategories of adaptive reuse (AR). The second section presents and discusses the participants' evaluations of shopping malls in Ankara in terms of their AR potential.

### 3.1.Evaluation of Participants' Views on AR Subcategories

Within the scope of the study, participants were asked to score the benefits of AR across economic, social, environmental, administrative, and physical dimensions on a scale from 1 to 9. The data obtained from this evaluation are presented in Table 1. According to the table, the average score for economic benefits was 7.16; for social benefits, 7.16; for environmental benefits, 7.92; for administrative benefits, 4.56; and for physical benefits, 4.92. These averages indicate that participants perceive AR to be most beneficial in environmental terms, followed by economic and social benefits.

***Table 1.*** *Average Scores of AR Benefits by Economic, Social, Environmental, Administrative, and Physical Dimensions*

| | Average Points |
|---|---|
| Economic | 7,16 |
| Social | 7,16 |
| Environmental | 7,92 |
| Administrative | 4,56 |
| Physical | 4,92 |

Within the scope of the research, semi-structured interviews were conducted with participants to examine the benefits of AR in economic, social, environmental, administrative, and physical dimensions in detail. As a result of the interviews, 25 different audio recordings were transcribed and thematic analysis was performed. With the analyses, themes were obtained according to the most emphasized features of adaptive reuse (Table 2).

***Table 2.*** *Distribution of Themes of AR Benefits in Economic, Social, Environmental, Administrative, and Physical Aspects*

| **AR** | **Themes** |
|---|---|
| **Economic Aspect** | Cost Advantage<br>Construction Time<br>Sustainable Investment<br>Rent Control |
| **Social Aspect** | Urban Memory<br>Social Space Need<br>Changing Habits |
| **Environmental Aspect** | Carbon Footprint<br>Efficient Use of Resources<br>Waste Problem |
| **Administrative Aspect** | Regulation Problems<br>Planning Deficiency<br>Investor Awareness<br>Role of Public Institutions |

| | |
|---|---|
| **Physical Aspect** | Structural Constraints<br>Structural Advantages<br>Technical Difficulties<br>Adaptation to Urban Context<br>Functional Diversity and Social Complexity |

### 3.1.1.Economıc Aspects of Adaptive Reuse

The economy heading was the most emphasized topic by the participants in the interviews conducted within the scope of the research. Participants expressed extensive opinions on the fact that the budget issue will inevitably confront project stakeholders in a real transformation project for various reasons. In line with the data obtained from the interviews, AR in terms of economy; It is grouped under four themes: cost advantage, construction time, sustainable investment, and rent control.

***Cost Advantage:*** Participants stated that AR is more economical than demolishing and rebuilding an existing structure for various reasons. In this context, participants emphasized that the use of existing building stock's solid foundations and load-bearing systems, and the absence of additional costs (demolition waste disposal, transportation, labor, etc.) resulting from demolition provides a cost advantage. In addition, the easier bureaucratic processes such as obtaining a new license were also mentioned among the economic advantages by some participants.

***Construction Time:*** Under this theme, participants stated that the total construction time is shortened with AR since there is no need for excavation and structural work stages. Considering that the structural work generally constitutes 30%-40% of the total construction, it can be predicted that the total construction production process will decrease by 30%-40% as a result of AR.

***Sustainable Investment:*** Participants emphasized that the transformation process provides long-term sustainability by reducing the resource consumption and environmental impact caused by demolition. They stated that this situation is a more beneficial approach both environmentally and economically.

***Rent Control:*** Under this theme, participants emphasized that Adaptive Reuse (AR) could reduce pressures related to rent increases following demolitions and alleviate burdens on local governments. They highlighted that this could shift planning processes to a more ethical and sustainable foundation. In our country, one of the motivations for demolishing and rebuilding structures is to increase construction area for greater profit. The Urban Transformation Law, created to address Turkey's seismic reality and improve our insufficiently resilient building stock, has ironically turned the demolition and reconstruction of buildings into a new rent-seeking opportunity. Consequently, demolishing and rebuilding under the law, rather than transforming existing structures, often provides investors with larger square footage and profits in many cases. This situation reduces the feasibility of transformation compared to demolition and reconstruction. In city centers, high-density mega projects that could be considered urban crimes have emerged. To increase the viability of AR, decision-makers should establish strict rules regarding density bonuses or even reduce them, which could help solve the problem.

### 3.1.2.Socıal Aspects of Adaptive Reuse

The social aspect was the second most frequently mentioned topic in interviews (150+ mentions). There is strong support for AR in this context as well, and when approached from a social perspective, AR is seen as extremely advantageous compared to demolition and reconstruction. Based on interview data, the social benefits of AR are grouped under three themes:

***Urban Memory:*** Participants stressed that AR is crucial for preserving urban memory and maintaining connections with the past, particularly for historically and culturally significant buildings. They stated that transformation should be preferred over demolition to protect historical fabric and prevent cultural damage. Over time, buildings become part of the city and ingrained in society's urban memory. Some structures may even become inseparable parts of the city due to their longevity and location. In such cases, demolishing and replacing them may upset residents. With AR, buildings embedded in urban memory remain intact. Their identity, cultural value, place in collective memory, and meaning in the city continue to exist. Derelict buildings are "treated" through architecture and reintegrated into urban life, strengthening ties with the past.

***Need for Social Spaces:*** Participants pointed out that limited spaces for socialization in cities and the comfortable, secure, air-conditioned environments of shopping malls have made malls fulfill social needs. They noted that mall transformation processes should consider society's need for social spaces. People have satisfied their socialization needs since the dawn of civilization, starting from their private homes to semi-private and public spaces. These public spaces have traditionally included streets, avenues, and squares—various sub-spaces of the city.

Looking at Ankara, the focus of this research:

• Ankara has a challenging climate—very hot in summer and very cold in winter. People seek warm spaces in winter and air-conditioned spaces in summer for socialization.

• Ankara lacks natural guiding features like a coastline or river that could serve as urban focal points. The city is dispersed, and spaces for socialization are more limited compared to coastal cities.

Due to these two main reasons, malls in Ankara are seen not only as shopping centers but also as socialization hubs and, increasingly, as "life centers," as reflected in recent mall names. These spaces, protected from the climate (cool in summer, warm in winter), with free parking, baby care rooms, well-maintained restrooms, and security, function as next-generation urban centers for Ankara residents. From shoppers to those browsing or passing time, diverse groups frequent these spaces. Thus, as participants noted, considering social space needs during mall transformation is essential.

***Changing Habits:*** Participants stated that with the rise of e-commerce, there is widespread anticipation that malls will lose their function as shopping centers and transform into new uses. They mentioned that malls could adapt to functions like logistics hubs, cultural centers, or educational facilities. In this transformation process, they emphasized the importance of societal preferences, property owners, and administrative institutions, as well as the need to preserve buildings that have left a mark on urban memory. Participants also noted that since malls are products of consumerist culture and shape consumption habits, their transformation could contribute to developing more conscious consumption. They suggested that this transformation could alter consumption patterns and support more sustainable models.

### 3.1.3.Envıronmental (Ecologıcal) Aspects of Adaptive Reuse

Environmental/ecological issues were the third most discussed topic (100+ mentions). When viewed from an environmental perspective, AR is seen as highly advantageous compared to demolition and reconstruction. All interviewees agreed that the less humans interfere with the environment, the more ecological it remains. Based on interview data, the environmental benefits of AR are grouped under three themes:

***Carbon Footprint:*** Participants reported that transforming malls through AR would cause less environmental harm by reducing carbon emissions and greenhouse gases associated with demolition. They also emphasized that minimizing the use of non-recyclable materials like reinforced concrete during transformation could contribute to sustainable construction practices. The carbon footprint measures a structure's environmental impact in terms of greenhouse gas emissions, starting from excavation and continuing throughout its lifespan. AR eliminates the carbon footprint from demolition and rough construction phases. With good design, the new version of the building can further reduce its previous carbon footprint through material choices.

***Efficient Use of Resources:*** Participants stated that AR reduces the need for new material production, enabling more efficient use of natural resources. They highlighted that this limits material consumption and supports sustainable construction models. Buildings that avoid demolition and rough construction phases do not require new concrete, steel, glass, or other construction materials, conserving natural resources like energy and water.

***Waste Problem:*** Under this theme, participants pointed out the rubble problem and high disposal costs associated with demolition, noting that AR eliminates these issues. They reported that AR reduces environmental pollution and resource waste, supporting a sustainable approach. When a building is demolished and rebuilt, valuable materials are salvaged, but nearly the entire old structure becomes waste. With AR, no demolition waste, rubble, or harmful gases are produced since excavation and rough construction are avoided.

#### 3.1.4.Admınıstratıve Aspects of Adaptive Reuse

Administrative issues were not seen as highly significant in interviews. Some participants believed AR is administratively advantageous, while others argued the opposite. Based on interview data, administrative aspects of AR are grouped under four themes:

***Regulatory Problems:*** Participants reported that incomplete archives of old projects and constantly changing regulations create serious challenges for AR projects. These issues can delay processes and increase costs. With each regulatory update, older buildings fail to meet new requirements. Over time, buildings may comply with almost none of the current regulations, from density calculations to fire safety, thermal insulation, and more. Sometimes, under new plans, a building may fall outside required setbacks or even its own lot. In some cases, the existing square footage or number of units may not meet new standards. AR exempts architects/investors from this regulatory vortex, as noted by some participants.

***Planning Deficiencies:*** Participants noted that malls were originally built without adequate consideration for urban planning and transportation, causing problems during transformation.

***Investor Awareness:*** Participants stated that malls were built with a profit-driven mindset, and investors often neglect urban/social benefits during transformation. Investors are expected to have some urban consciousness and adopt a more flexible approach, especially regarding rental expectations, to make AR viable.

***Role of Public Institutions:*** Participants emphasized that municipalities and public institutions should actively guide AR to align with societal and urban needs. Since mall locations, sizes, and openings are regulated by municipalities and commercial entities, raising awareness about AR among these institutions, offering incentives, economic support, and new models (e.g., mandatory 5% library or museum spaces in malls) could significantly advance transformation.

#### 3.1.5.Physıcal Aspects of Adaptive Reuse

When examined physically, AR has both advantages and disadvantages compared to demolition and reconstruction. Based on interview data, physical aspects of AR are grouped under five themes:

***Structural Constraints (Physical Dimensions, Natural Light, and Ventilation):*** Participants noted that AR may limit design freedom due to existing structural elements, making adaptation to new functions challenging. Issues like floor height and spans may hinder new programming. Malls' deep plans and enclosed spaces often lack natural light and ventilation, requiring solutions during transformation.

***Structural Advantages:*** Participants highlighted existing security systems, transportation/parking infrastructure, service facilities, and amenities (e.g., restrooms, prayer rooms) as advantages that can be retained in AR. While debates continue about whether malls—with X-ray screenings at entrances—qualify as urban spaces, their perceived safety (e.g., security guards, cameras) attracts visitors. In Ankara, malls with metro access are most preferred. Existing accessibility and parking (sometimes thousands of spaces) greatly facilitate successful AR.

***Technical Challenges:*** Participants addressed difficulties in updating outdated electrical, plumbing, HVAC systems, and load-bearing structures that may have degraded over time, requiring thorough analysis and reinforcement.

***Integration with Urban Context:*** Participants stressed that malls' large, dominant scale must be carefully reconsidered during AR to ensure harmony with urban fabric and surroundings.

***Functional Diversity and Social Mix:*** Many participants advocated reducing commercial space in favor of civic/cultural uses (e.g., libraries, parks) and designing transitional zones for comfort. Malls already simulate urban environments but should do so more authentically. Successful malls periodically renew tenant mixes and activities to stay relevant. Urban design experts emphasized the importance of "intermediate zone design" for user comfort.

### 3.2 Evaluatıon of Partıcıpants' Perspectıves on The Adaptıve Reuse Potentıal of Shopping Malls in Ankara

The second phase of the research aimed to identify the adaptive reuse (AR) potential of shopping malls in Ankara. Participants were provided with 29 pre-prepared mall profile cards and asked to evaluate five malls of their choice based on transformation potential. They were instructed to make selections assuming all malls had become functionally obsolete. Participants ranked their five selections by transformation priority, assigning 5 points to the highest priority, down to 1 point for the fifth. The scoring results are presented in Table 3.

***Table 3.*** *Distribution of AR Potential Scores for Shopping Malls in Ankara*

| SM | Total Points | Votes Received |
|---|---|---|
| **Karum SM** | 99 | 24 |
| **Kızılay SM** | 61 | 15 |
| **Atakule SM** | 42 | 12 |
| **ATG SM** | 27 | 9 |
| **Next Level SM** | 22 | 10 |
| **365 SM** | 12 | 6 |
| **One Tower SM** | 12 | 5 |
| **Bilkent SM** | 11 | 4 |
| **Kentpark SM** | 11 | 4 |
| **Armada SM** | 10 | 5 |
| **Ankamall SM** | 8 | 3 |
| **Cepa SM** | 8 | 4 |
| **Panora SM** | 8 | 3 |
| **Nata Vega SM** | 8 | 3 |
| **Metromall SM** | 7 | 2 |
| **Kuzu Effect SM** | 7 | 4 |
| **Atlantis SM** | 5 | 2 |
| **FTZ SM** | 3 | 2 |
| **Göksu SM** | 3 | 1 |
| **Gordion SM** | 3 | 3 |
| **Taurus SM** | 3 | 1 |
| **Anatolium SM** | 2 | 1 |
| **Arcadium SM** | 0 | 0 |
| **Optimum SM** | 0 | 0 |
| **Forum SM** | 0 | 0 |

| | | |
|---|---|---|
| **Antares SM** | 0 | 0 |
| **A City SM** | 0 | 0 |
| **Podium SM** | 0 | 0 |
| **Vega S. SM** | 0 | 0 |

In subsequent evaluation, participants scored each mall's suitability (1-9 scale) for conversion to specific building typologies, where 9 indicated optimal compatibility and 1 complete incompatibility.
The typologies evaluated were:
• Urban/cultural facility
• Administrative institution
• Healthcare/educational facility
• Hospitality
• Office/commercial
• Residential
• Mixed-use
• Participant-suggested alternative use

Karum Shopping Mall emerged as the clear leader in both vote count and total points. As one of Ankara's first shopping malls, its central location, frequent usage, and prominent place in collective memory make it a significant urban landmark. Its iconic association with the adjacent Sheraton Hotel Tower further enhances its cultural value. Of 25 participants, 24 identified it as the highest-priority conversion candidate, awarding it 99 total points - a substantial lead over other malls. These results confirm Karum Shopping Mall's status as a cherished urban asset.

Regarding functional conversion, urban/cultural or mixed-use received the highest average score (8/9), followed by office conversion. Residential conversion was deemed particularly unsuitable (lowest scores), reinforcing participants' perception of its cultural significance. The mall's strong association with urban identity suggests it has effectively become part of the city's essence.

## 4. CONCLUSION

The adaptive reuse of functionally obsolete shopping malls presents environmental, urban, cultural, social, and economic benefits. While investors and institutions hold decision-making authority, architects will play pivotal roles in ensuring successful transformations that enhance urban value.
In Ankara, Karum Shopping Mall demonstrates the highest conversion potential. As an established urban landmark, it is perceived as a valuable civic asset. While various reuse options were proposed, mixed-use conversion emerged as the optimal strategy. For large-format retail structures, functional diversification - rather than single-use conversion - appears most effective for extending building lifespans.
Key findings:

1. Urban memory significantly influences reuse potential evaluations
2. Mixed-use adaptations are preferred over single-function conversions
3. Centrally located, historically significant malls have highest conversion priority
4. Architectural teams are crucial for realizing quality adaptive reuse projects

This research provides a methodological framework for evaluating reuse potential that can be applied to other retail structures in transition.

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Research Article GU J Sci, Part B, 13(2): 227-241 (2025)

Gazi University

**Journal of Science**

PART B: ART, HUMANITIES, DESIGN AND PLANNING

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# Measurement of Integration of Shared Bicycle Stations to Rail System in Providing Sustainable Mobility; Examining Examples from Turkey

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**Article Info**

*Received: 23/05/2025*
*Accepted: 18/06/2025*

**Keywords**

*Sustainable Mobility,*
*Intermodality,*
*Shared Cycle and Rail System Relationship*

**Abstract**

In recent years, the paradigm shift towards sustainable mobility in transportation planning has led to an acceleration in scientific studies aimed at improving the performance of sustainable urban transport modes. The aim is to increase sustainability performance by facilitating the transition between sustainable modes within sustainable mobility systems. The concept of intermodality is key to overcoming the origin and destination transport problem (the first and last mile problem) in public transport. Shared bicycle systems, which support rail public transport, are a tool that can increase the performance of sustainable urban mobility as an intermodal travel model, overcoming the first and last mile problem. Well-planned shared bicycle systems that are well-integrated with rail systems increase the success of rail systems in cities and enhance their sustainability impact. This paper aims to present literature on the integration of shared bicycle stations into rail systems, evaluate the level of integration of urban rail systems with shared bicycle systems in Turkey and provide recommendations for transport policies to increase the sustainability impact of rail systems. Additionally, measuring the spatial accessibility of shared bicycle stations within a pedestrian access distance of rail system stations using the isochron mapping method provides a suggestion that can be used elsewhere in the world to measure the level of intermodality between rail systems and shared bicycle systems.

Note: This article is based on the topics covered in the doctoral dissertation of Oğuz Fatih Bayraktar at Gazi University, Institute of Science, Department of Urban and Regional Planning.

## 1. INTRODUCTION

Since the mid-19th century, the bicycle has been used as a means of urban transportation in Europe, especially in France. The inability to easily purchase automobiles has allowed the bicycle to become an effective mode of transportation in urban areas. During this same period, the bicycle played an important role in the memory of urbanization due to the accelerated trend of urbanization resulting from the Industrial Revolution. However, the increasing production of private vehicles after World War II, coupled with the separation of workplace and residential functions in spatial planning, led to a decline in cycling's importance in urban spaces. Consequently, cycling evolved into a recreational activity. In the 1980s, the concept of sustainability emerged, and sustainable urban and transportation planning paradigms that prioritize pedestrians and bicyclists over traditional approaches based on the convenience and speed of motorized transportation gained importance. Advances in information and communication technologies in the 2000s led to the development of intelligent transportation systems, which provide real-time traffic information and shared bicycle infrastructure, bringing a new dimension to urban cycling mobility.

The concept of bicycle culture has undergone a series of transformations in its perception and application. During the Industrial Revolution, it was primarily utilized as a fundamental mode of transportation. Following the Second World War, it emerged as a secondary transportation option, particularly appealing to individuals with lower and middle incomes. Subsequently, from the 1980s onwards, it gained

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prominence as a clean and sustainable form of transportation. In the 2000s, it evolved into a paradigm of smart mobility, and in the 2020s, it has re-emerged as a popular choice for healthy mobility.
While transportation policies aimed at augmenting infrastructure and superstructure capacity with a singular focus on the expansion of motor vehicle infrastructure have yielded immediate solutions to transportation challenges, these measures have concomitantly engendered novel issues, namely the proliferation of automobile ownership, a phenomenon that has emerged in the long term. The increase in automobile ownership has provided people with unlimited access, and individuals' drive for unlimited access has accelerated the consumption of limited resources, creating negative impacts on the sustainability of the urban environment. In this context, scientific studies on urban mobility with a focus on sustainability have become increasingly prevalent.

According to the United Nations Human Settlements Programme's Global Human Settlements Report, a paradigm shift in transportation planning is underway. The traditional approach to transportation planning, which prioritizes the efficiency of motorized traffic based on speed and convenience, is being superseded by a new paradigm focused on sustainable mobility. This new approach emphasizes accessibility, aiming to minimize the need for long-term movement, reduce the number of motorized trips, shorten urban travel distances, and modify the mode split. The objective of sustainable urban mobility is to encourage mobility patterns that curtail automobile dependency and promote non-motorized and collective transportation options [1].

Intermodality, defined as the utilization of multiple transportation modes for a single journey, is frequently discussed as a pivotal measure to enhance sustainable mobility, particularly in urban areas [2].

In recent years, the concept of intermodality—defined as the integration of sustainable mobility modes to reduce access times—has emerged as a new research topic in urban and transportation planning. Intermodality has been demonstrated to enhance accessibility to origin and destination points (i.e., first and last destination points) in urban journeys made by public transportation. Intermodality has also been demonstrated to increase the use of sustainable modes by increasing the "symbiotic" relationality of modes [3]. Given that public transportation commences and concludes at the origin and destination points on foot, respectively, the accessibility of stops or stations exerts an influence on the travel times of public transportation modes [4]. While walking is the most prevalent mode of transportation to reach public transportation, the restriction of the velocity of pedestrian transportation for extended distances and durations diminishes its appeal.

A fundamental distinction between urban rail systems and public transportation by bus is the reliance on a fixed network. Public transportation by bus is a more advantageous and convenient sustainable mobility mode for providing access to neighborhood units, as it has a more flexible structure compared to rail systems. Conversely, rail systems offer the advantage of traversing greater distances than buses, facilitating expeditious transit and seamless integration between urban activities. Despite the potential weakening of rail integration with certain neighborhood units due to their dependence on a fixed network, enhancing rail accessibility can be achieved through the augmentation of intermodality by means of shared bicycle systems. The integration of shared bicycle systems as a complementary mode of transportation to rail public transportation has been identified as a strategy to enhance the overall performance of sustainable urban mobility as an intermodal travel model.

ITDP 2018 underscores that, particularly in European cities, enhancing the reach of public transportation can be achieved by strategically positioning bike-sharing stations in close proximity to bus and rail stations. This approach ensures seamless connectivity between the origin and destination of urban journeys. In particular, Germany and the Netherlands have implemented shared bicycle stations at bus and rail stops to address the challenges associated with the first and last mile of public transportation [5].

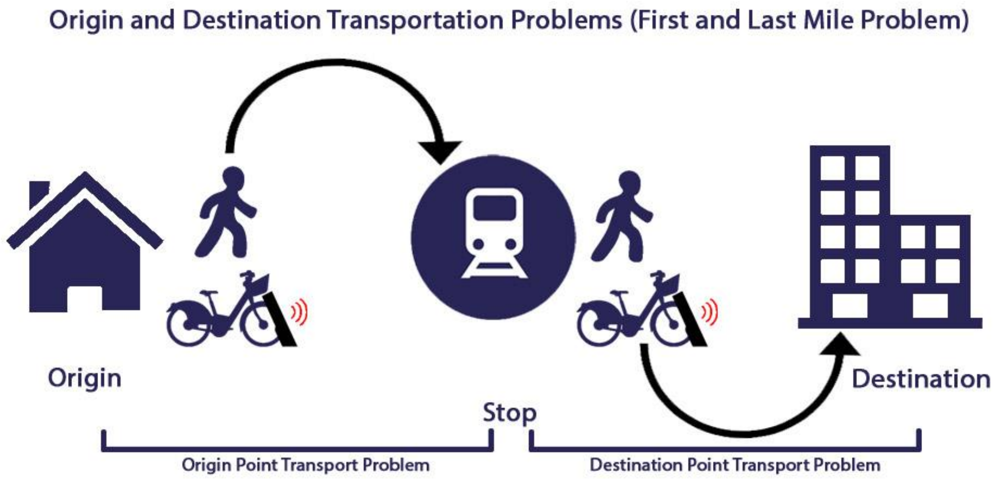



***Figure 1.*** *Origin and Destination Transport Problem in Public Transport (Figure produced by the authors)*

The term "first and last-mile problem" refers to the disconnection between public transportation and the accessibility level at origin or destination. This parameter is of significant importance in determining whether passengers prefer public transportation for their daily commutes [6]. Hussin et al. (2021) defined the first mile as the journey from the initial starting point to the public transportation stop, and the last mile as the journey from the public transportation stop to the desired destination. As metropolitan areas expand, urban transportation becomes increasingly challenging for individuals who do not possess private vehicles. Given that public transportation systems are designed around fixed stops at specific locations, the development of first- and last-mile mobility solutions is crucial for facilitating access to these stops. [7]

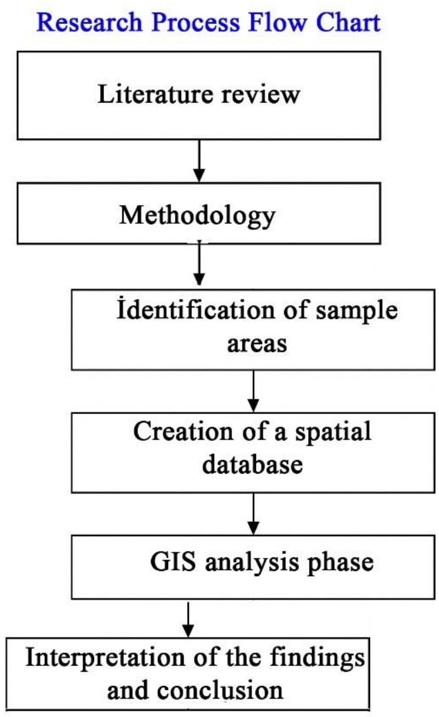



***Figure 2.*** *Research Process Flow Chart*

## 1.1. LITERATURE REVIEW

The foundation for the bicycle-sharing system was initially developed in Amsterdam in 1965 as part of the White Bike Plan, which provided complimentary bicycles. The inaugural paid bicycle-sharing system was initiated in Copenhagen in 1995 and has since evolved into a sophisticated bicycle rental system [8].

Birkholz (2009) posits that it is not always feasible to ride a bicycle on rail and public transportation, and to have a secondary bicycle at the beginning or end of the journey. In response to these challenges, Birkholz (2009) emphasized the benefits of bicycle rental systems or public bicycles as a solution for bicycling in all circumstances [9].

A meticulously designed shared bicycle system can serve as a pivotal integrated transportation mode, facilitating seamless mobility for urban rail systems. This is particularly crucial in addressing the so-called "first and last mile problem" in rail transportation, which pertains to the challenges of commuters navigating from their origin points to transfer stations and subsequently to their final destinations [10]. Recent research on bicycle-based transit-oriented development (B-TOD) has demonstrated that the estimated access distance for cyclists to access rail transit is 1.96 km (1.2 miles). [11].

Jonkeren et al. (2019) found in their study of bicycle-train passengers in the Netherlands that improving the availability of shared bicycle systems at the activity end of train journeys could make bicycle-train integration more attractive [10]. It has been posited that, given the fact that the speed of a bicycle is approximately three times that of walking speed, a bicycle can travel three times the distance of a walker, thereby connecting to nine times the total access coverage area. This would enable rail system stations to connect to more residential areas (Fleming 2016 and Jonkeren et al.) [12], [13].

Griffin and Sener (2016) state that rail public transportation has a special relationship with shared bicycles, that the high speed of rail and the lack of distance between stops can be compensated by bicycle sharing, and that bicycle rail integration can provide long-term lasting effects due to the permanence of rail stations compared to buses [14].

According to Kager et al. (2016), the integration of bicycles and rail systems within a travel chain through intermodality fosters a significant synergy. This synergy fosters the development of an integrated transportation system, one that combines the flexibility of bicycles with the efficiency of rail systems. The integration of bicycles into the rail system serves to expand the spatial accessibility scope, thereby extending the reach of the rail system to areas that were previously inaccessible. This augmentation in accessibility facilitates the rail system's access to a more extensive population base. The integration of bicycles and public transportation has been shown to create a symbiotic structure that results in a new mode of transportation [3].

According to the findings of Martens (2007), the integration of public transportation and bicycles in the Netherlands resulted in a notable increase in both rail travel and bicycle utilization. The survey, administered as a component of the study, revealed that 15% of the participants indicated that the integration of bicycles and rail systems had supplanted previous commuting methods that relied on private vehicles. Van Mil et al. (2020) posited that the flexibility of bicycles, when combined with the speed and comfort of public transportation, has the potential to emerge as a competitive sustainable multimodal transportation alternative to cars [15].

Cervero et al. (2013) posit that the implementation of shared bicycle facilities could assist in addressing the "last-mile" challenge experienced by individuals exiting rail station complexes [16]. The ITDP (2013) proposes the integration of shared bicycles within public transportation systems as a potential solution to the "last-mile" problem for trips that are not within walking distance of stations [5]. Mahajan et al. (2024) contend that to effectively address the "last-mile" challenge in rail systems, it is essential to strategically locate a substantial proportion of shared bicycle stations within a 5-minute walking distance (400 meters) from public transportation hubs. Improving accessibility from public transportation stops to bicycle stations also supports a sustainable transportation network that can reduce traffic congestion and carbon emissions while promoting a healthy lifestyle [17].

The efficacy of bicycle-sharing systems is contingent upon the strategic placement of a substantial number of stations, with the objective of minimizing the distance that passengers must traverse on foot to retrieve or deposit bicycles in proximity to their ultimate destinations. In Paris' Vélib bike-sharing system, stations are located at a rate of 300 meters per station, while in Europe and North America, the rate is 300 to 400 meters per station [5]. Bike-sharing stations function as complementary links in the travel chain between origin and destination points, thereby serving as an effective feeder mode that contributes to the effectiveness of sustainable mobility systems. In the extant literature, the maximum distance between stations recommended by shared bicycle system operators is defined as 400 meters [14, 18].

A study conducted in North America examined station location issues to encourage multimodal cross-flow between public transportation and bike-sharing systems. The study revealed that 53% of bike-sharing operators preferred a distance of 275-400 meters between stations, and that bike stations should be located no more than 400 meters away from public transportation. [18].

Ma, Liu, and Erdoğan (2015) conducted a study in Washington to ascertain the extent to which bike-sharing systems benefit public transportation systems. The researchers found that a 10% increase in the Capital Bikeshare (CaBi) bike-sharing system resulted in a 2.8% increase in subway trips. Moreover, it has been asserted that bicycle-sharing systems do not constitute a comprehensive replacement for public transportation; rather, they function as a complementary element [19].

Shu et al. (2019) stated that the distance between the shared bicycle station and the user is an important factor in the desire to use bicycles in the Chinese sample, that a long walking distance reduces the desire to use public bicycles, and that, according to system operators, the appropriate distance between bicycle stations and public transportation stations should be 120 meters [20]. In Paris, shared bicycle stations are planned to be located at a maximum distance of 300 meters, with one station for every four residential blocks [8].

***Table 1.*** *Accepted Optimal Distances Between Shared Bicycle Systems and Rail System Stops in the Literature*

| Literature Findings | Ideal distance to shared bike stations |
|---|---|
| Banerjee vd.[6] | 300m. |
| ITDP Paris VELİB System [5] | 300m. |
| ITDP (Europe and North America) [5] | 300-400m. |
| Mahajan et al. [15] | 400 m. |
| Shahen Cohen ve Martin [16] | 400m. |
| Shu et al.[18] | 120m. |

A study conducted in Palermo using GIS on intermodality between bicycles and rail systems indicates that combining public transportation and bicycles can significantly reduce private vehicle use, peak hour traffic congestion, air pollution, and noise pollution. In this study, a buffer analysis of rail system and bicycle integration was conducted to calculate the population accessing intermodality. Integration between rail system vehicles and the bicycle sharing system is achieved through bicycle stations located near rail system stations. [21]

This article aims to provide various benefits to transportation policies aimed at increasing the sustainability effects of rail systems by evaluating the integration levels of urban rail systems with shared bicycle systems in Turkey. Additionally, by measuring the spatial accessibility of shared bicycle stations within walking distance of rail system stations using the isochrone mapping method, it proposes a methodology that could be applied in other global case studies to assess the intermodal integration levels between rail systems and shared bicycle systems.

## 2. METHOD

Cities in Turkey with urban rail public transportation systems and cities with shared bicycle rental systems were selected for comparison. A total of 12 cities in Turkey currently have urban rail public transportation systems and 10 of these cities have shared bicycle rental systems.

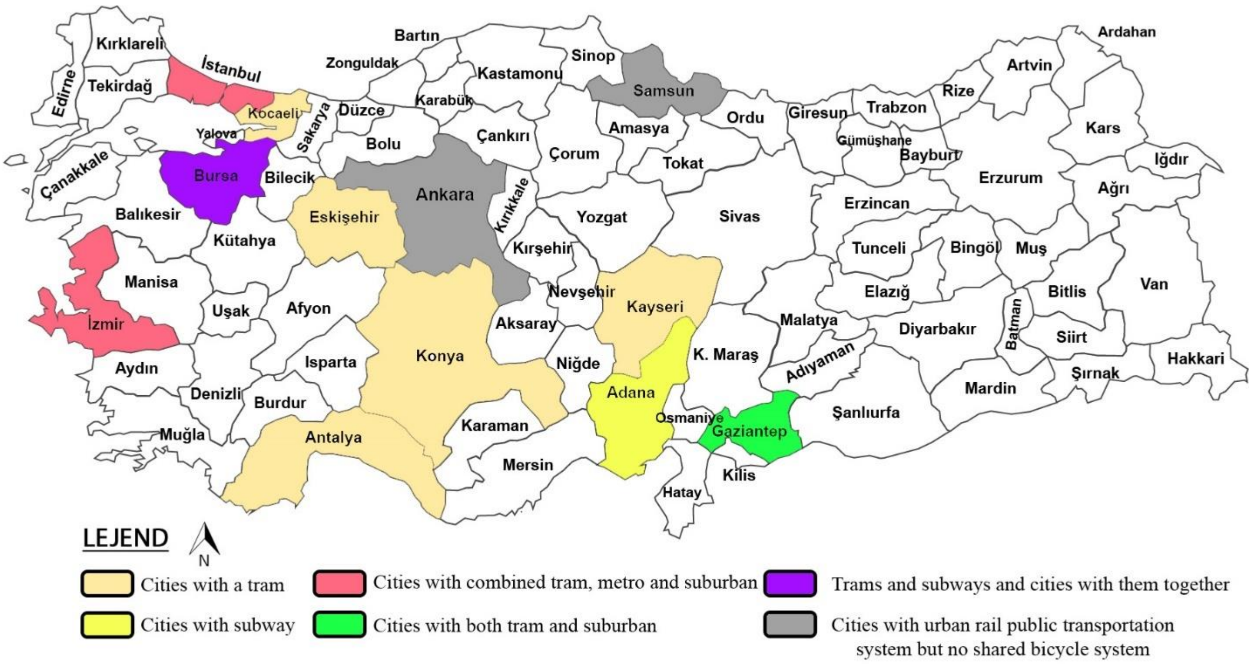



***Figure 3.*** *Types of Rail Systems of Sample Cities in Turkey (Figure produced by the authors)*

***Table 2.*** *Transportation Data for Cities in Turkey with Urban Rail Public Transportation and Shared Bicycle Systems*

| City | Rail System Type | Shared Bicycle System Feature |
|---|---|---|
| Adana | Metro (13 Stations -Adana Metro) | 9 Stations 82 Bikes |
| Antalya | Tram (68 Stations -AntRay) | 9 Stations 90 Bikes (Antbis) |
| Bursa | Metro (40 Stations -Bursaray)<br>Tram (36 Stations) | 37 Stations (Nilespit) |
| Eskişehir | Tram (77 Stations -ESTRAM) | 3 Stations 30 Bikes (Espedal) |
| Gaziantep | Suburb (16 Stations Gaziray)<br>Tram (47 Stations) | 7 Stations 101 Bikes (Gazibis) |
| İstanbul | Metro (130 Stations)<br>Suburb (48 Stations<br>Tram (81 Stations) | 120 Stations (ISBIKE) |
| İzmir | Metro (24 Stations)<br>Suburb (41 Stations İZBAN)<br>Tram (46 Stations) | 60 Stations (Bisim) |
| Kayseri | Tram (75 Stations) Kayseray | 80 Stations 1000 Bikes (Kaybis) |
| Kocaeli | Tram (21 Stations) | 74 Stations 550 Bikes (Kobis) |
| Konya | Tram (40 Stations) | 80 Stations 1000 Bikes (Aarbike) |

*Note: Since the accessibility analysis will be carried out by accepting the intersecting duplicate stops on different rail system routes as a single stop, they are counted as a single stop in the list.*

A Geographic Information System (GIS) database has been developed for 10 cities in Turkey to assess the degree of integration between urban rail systems and bicycle-sharing systems. The database encompasses rail system stations, lines, and bicycle-sharing stations. The data collection utilized for geographic analysis was obtained from the ULASAV open data portal [20], the open data portals and servers of metropolitan municipalities [22], [23], [24], [25], [26], the OpenStreetMap Overpass Turbo application [27], municipalities' official websites, and shared bicycle service providers' applications and websites. The most recent route and stop data were stored in the Shapfile format using QGIS 3.36 software, and a spatial database specific to 10 cities was created (see Appendix). Subsequently, an isochrone map method was applied as a GIS analysis.

**Isochronous map method**

Conventionally, accessibility measurements in GIS environments have been derived using the buffer analysis method, which calculates a bird's-eye view buffer area at an accessibility radius distance that is independent of the network. Recent progress in network analysis has given rise to the development of software capable of facilitating network-focused morphological urban analysis within the GIS environment. The isochrone map method is employed to analyze the actual service area by combining polygons formed by points that can be reached within a specified time or distance based on the urban network. The utilization of the isochron map method traces its origins to the early 20th century, having been employed in the context of inter-city transportation in London and in the measurement of the access area of the public transportation network in Toronto in the 1940s [28].

The fundamental principle of isochronous map creation entails the calculation of all endpoints that can be reached from a designated starting point within a specified time or distance (e.g., 5 minutes or 400 meters) on a real spatial network. These endpoints are then transformed into a convex hull, thereby forming a buffer polygon that represents all accessible areas [28], [29]. The basic inputs are a defined starting point, road network data, travel time, and mode of transportation.

The isochrone map method will be used to measure the pedestrian accessibility coverage area of shared bicycle stations within a 5-minute time frame. An isochrone map can be generated using the Open Route Service ORS Tools plugin [30], an open-source GIS software tool, based on OSM map road network data. By opening the QGIS plugin ORS Tools, the locations of shared bicycle stations processed into the spatial database are selected. After selecting the mode of transportation (pedestrian, bicycle, private vehicle, etc.), a metric based on time or distance is selected, parameters are defined, and the isochrone map analysis is applied. The isochrone map outputs for each point, corresponding to a 5-minute walking distance, are displayed as layers in the QGIS layers section.

The QGIS ORS Tools plugin employs the Range-Dijkstra (time-controlled propagation) algorithm to generate isochrone maps. The algorithm functions on a road network (graph) based on the principle of accessibility coverage from a designated starting point to a specified time or distance limit. ORS employs OSM data to generate a directed and weighted road network structure. Nodes (V) are indicative of road junctions or decision points, edges (E) are indicative of road segments, and weights represent estimated travel times based on distance, time, or modes.

Steps:
1. Select the starting point: $d(n_0)=0$
2. Nodes are kept in a priority queue
3. The distance to each new node is calculated as follows: $d(n)=min(d(n), d(current)+ w(current\text{-}n))$
4. If $d(n)>T$, propagation stops (T: threshold time or distance)
5. Nodes satisfying the condition $d(n)\leq T$ form the isochronous area. [31], [32], [33], [34]

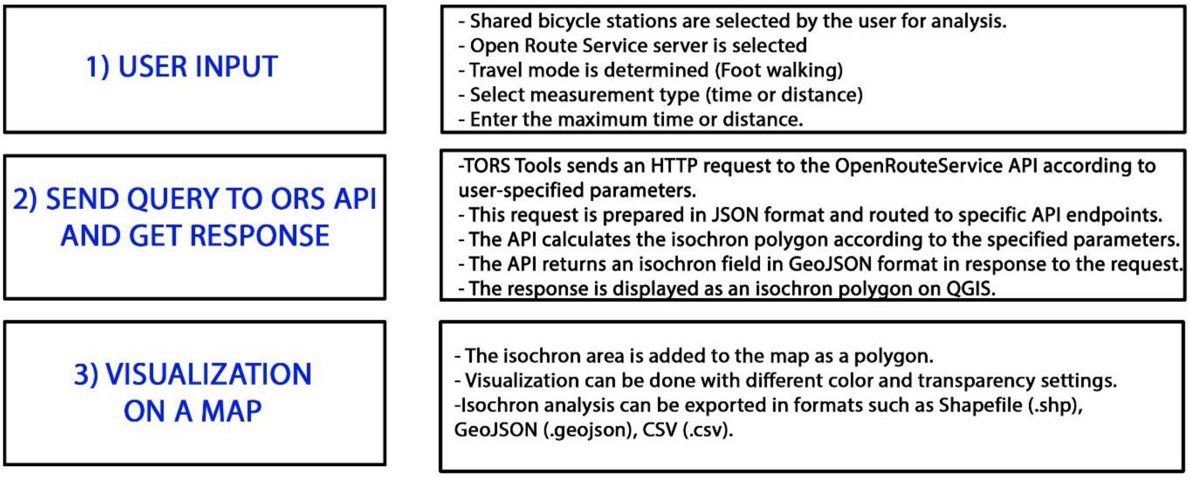



***Figure 4.*** *Isochron Map Creation Stages of ORS Tools Plugin (Figure produced by the authors)*

The aforementioned method was implemented through the utilization of the QGIS ORS Tools plugin, with the objective of identifying areas within a 5-minute access radius of each shared bicycle station within a spatial database created for ten cities in Turkey. The definition of integrated stations encompasses railway stations within a 5-minute access distance that enable intermodal transfers. Conversely, stations that are located more than 5 minutes away were classified as non-integrated stations.

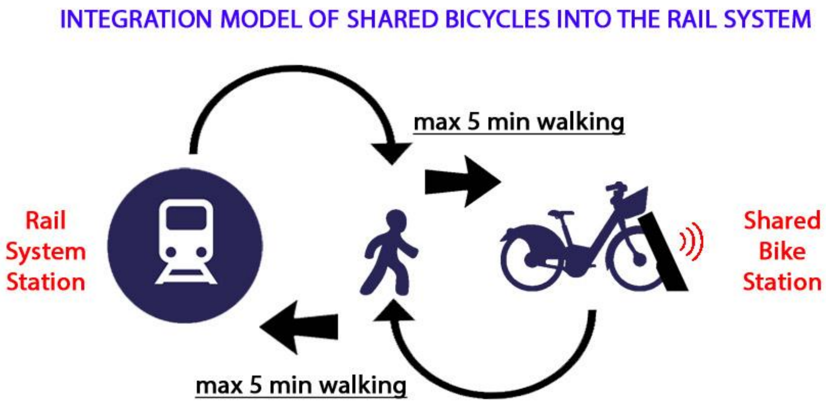



***Figure 5:*** *Integration Model of Shared Cycling into Rail System (Figure produced by the authors)*

In order to measure the level of integration of urban rail and shared bicycle systems in Turkey, the share of the number of rail stops within 5 minutes walking distance of each bicycle station in the total number of rail stations was calculated by counting the number of stops per isochron polygon for each city through QGIS (Select By Area).

The classic location theory assumption posits that accessibility is determined by dividing space into circular buffers. Conversely, the isochronous mapping method delineates the tangible scope of accessibility in relation to spatial and urban network configurations.

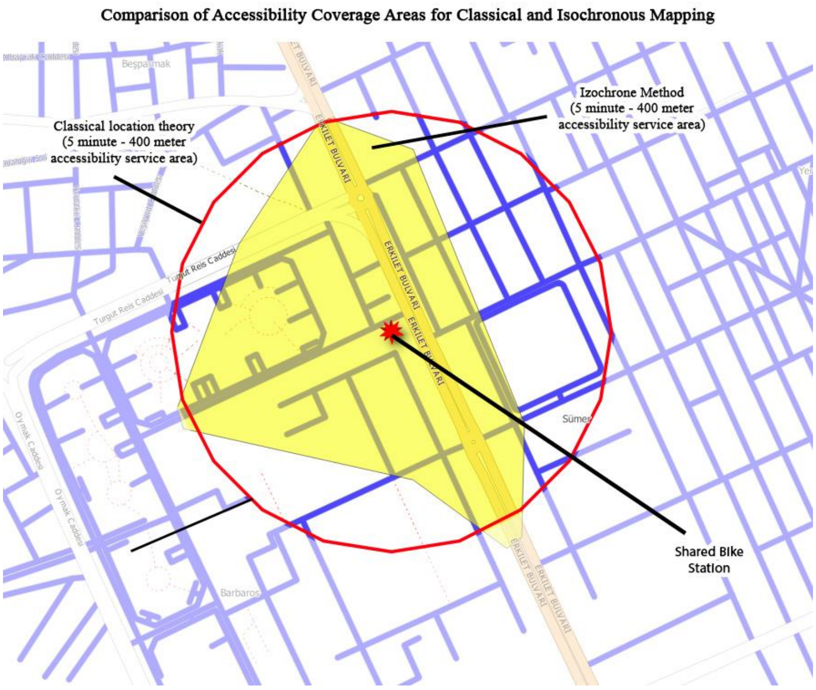



***Figure 6:*** *Comparison of Accessibility Covearege Areas for Classical and Isochronous Map*

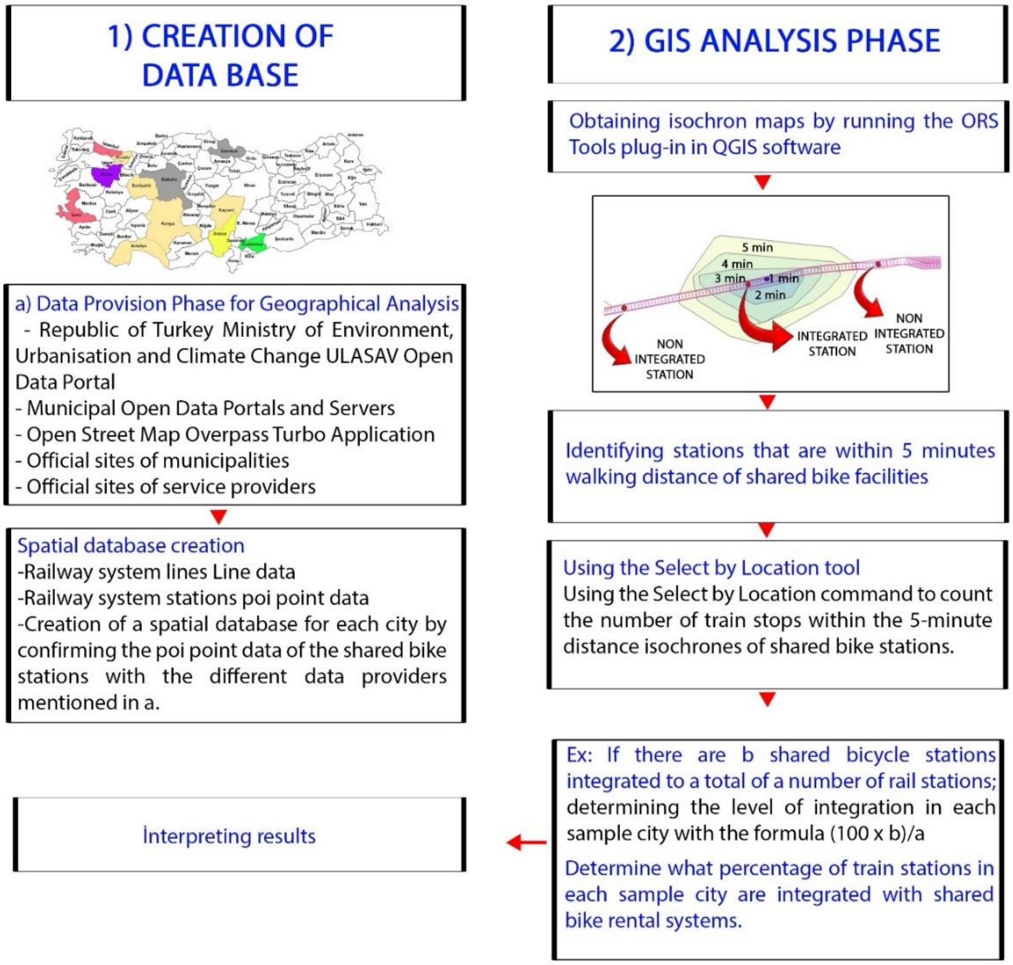



***Figure 7.*** *GIS Analysis Process Flowchart (Figure produced by the authors)*

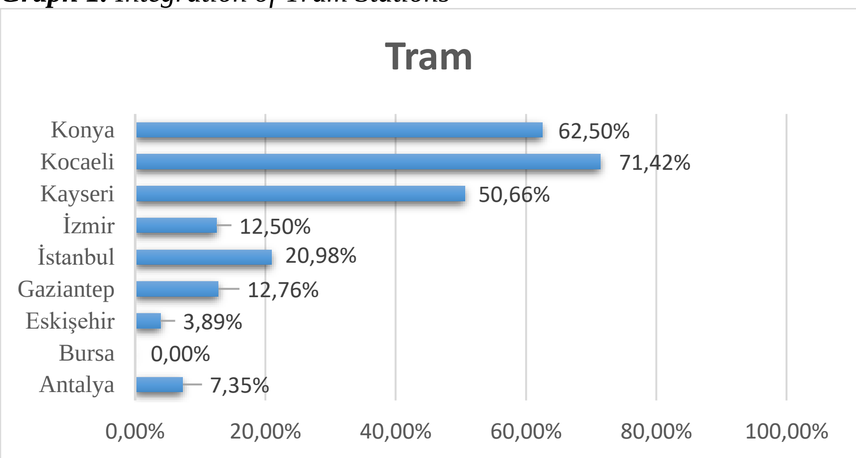
## 4.FINDINGS (BULGULAR)

The methodology delineated in the article was employed to assess the integration levels of urban rail systems with shared bicycle systems within a 400-meter walking radius in Turkey. An analysis was conducted on a total of 10 cities that have both rail systems and shared bicycle systems. The integration percentages were calculated separately for tram, metro, and suburban rail systems, as well as for the total integration percentage.

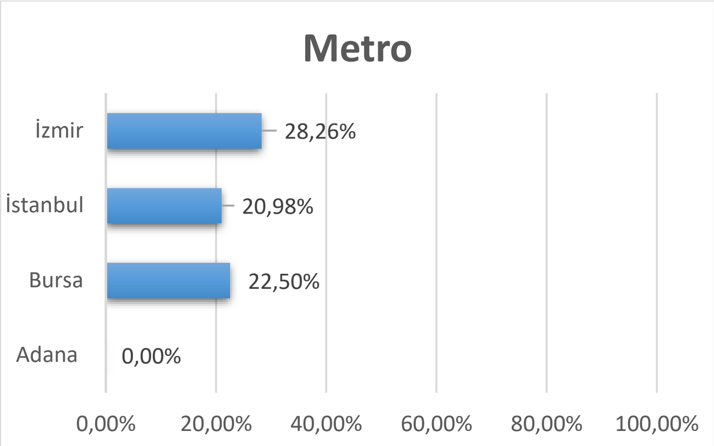
***Table 3.*** *Results of Integration Measurement of Shared Bicycle Systems with Rail System Stops in Turkey (Table produced by the authors)*

| *City* | Number of Rail System Stations | Number of Shared Bicycle Stations within 400 m. | Integration Level (%) | |
|---|---|---|---|---|
| Adana | 13 Stations -Adana Metro | 0 | %0 | %0 |
| Antalya | 68 Stations -AntRay | 5 | %7,35 | %7,35 |
| Bursa | 40 Stations -Bursaray | 9 | %22,5 | %11,84 |
| | 36 Stations -Tram | 0 | %0 | |
| Eskişehir | 77 Stations -ESTRAM | 3 | %3,89 | %3,89 |
| Gaziantep | 16 Stations -Gaziray | 0 | %0 | %9,52 |
| | 47 Stations - Tram | 6 | %12,76 | |
| İstanbul | 130 Stations -Metro | 5 | %3,84 | %9,65 |
| | 81 Stations -Tram | 17 | %20,98 | |
| | 48 Stations -Suburb | 3 | %6,25 | |
| İzmir | 24 Stations -Metro | 3 | %28,26 | %15,31 |
| | 46 Stations -Tram | 13 | %12,5 | |
| | 41 Stations -İZBAN | 1 | %2,43 | |
| Kayseri | 75 Stations - Kayseray | 38 | %50,66 | %50,66 |
| Kocaeli | 21 Stations -Tram | 15 | %71,42 | %71,42 |
| Konya | 40 Stations -Tram | 25 | %62,5 | %62,5 |

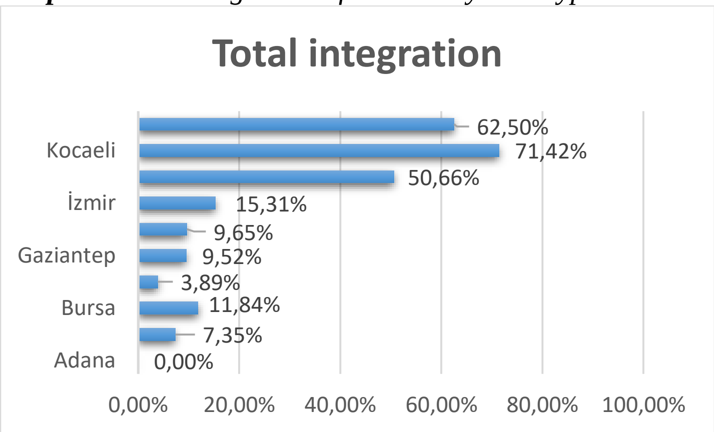
***Graph 1.*** *Integration of Tram Stations*



***Graph 2.*** *Integration of Metro Stations*




***Graph 3.*** *Total Integration of All Rail System Types*




## 5. CONCLUSION

One of the main findings of the spatial analysis conducted on samples in Turkey regarding the integration of sharing bicycle systems into rail systems is that there are shortcomings in addressing intermodality in order to increase the sustainability impact of rail systems. In particular, the weaknesses in the integration level of shared bicycle systems into rail systems in most of the samples are among the weaknesses in promoting non-car public mobility.

The isochron mapping analysis revealed that the integration levels of shared bicycle systems with the rail system exceeded 50%, particularly in Kocaeli (71.42%), Konya (62.5%), and Kayseri (50.66%). However, the integration level was found to be low in larger metropolitan areas, such as Istanbul and Izmir.

The suitability of the urban morphological structures of some samples studied in Turkey may be a factor in the high levels of integration with bicycle and rail systems. The morphological structures of Konya and Kayseri, which share similarities in terms of topography and urban fabric, provide opportunities for the spread of shared bicycle systems in urban spaces, making their integration levels with rail systems higher than those of other cities. However, the low level of integration in cities like Adana and Eskişehir, which have topographies suitable for bicycles and rail systems, can be attributed to insufficient investments in shared public bicycle systems.

The number of shared bicycles and stations in the sample cities of Kayseri, Kocaeli, and Konya is higher than in other cities. One of the main reasons for the high level of integration found in these cities is the higher number of shared bicycles and stations compared to other cities. This finding is consistent with the quantitative findings in the literature, such as those reported by Martens (2007) and Ma, Liu, and Erdoğan (2015), which indicate that an increase in the number of bicycles is associated with an increase in the use of rail systems.

Findings in other studies in the literature that the high speed of rail systems makes pedestrian access difficult due to insufficient distance between stops are consistent with the findings in the Istanbul and Izmir samples. The morphological structure of these cities, with its topographical difficulties and scattered settlements, negatively affects the linear development of rail systems. Additionally, the complexity of these cities' transportation identities negatively impacts the integration of transportation modes. In cities like Istanbul and Izmir, which have high-speed rail systems, the lack of adequate distances between stations can be addressed through shared bicycle systems, thereby enhancing sustainable mobility.

The results show that the level of integration of shared bike stations with the tram is higher than with the metro, but the level of integrated design of shared bike stations with metro stations is low. This situation has a negative impact on the objectives of increasing the sustainability impact by expanding the scope of access to metro and suburban stations in an integrated manner with bicycles, as it allows a faster transit passage compared to the tram.

In this context, it can be seen that most of the sample cities are not sufficient to meet the expected sustainability impact objectives of the rail system, such as accessibility to a larger population and reduction of motorized vehicle use. Holistic urban transport policies need to be developed to extend the spatial coverage of a well-designed shared bike system, enabling the rail system to reach more land use types such as housing, workplaces, etc., i.e. more population. By integrating public shared cycle systems with the rail system, it may be possible to increase the expected sustainability impacts of the rail system by eliminating the first and last mile problem.

Considering the potential of bike-sharing systems to overcome the first and last mile problem of rail systems, sustainable mobility policies should be developed. Policies should be developed to improve sustainability performance by integrating bike-sharing systems into rail system lines designed as a mode of public transportation, and the provision of public bike-sharing systems should be improved.

While most studies in the literature focus on improving pedestrian accessibility to rail systems, this study distinguishes itself from others by highlighting the powerful role of shared bicycles in increasing accessibility coverage by serving as a bridge between pedestrian and public transportation modes in two-way transportation, and by assessing the first and last mile mobility problem. In the context of improving sustainable transportation in Turkey, the widespread adoption of shared bicycle systems is essential for developing initiatives aimed at addressing the disconnect in accessibility levels between rail systems and their starting or destination points.

The article presents an original method that can be used in national and international literature to measure the spatial accessibility of shared bicycle stations to the rail system using the isochron mapping method. This enables the intermodality levels of rail systems with shared bicycle systems to be determined. This method can be used to determine the level of access to public transport stops for shared bicycles, and can be applied to other urban areas to measure the level of intermodality for sustainable mobility.

Limitations; The isochronous mapping method used in this study more accurately represents 2D coverage, which is sensitive to the urban network pattern, than traditional buffer analysis methods. However, studies should be developed to produce 3D access coverage maps that include the effects of topography.

**ACKNOWLEDGMENTS**

This article is based on the topics covered in the doctoral dissertation of Oğuz Fatih Bayraktar at Gazi University, Institute of Science, Department of Urban and Regional Planning.

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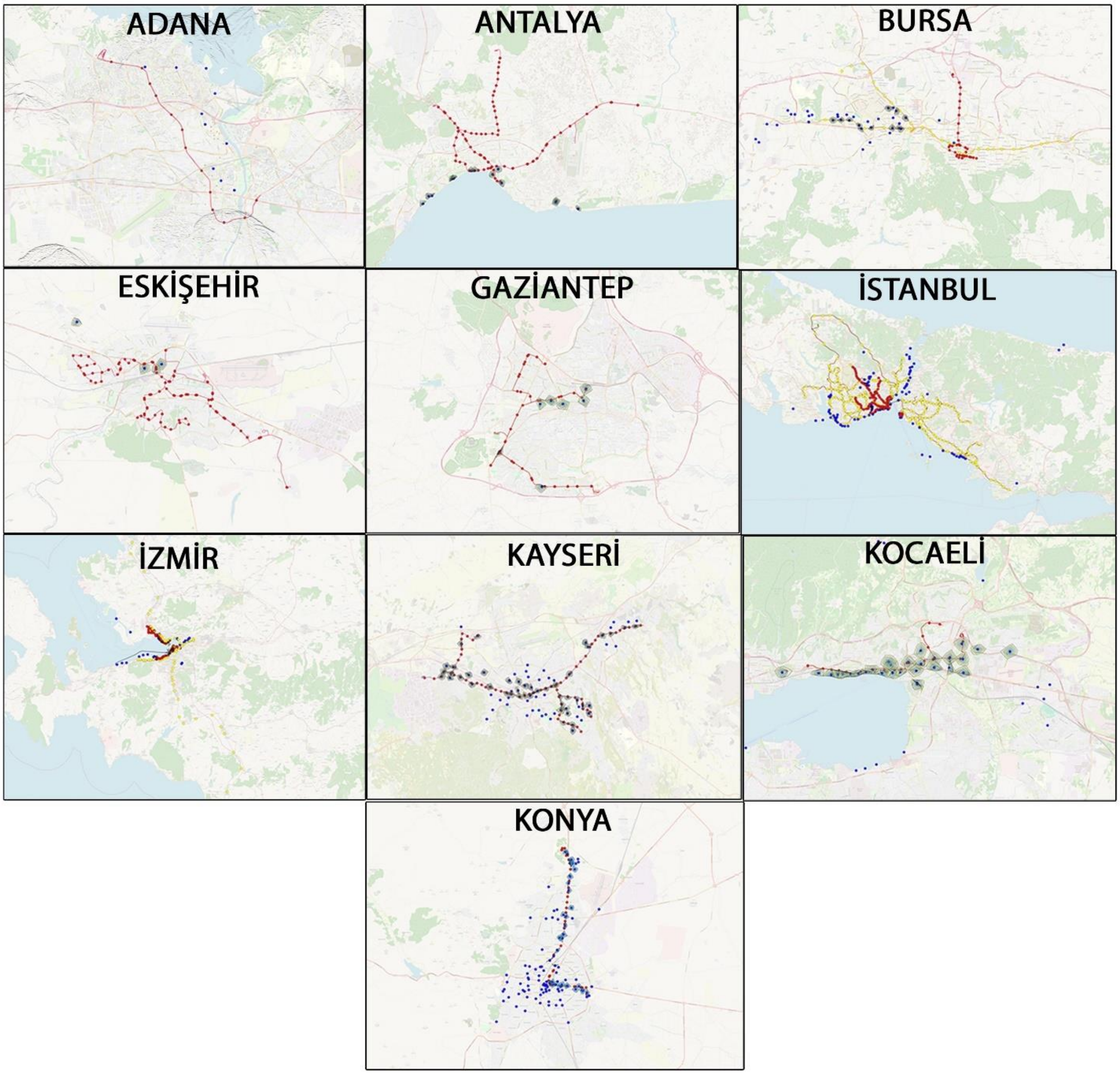
**APPENDIX**

Spatial database created for 10 sample cities (consisting of vector lines and rail system line data for rail system stations and shared bike stations).



Review Article GU J Sci, Part B, 13(2): 243-261 (2025)

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**Journal of Science**

PART B: ART, HUMANITIES, DESIGN AND PLANNING

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# A Bibliometric Analysis on Hybrid Rainwater Reuse-Greywater Recycling Systems in Buildings

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**Article Info**

*Received: 21/04/2025*
*Accepted: 23/06/2025*

**Keywords**

*Rainwater Harvesting,*
*Greywater Recycling,*
*Bibliometric Analysis,*
*Hybrid Water Systems,*

**Abstract**

As urbanisation, population growth, and climate change continue to increase, the availability of water resources is declining. Buildings are places where people spend most of their daily lives and are responsible for a significant portion of the consumption of resources. Water is the leading source of these resources. Therefore, efficient and economical water consumption is substantial. Utilising alternative water sources, such as rainwater and greywater, for applications that do not necessitate potable water quality is a key strategy to help minimise the excessive reliance on main water supplies. Integrated systems where rainwater and greywater are used together in buildings or to complement each other are called "hybrid rainwater-greywater systems". This research aims to conduct a bibliometric analysis of existing literature on hybrid rainwater harvesting-greywater recycling systems within buildings. Scopus and Web of Science databases were used for this purpose. The outcomes were visualised using mapping techniques through VOSviewer software. The results indicate that hybrid rainwater harvesting-greywater recycling systems have not yet garnered adequate attention in research. Therefore, it is evident that hybrid water systems will be the subject of more research in the future. In particular, studies on the development of storage tank design and treatment methods that affect these systems' environmental, social, and economic aspects are expected to contribute significantly to developing the sustainability components of hybrid water systems.

## 1. INTRODUCTION

Approximately three-quarters of the Earth's surface is covered with water. However, only 2.5% of this water can be used by humans [1]. Increasing water demand, water scarcity, water stress, water conflicts, and water management problems due to reasons such as urbanisation, climate change, and population growth are among the most significant issues of our day. For this reason, many studies are being conducted on these issues in our century. While the need for water increases with population growth, rapid urbanisation, and industrialisation, water resources are gradually decreasing and becoming polluted due to environmental pollution, unconscious water consumption, and climate change [2]. In addition, unsustainable water use during the usage phase causes the decrease and pollution of water resources [3]. In light of this, there is a need for more strategic and sustainable methods in water management to relieve the strain caused by the growing demand for water [4].

Although one of the UN 2030 Sustainable Development Goals is “Clean Water and Sanitation”, water scarcity is rapidly growing globally. This situation negatively affects the increasing number of domestic, commercial, industrial, and agricultural water consumers worldwide [5]. Sustainable Development Goals aim to prevent the loss of natural resources by implementing sustainable development policies. Water is at the forefront of these resources. Although water is considered an infinite resource by many people, it has been the subject of many studies that it is gradually decreasing and that water wars will emerge shortly. For this reason, water must be delivered safely to future generations in terms of quantity and quality. Sustainable water management plays a significant role in achieving this requirement. Urban, agricultural, and industrial water use can be completed efficiently with sustainable water management.

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According to a report published by UNICEF and WHO in 2019, approximately 2.2 billion people worldwide do not have access to safe drinking water [5]. This situation, defined as urban water scarcity, is expected to become much more significant in the future. The realisation of this prediction will be a substantial obstacle to achieving the eleventh Sustainable Development Goal, “Sustainable Cities and Communities”, and the sixth, “Clean Water and Sanitation”. Urbanisation, population growth, and socioeconomic development are expected to increase urban, industrial, and domestic water demand by 50-80% in the next thirty years. It is estimated that population growth from 2016 to 2050 will increase water demand, and approximately one billion people will face urban water scarcity [6]. Global water consumption is predicted to increase by 17% in agriculture, 20% in industry, and 70% in domestic consumption in 2025 [7].

Unsustainable water consumption during the usage phase of buildings causes a daily decline and deterioration in water resources [3]. To achieve sustainable water management at the building level, sustainable solutions that reduce water consumption and use alternative water sources must be developed [8]. The most important alternative water sources for saving drinking water include rainwater and greywater [9]. Rainwater and greywater are used at the building scale through rainwater harvesting systems and greywater recycling systems.

Systems where rainwater collected from roofs in buildings is used for purposes that do not require drinking water quality, such as toilet cisterns, garden irrigation, washing clothes, and vehicle washing, are defined as “rainwater harvesting systems.” In this system, rainwater is first flushed away before being transferred to the storage tank via gutters and downpipes on the roofs and then pre-treated to make it ready for use. Systems that purify slightly polluted water from hand wash basins, washing machines, and showers to be used where no manual contact is required, such as toilet flushing and garden irrigation, are called “greywater recycling systems.” These alternative water sources, which are used instead of tap water and provide drinking water savings, also reduce the load on rainwater networks and wastewater discharge systems. Thus, besides their environmental benefits, they contribute economically by lowering water bills.

Hybrid rainwater-greywater systems are systems that allow the use of rainwater and greywater, which are alternative water sources, in an integrated manner within the same building. Greywater coming from sinks, washing machines, and shower/bath/bathroom areas can be treated and used for end-uses such as toilet cisterns and garden irrigation. Rainwater harvested from roofs or impermeable surfaces can be stored and used for end-uses such as toilet reservoir, washing machines, garden irrigation, vehicle washing etc. These two alternative water sources can be evaluated at the same end-use or in different end-uses. This end-use may vary depending on stakeholders such as the consumer or the designer. This study aims o examine the studies conducted on hybrid systems using the bibliometric analysis method.

## 2.METHOD

Bibliometric analysis is the systematic scanning and statistical examination of research conducted on a subject. The year the study was conducted, the author(s) of the study, the source of publication, and the field of research constitute the subject of bibliometric analysis [10, 11].

Different stages have been specified in other studies for the bibliometric analysis method. These generally consist of 6 basic stages: determining the purpose of the study, data collection, data preprocessing and data cleaning, determining analysis techniques, performing analyses according to the selected techniques, and reporting [12, 13, 14]. The method of this study was created by following these stages.

Step 1: This study aims to examine studies conducted on hybrid water systems in buildings using the bibliometric analysis method.

Step 2: Different databases are used to obtain data using the bibliometric analysis technique, one of the research methods used to examine previous studies on a subject and find research gaps [14]. Scopus and Web of Science databases were used in this study. The databases first show the results by entering the keywords related to the subject to be researched in the search section. Therefore, selecting specific and completely covering words about the subject to be examined is essential. Since this study was conducted as part of research on alternative water resources that can be used in buildings, the keywords “rainwater”, “rainwater harvesting”, “greywater”, and “greywater recycling” were entered into the databases. The “title”, “abstract”, and “keywords” sections were selected in both databases for the places where the search will be made. This study aimed to find publications where the keywords rainwater harvesting and greywater recycling were used simultaneously. For this reason, the “All field” option was not preferred.

After determining the place where the keywords would be searched, a systematic search was performed. This systematic search was performed as ("rainwater" OR "rainwater harvesting" OR "rain water" OR "rainwater reuse" OR "rainwater recycling") AND ("greywater" OR "greywater recycling" OR "greywater reuse" OR "greywater" OR "grey water" OR "grey water recycling" OR "grey water reuse"). Here, the OR command is intended to include any of the words in parentheses in the places where the search will be made, and the AND command is intended to select each word in parentheses. Thus, it is anticipated that studies where both rainwater and greywater are researched together will be reached.

Step 3: After entering the keywords, 41 and 34 studies were reached in Scopus and Web of Science databases, respectively. Then, the English language was filtered, and studies written in different languages were eliminated. After filtering, 40 and 34 studies were reached in Scopus and Web of Science databases, respectively. In addition, pre-processing and data cleaning were performed to correct repetitions and spelling errors. Publications that did not have full text and whose abstracts directly included research outside the building as an alternative water source use location were also separated, and finally, 33 studies were obtained in the Scopus database, and 32 studies were obtained in the Web of Science database. 29 studies in both databases were common, and a total of 36 different studies were found. 2 of these were screening articles, and 3 were congress papers.

Step 4: To perform the bibliometric analysis, citation analysis, co-citation analysis, keyword analysis, bibliographic coupling analysis, and co-authorship analysis techniques were used. In addition, analyses were performed regarding the publication years and research areas of the studies.

Step 5: The free VOSviewer software was developed to visualise the results of bibliometric analyses (Van Eck and Waltman, 2010). The results obtained from the databases were transferred to the VOSviewer software and presented as bibliometric mapping.

Step 6: The results of the bibliometric analysis, network maps, and visualisations are presented in the discussion and results section.

## 3. FINDINGS AND DISCUSSION

In this section, the findings from the analysis are showcased through the application of bibliometric analysis methods and the VOSviewer software. Furthermore, the outcomes are examined by considering the aspects of publication years, authorship, nations, keywords, sources, research fields, and institutions.

### 3.1. Publication Years

Figure 1 illustrates the number of studies conducted on the subject in the databases by year. The years in which regular publications appear on a topic are those in which active publications are made [12]. Both databases, 2012 to 2018, are active publication years for this topic. At least 2 studies have been published in both databases from 2015 to the present. Since the number of publications regarding the studies that constitute the subject of this study is limited, year filtering was not performed.

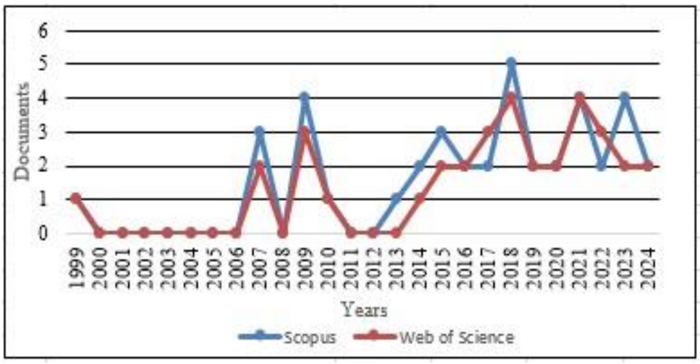


***Figure 1.*** *Publications by years (Scopus and WOS database)*

### 3.2. Analysis of Authors

Table 1 presents the publication and citation counts of the authors who contributed to the research identified in the databases. Notably, Ghisi, E., Chong, M. M., Leong, J. Y. C., and Poh, P. E. have conducted considerable research in this area and received numerous citations. Although Stec, A. has three publications listed in the Scopus database, he trails behind the other authors regarding the citation totals. Therefore, it can be concluded that the works of the authors highlighted in Table 1 should certainly be explored in future research on hybrid water systems.

***Table 1.*** *Authors by Documents and Citations (Scopus and WOS, 2024)*

| | Scopus | | Web of Science | |
|---|---|---|---|---|
| **Author** | **Documents** | **Citations** | **Documents** | **Citations** |
| Ghisi, E. | 6 | 345 | 6 | 323 |
| Chong, M.N. | 2 | 135 | 2 | 115 |
| Leong, J. Y. C. | 2 | 135 | 2 | 115 |
| Poh, P. E. | 2 | 135 | 2 | 115 |
| Stec, A. | 3 | 85 | 2 | 62 |
| Oviedo-Ocana, E.R. | 2 | 70 | 2 | 59 |
| Ward, S | 2 | 70 | 2 | 59 |
| Mo, W. | 2 | 22 | 2 | 19 |

The bibliographic matching of authors in the studies obtained from the Scopus database is shown in Figure 2. In the analyses, the minimum number of publications for an author was selected as 2, and the minimum number of citations was selected as 1. 8 out of 120 authors provided the threshold values. The most substantial connection belongs to Ghisi, E., who is in the middle of the network centre. It was determined that the authors in the publications in the Scopus database formed two different clusters. Chong, M. M., Leong, J. Y. C., and Poh, P. E., who follow Ghisi, E. regarding publication and citation numbers, formed the green cluster. Other than these, Oviedo-Ocana, E. R., Ward, S. Mo, W. and Stec, A. formed the red cluster together with Ghisi, E. It is concluded from this that the authors with the most publications and citations have established a powerful academic connection with each other in their studies. It is understood that they have greatly influenced each other in their studies and that it is essential to review the works of these authors in the studies to be carried out in the following years.

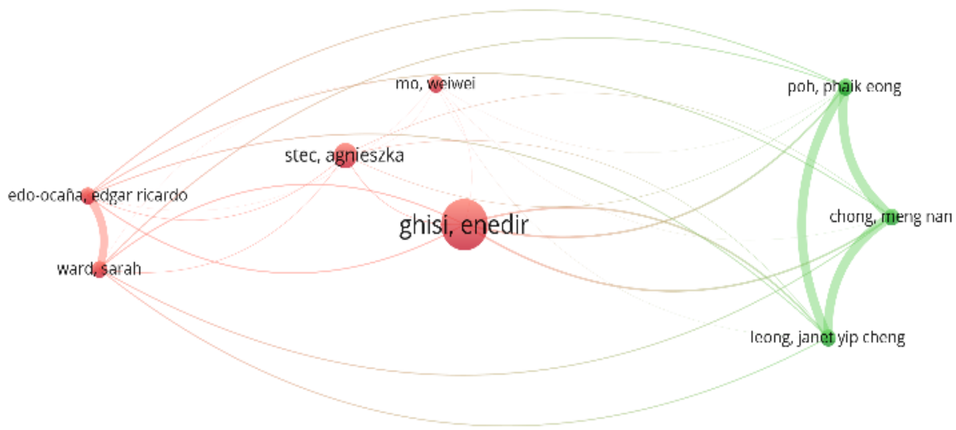


***Figure 2.*** *Bibliographic coupling of authors (Scopus, 2024)*

Similar results are also seen in the Web of Science database analysis. 9 out of 99 authors met the threshold values of at least 2 publications and at least 1 citation. The bibliographic matching of authors of publications obtained from the Web of Science database is shown in Figure 3. These results formed 2 different clusters. The authors forming the green cluster are Chong, M. M., Leong, J. Y. C., and Poh, P. E., as in the results obtained from the Scopus database. The authors forming the red cluster are Ghisi, E., Oviedo-Ocana, E. R., Ward, S. Mo, W., and Stec, A., as in the results obtained from the Scopus database. In addition to these authors, Dominguez, I. is also included in the red cluster in the results obtained from the Web of Science database.

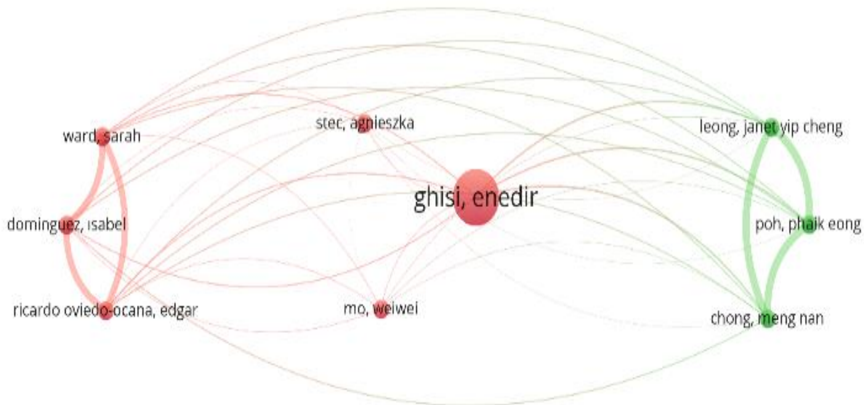


***Figure 3.*** *Bibliographic coupling of authors (WOS, 2024)*

### 3.3. Analysis of Countries

Figure 4 illustrates the number of publications from various countries concerning the study topic. Brazil stands out as the leading country with 8 publications across both databases. The prominent factor contributing to Brazil's leadership in this study area is Ghisi, E., who also ranks highest in the author analysis. In the publication data from the Scopus database, the United Kingdom has 5 publications, followed by China and the USA, each with 4. Additionally, Australia, Colombia, Germany, Malaysia, and Poland contributed 3 publications on the topic. In the Web of Science database results show that China and the USA tied for second place with 5 publications, trailing behind Brazil. The United Kingdom follows with 4 publications, while Australia, Colombia, and Germany each have 3. The publication counts for these three countries are the same in both databases. Malaysia and Poland each have 2 publications, which are also equal. Czech Republic has 2 and 1 publications in Scopus and Web of Science databases, respectively.

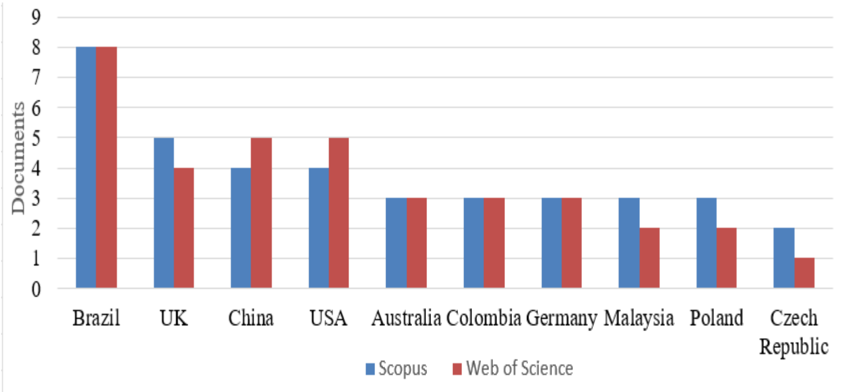


***Figure 4.*** *Publications by Countries (Scopus and WOS, 2024)*

The connection between the countries where the most cited studies in the Scopus database were conducted is shown in Figure 5. The map was created according to the countries where at least 2 publications were made, and at least 1 citation was received. 8 out of 24 countries met the threshold values. Brazil, one of the countries with the most publications, is also at the centre of the map of the countries with the most citations and the most substantial network. Colombia, Australia, Poland and Great Britain are the other countries that make up the red cluster with Brazil. China, Malaysia and the USA are the countries that make up the green cluster.

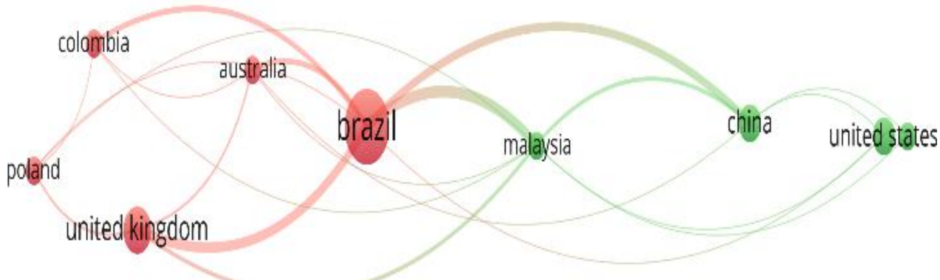


***Figure 5.*** *Most Cited Countries (Scopus, 2024)*

The results in the Web of Science database are shown in Figure 6. In this database, 9 out of 20 countries met the threshold values. According to the results obtained from the Web of Science database, as in the results obtained from the Scopus database, two clusters, green and red, were formed in the connection map created according to the citations of the countries. In the graph, where Malaysia, China, the USA and Germany, which form the green cluster, have a strong connection, the interaction between Brazil, Australia, England, Poland and Colombia, which form the red cluster, is seen.

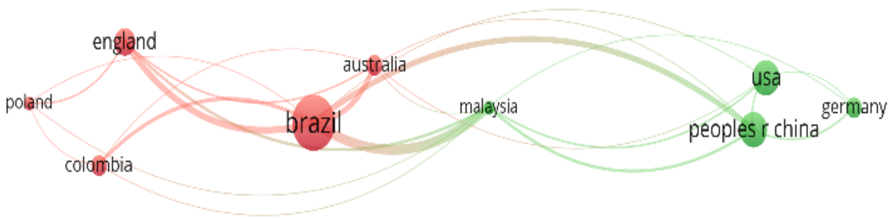


***Figure 6.*** *Most Cited Countries (WOS, 2024)*

### 3.4. Co-occurrence of Keywords

Figure 7 displays a map of keywords that appear in at least two publications from the Scopus database studies. Out of 134 keywords, 21 exceeded the threshold value. These 21 identified keywords were reviewed for any duplicates or spelling mistakes. The terms rainwater, greywater, rainwater harvesting, and greywater reuse are prevalent across nearly all clusters. Additionally, the red cluster includes terms such as potable water savings, final water consumption, and financial analysis. A similar pattern is found in the green cluster, where stormwater management and greywater reuse keywords are accompanied by water conservation and minimization of wastewater. The blue cluster comprises rainwater harvesting and greywater recycling, along with water savings and green roofs. Other significant keywords pertinent to hybrid water system research include environmental impact, financial feasibility, sustainability, greywater treatment, and domestic water supply. This leads to the conclusion that many studies focus on economic analyses and environmental impact assessments related to water savings through alternative water sources.

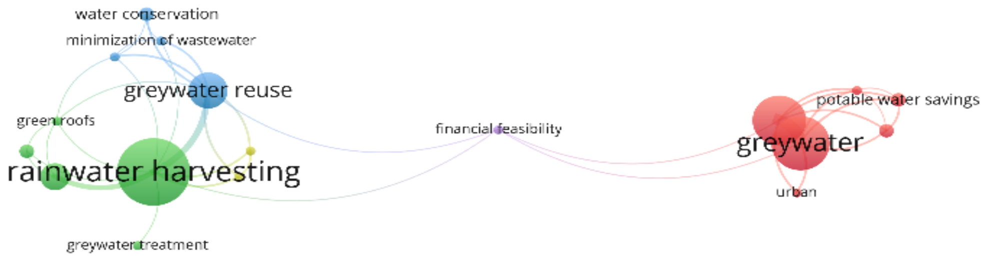


***Figure 7.*** *Co-occurrence of keywords (Scopus, 2024)*

Figure 8 shows the mapping of keywords found in at least 2 different studies in the Web of Science database according to the number of citations. 18 words out of 119 provided threshold values. Similar clusters formed by the results in the Scopus database are also found in the results obtained from the Web of Science database. The red cluster consists of rainwater, greywater, urban, water end-uses, potable water savings, and financial analysis. The blue cluster consists of greywater reuse, stormwater management, minimization of wastewater, and water conservation. The green cluster consists of green roofs and water savings, greywater recycling, and rainwater harvesting. In addition, similar to the results obtained from the Scopus database, the words life cycle assessment, environmental impact, financial feasibility and greywater treatment are other keywords used in hybrid water system studies.


***Figure 8.*** *Co-occurrence of keywords (WOS, 2024)*

### 3.5. Analysis of Sources

The first five sources of documents related to the research topic, ranked according to both publication and citation numbers, are given in Table 2. While the Journal of Cleaner Production leads in the number of publications, the Building and Environment source has a higher citation count. This pair of sources is succeeded by Water (Switzerland), Desalination, and Urban Water Journal. Similar to Scopus, the Journal of Cleaner Production also ranks first in publications within the Web of Science database. Thus, it is evident that the Journal of Cleaner Production is one of the key journals related to this subject. It has also been determined that the journals listed in the top five are prevalent across both databases.

***Table 2.*** *Top 5 Sources by Documents and Citations (Scopus and WOS, 2024)*

| | Scopus | | Web of Science | |
|---|---|---|---|---|
| **Journal** | **Documents** | **Citations** | **Documents** | **Citations** |
| Building and Environment | 2 | 299 | 2 | 283 |
| Journal of Cleaner Production | 5 | 247 | 8 | 261 |
| Water (Switzerland) | 3 | 81 | 4 | 65 |
| Desalination | 2 | 207 | 2 | 176 |
| Urban Water Journal | 2 | 14 | 3 | 73 |

Figure 9 shows the bibliographic coupling of the sources where the studies in the Scopus database are published. The red cluster consists of the sources that form 3 different clusters: Journal of Cleaner Production, Water (Switzerland), Urban Water Journal and Resources, Conservation, and Reuse. The blue cluster comprises Water Science and Technology and Desalination, while the green cluster comprises Building and Environment and Water Science and Technology.

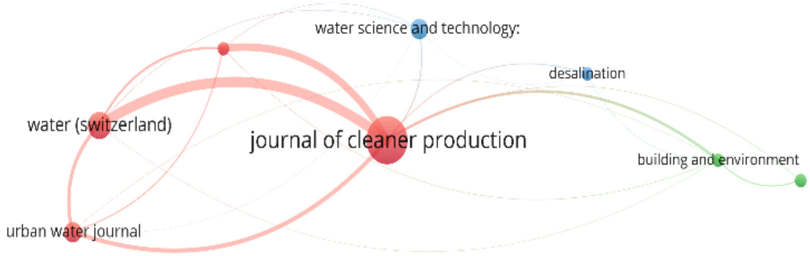


***Figure 9.*** *Bibliographic coupling of sources (Scopus, 2024)*

According to sources, Figure 10 illustrates the bibliographic coupling of publications in the Web of Science database. Similar to the results in the Scopus database, the Journal of Cleaner Production is again at the centre of the network. In addition, other sources that make up the red cluster are Urban Water Journal, Water (Switzerland), and Water Science and Technology. Resources, Conservation and Reuse and Building and Environment are other notable sources.

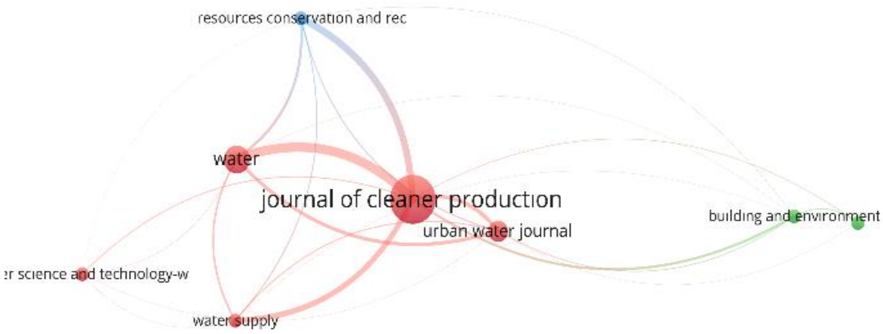


***Figure 10.*** *Bibliographic coupling of sources (WOS, 2024)*

### 3.6. Research Areas

Table 3 includes the publication numbers and percentages of studies obtained from the Scopus database according to their fields of study. Studies on hybrid systems are included in the fields of Environmental Science, Engineering, Social Sciences and Energy. The number of documents in the table is higher than the total number of studies obtained because a document falls into more than one research field.

***Table 3.*** *Research Area Categories (Scopus, 2024)*

| Research Area | Documents | Percentage |
|---|---|---|
| Environmental Science | 37 | 38.5% |
| Engineering | 14 | 14.6% |
| Social Sciences | 12 | 12.5% |
| Energy | 8 | 8.3% |
| Business, Management and Accounting | 7 | 7.3% |
| Agricultural and Biological Sciences | 4 | 4.2% |
| Biochemistry, Genetics and Molecular Biology | 4 | 4.2% |
| Chemical Engineering | 2 | 2.7% |
| Chemistry | 2 | 2.1% |
| Economics, Econometrics and Finance | 2 | 2.1% |
| Other | 2 | 2.7% |

A similar situation is seen in the results in Table 4 obtained from Web of Science. Engineering, Environmental Sciences Ecology, and Water Resources research areas are where hybrid water systems studies are published the most. In addition to these areas, Construction Building Technology, Geography and Geology fields are included in the research areas of hybrid rainwater harvesting-greywater recycling systems studies.

***Table 4.*** *Research Area Categories (WOS, 2024)*

| Research Area | Documents | Percentage |
|---|---|---|
| Environmental Sciences Ecology | 23 | 67.6% |
| Engineering | 22 | 64.7% |
| Water Resources | 17 | 50% |
| Science Tech. Other Topic | 7 | 20.6% |
| Construction Building Technology | 2 | 5.9% |
| Geography | 1 | 2.9% |
| Geology | 1 | 2.94% |

### 3.7. Analysis of Affiliations

The affiliations to which the authors of the studies on hybrid water systems are affiliated are listed in Table 5. Since many organisations are related to this study topic, the first 5 organisations with the most publications are included in the table. According to the results in the two databases, hybrid system studies appear the most prevalent in Universidade Federal de Santa Catarina, with 7 publications. The main reason is that Ghisi, E. works in this organisation. The University of Exeter has the same number of publications in both databases, with 3. Politechnika Rzeszowska im. Ignacego Łukasiewicza and Universidad Industrial de Santander have 3 and 2 publications in Scopus and Web of Science databases, respectively. Monash University Malaysia is ranked 5th in both databases with 2 publications.

***Table 5.*** *Affiliations by Documents (WOS, 2024)*

| Research Area | Scopus | WoS |
|---|---|---|
| Universidade Federal de Santa Catarina | 7 | 7 |
| University of Exeter | 3 | 3 |
| Politechnika Rzeszowska im. Ignacego Łukasiewicza | 3 | 2 |
| Universidad Industrial de Santander | 3 | 2 |
| Monash University Malaysia | 2 | 2 |

### 3.8. Description of Studies

Alternative water source systems have been the subject of many studies in the literature from social, economic and environmental perspectives. In addition, there are studies in the literature examining the quality of these resources.

Several studies have noted that water saving effectiveness has been evaluated in the context of environmental or economic evaluations of alternative water supply systems. This focus is due to the fact that the primary aim of these systems is to help decrease water usage or, in simpler terms, to conserve water.

One of the basic components of alternative water source systems is the storage tank. Tank design dramatically affects the performance of alternative water source systems both environmentally and economically. Another critical component of these systems is the treatment method. Especially the fact that greywater is more polluted than rainwater has led to the development and increase of greywater treatment technologies. Treatment methods affect alternative water source systems both environmentally and economically and in terms of water quality. Therefore, selecting the proper treatment method affects the system's performance as much as the tank sizing.

Table 6 presents research on evaluating alternative water resources, focusing on environmental, social, and quality factors. These studies explored various treatment techniques or assessed water quality without any treatment. The findings indicated that rainwater necessitates less treatment because it is cleaner than greywater. After the first flush separation, rainwater can be utilised for washing vehicles, washing clothes, irrigation, cleaning floors, cooling towers, fire hydrants, emergency tanks, and toilet flushing. Following a series of treatment processes, greywater can be employed for toilet flushing and irrigation, which do not require drinking water standards. Different studies applied chemical, physical, and biological treatment methods either in combination or individually. It was determined that while extending the greywater treatment process improves water quality, it tends to diminish both environmental and economic efficiency.

When the studies that addressed the issue from an environmental perspective were examined, it was seen that greywater recycling systems were considered independent of the climate. Greywater is produced regularly and reducing the load on sewage systems. Additionally, when a treatment method such as an artificial wetland is used, it can have less environmental impact than rainwater harvesting systems. [24, 27]. The most significant environmental contributions of alternative water sources are the reduction of water consumption and the load on the urban sewage and rainwater infrastructure networks.

On the other hand, Table 6 includes studies on the perspectives of suppliers, local administrators, and users who are stakeholders of alternative water resources. In these studies, it has been determined that users generally have a more positive view of rainwater than greywater. In studies on water quality, basic methods used to treat greywater have been included. It has also been observed that the desire to use alternative water resources varies in different cultures and countries. Therefore, the storage volume and treatment method must be user-oriented when designing alternative water resources systems.

***Table 6.*** *Studies examining alternative water resources in terms of quality, environmental and social aspects*

| Study | Aim | Findings |
|---|---|---|
| [16] | Quality (Comparing rainwater and greywater quality) | There are many pollutants found in reservoirs fed with greywater. Rainwater and mains water are of similar quality. |
| [17] | Quality (Impact of rainwater and greywater treatment methods in office buildings) | Rainwater treatment has been found to be more economical and effective than greywater treatment. |
| [18] | Quality (Quality status of alternative water sources after treatment) | It has been determined that greywater can be used after basic treatment and that rainwater will require less treatment. |
| [19] | Social (Socio-economic motivation for using alternative water sources) | A survey conducted over the Internet has concluded that women and low-income households use alternative water sources more. |
| [20] | Social (User and manager perspectives on alternative water sources) | The surveys conducted with managers and users have found that the perspective on greywater is negative due to health risks. |
| [21] | Social (User perspectives on greywater and rainwater systems) | A survey conducted in 200 households has concluded that 80% of the participants would be willing to use the systems if the necessary incentives were provided. |
| [22] | Social (Motivation for using alternative water sources) | As a result of the surveys, it has been concluded that the number of households and low income increase the use of alternative water sources. |
| [23] | Social (Acceptability of alternative water sources) | A survey conducted with 1200 participants in 12 countries has concluded that 75% of the participants would be willing to use the systems if there is an economic incentive. |
| [24] | Environmental (Energy saving potential of rainwater and greywater systems) | The greywater system has shown 50% better energy performance than rainwater due to the use of artificial wetlands in treatment. |
| [25] | Environmental (Environmental performance of hybrid systems) | Hybrid systems provided 41.9% water savings and 40% wastewater reduction. |
| [26] | Environmental (Impact of green roof system on greywater treatment and rainwater collection) | The green roof improved greywater quality and reduced rainwater runoff. |
| [27] | Environmental (Environmental performance of alternative water sources) | Since the greywater system does not consider treatment, the greywater system provided 3 times more energy savings than the rainwater system. |

Table 7 includes studies examining alternative water source systems economically. Different building types across various countries have produced varying outcomes in these studies. The reason for the different results is that there are many variables affecting the performance of these systems. Variables such as location, building type, number of users, rainwater demand, where rainwater will be collected, and the tank size of the rainwater harvesting system affect the investment cost. On the other hand, end-uses constituting the greywater source, greywater demand, and greywater treatment methods also affect the investment cost of the greywater recycling system as well as the operating and maintenance costs.

Another factor affecting the economic performance of the systems is the economic status of the countries. Although different financial indicators are selected in different studies when evaluating economic performance, net present value, payback period, internal rate of return, and benefit/cost are the most frequently selected indicators. While some research suggests that alternative water sources are financially feasible [32, 29, 28, 33, 36, 30, 35], other studies have determined that they are not economically favourable [37, 9]. Although the climate zone where the system will be installed, different purification methods, the economic situation of the countries, water prices, and electricity prices reveal this difference, it can be said that the most critical factor affecting the economic attractiveness of the systems is the investment cost.

***Table 7.*** *Studies examining the economical performance of alternative water sources*

| Study | Aim | Finacial Indicators | Findings |
|---|---|---|---|
| [9] | Economic analysis of rainwater and greywater systems | [1]PP, [2]NPV | The payback periods of the systems were found to be high. They are not economically attractive. |
| [28] | Economic analysis of rainwater and greywater systems in multi-storey residential buildings | PP, NPV | The payback periods of hybrid systems were found to be less than 8 years. |
| [29] | Life cycle cost analysis of rainwater and greywater systems | NPV, PP | Although the systems were high-cost, they were found to be economically viable. |
| [30] | Economic analysis of hybrid system in university building | [3]B/C, PP | 48% water savings were achieved with the hybrid system. A payback period of 6 years was found. |
| [31] | Economic analysis of rainwater and greywater systems | PP, NPV, B/C, [4]IRR | It was concluded that only greywater and hybrid systems could be applied, and the rainwater system alone was not economical. |
| [32] | Economic evaluation of rainwater and greywater systems | PP, NPV, B/C | Hybrid systems were found to be more economically viable. |
| [33] | Water saving and economic analysis of hybrid system | PP, NPV | The hybrid system saved 51.6% of water. A payback period of 5.25 years was found. |
| [34] | Life cycle cost analysis of greywater and rainwater systems | PP | It was concluded that the greywater system had a demand meeting rate of 70-90% and the rainwater system had a demand meeting rate of 50-70%. |
| [27] | Economic performance of alternative water sources | NPV | The greywater system provided 10 times more net present value than the rainwater system, depending on the treatment system. |
| [35] | Economic performance of hybrid systems | PP | It was concluded that the hybrid system had a payback period of less than 5 years. |
| [36] | Economic evaluation of hybrid water system | NPV, IRR, PP | The hybrid system provided 38% water savings. The payback period was found to be slightly more than 10 years. |
| [37] | Economic analysis of hybrid water systems | NPV, B/C, PP | It was concluded that the hybrid system was not economically attractive due to high investment costs. |
| [38] | Economic analysis of rainwater and greywater systems | NPV, PP, IRR | It was concluded that the payback periods of hybrid systems vary between 89-132 months. |

[1]PP: Payback Period, [2]NPV: Net Present Value, [3]B/C: Benefit/Cost, [4]IRR: İnternal Rate of Return

Table 8 includes studies examining alternative water sources in terms of water-saving potential. Most studies revealed that hybrid rainwater harvesting-greywater recycling systems provide more water savings compared to systems where the sources are used alone. When two different sources are compared, only one study was found where the water-saving potential of the rainwater system was better than that of the greywater system [24]. Compared to other studies, the greywater system was superior to the rainwater system regarding water saving. The most important reason for this is that the greywater system is not dependent on the climate. The rainwater harvesting system has more unknowns compared to the greywater recycling system. For this reason, it has fallen chiefly behind the greywater system in terms of efficiency.

***Table 8.*** *Studies examining the water saving performance of alternative water sources*

| Study | Aim | Findings |
|---|---|---|
| [39] | Performance and efficiency of hybrid systems | It was concluded that adding a rainwater system to a greywater system had no effect in terms of water efficiency. |
| [40] | Evaluation of the potential of alternative water sources | Greywater was found to be more advantageous than rainwater due to its independence from climate. |
| [41] | Systems that can solve water shortages due to climate change | The importance of alternative water sources was emphasized. |
| [42] | Environmental impact of green roof, rainwater, and greywater systems | The highest level of water saving was achieved when greywater and rainwater were used together. |
| [30] | Performance of hybrid system in university building | The hybrid system provided 48% water saving and 59% wastewater reduction. |
| [24] | Water saving potential of rainwater and greywater systems | In terms of water saving, the rainwater system provided twice as much savings as the greywater system. |
| [43] | Reservoir design for alternative water sources in Ankara | Around 40-46% of water saving was achieved with the hybrid system. |
| [44] | Performance analysis of alternative water sources | The hybrid system provided more water savings than when alternative water sources were used alone. |
| [45] | Hybrid system performance in residential and commercial buildings | Hybrid systems were found to be more effective than when alternative water sources were used alone. |
| [46] | Performance of hybrid system in office building | The hybrid system reduced water consumption and wastewater discharge. |
| [47] | Evaluation of the efficiency of alternative water sources | It was determined that greywater was more effective in areas with high populations. |

Table 9 includes information on the rainfall data, discount rates, and storage tank design methods used in studies examining alternative water sources from environmental, economic, and social perspectives. It also includes information on the final consumptions that constitute the greywater source and the purposes for which the alternative water sources are used. It is observed that most studies use at least 10 years of precipitation data. Since the discount rates are selected according to the economic conditions of the countries, different rates have been evaluated in different studies. In the studies examined, end-uses that constitute the greywater source were selected as the water coming from the bathroom, sink, and washing machine, which is relatively less polluted. On the other hand, alternative water sources were generally used for purposes such as toilet flushing, cleaning, irrigation, and emergency tanks that do not require drinking water quality [48]. Different software and methods were used in different studies to select the storage capacity of the alternative water source [49]. These methods are mainly based on the water balance model.

***Table 9.*** *Studies examining the water-saving performance of alternative water sources*

| Study | Rainfall Data (Year) | Discount Rate (%) | Greywater Supply | Greywater Demand | Rainwater Demand | Tank Design Method |
|---|---|---|---|---|---|---|
| [9] | 34 | 1, 5, 10 | [1]S., [2]L., [3]W.M. | [4]T. | T. | Neptune software |
| [28] | 3 | N.A. | S., L., W.M. | T. | T., W.M. | Neptune software |
| [40] | 80 | N.A. | S. | W.M., T., [5]I. | T. | UVQ tool (WBM) |
| [30] | 30 | 3 | S., L., W.M. | T., I. | T., I. | [9]WBM |
| [43] | 45 | N.A. | S., L., W.M. | T., I. | T., I. | Rippl Method |
| [31] | 24 | 3.5 | L. ve S. | T. | I., [6]C., W.M. | Trial and error method |
| [44] | 13 | N.A. | B., L., W.M. | T., I. | T., I. | SWMM software |
| [32] | 15 | 6.05 | B. | T., I. | T., I., Te., W.M. | Trial and error method |
| [45] | 35 | N.A. | B., L., W.M. | T., I. | T., I. | RainTANK tool (WBM) |
| [33] | 10 | 2.88 | W.M. | T. | Ç.M. | Netuno software |
| [34] | 10 | 0-6 | B., L., W.M. | T., I. | T., I. | Vensim software (WBM) |
| [27] | 30 | 3 | B., L., W.M. | T., I. | T., I. | Python software (WBM) |
| [37] | 20 | 3.5 | L. | T. | I., [7]E.T., [8]C.T. | WBM |
| [38] | 12 | 6.73, 11.73, 16.73 | B. ve L. | T. | W.M. | Netuno software |

[1]S: Shower, [2]L: Lavatories, [3]W.M.: Washing Machine, [4]T: Toilet cistern, [5]I: Irrigation, [6]C: Cleaning, [7]E.T.: Emergency Water Tank, [8]C.T.: Cooling Tower, [9]WBM: Water Balance Model

## 4. CONCLUSION AND RECOMMENDATIONS

The aim of this research is to investigate the importance and role of hybrid water systems combining rainwater and greywater for purposes where drinking water quality is not required in buildings. Previous research on this topic was reviewed using the Scopus and Web of Science databases with the search terms "rainwater harvesting and greywater recycling." After filtering, 33 studies were identified in the Scopus database and 32 in the Web of Science database. It was found that 29 of these studies were present in both databases, resulting in a total of 36 distinct studies. These studies were evaluated based on the year of publication, country of publication, author(s), research area, source of publication, and the affiliation where they were published. The findings were gathered from the databases concerning these categories.

Due to the limited number of studies on this topic, no year filtering was conducted. Aside from the period between 2012 and 2018, there were no active years concerning hybrid water systems. Consequently, it was determined that this topic has not yet garnered significant interest from researchers. However, it was found that a substantial number of publications originated from countries like Brazil, Great Britain, China, and the USA, despite them not being leading nations in the field of hybrid water systems.

The primary research domains concerning hybrid rainwater harvesting and greywater recycling systems include environmental science, engineering, social sciences, and energy research. Following these are disciplines like water resources and chemistry. The Journal of Cleaner Production and Building and Environment are prominent publications in this area. Other significant sources for studies on hybrid water systems include water-focused journals such as Water (Switzerland), Desalination, and Urban Water Journal.

When the affiliations are examined, Universidade Federal de Santa Catarina and Monash University Malaysia lead the way in hybrid water systems studies. Apart from these, no other noteworthy affiliation was found. It was determined that Ghisi, E., who works for Universidade Federal de Santa Catarina, is the leading author in this field. Brazil is at the top among the countries with the most publications thanks to Ghisi, E., who has 6 documents in both Scopus and Web of Science databases. When the authors with the most publications and citations were examined, it was revealed that the 6 authors following Ghisi, E. have the same number of publications with 2.

The keywords "rainwater harvesting, greywater recycling, potable water saving" were found together in the analyses, and "financial analysis, economic analysis" emerged remarkably. This situation emphasises the importance of economic feasibility studies regarding hybrid water systems. Hybrid water systems at the building scale have been the subject of many studies in terms of environmental, economic, and social aspects. Except for a few studies, it has been concluded that alternative water sources are generally economically feasible. It has been determined that the most critical environmental contributions of alternative water sources are water saving and reducing the load on the sewage and rainwater network infrastructure. The studies conducted from the perspective of alternative water sources determined that the participants were mainly reluctant to use greywater. It has been determined that the perspective on rainwater is better compared to greywater.

It has been observed that in studies where economic analyses of alternative water resources are made, at least 10 years of rainfall data are used, and the discount rate is selected according to the economic situation of the country where the research is conducted. During the design phase, the selection of where to obtain and where to use rainwater and greywater systems is made. It has been seen that various software is used to determine the volume of the tank, which is one of the essential components of alternative water resources systems. All of these software are based on the water balance model.

Alternative water systems vary in economic and environmental aspects depending on many factors such as location, size, building type, treatment method, number of users. Each situation is unique. Therefore, each needs to be designed and examined from environmental and economic perspectives. Which alternative water source will be used and how it will be used is determined during the design phase. Thus, the more efficient one is selected during the operation phase.

Future studies to improve and develop the feasibility of hybrid water systems are of great importance. Specifically, the design of storage tanks and treatment methods are fundamental elements that influence the utilization of alternative water sources across environmental, economic, and social dimensions. The social acceptability and financial feasibility of the proposed research on these components will play a direct role in minimizing environmental impacts. Last but not least, future research on advancing storage tank design and treatment techniques is expected to facilitate using alternative water resources.

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Research Article GU J Sci, Part B, 13(2): 263-277 (2025)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

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# Generative Design Approach in the Early Stage of High-Energy Performance Building Design with BIM-Based BEM Process

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**Article Info**

*Received: 25/04/2025*
*Accepted: 23/06/2025*

**Keywords**

*Generative Design*
*BIM*
*BEM*
*Early Design Stage*
*High Energy Performance*

**Abstract**

The design of high energy-performance buildings today increasingly emphasizes the importance of decisions made during the early design stages. In this context, the adoption of Building Information Modeling (BIM)-based Building Energy Modeling (BEM) approaches has been encouraged. This study investigates a generative design approach integrated with BIM-based BEM in the design process of high energy-performance buildings. The proposed method, developed for cold-dry climate conditions, enables architects to generate various building forms during the early design stage, analyze them in terms of energy performance, and identify optimized solutions. Through algorithms developed within the Revit-Dynamo environment, building forms were first generated based on form factor and floor area criteria. Subsequently, window placements and Window-to-Wall Ratio (WWR) values were parametrically defined for façade design. The resulting design alternatives were subjected to energy simulations using Green Building Studio and evaluated based on their Energy Use Intensity (EUI) values. The design options were visualized in a manner that allowed ranking according to the architect's objectives, thereby supporting the decision-making process. The findings indicate that compact forms with low form factors and façade-based window optimizations have a significant impact on energy efficiency. Within this scope, the developed framework emerges as an effective tool for sustainable and data-driven building design at the early design stage.

## 1. INTRODUCTION

The increasing demand for energy and the growing emphasis on sustainability have made energy efficiency a primary concern in building design. Designing high energy-performance buildings requires the integration of both passive and active design strategies, with early design stages playing a critical role in this process. Traditional design methods often offer limited alternatives during the decision-making process, and in cases where numerical analyses are either not integrated or are applied at later stages, the full potential for energy efficiency cannot be realized. Decisions made in the early design phase significantly influence a building's energy performance. Studies have shown that optimizing building form and orientation can reduce energy consumption by 30–40% [1]. Numerous researchers in the literature emphasize that integrating building performance simulations into the early design stage is essential for achieving high-performance buildings [2]. The application of energy simulations during early design enables the optimization of critical design decisions (such as form, orientation, window-to-wall ratio (WWR), and construction materials) that directly affect building performance [1].

Building Information Modeling (BIM) has emerged as a powerful tool for optimizing the energy performance of buildings during the conceptual design phase. BIM-based energy analysis enables project teams to explore various energy-saving alternatives during the early stages of design—when decisions have the greatest impact on life-cycle costs [3]. Through integration with energy simulation software such as EnergyPlus and IES, BIM allows designers to efficiently assess building performance in relation to factors such as orientation and window dimensions [4]. This approach facilitates the selection of energy-efficient materials and strategies within the framework of green building standards [5]. Studies have

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demonstrated that BIM-based optimization can lead to significant energy cost savings; in one case, a 58.46% reduction in energy costs was achieved over a 30-year period compared to the initial building model [6]. Overall, BIM-based methods offer a time- and cost-effective approach to evaluating and improving building energy performance in the early design stages.

Generative design is an approach that automates and optimizes the design process through the use of algorithms and artificial intelligence. This method enables the rapid evaluation of a large number of design alternatives and the generation of solutions aligned with predefined performance criteria [7]. Particularly in the context of goals such as energy efficiency, the generative design process can achieve optimization in terms of performance metrics such as thermal comfort and energy consumption [8]. The integration of artificial intelligence further advances the generative design process by providing predictive capabilities for evaluating building performance [9]. Compared to traditional and parametric methods, generative design has been identified as the most effective approach for energy-efficient design processes. Automating the design process and optimizing it based on specific criteria not only allows architects to focus on creative aspects but also positions energy efficiency as a fundamental design parameter. The capacity of generative design to produce multiple alternatives and its adaptability to sustainability-focused objectives highlight it as a powerful method for addressing contemporary architectural challenges [10].

In this context, the generative design approach supported by Building Information Modeling (BIM)-based Building Energy Modeling (BEM) offers a significant advantage during the early design phase. While BIM digitizes the building design process and enables the integration of energy modeling and optimization workflows, generative design algorithms allow for the rapid and effective generation of diverse design alternatives. As a result, the impacts of design decisions on energy performance can be anticipated and optimized at much earlier stages of the design process.

The building envelope functions as the primary boundary separating a structure from its environmental conditions, while also exerting formal influence at the urban scale. In this context, the envelope is considered one of the most defining elements of a building. Moreover, it plays a critical role in determining the building's energy performance. Contemporary architectural design processes increasingly consider environmental sustainability; however, a strong focus on improving energy performance can often come at the expense of other architectural values such as aesthetics and functionality [11]. This imbalance may result in building envelopes that are energy-efficient but lack functional adequacy and visual quality, overlooking user needs, spatial quality, and formal coherence. Achieving an appropriate balance is only possible through a holistic application of architectural composition principles throughout the design process.

The form of the building envelope is typically defined during the early design stages and undergoes only limited modifications throughout the remainder of the design process. Due to the time-consuming and complex nature of energy simulations, energy consumption values of buildings are often not calculated during the early design phase. This hinders the ability to evaluate design decisions in terms of energy efficiency. To address this issue, a number of energy-efficient design rules have been developed to guide the design process at early stages [12]. However, while such rules can contribute to the design process, they are generally generic in nature and often fall short when applied to complex building geometries.

Buildings, as structures with long life cycles and high levels of energy consumption, play a critical role in environmental sustainability. In this context, the form of the building envelope has a direct and decisive influence on its energy performance [13], [14]. Therefore, relying solely on general design guidelines does not constitute a sufficient strategy for the development of energy-efficient building envelopes.

The building envelope shaping approach presented in this study is based on two fundamental principles: first, the theoretical and practical significance of architectural composition principles in the design process; and second, the instrumental role of energy simulations in achieving energy-efficient design. The primary motivation behind this research arises from the need to quantitatively reveal the impact of formal design decisions on energy performance. In doing so, it provides designers with the opportunity to revise and improve building envelope forms when energy performance expectations are not met. Generative design systems are defined as models based on a set of computational rules designed to produce alternative design solutions [15], [16], [17]. These systems not only ensure the intended formal diversity but also encode predefined design constraints to guide the design process. Accordingly, through a well-structured rule set, generative design systems can offer formal variation while maintaining stylistic coherence and design language consistency. This dual capacity supports creative freedom while ensuring design integrity.

Unfortunately, the traditional design process is largely incompatible with the use of complex generative design systems such as shape grammars. In scenarios where only a single design output is pursued, alternative designs may be considered, but a formally defined design system is typically not established. However, exploring design diversity through a well-structured design system necessitates the construction of that system, and if only one output is ultimately required, the benefits of such an exploratory process may not justify the effort involved. With some exceptions, the practical application of generative design systems—particularly shape grammars—is generally limited to contexts in which multiple outputs are needed, such as mass housing production and customization scenarios [18], often in conjunction with prefabricated building systems.

This study aims to investigate how generative design approaches can be employed to generate design alternatives in the early stages of high-energy-performance building design by integrating BIM-based BEM methods. The integration of BIM-based energy simulations with generative design algorithms will be explored, and new strategies will be developed to enhance energy efficiency in architectural design. The findings will serve as a guide for architects and engineers in optimizing design processes and contributing to sustainable building design.

### 1.1.BIM base BEM

Building Information Modeling (BIM) can facilitate the evaluation of building energy performance in the early stages of the project process, thereby enhancing the impact of design decisions on energy efficiency and cost [19]. In this regard, BIM-based Building Energy Modeling (BEM) methods have become increasingly popular and have emerged as an adaptable approach to integrated design processes [2]. Building energy simulations play a critical role in reducing energy consumption [20]. However, existing energy simulation tools are time-consuming due to the need for manual data entry, and they have a high likelihood of errors. Additionally, in cases of missing data, experts may be forced to use hypothetical values, which can lead to inconsistent results [21]. The integration of BIM-based BEM can eliminate the manual modeling process, making energy analyses more efficient and reliable. However, overcoming current software and workflow challenges is necessary to achieve full integration. The BIM-based BEM process consists of various components that contribute to the overall workflow [22]. An overview of the BIM-based BEM process is shown in Figure 1.


***Figure 1:*** *Overview of the building information modeling-based building energy modeling process*

The integration of Building Information Modeling (BIM) and generative design has emerged as a promising approach for achieving high energy performance in building design [23]. Generative design is an iterative, rule-driven process based on algorithmic and parametric modeling, which allows for the automatic exploration and optimization of design possibilities by defining a high level of constraints and objectives. When combined with BIM's ability to create, record, and manage digital information about a building throughout its lifecycle, this approach can facilitate the constructability of generative design solutions and enhance the capabilities of BIM in the early stages of design [8].

In the study conducted by Utkucu et al. (2023), the multi-criteria optimization of building performance was addressed through an integrated design approach based on Building Information Modeling (BIM).

The study proposes a three-phase interdisciplinary design process—conceptual, schematic, and detailed—through the integration of various analysis tools, such as energy simulation and computational fluid dynamics (CFD), with the BIM platform. The method emphasizes data sharing and interoperability between software during the 3D modeling process, achieving up to 75% energy savings in a two-story residential building case study and enabling the building to achieve an "A" energy class rating [24]. However, the study does not cover the early stages of the design process or the generation of alternatives regarding the building form.

One of the key advantages of generative design is its ability to manage an increasing number of variables and parameters using computational power. This approach can offer significant benefits in early-stage high-energy-performance building designs by allowing designers to test multiple and complex alternatives [25]. The decisions made at this stage can have a significant impact on the environmental performance of the building.

### 1.2. Generative Design Systems

Generative design systems fundamentally encode the transformation of design forms using algorithms and mathematical rules. These systems simplify the design process significantly by offering different options and enabling the exploration and evaluation of various alternatives [26]. The use of real computation and digital technologies helps designers enhance their ability to develop new and effective design processes [16]. Generative design systems are defined as mechanisms and processes that provide opportunities to generate unexplored forms.

Generative design processes generally follow and repeat four steps: Representation, Production, Evaluation, and Feedback. These operations are based on an input-output relationship. Cagan (2005) explained that the representation phase involves defining the design problem and assists in generating suitable techniques. Production encompasses the performance of the entire mechanism and its components. Evaluation represents the testing phase of the system, demonstrating how successfully the relationship between the objectives and constraints is achieved. Additionally, feedback is the final step in which design improvements are provided for the next phase [27].

Generative design algorithms systematize the design process, allowing human designers to explore their creative space more deeply. In this context, shape grammar enables the generation of solutions with rapid and formal diversity by transforming specific design rules into a computational framework. These methods support users in making effective design decisions without the need for interdisciplinary knowledge [14]. In his doctoral thesis, Boumaraf (2022) categorizes generative design methods into nine systems: Algorithmic Systems, Shape Grammar, L-Systems (Lindenmayer Systems), Cellular Automata Systems, Genetic Algorithm Systems, Voronoi Systems, Subdivision Systems, Topology Optimization Systems, and Swarm Behavior Systems [28].

A shape grammar-based parametric design system is a proposed method for achieving flexible designs while maintaining architectural composition principles. The unique characteristics of shape grammars offer the opportunity to explore meaningful design diversity [29]. The basic components of shape grammars, as shown in Figures 2 and 3, are form rules that define the spatial transformation of a geometric shape. These rules consist of two components: the Left-Hand Side (LHS) and the Right-Hand Side (RHS); the RHS represents the transformed version of the LHS. Shape grammars begin with a specific set of forms, symbols, and transformation rules, and require an initial form in which at least one rule matches the LHS. The rules continue to be applied by iteratively transforming the shapes. Five common types of transformations are defined in the literature: addition, subtraction, division, modification, and displacement. These transformations allow for the generation of new forms by either maintaining or altering the structure of the original shape, enabling the productivity of shape grammars [14].

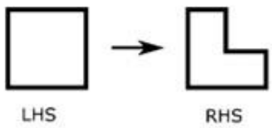



***Figure 2:*** *A common shape rule that includes LHS and RHS shapes [14]*

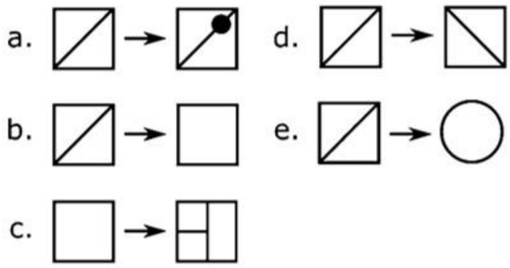



***Figure 3:*** *Examples of shape rules based on different types of transformations: (a) addition, (b) subtraction, (c) division, (d) permutation, and (e) substitution [14]*

### 1.3. Generative Design and BIM Integration

Generative design is the process of automatically generating a multitude of alternative solutions through computer software to achieve specific design goals. In this process, designers define certain parameters (such as material types, building height, cost constraints, etc.), and the software generates various design options that align with these parameters. Thanks to generative design, multiple alternative design solutions can be produced simultaneously, with optimized solutions based on performance criteria (such as energy efficiency, cost-effectiveness, structural durability, etc.), offering more innovative and unconventional design options compared to traditional design methods.

The integration of generative design with Building Information Modeling (BIM) combines the advantages of both technologies, enabling the creation of smarter and more efficient design processes. In this way, alternative design solutions generated through the generative design process can be directly integrated into BIM models for visualization and analysis [30]. While generative design presents optimized solutions based on performance criteria, these solutions are detailed using the BIM model. BIM ensures that all project stakeholders work on the same model, while the generative design process provides more coherent and optimized design solutions based on inputs from various stakeholders [28]. The integration of generative design and BIM facilitates the realization of more innovative, efficient, and sustainable projects in the construction and architecture sectors. This integration contributes to the successful completion of projects by enabling better decision-making from the early stages of design.

## 2. METHOD

BIM-based BEM (Building Energy Modeling) technologies provide an opportunity to compare design options and create the best solution to improve the building's ecological footprint. However, as observed in this research, design experts are still striving to reorganize their processes in order to maximize the benefits of these technologies. In this article, a BIM-based BEM framework, suitable for the early stages of the design process, is proposed to facilitate and systematize information sharing. In the first step, an algorithm suitable for our purpose is created using Revit-Dynamo. Dynamo parametric programming, Revit-Dynamo interaction commands, and built-in mathematical operations are used to control decision variables. The program modules have the ability to capture decision variables from model components and establish connections between them. Complex information is flattened into parallel control modules that can globally regulate the model with less human intervention by altering decision variables. The interface between the building model and simulation tools can be connected through Python programming, which enables real-time data interaction between Dynamo open-source packages, the modeling platform, and the simulation platform. In the proposed process, Green Building Studio (GBS) is used to simulate energy consumption.

The proposed framework has been developed to support sustainable building design in the early design phase by integrating a generative design approach within the BIM-based BEM environment. It aims to generate, analyze, and optimize different design alternatives in terms of energy performance. During the conceptual design process, the primary objective is to automatically generate high energy-efficiency building forms and then determine parameters such as window placement, size, and opacity/transparency ratio for the building envelope design. The workflow developed within this scope offers a systematic approach that integrates energy-efficient design criteria with the generative design process.

In the first phase, performance criteria such as form factor and total floor area are defined to guide the design process. Subsequently, alternative building forms are parametrically generated in the Revit-Dynamo environment within the framework of shape grammar rules. The most optimal form is selected by targeting the minimum form factor and maximum floor area. In the second phase, building envelope design alternatives are created to achieve the lowest possible Energy Use Intensity (EUI). In this context, variables such as window position, size, and transparency ratio are parametrically defined. The resulting geometries are converted into gbXML format to be compatible with energy simulations and transferred to BEM software. Based on energy analyses performed with climate and location data, the form with the highest energy efficiency is identified, and the optimum design is selected. The process is iteratively repeated if necessary, and based on the findings, the design process either moves to the next phase or undergoes further optimization.

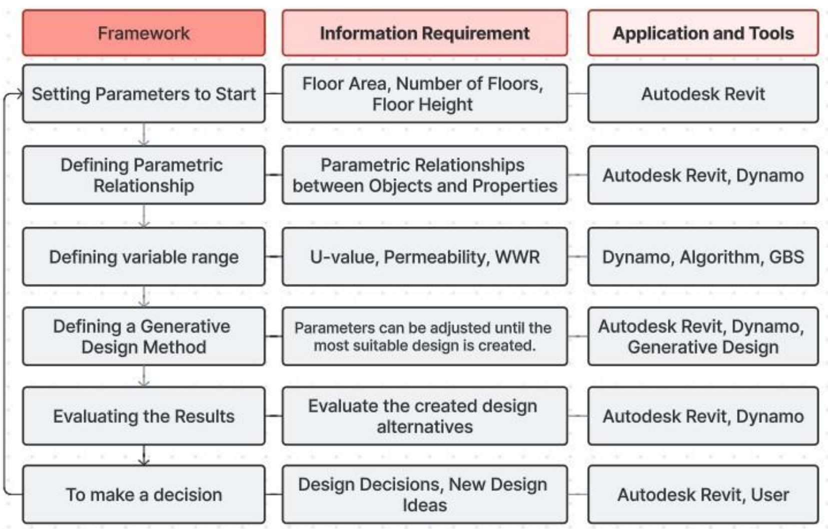



***Figure 4:*** *The proposed framework process and the tools and practices used in the process*

The algorithm developed on the Dynamo platform is designed to support Generative Design processes. The inputs of the algorithm consist of various parameters that define the building form. These parameters enable the design to be optimized in accordance with both geometric and performance criteria. The outputs of the algorithm are evaluated based on performance-driven objectives such as maximizing floor area and minimizing form factor. During the building form generation process, shape grammar rules are applied to establish a systematic design language. These rules provide fundamental principles for generating and optimizing building geometry. As a result, the algorithm functions as a design tool aimed at producing building forms optimized for both aesthetics and energy efficiency.

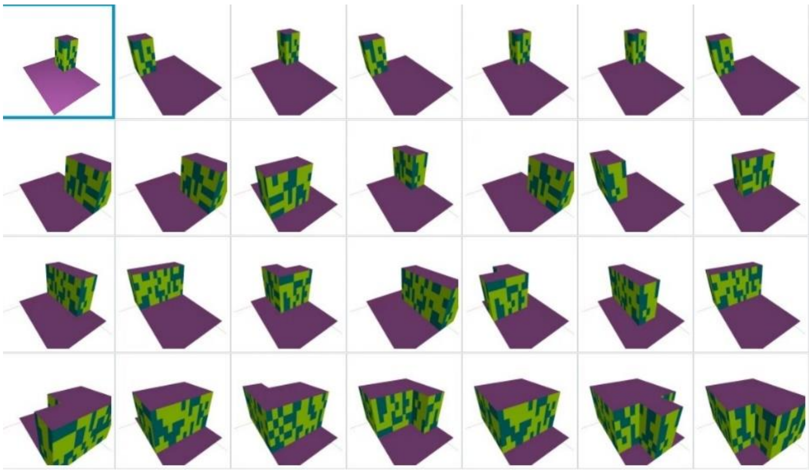
The form factor is a term used to assess the impact of a building’s design on energy efficiency and heat transfer. It measures how the shape, proportions, and external surface of a building influence its energy performance. A simple formula for calculating the form factor is expressed as follows:

Form Factor (F) = Surface Area (A) / Volume (V)

- Form Factor (F) reflects the effect of a building's shape and proportions on energy efficiency.
- Surface Area (A) refers to the total area of the building’s external envelope.
- Volume (V) indicates the internal volume of the building.

This simplified form factor equation is useful for understanding how the compactness and shape of a building affect its energy performance. A higher form factor represents a smaller internal volume relative to the external surface area, which can increase energy loss. Conversely, a lower form factor indicates less external surface area relative to the internal volume, contributing to improved energy savings. The form factor is utilized in the optimization of building design and in the assessment of strategies for enhancing energy efficiency. A well-designed building may exhibit a lower form factor, thereby supporting energy conservation.

The 12-square grid system, defined as the starting point, establishes a fundamental framework for the design process. Within this system, rules are defined for generating shape variations, such as the positions of squares, points of connection, as well as subtraction and addition operations. However, the rule prohibits two squares from joining at only a single point. By integrating these rules into algorithms, a systematic generation of diverse forms can be achieved automatically. Additionally, a parametric control mechanism is implemented to allow greater flexibility in shaping the design. At this stage, parameters such as size, height, and number of squares are incorporated into the algorithm, enabling the creation of diverse variations that are both aesthetically and functionally distinct. This process facilitates the systematic development of the design and allows for the controlled generation of complex structures.



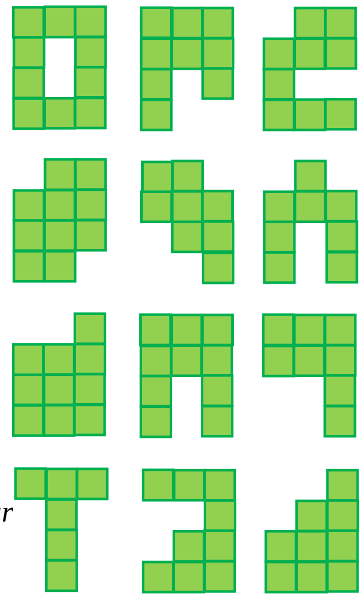


***Figure 5:*** *Possible Forms That Can Be Produced with Shape Grammar Rules*

At the end of this phase, various building forms are systematically analyzed to determine the most appropriate form in line with performance goals. During this analysis process, different formations are compared based on key performance parameters such as form factor and floor area. The comparisons are carried out using criteria such as energy efficiency, material usage, and structural integrity. This stage of the design process not only meets performance requirements but also takes broader objectives into account, including sustainability and economic efficiency. Ultimately, the design alternatives that offer the most efficient outcomes are evaluated, and the optimal option in terms of building form is selected. Based on this selection, the design process advances to the next phase. This process is supported by a holistic approach that aims to maximize the impact of early-stage design decisions on overall building performance.

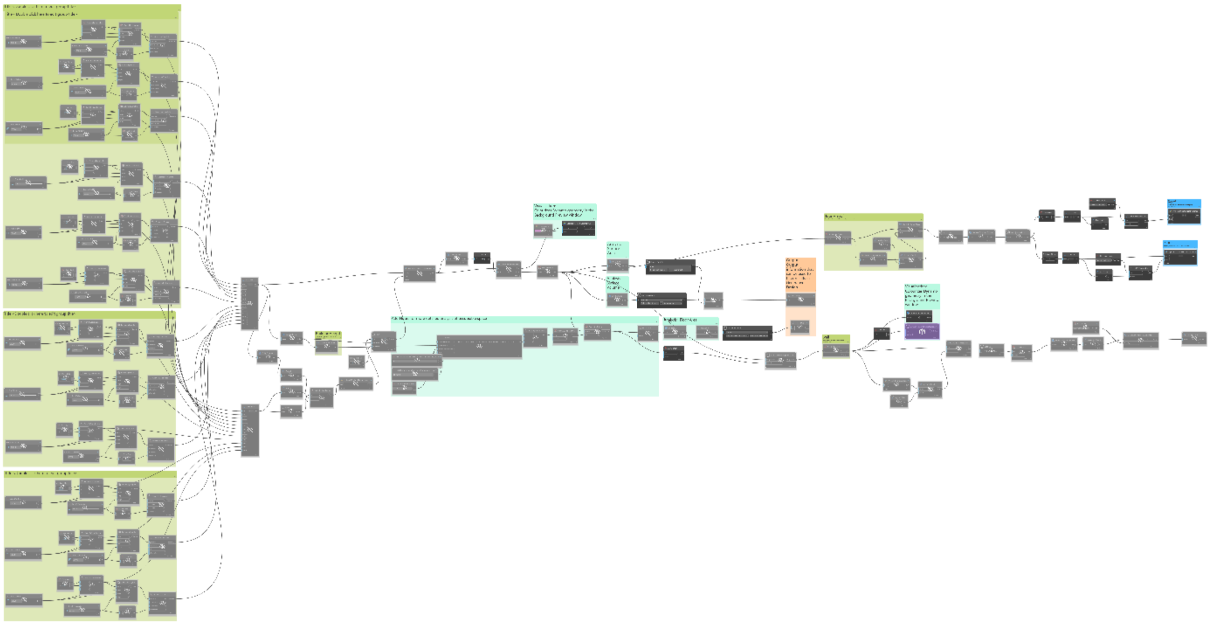


***Figure 6:*** *Developing Form Grammar Based Algorithms for Generative Design*

This algorithm developed in Dynamo constitutes the first phase of the proposed process and applies generative design using a shape grammar approach for building form optimization. The algorithm comprises stages including the generation of building geometry, the creation of form variations, and the analysis of these forms based on defined criteria. Figure 6 illustrates the algorithm developed within the Dynamo environment. The algorithm consists of the following main components:

a) Shape Grammar Rules (Left Section – Green Areas) The components at the beginning of the algorithm include rule definitions that govern the creation of the building form. These components are composed of modules that define the shape grammar rules and include input parameters for generating alternative form variations.
b) Geometry Generation (Central Section – Grey Modules) In this section, various form variations are generated according to the shape grammar rules, leading to the formation of the building mass. While deriving possibilities for alternative forms, building components (walls, floors, roofs) are modeled and prepared for the analysis process.
c) Performance Analysis (Right Section – Blue and Orange Areas) The generated building forms are evaluated by analyzing the surface area-to-volume (SA/V) ratio and floor area. Surface area and floor area calculations are conducted, and the results are compared to identify the optimal form variations.
d) Optimization and Outputs (Far Right Section – Purple and Red Areas) The outputs of the generative design process are analyzed to select the most suitable building form. Alternatives with optimal form factors and maximum floor areas are identified. Finally, parametric analyses of the final model are completed, and the design outputs are produced.

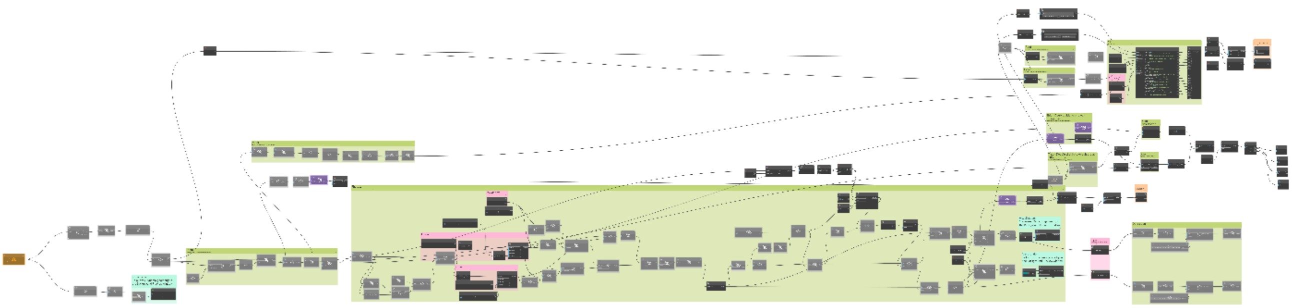


***Figure 7:*** *Developing EUI and WWR Based Algorithms for Generative Design*

In this algorithm, a BIM-based generative design approach was developed to optimize building envelope parameters in terms of energy performance during the early design phase. The proposed method is structured around a visual algorithm that integrates parametric modeling, energy simulation, and optimization processes using Revit and Dynamo software (Figure 7). The process consists of three main stages: parametric modeling, energy analysis, and optimization. The structural components and operational logic of the algorithm are outlined below:

a) Input Parameters (Left Section) The nodes located on the left side of the algorithm represent the parametric inputs used in the generative design process and play a fundamental role in defining the design space. These parameters include variables that directly influence design decisions such as window-to-wall ratio, window placement, opaque/transparent surface ratio, and location data. Minimum and maximum value ranges are defined for each parameter to constrain the algorithm’s search space, thereby enabling the generation of valid design alternatives based on both geometric and performance-based criteria.

b) Parametric Modeling and Geometry Generation (Central Section) In the central section of the algorithm, the defined parametric inputs are processed to generate various façade configurations and window placement alternatives. This process is guided by a set of rules that direct the façade design, wherein the applied rule sets—similar to the shape grammar approach—govern window sizing and positioning.

c) Energy Calculations and EUI Evaluation: In the middle and right sections of the algorithm, energy performance analyses are conducted for each generated design variation. Within this scope, performance indicators such as total heating and cooling loads, thermal energy demands, and Energy Use Intensity (EUI) are calculated. During the analysis, the geometric data generated in Revit are converted into gbXML format and transferred to the Green Building Studio energy simulation platform, where they are evaluated together with climate data. This integration enables the calculation of EUI for each design variation.

d) Optimization Process (Lower Right and Mid-Right Sections) In the lower right section of the algorithm, the design variations are analyzed and compared according to energy performance criteria. At this stage, a genetic algorithm optimization technique is applied to determine the window configuration and envelope design with the lowest EUI. The optimization operates iteratively, generating new variations in each cycle based on previous results to enhance performance. In this way, the algorithm systematically and data-drivenly identifies the most suitable solution aligned with the design objectives.

e) Visualization of Results and Output (Far Right Section) The outputs of the algorithm are presented through a visual analysis panel that displays the optimal design variation graphically and enables automatic data transfer to the Revit environment. The user can comprehensively evaluate the selected optimal solution in terms of both numerical performance data and geometric features. Through this integration, the design process is driven not only by visual aesthetics but also by energy performance-based criteria, thus enabling a data-informed and integrated decision-making process.

## 2. RESULTS AND DISCUSSION

Table 1 presents the input parameters defined for the execution of the developed generative design algorithm, along with their respective minimum and maximum value ranges. These parameters comprehensively describe the geometry and physical characteristics of the building, including Energy Use Intensity (EUI), floor area, thermal transmittance coefficients (U-values) of building components, window opening ratios, number of floors, and floor height. Additionally, environmental and system-related variables that influence energy performance—such as solar heat gain coefficient (SHGC), Window-to-Wall Ratio (WWR), lighting power density, and equipment power density—are also included. These data constrain the algorithm’s search domain and constitute the numerical inputs required to generate optimized design solutions. This ensures both the validity of the design variations and the reliability of the energy simulations. Furthermore, this study specifically focuses on a four-story residential building located in Ankara, Turkey.

***Table 1:*** *Input Parameters and Value Ranges Defined for the Proposed Algorithm*

| Parameters | Unit | Min | Max | Parameters | Unit | Min | Max |
|---|---|---|---|---|---|---|---|
| EUI target | kWh/ m² | 80 | 120 | Number of floors | - | | 4 |
| Floor area | m² | 200 | 300 | Height | m | 3 | 3.6 |
| Upper window space from each floor | m | 0.6 | 0.8 | WWR | % | 10 | 50 |
| Lower window space from each floor | | | | | | | |
| Ground floor space of the building | m | 0.6 | 0.8 | Solar gain factor | W/m² | 180 | 200 |
| Ground from the roof of the building | | | | | | | |
| Lighting power | W | 4500 | 5000 | Device power | W | 2800 | 3000 |

The building envelope components used in this study were designed in accordance with the high-performance thermal insulation criteria established by the Passive House Institute. The exterior walls feature a multi-layered construction system, with each layer's thermal properties and material composition detailed in Table 2. The thermal transmittance coefficient (U-value) of the exterior wall, calculated in accordance with ISO 6946, was determined to be U = 0.13 W/m²K. This value is suitable for minimizing energy losses in cold and dry climatic conditions. For windows, a U-value of 0.85 W/m²K was adopted. This window performance rating contributes to enhancing overall building energy efficiency by providing high levels of insulation.

***Table 2:*** *Thermal properties of the external wall.*

| Wall | Layers | Thickness (mm) | Thermal Conductivity [W/(m·K)] |
|---|---|---|---|
|  | Interior finishing (plaster) | 10 | 0,8 |
| | Gypsum fibreboard | 25 | 0,36 |
| | Insulation (Rockwool) | 50 | 0,033 |
| | Concrete wall | 250 | 2,3 |
| | Adhesive | 10 | 0,16 |
| | Insulation (Rockwool) | 200 | 0,035 |
| | Basecoat | 6 | 0,16 |
| | Exterior finishing (plaster) | 10 | 0,8 |

Based on the initially defined parametric inputs, the algorithm is capable of generating a total of 4,096 different building form alternatives. However, this extensive solution space was narrowed through predefined design constraints to identify the most energy-efficient solutions. Within the scope of these constraints, alternatives with a minimum form factor and maximum floor area were prioritized. As a result of the preliminary filtering process, only 10 forms were deemed suitable for energy performance analysis (Figure 8). This approach facilitates a more efficient evaluation of design alternatives, enabling optimal use of computational resources and supporting more accurate decision-making during the early design phase.

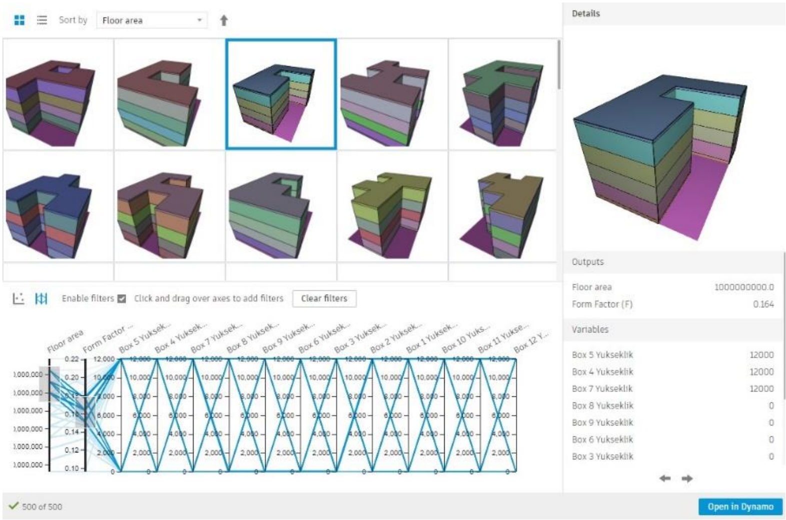



***Figure 8**: Visual and Numerical Analysis of Building Masses Generated Through the Generative Design Process Based on Form Factor and Floor Area.*

The interface developed in this study enables both visual and numerical comparison of alternative building masses generated during the generative design process. Each variation is analyzed based on key performance indicators such as form factor and floor area, allowing systematic selection of solutions that meet predefined criteria (e.g., low form factor and maximum floor area). This transforms the design process from an intuitive approach into a data-driven, rapid, and optimized decision-making framework. The ability to visually monitor selected solutions and directly integrate them into the BIM environment (Revit) supports a holistic and performance-oriented design methodology.

In the second stage, the selected optimal building form—identified through the first algorithm—was integrated into a second algorithm to refine façade design. In this phase, window positions and opening areas were defined for each façade, and corresponding WWR (Window-to-Wall Ratio) values were applied. These ratios were determined based on national standards (TS 825, BEP Regulation) and current literature addressing energy efficiency in cold and dry climate conditions. Table 3 presents the proposed WWR ranges for each façade orientation and summarizes the reference values underpinning the algorithm's decision parameters.

*Table 3: WWR Values Suitable for Cold-Dry Climate Conditions*

| **Facing Direction** | **WWR** | **Facing Direction** | **WWR** |
|---|---|---|---|
| North | %10 – %25 | East | %15 – %35 |
| South | %30 – %60 | West | %15 – %35 |

The Generative Design process was carried out using Autodesk Revit software. A genetic algorithm was employed in the production of design options, with the algorithm's initial parameters defined as follows: a population size of 100, a generation count of 20, and an initial seed value of 1. These parameters were selected to ensure sufficient diversity within the solution space and to explore various design possibilities. Figure 8 presents the data frames and interface presented to the user as a result of the optimization process. In this interface, the energy performance of the designs was analyzed based on variations in window placements and WWR (Window-to-Wall Ratio) across different façades. The 3D models shown in the visual represent different design alternatives, each with different window ratios. This allows the user to visually compare and assess alternative solutions in terms of energy efficiency.

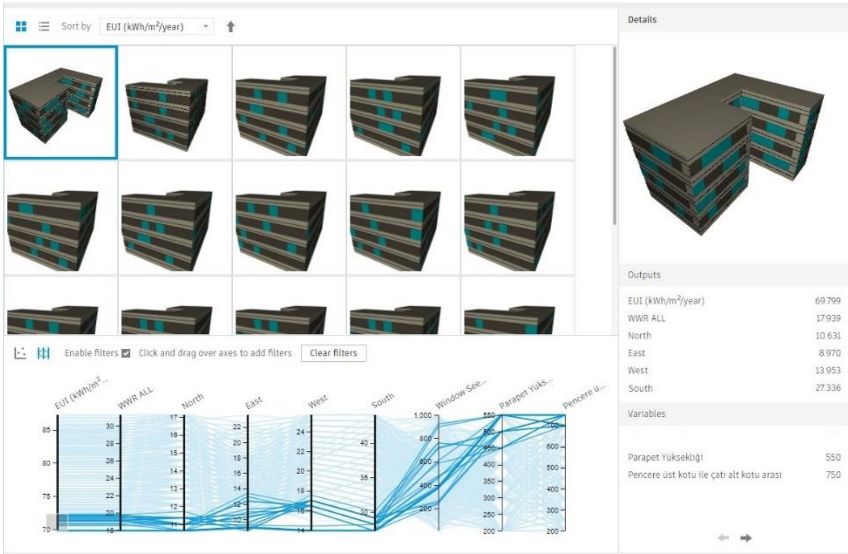



***Figure 9:*** *User interface visualizing the energy performance of design alternatives generated through the generative design process, along with façade-based WWR values and geometric variables.*

For each alternative design, the system calculates and presents data such as Energy Use Intensity (EUI), Window-to-Wall Ratio (WWR) for each façade, Total WWR, the distance between the top of the window and the bottom of the roof, and parapet height. When the user selects any of the generated solutions, they can view all of these data in detail. Additionally, the system provides flexibility for architects to define sorting criteria based on the design goals. The ability to sort the data allows for the comparison of design scenarios with different priorities, enabling the user to easily identify the solution that best aligns with their criteria. Table 4 presents the alternative designs sorted in ascending order based on EUI values, with the solution having the lowest EUI value positioned at the top. This facilitates a direct comparison of energy performance across different design alternatives.

***Table 4****: Output data of design alternatives created using the Revit Generative Design interface.*

| **EUI** (kWh/m²/Year) | **WWR All** | **North WWR** | **East WWR** | **South WWR** | **West WWR** | **Upper window space from each floor (mm)** | **Lower window space from each floor (mm)** |
|---|---|---|---|---|---|---|---|
| 69.799 | 17.939 | 10.631 | 8.970 | 27.336 | 13.953 | 550 | 750 |
| 70.593 | 18.547 | 10.991 | 9.274 | 28.263 | 14.426 | 500 | 750 |
| 70.593 | 18.687 | 10.631 | 10.963 | 27.336 | 15.946 | 550 | 750 |
| 70.930 | 18.805 | 10.991 | 9.274 | 28.263 | 16.486 | 550 | 700 |
| 71.266 | 19.062 | 10.991 | 10.304 | 28.263 | 16.486 | 500 | 750 |
| 71.387 | 19.155 | 11.351 | 8.514 | 29.189 | 17.027 | 450 | 750 |
| 71.426 | 19.185 | 10.631 | 12.956 | 27.336 | 15.946 | 550 | 750 |
| 71.602 | 19.320 | 10.991 | 11.334 | 28.263 | 10.486 | 500 | 750 |
| 71.735 | 19.421 | 11.351 | 9.578 | 29.189 | 17.027 | 450 | 750 |
| 71.939 | 19.578 | 10.991 | 12.365 | 28.263 | 16.486 | 550 | 700 |

Upon reviewing the data, it is observed that higher WWR (Window-to-Wall Ratio) values are applied, particularly on the south façade. This approach is an appropriate design strategy for maximizing passive heat gains in cold and dry climatic conditions. On the other hand, lower WWR values were preferred for the north, east, and west façades, aiming to limit heat losses and enhance energy efficiency. This approach highlights the impact of façade-specific strategies optimized for climatic conditions on overall energy performance.

## 3. CONCLUSION

This paper highlights the novelty of our work by focusing on the generative design algorithm developed for BIM projects. By testing this methodology, a new approach has been presented that allows architects to evaluate various design solutions at the conceptual level. This early evaluation helps architects determine the most optimal design option from the outset, leading to time and cost reductions in later stages of the design process. This aspect of the research has practical implications for decision-making in architectural practice and building design. However, it is important to acknowledge certain technical limitations in the study. The algorithm we developed specifically evaluates shapes formed by a combination of 12 grid cells, excluding other complex structural shapes from the evaluation process.

The developed methodology offers architects alternatives based not only on visual aesthetics but also on energy efficiency performance criteria. With the help of parametric algorithms and energy simulation tools developed within the Revit-Dynamo environment, different building forms and façade designs were systematically analyzed to determine optimal solutions. Analyses conducted under cold-dry climate conditions demonstrated that the preference for higher Window-to-Wall Ratios (WWR) on the south façades positively influenced passive heat gains and energy consumption. On other façades, lower WWR values were used to limit heat losses. Additionally, the effects of geometric parameters such as form factor and floor area on energy performance were quantitatively shown, confirming that more compact building forms lead to higher energy efficiency. In conclusion, this research demonstrates that integrating generative design in the early design phase offers a powerful method for developing sustainable and energy-efficient building solutions. The developed methodology presents decision-makers with a systematic and data-driven design process, with the potential to establish a balanced relationship between architectural quality and energy performance.

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Research Article GU J Sci, Part B, 13(2): 279-294 (2025)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

http://dergipark.gov.tr/gujsb

# Evaluating How the Concept of Identity Influences Urban Furniture Design: A Case Study

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**Article Info**

*Received: 23/05/2025*
*Accepted: 28/06/2025*

**Keywords**

*Urban,*
*Design,*
*Furniture,*
*Product.*

**Abstract**

The extent to which public spaces—shared areas of communal use—facilitate interaction between users and the city plays a critical role in enabling a place to be embraced by its inhabitants, thereby attaining the status of an "urban space" and fostering a sense of belonging among its users. Individuals maintain human activities within urban spaces, including socio-cultural relations, traditions, and interactions concerning shared values. In this regard, cities' functional structures and amenities contribute significantly to cultivating urban consciousness among their communities. Individuals' relationships with the city are paramount for developing a sense of ownership and fostering urban identity.

At this juncture, the concept of identity emerges as a pivotal analytical instrument for scrutinizing both individuals and social groups, facilitating an understanding of individual and collective formations, and assessing these findings within the framework of urban and spatial design methodologies. Consequently, it is imperative to accurately comprehend how identity is structured within social groups and the broader societal dynamics. This study explores the processes of formation and differentiation of identity and subgroups through the lens of Tajfel and Turner's "Social Identity Theory"—a foundational framework in this domain. The research examines how identity influences the design processes of urban elements, particularly urban furnishings, and how these influences manifest in practice. The data collected for this investigation comprises responses from officials in relevant departments across selected cities, with whom interviews were conducted. In conclusion, the findings about the impact of identity on the design processes of urban furnishings as components of urban space are assessed.

## 1. INTRODUCTION

The relationship between urban environments and design has increasingly emerged as a significant area of academic inquiry, particularly as urban spaces develop into more systematic clusters, crafted in inclusive and need-oriented forms. The concept of "place" is no longer confined to a physical area that solely satisfies basic physiological requirements such as shelter and nourishment; instead, it continues to evolve into distinct constructs shaped by the meanings and codes ascribed to them by the individuals who inhabit these spaces. Consequently, this ongoing transformation fosters connections between individuals and urban areas, which are enriched by various concepts, including identity, needs, discourse, tradition, historical context, and collective memory.In contemporary society, frequently referred to as modern, the urban context is increasingly characterized as a construct that embodies inclusivity, affirms identity, and responds effectively to the identification of needs, while simultaneously providing a platform for action-oriented solutions.The conceptual expression of these individual and space interactions is spatial perception. Spatial perception refers to the transformation of abstract and concrete elements that an individual acquires during his/her connection with the physical environment in which he/she lives into a perceptible form in the individual (Özen, 2006). Spatial perception also directs the individual's attitudes and behaviors within the physical environment in which he/she lives.This positions urban spaces and cities on a larger scale as arenas necessitating collaboration, interdisciplinary expertise, and participatory problem-solving approaches. Within the hierarchy of needs delineated by contemporary social structures, various stakeholders assume roles contributing to urban space and society. These roles may encompass

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the articulation of discourses regarding the city, which, at times, concentrate on spatial organization, and at other times, focus on the relationship between individuals and the broader societal framework. Such discourses have established urban studies as an interdisciplinary field rooted in normative, pragmatic, and positivist intellectual traditions (Cömertler, 2003).

However, in the ensuing postmodern era, individuality has emerged as the central subject of social structure. Concurrently, the evolving and transformative nature of cities and societies has influenced the trajectory of design as a practice. The allegiance to authority, which was prominent in the early modern period, has gradually yielded to a more inclusive model, wherein individual influence is increasingly reflected in urban decision-making processes. Consequently, contemporary urban design can be characterized as a participatory act. The designer, who is responsible for the act of designing in the design process, must analyze the codes of the individual and society in a proper way and carry them to the world of objects, as he undertakes a mission to convey the discourse between the past and the future of life. In this respect, the designer's analysis of all permanent and temporary values and accumulations of the individual or social groups plays a role in shedding light on the act of designing (Loos, 2012).

The presence of multiple components within urban spaces—including dynamics of local authorities, individual identities, city character, material structures, and traditions—necessitates a participatory approach. Each of these subcomponents possesses specific requirements and problem-solving frameworks. Centrally defined problems and top-down solutions frequently prove insufficient in producing coherent outcomes within urban contexts. Consequently, collaboration between institutional authorities and individual participants is deemed necessary. Although participatory approaches are often perceived as essential in interventions targeting urban areas, they are frequently disregarded. Numerous sources within the academic literature support this argument.

The fundamental premise of this study is to examine the interplay between urban environments, identity, and objects through empirical data. Within this framework, the study presents the following research questions:

- Is the concept of identity considered a design criterion in the creation of urban products?
- If identity is regarded as a fundamental design criterion in urban products, in which contexts and in what manner does this manifest?

In this context, one of the significant components of urban space—urban furnishings—is assessed in terms of identity and subcategories (e.g., cultural, national, and traditional). The dataset was derived from these assessments.

In the literature review phase, various key texts were examined to comprehend the production and nature of urban space. Works such as Lefebvre's *The Production of Space* (2014) and Smith's *Uneven Development: Nature, Capital and the Production of Space* (2008) elucidate the process underlying space formation. Simultaneously, Harvey's *Social Justice and the City* (1999) and Lefebvre's *Everyday Life in the Modern World* (2007) investigate the everyday practices of urban residents and the significance of social interactions within urban environments. Key texts that address the influence of urban authorities on space, including Foucault's *Subject and Power* (2014), Castells' *The City and the Grassroots* (1997), and Brenner's *For the People, Not for Profit* (2014), enrich the literature by discussing these issues from sociological and philosophical perspectives. These sources chiefly concentrate on the sociological reflections regarding the interaction among cities, authority, and individuals within urban space.

Beyond these sociological insights, this study seeks to evaluate identity and its associated subcategories (e.g., cultural, national, and traditional identities) through the perspective of user-object interaction. The analysis concentrates on urban products—specifically urban furnishings—as fundamental components of urban space. Consequently, this study employs a micro-scale approach to the intricate concept of urban space. It aims to investigate the implications of the interaction between identity and objects within this context. In this scenario, the interactions among urban residents, pertinent urban authorities, and design processes are assessed regarding identity and its subcategories (such as traditional, cultural, national, and modern identity). The objective is to explore how urban furnishings—as essential elements of urban space—are influenced by these interactions and to deliberate on the degree to which the resultant urban products reflect and encapsulate identity-related constructs.

## 2. METHOD

According to a recent study conducted by the Economist Intelligence Unit in 2023, the top ten most livable cities in the world are ranked as follows: Vienna (Austria), Copenhagen (Denmark), Melbourne (Australia), Sydney (Australia), Vancouver (Canada), Zurich (Switzerland), Calgary (Canada), Geneva (Switzerland), Toronto (Canada), and Osaka (Japan). This ranking is based on several indicators, including educational attainment, quality of life, healthcare services, relations with local governments, and urban infrastructure. From this perspective, it is evident that European countries, which demonstrate above-average performance in these indicators, are positioned as urban centers that primarily meet the criteria for urbanization. Therefore, commencing with European cities, urban centers that have attained a certain level of urban development systems, possess historical continuity, and exhibit mature urban and social structures have been incorporated into this study, based on their capacity to satisfy the prerequisites above.

Particularly in research domains such as urban studies, characterized by dynamic and transformative structures, it is imperative to develop a methodology that neither constrains design research nor impedes data collection. Consequently, qualitative research methods offer a flexible and dynamic framework for researchers. Accordingly, the research methodology employed in this study has been constructed based on qualitative research methods within the defined parameters.

This study concentrates on urban furnishing elements within the framework of urban design. The variability among working groups, the potential increase in the variety of types, and the inherently dynamic nature of urban space necessitate a flexible and exploratory methodological framework. In this regard, particularly in design studies focusing on the interplay between the city, space, and users, the adaptability of the method to the research process and its revisability in response to emerging variables significantly enhance the effectiveness of the research.

This research has been derived from a doctoral dissertation conducted within the same framework. Following the identification of the study group, the next step in the research process involved the design of data collection tools. To construct these tools, the official websites of local government offices in the selected cities were reviewed to ascertain the presence of sub-departments related to urban planning and design. Based on the findings, the local government departments of the cities listed in Table 1—such as the Urban Affairs Department, Urban Design Office, Urban Furniture Unit, City Planning Department, Engineering and Design Office, City Council, and Regional Planning Office—were contacted via email. The content of this correspondence included an explanatory note regarding the research topic, the doctoral study from which it was derived, and the data collection process.

In developing the research methodology and the content for online survey study, a thorough review of the literature about urban studies was conducted, with particular emphasis on prominent scholars and their key focus areas. A notable contributor to this field is Kevin Lynch, who presents a comprehensive perspective on the interaction between urban environments, spatial dynamics, and their inhabitants. In his seminal work, The Image of the City (1960), Lynch employed cognitive mapping techniques across three cities to elucidate the components of what he termed the "urban image" or "social image." Based on his research outcomes, he highlighted three essential elements of an effective urban image: structure, identity, and meaning. By Lynch's framework, this study concentrates on the contextual and formal consequences of the interaction between urban furnishing elements, regarded as objects within urban space, and the notion of identity.

The rationale for primarily utilizing open-ended questions was to enable the pertinent departments to articulate their processes regarding designing and producing urban furnishing elements in their terminology. These qualitative responses can subsequently be analyzed to investigate the relationship between design and identity. Consequently, the questions were constructed to examine the pathways adopted in the selection of urban furniture, the methods by which local governments communicate and exchange ideas with the public throughout this process, whether design professionals or mass production firms are engaged in furnishing decisions, whether identity serves as a design criterion in the selection of urban furniture, and how identity and urban furniture are conceptually interrelated. To enhance response rates and facilitate quicker responses from local departments, follow-up questions were devised as multiple-choice items utilizing Google Docs.

## 3. THE RELATIONSHIP BETWEEN URBAN SPACE AND DESIGN

Cities, which are established by communities to sustain their existence within a particular order and which play a significant role in framing these actions, also contribute to cultural accumulation by guiding interpersonal relations within a defined structure. Within this relational system, tangible elements—namely, material components—serve a decisive role alongside the abstract building blocks of cities. These components include buildings, roads, and urban furnishings that constitute the physical infrastructure of cities. When all these elements coalesce into a coherent and consistent whole, such places begin to be recognized as "cities."

In his definition of the city, Lynch (2010) articulates that it constitutes a framework where "clarified areas, distinct streets, or recognizable markers can be easily distinguished or readily organized into a comprehensive model." According to Lynch, a location inhabited by communities can be recognized as a city if it exhibits a systematic unity. An essential prerequisite for formulating such a definition is that the "place" must be legible and possess a fabric formed by symbols that enable it to be identified from an external viewpoint. Consequently, discussing a unified fabric comprising legible, coherent, and continuous units from outside its boundaries is feasible.

The extent to which public spaces—defined as shared-use areas—facilitate interaction is paramount for a locale to be adopted by its inhabitants, attain the designation of "urban space," and cultivate a sense of belonging among its residents. Individuals maintain social and cultural interactions, traditions, and engagements with shared values within urban environments. In this context, the functional structure and furnishings provided by cities for their users play a crucial role in developing urban consciousness within communities. Individuals' interactions with the municipality significantly enhance a sense of ownership and urban awareness. As “places” progressively urbanize and experience heightened population density, the necessity for diverse forms of public infrastructure has arisen. Consequently, it is posited that these public amenities, which constitute part of the city's physical attributes, have begun to impact the legibility, form, and recognizability of space.

When referencing the units contributing to legibility, one can comprehend meaningful compositions that arise through specific regulations and physical interventions defined by a system of rules, contemporary technological capabilities, and societal requirements. Legibility and continuity emerge from problem-driven processes formulated within a distinct framework. These challenges, over time, require systematic thinking and persistent problem-solving. At the heart of design methodologies lies a process in which a particular situation and systematically developed solutions intersect. In this context, cities represent a large-scale domain within the overarching framework of design challenges. Transformations and social movements have influenced the material components of urban areas by evolving needs, occasionally leading to their alteration or reconfiguration.

In the realm of urban environments and design, particularly concerning the research process that focuses on urban furnishing elements, the diversity of working groups, the expanding array of potential variables, and the dynamic nature of urban space as an area of inquiry necessitate a flexible and exploratory methodological framework. Consequently, a methodological model developed within this framework serves as an essential means for diversifying and enriching research data through novel findings, presenting a valuable approach in examining relatively underexplored or challenging-to-access topics (Bengtsson, 2016). As a result, in design research that investigates the relationship between the city, space, and its users, the method's capability to adapt to the research process and be modified in response to variables facilitates a more effective and responsive study execution.

### 3.1. The Role of the Industrial Designer in Urban Design Processes

Urban areas have consistently evolved from their initial forms to contemporary urban structures, adhering to a continuous trajectory of modification. Throughout this historical progression, settlements have been associated with concepts such as site, polis, commune, and city; these changing terminologies illustrate socio-cultural and economic transitions that have mutually influenced each other (Kavruk, 2002). Such transformations have profoundly affected cities' cultural and physical aspects, resulting in urban spaces being reinterpreted and reshaped throughout history.

All entities in the universe, whether living or non-living, possess a form that evolves. This phenomenon has instilled in humans the impulse to interpret, adapt, and reshape forms according to needs. Shifting needs and societal transformations have reconfigured every object or structure, and these changes have naturally influenced cities (Şentürer, 1995). As such, the demands of each era, along with its technological and economic conditions, have compelled individuals to engage in a continuous cycle of interpreting, evaluating, critically assessing, and reshaping the physical environment. As a reflection of this cycle, the products, structures, and physical spaces designed over time have gradually acquired their present forms. This systematic approach has led societies to pursue improved, more functional, and ideal forms—an aspiration reflected in shaping structures and products (Şentürer, 1995).

Considering that the individual and society are primary fields of interaction within the design discipline, analyzing identity from psychological and sociological perspectives is essential to ensure consistency between the designed object and its user or context. When design processes are executed without thoroughly examining individual or collective behavior, the resulting product, upon introduction to the market or integration within a space, may become an object lacking in meaning or clarity, ultimately evolving into something unrecognizable or alien to its environment.

Urban theorist Kevin Lynch (1960) addresses the interpretation and transformation of urban space through legibility. He argues that the successful design of physical environments hinges on the capacity to establish systematic urban textures that contribute to a coherent and intelligible whole. Lynch draws a parallel between cities and organisms, proposing that, akin to a cell's necessity to function harmoniously with its surrounding structures to sustain its existence, urban structures and their internal components must engage in a similarly interdependent relationship.

According to this approach, material elements must be conceived harmoniously with their urban context and reinterpreted in response to urban transformations. This process does not merely imply change for its own sake; rather, it encompasses the maintenance and preservation of existing structures by the requirements of the space, enabling them to retain their relevance and functionality. Consequently, legible structures hold significant importance from the perspective of city users. The user- the urban dweller—must possess the capacity to perceive, interpret, and internalize the built environment with which they engage. A sense of belonging materializes through this interaction and harmony, reinforcing the meaningful relationship between the product and its urban space.

As a subject of the design process, the individual contributes to design through various underlying elements and values. Chief among these are memory, which encompasses personal data; identity, which serves as a reflection of memory; and collective values, which arise from these interactions on a societal level. The designer is responsible for shaping a product's formal and functional aspects per these foundational codes, ensuring a proper connection between the user and the product. Consequently, the concept of identity is of great significance in the design literature, as it facilitates an accurate analysis of the subject who will engage with the object and aids in interpreting their underlying components. Initiating discussions regarding identity—an element that profoundly influences the relationship between form and meaning—within the design process presents the opportunity to contribute to creating a coherent realm of designed objects.

## 4. THE CONCEPT OF IDENTITY AS A COMPONENT IN URBAN FURNITURE DESIGN

Cities serve as prominent arenas where modern societies become profoundly evident, acting as the primary locations for experiencing the transformations intensified by industrialization. These transformations significantly shape the identities of cities and differentiate them through their distinctive characteristics. The comprehensive concept known as urban identity encompasses the elements that set a city apart from others, foster its unique qualities, and influence the formation and evolution of these features. Each city embodies attributes that render it distinctive from its natural, artificial, and socio-cultural components (Le Bon, 2009). Urban identity reflects how societies coexist and engage with their environment within physical space. This identity manifests as an expression of individual and collective relationships and interactions. It constitutes a dynamic structure continuously reproduced according to temporal variations and evolving social, economic, political, and cultural contexts (Tajfel, 1979).

Numerous factors contribute to the formation of urban identity, including the city's historical, architectural, and artificial elements, its natural beauty, local traditions and customs, and the spatial and symbolic values ascribed to it by its inhabitants. These components transform the city into a unique space and enhance its value based on its inherent characteristics. Consequently, urban identities are products of thoughts, experiences, interpretations, and actions (Tajfel, 1981). These identities emerge as reflections of individual and collective interactions and are dynamic constructs reproduced in response to prevailing conditions. In this context, the city and space are in constant motion and renewal. Both encompass elements that mutually bring each other into existence. Space possesses specific qualities that shape its users while simultaneously being shaped by them. The most significant attributes are identity formations and reflections on the natural and built environment.

### 4.1. Identity as a Design Code

Although the concept of identity represents one of the fundamental subjects of sociological research, it also serves as an indispensable component of objects and products due to its direct impact on the user. In this context, it is imperative to accurately comprehend how identity is structured within social groups and societal dynamics. Among the studies that examine identity formation and its subdivision into subgroups, Tajfel and Turner's Social Identity Theory is regarded as essential for understanding the structural formation of identity and its subcategories. This theory elucidates how individuals' group memberships influence their self-perception and behaviors. According to the theory, individuals construct their social identities by categorizing themselves and others within their social environment. These categories encompass affiliations such as religion, culture, nationality, and race. Social identity is formulated through an individual's self-definition as a member of a specific group and the emotional significance they attribute to this membership (Turner, 1982). Social classification enables individuals to differentiate between social groups and determine their membership in one or several. These memberships become integral to the individual's self-concept and delineate their societal position. This process further allows individuals to recognize their own group's distinct characteristics and make comparisons between groups.

### 4.2. The Classification of the Concept of Identity

Social Identity Theory offers a crucial framework for comprehending intergroup relations and the behaviors that emerge from individuals' group affiliations. It elucidates how individuals may cultivate prejudices due to group memberships and how intra-group solidarity can be established. Le Bon's examination of crowd psychology investigates how individuals act within crowds and how their identities may become diluted. According to Le Bon, individuals encounter a sense of anonymity within crowds, significantly influencing their behavior. Drawing inspiration from Le Bon's research on crowd psychology, the works of Tajfel and Turner thoroughly explore how group memberships impact personal identity, perception, and cognitive reasoning capabilities.

Social Identity Theory serves as a fundamental framework for understanding the influence of group memberships on individuals' self-perception and behavior. This theory examines the actions of individuals within social environments and the impact of group dynamics on individual behaviors

(Demirtaş, 2003). Ultimately, Social Identity Theory provides a significant perspective for analyzing individual behavior in social contexts and illustrates how group affiliations shape personal identity. It underpins numerous studies in social psychology and functions as a tool for examining individual behavior within group dynamics. Within the context of Tajfel and Turner's *Social Identity Theory* and the ensuing literature on identity, it is possible to delineate subcategories of identity—such as individual identity, cultural identity, national identity, traditional identity, religious identity, modern identity, and postmodern identity—as outcomes of social interactions that shape both individual and collective identities. From this viewpoint, identities are formed within historical processes and societal structures, and are not easily altered at the discretion of the individual. Identity is intrinsically historical and encompasses dimensions related to personal subjectivity. The individual can be regarded as a historically situated entity; therefore, identity cannot be comprehended in isolation from the broader social and historical context in which the individual exists.

Interactions with society influence the construction of individual identity. According to Berger, just as society is a product of human activity, the individual is likewise a product of society. This dialectical relationship illustrates that identity is formed and sustained within a social context. This interaction shapes identity and indirectly affects the environment and its components through individual choices and preconceptions. Individuals begin to mold their surroundings and material elements through the social groups or communities they belong to, whether through implicit assumptions or conscious preferences. Over time, this interaction manifests itself in both space and objects. One of the most significant indicators of this phenomenon is the emergence of distinguishable, legible, or recognizable spaces that do not simply replicate one another. In this context, examining the concept of identity about urban products, within the scope of this study, seeks to discuss how social identity formation and its subcategories influence objects and the built environment.

## 5. COMPARATIVE EVALUATION OF DATA OBTAINED FROM THE CITIES COMPRISING THE STUDY GROUP

The inquiries that constitute the primary framework of this study and generally delineate the research parameters elucidate the transformations in the product design process within the realms of identity and object in this design research, which will be conducted within the confines of the city, user, and product. This evaluation, which examines urban-related studies from an industrial design perspective, will explore the interaction of urban furniture—products pertinent to the city—with the urban space, the methodologies through which local authorities articulate this interaction, the roles of individuals and designers in this process, and the impact of identity codes on the design or selection of urban furniture, all through their relationship with the city and urban furniture. In this manner, the contexts and forms in which identity codes manifest in urban products will illuminate the study's contribution to the design research literature.

***Table 1.*** *Cities and relevant authorities forming the working group*

| Which city are you answering questions on behalf of? | The Authority of Urban Design Unit |
|---|---|
| 1-Vilnius, Lithuania | Indra Bieliūnaitė |
| 2-Riga, Latvia | Evelina Ozola |
| 3-Melbourne City Council, Australia | Andrew Roche |
| 4-Seoul, South Korea | Linda H. Yoh |
| 5-Prague, Czech Republic | Kristina Ullmannova |
| 6-Rotterdam, Holland | Judith Marcellis |
| 7-Stadt Zürich (Tiefbauamt), Switzerland | Carina Habelt |
| 8-Warsaw, Poland | Anna Paz |
| 9-City of Helsinki, Finland | Pia Rantanen |
| 10-Ljubljana, Slovenia | Mojca Gabric |

In response to the feedback obtained from the contacted municipalities throughout the process, design unit officials from the cities of Zurich, Rotterdam, Helsinki, Prague, Warsaw, Seoul, Vilnius, Melbourne, Ljubljana, and Riga engaged in semi-structured interviews. The research dataset was compiled based on the responses provided by the officials of the urban design offices in these cities. Among the primary objectives of these design units are: the formulation of design guidelines for urban products, the delineation of the framework governing the relationship between the city and buildings, the establishment of requirements for public products via tenders, the organization of product design activities and competitions, the analysis of the needs of urban spaces, and the assurance of the provision of material elements within the city by public demands.

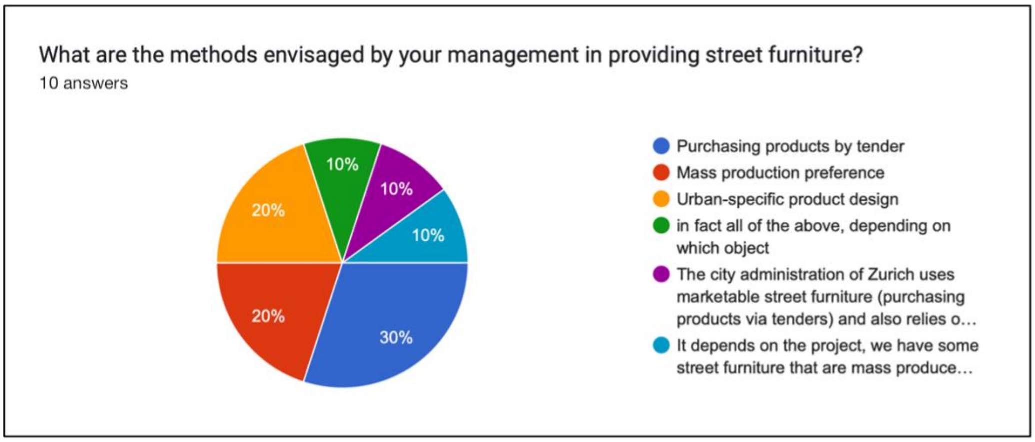


***Figure 1.*** *Graphical representation of the answer to the relevant question*

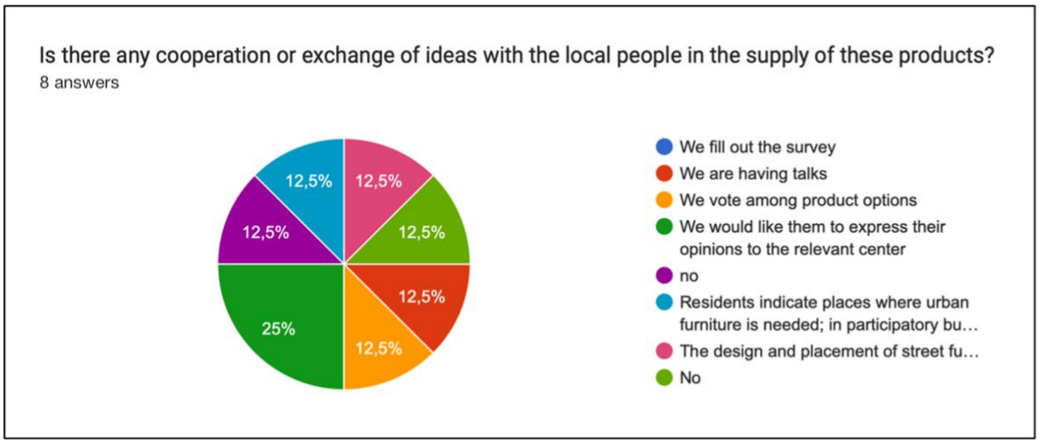


***Figure 2.*** *Graphical representation of the answer to the relevant question*

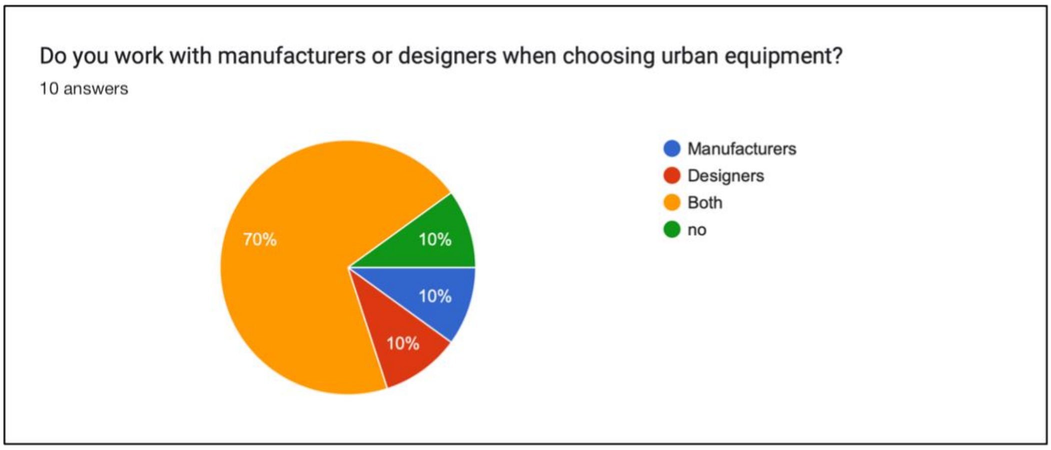


***Figure 3.*** *Graphical representation of the answer to the relevant question*

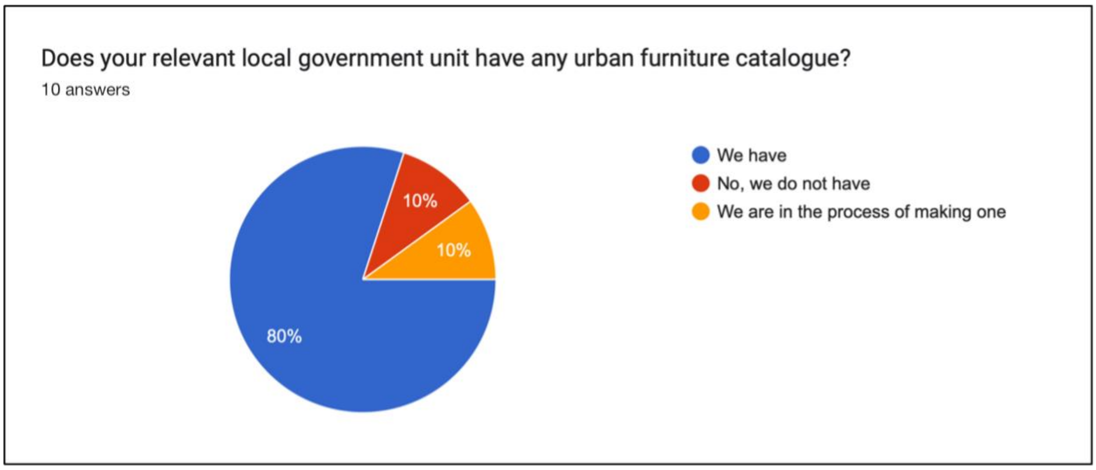


***Figure 4.*** *Graphical representation of the answer to the relevant question*

***Table 2.*** *Representation of the answer to the relevant question*

| **If you have such a catalogue, how were the products in this catalog chosen?** |
|---|
| 1- This part has not been answered. |
| 2-The products were chosen considering the quality and price range of products, their availability in Latvia and suitability to the climate, as well as matching the styles of the products already in use in the cityscape. |
| 3-Developed by industrial designers in consultation with various stakeholders. |
| 4-Not that of( because of urban-specific products design, we do not have catalog). |
| 5-It is one of many. It is important to have a visually appropriate and specific design, on the other hand many other criterions must be met: ergonomics, economy of investment and maintenance, durability etc. |
| 6-Products that make the catalogue must meet our requirements regarding design, sustainability, accessability, solidity etcetera. Before entering the catalog they are tested through carefully monitored pilots. |
| 7-The standards and the associated catalog of elements (Elementkatalog) promote integral solutions in the city. Design, function, maintenance and costs are equally important criteria when selecting street furniture. Further requirements (maximum dimensions, colors, materials, etc.) are defined in the urban space standards. |
| 8-Urban Architecture & Spatial Planning Department, or other city units, order individual projects of furniture like benches, waste bins, drinking fountains, etc. in variants adapted to the architectural environment. |
| 9-Own city design and furniture by tender. |
| 10-Some of the proudct were already in use, some of them were choseen on public tenders and some of them were design for some specific project and became part of the catalouge. |

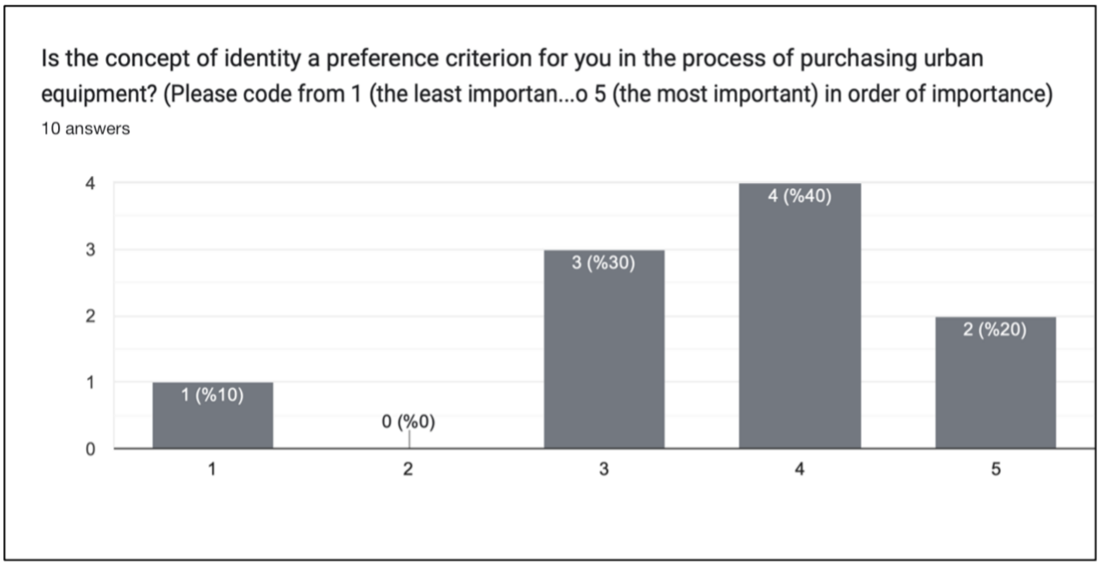


***Figure 5.*** *Graphical representation of the answer to the relevant question*

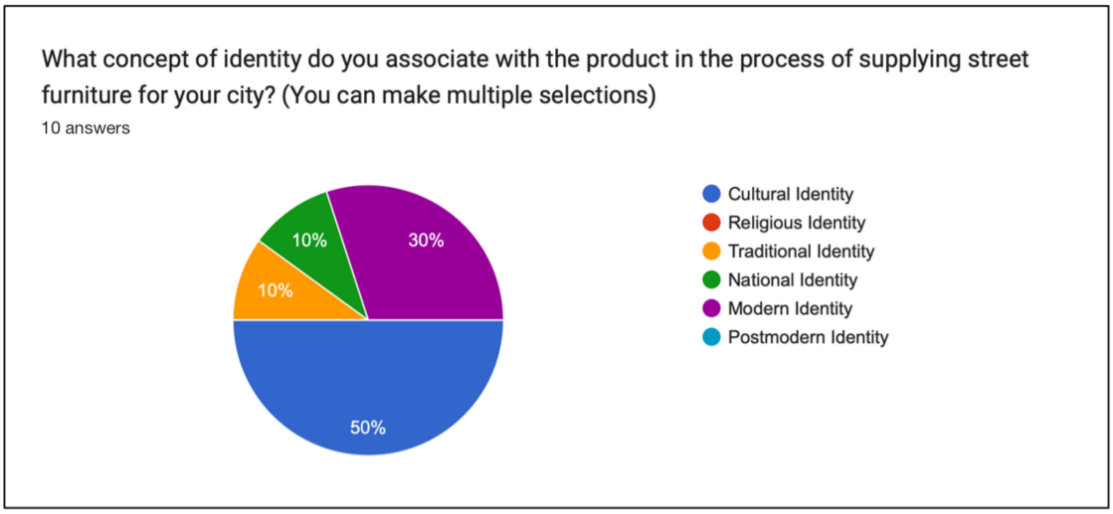


***Figure 6.*** *Graphical representation of the answer to the relevant question*

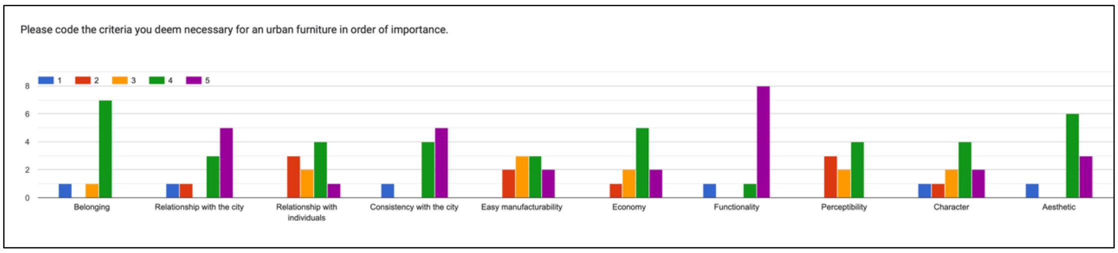


***Figure 7.*** *Graphical representation of the answer to the relevant question*

***Table 3.*** Table showing the answers given to the relevant question

| **How do you interpret the relationship between street furniture and the city?** |
|---|
| 1-it is important that furniture correspond to the character of the city |
| 2-Street furniture is one of the ingredients that define the character of the city and it accommodates safe and comfortable being outdoors |
| 3-Street furniture plays a vital role in urban environments by enhancing functionality, safety, and accessibility. It adds aesthetic appeal, encourages social interaction, and can boost local economies. |
| 4-Seoul city's vibrant images and appealing fun nature which represent the city's identity – past, present and future. |
| 5-It should be clarified what is the meaning of "the city" in this case. If I define the city as an spatial entity populated by people, I would state that the furniture is an equipment of this space serving the needs of its people. |
| 6-Like in a house furniture is necessary to make people feel welcome and at home. Moreover street furniture makes urban life livable: we need wastebins and lampposts to have a functional city |
| 7-The relationship between street furniture and the city is important. Zurich attaches great importance to a uniform cityscape (identity-creating). The standards and the catalog of elements (Elementkatalog) promote integral solutions in the city. The element catalog provides a standard element for each relevant functional and urban space requirement, in some cases also in variants. The significance level and spatial type determine which elements can be used where. The significance plan (Bedeutungsplan) (another instrument for urban space design) specifies the importance of a public place in the city. |
| 8-Most street furniture is based on designs developed especially for Warsaw. It is important for us. |
| 9-They are a part of the identity of the city |
| 10-Design of the public space including street furniture is the mirror of the city. |

***Table 4.*** Table showing the answers given to the relevant question

| How do you interpret the relationship between identity and urban furniture? |
| --- |
| 1-The aesthetics of urban furniture along with architecture, surfaces and greenery define the identity of a place. |
| 2-It contributes to the visual identity of public spaces, making them distinctive and memorable. |
| 3-Seoul is the city of dynamic space and vibrant brand. Seoul city government design policy 2.0 all for citizens as inclusive, active design - and evoke feeling of Love, WoW, Fun nature which represent city's brand identity " SEOUL MY SOUL". |
| 4-Our goal is that the city has a set of high quality street furniture, that provides sufficient range of design to serve in different kinds of environments and circumstances within the city, but is at the same time limited in number to be sustainably serviced and managed. |
| 5-Urban furniture can emphasize the identity and character of a city |
| 6-Identity of street furniture is important. Contextualized furnishing is possible for important locations in the city, for example the important square 'Sechseläutenplatz' with mobile chairs. |
| 7-Residents often report necessity of equipment in their local environment and the city ussually responds to these requests. We think this situation is related to local identity and expectations. |
| 8-It is important that each peace find its place in the identity of the people and the city. |
| 9- This part has not been answered. |
| 10- This part has not been answered. |

***Table 5.*** Table showing the answers given to the relevant question

| If you have different criteria in urban furniture production and preferences, please explain briefly. |
| --- |
| 1-The selection process of urban furniture for various city parts is very complicated - we have to follow the rules of public procurement, balance our needs and resources with the possibilities of the product design industry and insure continuity, quality and a unified image in the cityscape. Not every solution is available to every city. |
| 2-The furniture shall be long-lasting, safe, visually appealing |
| 3-Not that of |
| 4-The city aims to own the licences for the designs. However the city is still at the beginning of the journey to fulfil this goal. We have a document with recommendation for various street elements, including the furniture |
| 5-We also have a high ranking for sustainability and accessability; we feel that Rotterdam should be an inclusive city. |
| 6-design, obstacle-free construction, materials and colors, sustainability and circular economy, urban compatibility (robustness, function, etc.) |
| 7-The most important tool for society's influence on how city funds are spent is Participatory budgeting. Many ideas submitted in that process concern furniture. |
| 8-Durability. Our climate has four seasons from hot summers to freezing winters. |
| 9- This part has not been answered. |
| 10- This part has not been answered. |

***Table 6.*** Table showing the answers given to the relevant question

| Can you briefly talk about what makes the city you live in unique to you? |
| --- |
| 1-architecture, compact, green spaces, nature |
| 2-The rich combination of historical architecture and nature. |
| 3-Our city is unique because of its vibrant cultural diversity, rich history, and dynamic blend of modern and historic architecture. |
| 4-Seoul has its uniqueness in many ways. Seoul has its vibrant atmosphere, easily open access to public space and transportation that you feel comfortable and safe. Moreover, the city has its past, present, and future look & feel. Not only old palaces nearby the high-rise, high tech buildings but also streets and alleys that provide active way-find system that guide you to Han river and Mountains. These are the reason I love to live in Seoul. I bet you visit Seoul, you will definitely love the city! Thank you! |

| |
|---|
| 5-Rotterdam is a modern city with a special kind of robustness that I haven't seen yet in other cities. At the same time the robustness is softened by beautiful architecture and more green every year. |
| 6-The Zurich urban space appears calm, open and clear. Clear, elegant forms derived from the function characterize the space and the elements used. The color spectrum is restrained. The urban space is geared towards the needs of the users and is accessible to all people without barriers. It is inviting, safe and comfortable to use. People can spend time in the urban space, relax, move around and engage in various activities. Depending on the location, the possible uses are weighted differently. Spending time in an urban space means sitting, eating, waiting, resting, meeting, communicating and playing, among other things. All of this is possible in Zurich. |
| 7-Situation at the sea, nature, climate. |
| 8- This part has not been answered. |
| 9- This part has not been answered. |
| 10- This part has not been answered. |

In examining the relationship between identity codes and urban furniture, which constitutes the primary focus of this research, the processes through which products emerge were explored collaboratively from the perspectives of local authorities and designers, representing the two distinct facets of the product design and procurement process. The responses to the open-ended questions frequently reflect the rationale and methodologies employed in urban interventions as perceived by city authorities, while incorporating political implications. This dynamic arises from the fact that urban policies can be influenced by global transformations and shaped by concerns regarding alignment with contemporary movements. Lang (2002) ascribes these phenomena to designers operating under market-driven considerations and local governments striving to adhere to the “modern construction fashion.” While this explanation holds validity within practical approaches, it is imperative to emphasize that physical interventions in urban environments must be conducted based on data derived from individual and societal codes synthesis.

The holistic interaction of numerous components, including architectural structures, landscape arrangements, and the configuration of public spaces, plays a pivotal role in shaping the process through which modern cities acquire their identity. In this context, urban furniture not only functions as utilitarian objects but also mirrors the character of urban spaces, influences user experience, and significantly contributes to the formation of urban identity. The international responses to the inquiries underscore the multifaceted relationship between urban furniture and the city and their roles concerning identity. For example, the trends illustrated in the graphs between Figures 2 and 5, derived from responses to questions about preferences for urban furniture in public areas, reveal the criteria cities prioritize when selecting spatial elements. Notably, while local authorities engage with design experts, the procurement of products is primarily executed through tender processes, favoring mass-produced elements. Notably, Figures 4 and 5 underscore that democratic mechanisms such as participatory design and public procurement significantly influence the provision and design of urban furniture. This indicates that urban furniture transcends being merely a physical object; it also embodies the governance approach of the city and reflects the level of civic participation. In light of this, the impact of participatory methods and the perspectives of users (urban dwellers), which are frequently emphasized in urban studies, are manifestly significant in urban furniture design. Tajfel also emphasizes that urban identities emerge as products of thoughts, experiences, interpretations, and actions, asserting that the city and its space can only be comprehensively understood through interaction with all the structural elements that constitute them (Tajfel, 1981). Consequently, it is recommended that individual and societal experiences be given due consideration in the procurement or design of urban space elements to maintain a consistent identity.

The graphs illustrated in Figures 6 to 8 depict the relationship between urban furniture and the notions of city and identity from the perspectives of cultural and contemporary identity. The responses distinctly underscore functionality that addresses issues of belonging and spatial considerations. The elevated values in these graphs indicate that urban furniture assumes symbolic roles in addition to its functional attributes and plays a significant part in the emotional connections that urban residents form with their cities. As highlighted by Wirth, a leading researcher in urban studies, space is a construct that can influence individuals ' lifestyles and cultural significance (Wirth, 2002). Consequently, it is not merely a location that offers employment and residence; rather, it constitutes a multidimensional and holistic framework that evolves with cultural and social codes, encompasses individuals within a social group, provides a new identity, or facilitates the acquisition of one. The findings indicate that the selection of urban furniture considers not only aesthetic considerations but also factors such as sustainability, durability, and accessibility. Customized designs are favored according to the climatic conditions, user demographics, and spatial requirements of cities. For instance, climatic durability is emphasized in cities characterized by significant seasonal variations (such as those in the Baltic region). Conversely, in cities exhibiting high cultural diversity (such as Toronto or Zurich), designs are anticipated to be inclusive and reflect multicultural frameworks. This diversity underscores the initiatives of each city to reinforce its distinct identity values (traditional, national, cultural, etc.) and the inclination to perceive public spaces as platforms for reflecting these identities.

The relationship between urban furniture and the concept of identity has been evaluated from aesthetic and functional perspectives across various countries. Urban furniture, particularly street furniture, is anticipated not only to fulfill fundamental needs such as livability, safety, and accessibility but also to enhance urban aesthetics and visual coherence. For example, cities such as Zurich and Rotterdam emphasize that urban furniture serves as a "mirror of the city" and assert that these design elements must harmonize with comprehensive urban planning. Similarly, the local authority in Seoul highlights the "Seoul My Soul" branding strategy, positioning street furniture as emotional and cultural representations contributing to the city's identity. Furthermore, pilot furniture testing in certain cities illustrates that decisions are data-driven and that urban identity is shaped through experimental initiatives. Likewise, as indicated in Table 3, nearly all participants assert that urban furniture plays a pivotal role in defining a city's character. For instance, Zurich's "Elementkatalog" application facilitates the establishment of furniture standards that preserve the unique identity of each urban space. This underscores that identity is not solely constructed culturally or historically but is also produced physically and spatially.

## 6. CONCLUSION

Within the parameters of this study, the correlation between various types of identity and urban furniture is assessed through the design process decisions made by local authorities, informed by the experiences of urban residents and the methods of product procurement. In the semi-structured interview study, representatives from participating municipalities indicated that resident feedback informs the product design process at specific stages. This reveals that the sense of belonging to the urban environment and the sub-identity concepts associated with the city (including cultural, traditional, or national identity) manifest through public participation and influence the official transformation of urban products. Significantly, the observation that participatory design processes shape micro-scale yet consequential design decisions, such as those about urban furniture, emphasizes, based on the responses gathered, that the democratization of urban governance is a critical indicator of the acknowledgment of local identity that references traditional and national identity concepts.

In the context of urban space and character;

- Urban spaces are characterized as multi-faceted structures shaped concurrently by individual and societal preferences, alongside the perspectives of local authorities, sustaining their existence through a state of persistent dynamism.

- The responses indicate that these components significantly influence cities' cultural capacities and material characteristics, which begin to materialize in observable forms. This phenomenon occurs due to the transformative effects of evolving social movements that reshape the requirements of urban structures.

- Within this ongoing dynamism, it is unrealistic to anticipate urban spaces remaining static or unresponsive to the transformations around them. Therefore, as Scott and Roweis (2008) contend, comprehending the potentials and needs of urban spaces—and by extension, entire cities—necessitates their evaluation within the context of the social transformations unique to the socio-historical realities to which they are connected.

In the context of the impact of the local authorities on urban furnitures design process;

- The findings of this study reveal that local authorities adopt a variable stance in their decision-making processes concerning product procurement. Occasionally, objects are utilized solely to address specific issues and are classified as urban elements.

- Conversely, design decisions that cater to user needs and emerge from spatial exigencies take precedence in other instances.

- Consequently, in constructing a coherent and intelligible space, establishing systematic procedures executed within a planned framework, rather than relying on arbitrary decisions, will facilitate the creation of spaces and objects well-positioned to acquire a distinct identity.

In evaluations about the notion of authenticity—cited by local authorities about the cultural and traditional identities of cities—the principal themes that influence the configuration of objects within urban environments encompass harmony with the city's natural and environmental context, the existence of historical strata that convey remnants of the past into the present, the coexistence of contemporary structures designed according to current needs, and opportunities for social interaction.

These evaluations corroborate Lynch's (1960) assertion regarding the significance of identity as an essential component for transforming urban space into a coherent and delineable form. Urban infrastructure, which enhances the elements above, is positioned as an instrument that supports these authentic characteristics.

In the context of the impact of the identity on urban space and furnitures;

- Urban furnishing elements constitute essential components of urban aesthetics and are crucial carriers of urban identity.

- While these elements are designed to fulfill functional requirements, they are fundamental components that infuse meaning into space and enhance the relationship between individuals, memory, and place.

- These international evaluations illuminate the multi-layered semantic landscape of urban furniture and underscore the significance of such elements in the design of urban spaces.

The transformation of urban areas in alignment with both their users and historical context amplifies the distinctiveness of cities. It fosters a sense of spatial belonging by allowing residents to express their environments uniquely. Urban furnishing elements developed through more participatory, contextually coherent, legible, and identity-oriented approaches will substantially enhance the quality of urban life and cultivate a robust sense of belonging among city dwellers and the spaces they inhabit.

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Review Article GU J Sci, Part B, 13(2): 295-315 (2025)

Gazi University

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

http://dergipark.gov.tr/gujsb

# Historical Evolution of Industrial Design Terminology: Examples of Terms Formation

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**Article Info**

*Received: 11/05/2025*
*Accepted: 29/06/2025*

**Keywords**

*Industrial design,*
*Design discourse,*
*Design terminology*

**Abstract**

Industrial design discourses are predominantly constructed upon systems of thought appropriated from various disciplines, including economics, philosophy, and sociology. In a historical context, it becomes evident that the terminology associated with industrial design has primarily been established through the adoption and contextualization of concepts from more advanced fields of study. The evolution of industrial design terminology mirrors the socio-cultural understanding of the era in which the practice occurs. Despite the historical influence of diverse disciplines, industrial design has cultivated its distinctive narrative by reinterpreting the concepts sourced from these areas. This study, arranged in chronological order, examines how industrial design discourse has progressed through different historical periods, elucidating the transformations and alterations of fundamental concepts derived from various academic fields along the design continuum, as well as the role of interdisciplinary interactions in shaping design terminology, illustrated through sample concept products. In the study, a hybrid approach that integrates narrative review with historical-conceptual analysis is adopted. The research is grounded in the literature on design theory and history, professional association reports seminal statements by influential designers, and critical examinations of iconic design objects.

## 1. INTRODUCTION

The term “term” is defined by the Turkish Language Association as “a word that corresponds to a special and specific concept related to a field of science, art, profession, or subject,” while “terminology” is defined as “the science of terms.” Terminology represents a discipline that scrutinizes the naming, definition, and systematization of concepts specific to distinct fields of expertise [1].

In the 18th century, terminology, emerges as a necessary tool alongside the expansion of technology, communication, and the simultaneous accumulation of knowledge to address the challenges associated with these advancements. It acquires a scientific orientation only in the 20th century [2]. In the 19th century, the necessity for scientists to establish guidelines for the formulation of terms within their respective disciplines became apparent due to the escalating internationalization of science. Botanists (in 1867), zoologists (in 1889), and chemists (in 1892) articulated this necessity at their corresponding international meetings [2]. While scientists pioneered the development of terminology during the 18th and 19th centuries, engineers and technicians contributed to these efforts in the 20th century [2]. The accelerated pace of technological advancement generates a demand for the designation of new concepts and a requirement for consensus regarding the terminology employed. During the industrial era, the proliferation of education and the growing importance of written communication necessitated the codification of languages and the establishment of standardized writing systems. Consequently, in conjunction with natural language, the notion referred to as “standard language” emerged [2].

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The process of generating terminology within any particular domain—specifically, the emergence and systematization of novel terms—can be elucidated through both linguistic and epistemological frameworks. For instance, the introduction of a scientific discovery, a technological innovation, or a pioneering idea engenders the necessity for a new concept to be designated [3]. A completely original word may be formulated for the specified concept; alternatively, a new term may be derived from an existing lexeme; or an established word may acquire new, specialized meanings specific to the domain [2].

Industrial design terminology falls within this third category in the given context. The evolution of terminology in industrial design, an emerging field, was notably advanced by the scientific, cultural, and technological progress of the 20th century. Consequently, it can be asserted that the terminology of this field primarily comprises established terms from other disciplines. Through analogy, terms borrowed from diverse fields are assimilated with new, domain-specific meanings. In the literature, studies on industrial design terminology are typically limited to specific concepts or confined to particular historical periods. While such works contribute valuable insights into the development of certain terms or phrases, there appears to be a lack of comprehensive research that examines how design terminology has been shaped through interdisciplinary influences over time, and how these conceptual shifts are situated within the broader discourse of design.

This study examines the evolution of industrial design terminology through the lens of cross-disciplinary conceptual appropriation and recontextualization. Specifically, it elucidates how core concepts from various academic disciplines, such as engineering, architecture, psychology, and sociology, are transformed and internalized in the process of shaping the distinctive discourse and identity of the industrial design discipline. To achieve this, the study employs a narrative review methodology, supplemented by historical-conceptual analysis, to offer a contextual synthesis of key concepts and their transformations across different historical periods. Given the interdisciplinary and historically embedded nature of industrial design, this approach is well-suited to mapping the evolution of terminology by integrating diverse strands of literature. The study draws on a variety of data sources, including literature on design theory and history, seminal statements by influential designers, reports from professional associations, and interpretive readings of significant design artifacts from various periods. This framework underscores that terminology is not merely a linguistic phenomenon, but also a marker of the permeability of disciplinary boundaries and the circulation of knowledge across fields.

The selection of key concepts in this study is grounded in their representational value for critical historical junctures and epistemological shifts in the evolution of industrial design discourse. Functionality and standardization epitomize the modernist pursuit of efficiency and order in the early 20th century. Ergonomics and usability reflect the post-war focus on optimizing human-machine interfaces within increasingly complex systems. The emergence of user experience and emotional aesthetics during the 1980s coincides with the proliferation of digital media and the rise of experience-oriented, human-centered design approaches. Finally, sustainability and participatory design, gaining prominence from the 1990s onward, are indicative of a shift toward systemic thinking, where ethical, environmental, and sociopolitical considerations become integral to design practice and terminology. To underscore the significance of this study for industrial design, the subsequent section examines the importance of the concepts of terms and terminology within the field.

## 2. TERMS AND TERMINOLOGY

Modern terminology began to take shape in the 1930s, primarily through the contributions of E. Wüster. In his doctoral dissertation, Wüster advocated for more systematic approaches to terminology work, proposed foundational principles for managing terms, and outlined a methodology for organizing terminological data. The initial phase of terminology studies (1930–1960) concentrated on establishing structured methods for the formation of terms [2]. In the subsequent stage of development (1960–1975), the most significant innovations in terminology emerged from advancements in mainframe computing and documentation techniques. During this period, the first databanks were established, and the international coordination of principles about terminology processing was initiated. Notably, this stage marked the earliest efforts to standardize terminology within specific linguistic communities, reflecting a burgeoning interest in unifying concepts and terms across various disciplines and within distinct linguistic contexts. The third phase, commonly referred to as the "terminology boom" (1975–1985), was distinguished by a proliferation of language planning and terminology initiatives [2]. The widespread adoption of personal computers during this era significantly enhanced the potential for processing and organizing terminological information. Since 1985, the field has continued to evolve, primarily propelled by advancements in computer science [2]. Terminologists now benefit from tools and technologies that are increasingly suited to their requirements—more accessible, user-friendly, and efficient.

Theoretical discussions regarding the nature of terms arose subsequently, as practical terminology efforts expanded into specialized fields [2]. The theory of terminology has predominantly evolved from empirical experience and the need to address challenges in linguistic communication. In contrast to semantics, which emphasizes the relationship between words and their meanings, terminology is primarily concerned with the connection between real-world entities and the concepts that represent them [2]. This field is functional, designed not to exist in isolation but to facilitate communication within the realms of science, technology, and professional contexts. Consequently, terminological endeavors necessitate collaboration between subject matter experts and both general and applied terminologists to define and standardize the concepts and terms pertinent to a specific field. It can be best understood as the collection, analysis, organization, and presentation of the terminology of specialized domains, often spanning multiple languages. Its objective is to address genuine communication needs and enhance clarity and efficiency in professional interactions, whether directly or through translators and language standardization entities.

This pragmatic and service-oriented view of terminology aligns with the needs of contemporary society, where practical solutions often take precedence over theoretical reflection. As Guilbert noted, "the essential aim of the terminological lexicon is not the language itself" [2]. Terminology is inherently tied to the generation and use of knowledge and therefore must be understood in its social and functional context. Ultimately, terminology serves the professionals who rely on it as both a tool for communication and a means of structuring and understanding the conceptual foundations of their disciplines. Their interest in standardization stems from this dual role, which involves clearly and consistently linking terms with their respective concepts.

According to Cabré [2], terms are conceptual units that encode knowledge structure, not merely lexical labels for objects. Unlike general vocabulary, whose meanings are often context-dependent and shaped by syntactic usage, terms are understood to possess stable and unambiguous meanings. While ordinary words evolve organically within natural language, terminological units are anticipated to maintain normative and technical significance. In this regard, terms serve as coded representations of scientific concepts, devoid of semantic ambiguity, facilitating cognitive processes and communication within specialized domains. Consequently, the ontological necessity of terms within a language warrants attention.

Terms occupy a pivotal position in scientific, technical, and artistic disciplines, often surpassing the relevance of general vocabulary. The development of a discipline’s scientific identity is intricately connected to terminological endeavors, particularly in emerging or less formalized fields. Terms operate as instruments for delineating existing concepts and are integral in the generation of new knowledge [4]. As the breadth of scientific knowledge expands, the necessity to name, classify, and standardize concepts becomes imperative. This necessity has propelled the evolution of terminological systems. Within this context, Sowa [5] posits that specific subsets of terminology can function as effective entry points for formalization. He contends that established terminologies facilitate knowledge transfer and contribute to the logical structuring of concepts, thereby assuming a foundational role in shaping and organizing scientific domains.

## 3. THE EVOLUTION OF INDUSTRIAL DESIGN TERMINOLOGY

The evolution of industrial design terminology illustrates the dynamic interplay between technological innovation, cultural shifts, and the expanding role of design within society. As the discipline advanced from a function-oriented practice to a multifaceted field centered around human experience, new terminologies emerged to encapsulate evolving priorities and conceptual frameworks. Below is a historical overview emphasizing how key design terms were established and gained prominence.

### 3.1. Early 20th Century: Functionality and Standardization

Heskett [6] delineates the emergence of industrial design as a recognized profession and the establishment of its associated language, attributing these developments to the wave of industrialization and the principles of the modern movement at the onset of the 20th century. In a similar vein, design historian De Noblet [7] observes that the conceptual framework of industrial design evolved during the transition from handicrafts to industrial production. In this context, the shift from craft aesthetics to mass production aesthetics in the early stages of the design discipline facilitated the introduction of novel concepts into designers' lexicons [8]. The first half of the 20th century was characterized by the professionalization of industrial design and the institutionalization of its terminology. During this period, the identity of the designer became more defined, educational institutions and organizations started to emerge, and the terminology expanded in tandem with this institutional development. From the early 1900s until the Second World War, concepts such as functionalism and standardization gained prominence in design, coinciding with the ascendance of modernism. This shift was profoundly influenced by the socio-economic transformations brought about by the mature phase of the Industrial Revolution, including the development of mass production capabilities, the rise of consumer markets, and rapid urbanization. The prevailing modernist ideology, with its emphasis on rationality, efficiency, and progress, further legitimized these concepts. The concept of “standardization” in the field originated in the realms of production and engineering, driven by the need for cost-effective manufacturing and the interchangeability of parts, a necessity acutely felt during periods of industrial expansion and wartime production. Conversely, the two fundamental terms of the functionalist approach, “form” and “function,” were directly appropriated from the discipline of architecture into industrial design, reflecting a desire to create objects that were not only aesthetically pleasing in their simplicity but also ideally suited to their intended purpose and the new modes of industrial fabrication.

The concept of standardization in mass production originated with Simeon North's introduction of a novel perspective on arms production during the 18th century. To meet the substantial orders he received from the war department, Simeon North devised innovations that were later referred by Eli Whitney as “interchangeable parts” [9]. Over the years, this concept was formalized into what is now known as standardization. By the 20th century, it had developed into a notion that encompasses not only technical aspects but also broader domains, including quality, safety, environmental considerations, and user experience. The adoption of standardization in industrial design had significant practical implications, compelling designers to consider material properties, manufacturing tolerances, and assembly processes from the outset. This led to the development of design practices centered on efficiency, modularity, and complexity reduction, aiming to make products more accessible and affordable for a broader population.

In contemporary industry, the Ford Model T is extensively recognized as the most distinguished exemplar of the convergence of standardization and mass production. The production revolution instigated by Henry Ford through this model led to a profound transformation not only within the automotive sector but also in the broader methodology of industrial production. The significance of this influence lies in the fact that the term “Fordize” is frequently used in various articles to explain the concept of standardization [9]. This term delineates a production system characterized by mechanization, high volume, rapid production, and low costs. Following its application within the automotive sector, this concept subsequently served as a paradigm for industries such as furniture, electronics, and household appliances, evolving into one of the fundamental criteria within the industrial design process. Initially confined to technical standardization, the concept gradually broadened to include aspects of user experience. The Fordist model not only revolutionized production but also subtly began to shape design thinking toward system-level considerations, where the product was part of a larger ecosystem of manufacturing, distribution, and eventually, use. This laid an early, albeit indirect, groundwork for later considerations of usability and user-centeredness, even if the primary focus remained on production efficiency. Indeed, the broader discourse surrounding standardization within design theory, extending beyond mere production techniques, was fundamentally initiated by the modernist design approach and its guiding principle, “form follows function.”

In the terminology of industrial design, the concepts of function and form, which serve as the foundations of the modernist design approach and have significantly shaped 20th-century design discourse, hold profound significance [10]. According to Loos [11], the forms found in nature are determined by their functions. Consequently, the necessity for the form to follow function is regarded as a law of nature, and this principle should similarly apply within the realm of architecture. By this law, the architectural form must adhere to its function. This notion resonated throughout industrial design, laying the groundwork for understanding functional aesthetics [6]. The maxim “form follows function” emerged as a guiding principle for designers in architecture and across a diverse array of products, ranging from furniture to electronic devices [12]. During this era, when it was contended that form should be shaped solely by function, aesthetics was exclusively associated with machine production. In MoMA’s bulletin covering the 1940 exhibition Useful Objects Under Ten Dollars, McAndrews proposed a set of standards recognizing that such products were not exemplars of fine art and should not be evaluated in aesthetic terms [8]. Refer to Figure 1 for an illustration of an exhibition visual. This redefinition of aesthetics, often termed "machine aesthetics," had a profound impact on design philosophy, leading to a significant shift in the designer's focus: away from primarily decorative concerns or emulating handcrafted styles, towards becoming an orchestrator of form and utility derived from industrial processes. Design education, particularly within institutions like the Bauhaus, began to emphasize a rational problem-solving approach, integrating technical knowledge with artistic principles, and promoting an aesthetic sensibility derived from the inherent qualities of materials and manufacturing processes, rather than relying on applied ornamentation.

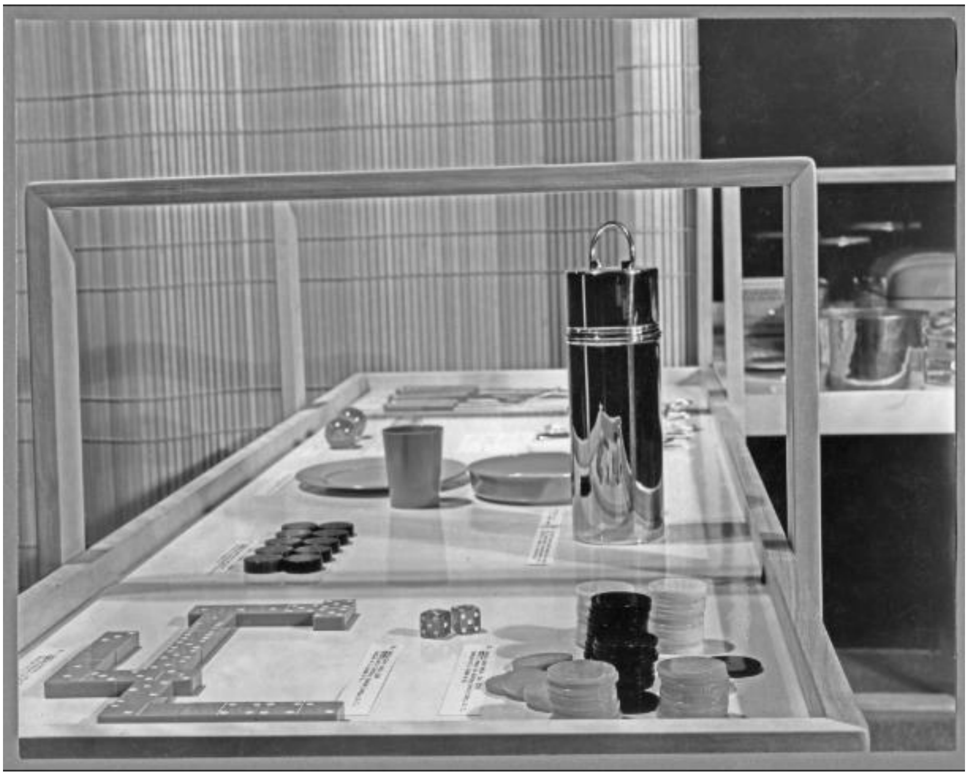

***Figure 1.*** *Image From The Exhibition – Source: MoMA [13]*

Indeed, the Deutscher Werkbund movement, founded in Germany in 1907, and subsequently the Bauhaus school, established in 1919, adopted an educational program that combined art and technology while emphasizing functional and simple design [14]. In the Bauhaus Manifesto, Walter Gropius sought to integrate the functional thinking necessary for industrial production with aesthetic education [15]. László Moholy-Nagy, by centralizing the harmony of form and function in design education, advocated for a close relationship between visual composition and intended use [16]. The modernist paradigm's function dominated design practice until the mid-20th century. Particularly following World War II, industrial designers in Europe and America ascribed great significance to creating practical designs that were easy to manufacture and devoid of unnecessary ornamentation [17].

The concept of standardization, which focused on objects in early modernism, gradually expanded to encompass the human element within production processes. The belief that every movement in the workplace should be grounded in mathematical and scientific principles paved the way for efforts to increase worker productivity. The emergence of concepts such as human factors and ergonomics during this period can also be traced to modernist thought. In this context, ergonomics first emerged within a framework that prioritized physical efficiency while marginalizing worker health, reflecting a utilitarian and mechanistic approach to labor.

### 3.2. Mid-20th Century: Ergonomics

In written texts, the application of ergonomic design can be traced back to the 4th century BC, with Hippocrates' creation of a surgeon's chair exemplifying one of the earliest instances of ergonomic design [18]. Hippocrates' work titled "In The Surgery" presents specific recommendations regarding the posture a physician should adopt to ensure comfort during surgical procedures [18]: "As for himself when seated, his feet should be aligned in a perpendicular line to the knees and brought together slightly with a small gap. The knees should be slightly higher than the groin and spaced enough to support the elbows and leave room for them."

The emergence of ergonomics, in its contemporary understanding, can be traced back to the 19th century. In this period, the rapid mechanization of production during the Industrial Revolution introduced significant challenges for workers, compelling them to adapt to the often repetitive and physically demanding conditions of the factory line. In response, the concept of "human factors" emerged in academic literature as an approach to enhance worker productivity. Behavioral scientists undertook research addressing these challenges, which were historically referred to as human engineering or human factors engineering [19]. Before World War I, Taylorism—characterized as the scientific analysis of workers—was introduced to enhance human efficiency within the workplace [20]. While aiming for increased output, Taylorism often viewed the worker through a mechanistic lens; however, it also pioneered systematic approaches to work analysis. Subsequently, Frank and Lilian Gilbreth, students of Taylor, established the foundational principles for what is currently termed time-and-motion study through their detailed analyses of tasks such as bricklaying and surgical procedures. They devised methods for quantifying work elements based on micro-level bodily movements; this technique remains integral to modern industrial engineering [21]. During World War I, human errors in pilot cabins, radar systems, and control panels resulted in significant consequences, starkly demonstrating that human performance, not just machine capability, was a critical determinant of system success and safety. This facilitated the evolution of this concept into a recognized modern discipline [8]. Human factors engineering was developed through examining static and dynamic anthropometry and exploring the interactions between humans and human-made objects [8]. The necessity for enlisting large numbers of men into the armed forces and allocating them to diverse specialized roles rendered the development of both intelligence tests and specialized aptitude tests imperative. Although the experiences during World War I contributed minimally to the human factors testing methodologies acknowledged today, they provided a novel insight into individual differences and how these variances could influence performance efficiency, subtly challenging purely standardized approaches to human work [19].

The term "ergonomics" was first introduced in 1857 by the Polish scientist Wojciech Jastrzębowski in the article titled *"An Outline of Ergonomics"* [22]. In this context, ergonomics is a scientific discipline that examines the harmonious interaction between humans and nature. While Jastrzębowski's framing was broad in scope, encompassing natural harmony, the modern understanding of ergonomics has become more focused on optimizing the interaction between humans and designed systems. The distinction between ergonomics and human factors engineering can be elucidated by examining how these concepts are defined and the emphasis placed on efficiency or the individual human being. Ergonomics traditionally emphasizes the physical fit between human bodies and tools, while human factors expand this focus to include cognitive processes and user behavior. The perspective that humans should adapt to machinery gradually transitioned to the recognition that machinery must adapt to human needs. For the first time during World War II, technology and human sciences collaborated systematically and in a coordinated manner. A diverse group of professionals, including physiologists, psychologists, anthropologists, medical doctors, and engineers, converged to address the challenges arising from the interaction between humans and complex military equipment, thereby leading to the institutionalization of ergonomics as a field. This wartime collaboration was pivotal, establishing ergonomics as a scientifically grounded design discipline. It necessitated the systematic application of data from the human sciences to design problems, transforming design practice from an often intuitive process to one informed by empirical research on human capabilities. This, in turn, began to reshape design education, demanding a more interdisciplinary curriculum. It has since been acknowledged as an interdisciplinary scientific field [23]. The successful outcomes of this multidisciplinary cooperation ensured the continued application of the ergonomic approach in the postwar industry, as knowledge gained in military contexts was transferred to the design of consumer and industrial products for a burgeoning mass market. The rise of mass consumption from the 1930s onward further propelled this, as considerations of usability and safety became significant criteria for industrial design in an increasingly competitive marketplace. According to Krippendorff (2005), ergonomics reflects the functionalist design ideal. On the contrary, Heskett [24] contends that when the alignment between an object and its user is paramount, ergonomic analysis informed by data regarding human dimensions becomes critically essential for assessing the appropriateness of a form for the intended user [24]. These perspectives suggest that ergonomics did not simply replace functionalism but rather redefined it, proposing that actual functionality must encompass human compatibility and well-being, effectively extending the maxim to "form follows function and human factors.

In the realm of industrial design, the principles of ergonomics were initially incorporated into the development of various products, including furniture, office equipment, automobiles, and household goods. Henry Dreyfuss is recognized for his substantial interest in ergonomics, serving as both a theorist and a practitioner within the field of industrial design. In his publication, "Designing for People" [25], he emphasizes the responsibilities of industrial design, particularly in terms of functionality, usability, and ethical considerations. He provides recommendations for integrating ergonomic principles into mass production processes. In the book above, he elucidates the necessity of considering diverse human dimensions in design, employing two hypothetical user models he designated "Joe" and "Josephine." Dreyfuss's collaboration with Bell Laboratories represents one of the earliest instances of systematic ergonomic industrial design. Notably, the Western Electric Model 302 Telephone stands out as one of the pioneering technological consumer products documented in the annals of ergonomics (see Figure 2). Dreyfuss's work was instrumental in popularizing ergonomic thinking within commercial industrial design, demonstrating its value beyond specialized military or industrial applications. His human-centered design philosophy, which considered diverse user needs and ethical responsibilities, significantly influenced how designers approached product development for mass markets.

***Figure 2.*** *Model 302 – Henry Dreyfuss ve Bell Labs 1937-1955 [26]*

Another significant example of ergonomic analysis in industrial design is the Herman Miller "Aeron" chair. The Aeron chair, meticulously designed for Herman Miller, was created with careful consideration of ergonomic data, focusing on the most minute details [24]. The commercial success and cultural impact of products like the Aeron chair consolidated the importance of ergonomic principles in contemporary design. However, while these achievements primarily addressed physical ergonomics, the rapid proliferation of information technologies and increasingly complex interactive systems in the latter half of the 20th century revealed an imperative for a deeper understanding of human cognitive processes, facilitating the emergence of usability and user experience as distinct yet interrelated domains of inquiry.

***Figure 3.*** *Aeron Chair – 1992 – Source: MoMA [27]*

In its early applications, ergonomics was primarily concerned with physical ergonomics and biomechanical efficiency, focusing on bodily fit, posture, and task performance, while largely overlooking human cognitive processes and emotional responses. The design grounded in anthropometric data, struggled to move beyond the assumption of a standardized human body, often neglecting the broader social, cultural, and environmental dimensions of design. However, the widespread adoption of information technologies in the latter half of the 20th century introduced new cognitive demands, indicating the necessity for a deeper understanding of mental processes. This shift laid the foundation for the emergence of interrelated research fields such as usability and user experience, which expanded the scope of ergonomic inquiry beyond physical parameters.

### 3.3. Mid-20th Century: Usability and User Experience

Over the years, classical ergonomics has evolved successfully, with a primary focus on designing hardware interfaces. However, in the future, information technology systems will increasingly depend on software and software interfaces to define the system's usability and user-friendliness [28]. Consequently, alongside physical ergonomics, a pressing need exists for substantial advancements in what has come to be recognized as "Cognitive Ergonomics." Cognitive Ergonomics refers to the systematic study, measurement, analysis, and modeling of human cognitive behavior about advanced technological systems. Given the extensive individual differences among system users—including intelligence, experience, memory, and motivation—the variability involved is anticipated to surpass that encountered in physical ergonomics [28]. This recognition marked a crucial shift, demonstrating that effective human-machine interaction hinged not only on physical fit but increasingly on understanding and supporting human cognitive processes, thereby establishing critical foundational principles for the later concepts of usability and user experience in complex systems, as purely physical approaches proved insufficient for the mental demands of emerging technologies.

During the Second World War, the Aero Medical Laboratory received a request from the Air Force to investigate the cause of a recurring error made by pilots and co-pilots during landing operations: retracting the landing flaps instead of the landing gear [29]. This issue was not comprehensively documented until several years later, in 1947, by Fitts and Jones:

> "I remember reading dozens of accident reports that concluded these accidents were caused by 'pilot error'. What I found while examining the cockpits of aircraft like the B-17, the flying fortress of those years, was two identical toggle switches side by side - one for the landing gear and one for the landing flaps. Given the stress of landing after a combat mission, it's understandable how these could easily be confused. I called it a designer error, not a pilot error. The specific solutions proposed at the time (separating controls and/or shape coding) were later supported by findings in the human factors literature. Another solution was more mechanical: installing a sensor on the landing struts to detect whether the weight of the airplane compressed them. If they were compressed, a circuit would disable the landing gear control in the cockpit."

Chapanis [30] expresses his first observations on cognitive ergonomics as follows:

> "During the war, our machines became so complex that in recent years we have had to start a new branch of technology: this activity, called human engineering, represents a new beginning in the application of psychological principles to industry."

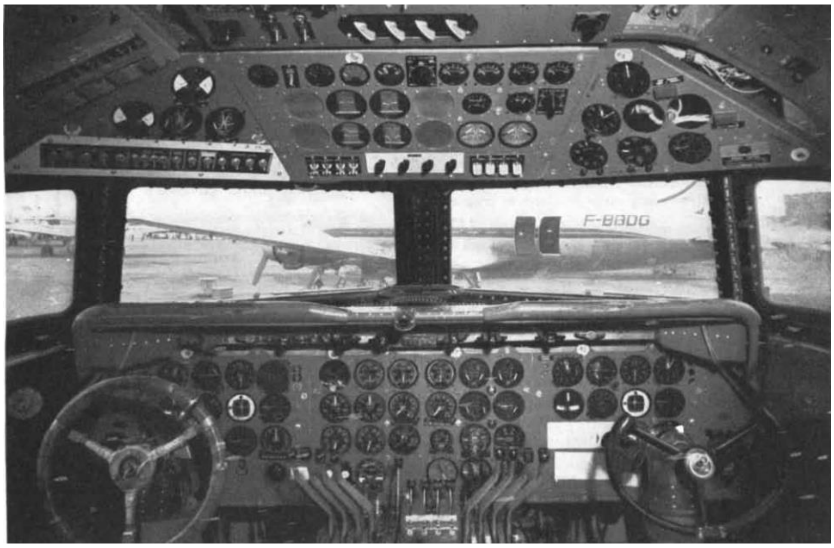

***Figure 4.*** *Instrument Panel of B-25 [30]*

Chapanis's observations, born from the crucible of wartime necessity, underscored a pivotal realization: as technology advanced, the bottleneck for system performance became increasingly human rather than mechanical. This understanding, initially critical in military and aviation contexts, was gradually integrated into industrial design as computational technologies began to permeate civilian and commercial spheres. By the late 1950s, the potential of computers within the industrial and business sectors was widely acknowledged, leading to the development of the first commercially viable machines, designed by computer specialists for data processing professionals. Commencing in the mid-1960s, the advent of minicomputers and remote terminal access to shared mainframes facilitated the integration of computers into users' daily lives. Nevertheless, the challenges encountered by non-specialists and the complexities associated with human-computer interaction were already becoming evident [28]. With the introduction of the microcomputer in 1978, and particularly following its widespread adoption post-1980, computers began to cater to a more diverse audience, including bank clerks, business executives, librarians, insurance agents, secretaries, stockbrokers, and even astronauts. This rapid expansion in computing capabilities led to increased usability challenges. Users transitioned from primarily computing professionals to voluntary participants [31]. Consequently, designers ceased to be representative of the average user. However, they may not have been fully aware of how distinct and unrepresentative they had become [28].

Similar to ergonomics, usability, which is fundamentally linked to human factors engineering, is semantically related to ergonomics. Initially, ergonomics was associated with anthropometry within the field of human factors and subsequently expanded to encompass psychology, particularly in the context of "human-machine interaction." In contrast, usability is defined from the user's perspective in terms of its components: effectiveness, efficiency, and satisfaction [32]. While rooted in the principles of ergonomics, usability broadened the scope beyond physical comfort and safety to systematically address the cognitive demands and ease with which users could learn, operate, and accomplish their objectives with a product, especially in light of the escalating complexity of interactive systems. This represented a significant expansion of the scope of design inquiry, extending its focus from the 'body' of the user to include the 'mind' as well.

The role of human factors in various phases of the design process, as well as the most effective methods for assisting designers in creating usable designs, has been explored intuitively and through empirical research over many years. Meister and Farr (1967) underscored several challenges that designers encounter when applying human factors knowledge to the design process, leading to the development of numerous manuals and textbooks that focus on general ergonomics within the context of broader systems [28]. The concept became central to design literature during the 1980s. Theorists such as Nielsen define usability as "the degree to which specific users can achieve specific goals effectively, efficiently, and satisfactorily," positioning the term directly within industrial design terminology and devising measurement methods for it [33]. Usability testing has become a standard stage in industrial design, where real users evaluate prototype products and gather ergonomic and usability data [34]. The integration of direct user feedback into the design cycle, often involving methods such as think-aloud protocols, heuristic evaluations, and persona development, has fundamentally altered design practice. These developments catalyzed the creation of discourses such as "user-centered design" and "human-centered design" in design theory. The integration of ergonomics and, subsequently, usability concepts into the field represented a significant turning point in the evolution of industrial design toward a human-centered approach, recasting the designer's role increasingly as an advocate for the user. Consequently, the limitations of the human body and mind have been incorporated into discussions within the field concerning function and form. With the incorporation of "human factors" into the design process, designers are prompted to regard products not merely as technical objects, but as tools that facilitate human experiences [35]. The conceptual framework provided by ergonomics has enriched design terminology with terms such as comfort, safety, usability, and adaptability [36]. This transformation also lays the groundwork for the concept of user experience, which emerges in the later stages of industrial design and establishes a foundation for a culture that prioritizes the human element in design. Particularly with the integration of information technologies and digital products into daily life, a new concept has rapidly gained prominence in industrial design terminology: user experience. User experience encompasses a comprehensive consideration of a user's interaction with a product, system, or service [37]. This includes not only physical ergonomics or usability (the 'can do' aspect), but also the emotions a user experiences, brand perception, and all impressions garnered throughout the interaction process (the 'feel and mean' aspect) [35]. The prominence of this concept in design literature is intricately connected to advancements in the field of human-computer interaction during the 1990s. Notably, with the widespread adoption of personal computers, software, and the internet, designers began to construct physical objects and dynamic interactive systems [38]. This transformation has contributed to the growing significance of the user concept and the recognition of experience as a key output of design. Consequently, design education began to incorporate methodologies from human-computer interaction, cognitive psychology, and user research to equip designers with the skills to create not only functional but also truly usable and engaging experiences.

Several important disciplines have contributed to the integration of the concept of user experience into the design language, including cognitive psychology, human-computer interaction, and marketing and consumer behavior. Cognitive psychology offers scientific insights regarding which information should be emphasized in interface design. It elucidates how a product should facilitate users during their initial interactions by deepening our understanding of mental processes, such as perception, learning, and memory [39]. The discipline of human-computer interaction is foundational in developing usability principles and interface design patterns for interactions with computer systems [40]. Terms like "graphical user interface," "menu hierarchy," and "feedback" have become part of the design vocabulary through this discipline [40]. Conversely, marketing and consumer behavior focus on user satisfaction, brand loyalty, and emotional design, illustrating that design should forge experiences that are not only functional but also pleasurable and engaging [41]. Donald Norman, a well-regarded cognitive scientist, gained prominence for his analysis of user interactions with products during the late 1980s and early 1990s. At Apple, he popularized the term "user experience" among a wider audience. In a collaborative paper with Henderson [42], Norman articulated a vision of user experience in design that transcended the confines of "human-computer interface" and "usability," encompassing the emotional and holistic dimensions of product usage. In his book The Invisible Computer [43], Norman emphasized that the success of technological products should be evaluated not solely on functional performance but also on the comprehensive experience afforded to the user, thereby systematically formalizing the user-centered design approach. Within this framework, designers are expected to cultivate a profound understanding of the end user's needs, expectations, and constraints and integrate user feedback and usage scenarios throughout the design process [44].

The concept of user experience extends to various subterms within industrial design terminology, including interaction design, service design, and experience design [38]. "Interaction design" refers to the design of reciprocal actions between the user and the product, such as pressing a button and the device's subsequent response. In contrast, "service design" seeks to ensure that services associated with a product are coherent and satisfactory for the user [45]. The term “experience design" occasionally extends beyond physical products, referring instead to the creation of user experiences across various spaces, events, or digital environments [46]. By the late 1990s and early 2000s, user experience design materialized as a distinct area of expertise. The ISO 9241-210 standard, published in 2000, outlined user-centered design processes, emphasizing the importance of usability and user experience criteria in a product’s success [47]. According to the ISO definition, user experience encompasses all perceptions and responses resulting from a user’s interaction with a system, including usability, ergonomics, and emotional satisfaction [47]. This standard rendered user experience a measurable and manageable objective for designers and corporations alike. Concurrently, academic discourse regarding user experience also increased. Hassenzahl and Tractinsky [37] underscored that user experience involves not only the efficient completion of tasks but also the creation of lasting impressions and emotional impacts on the user, advocating that design research should extend beyond mere usability (Hassenzahl & Tractinsky, 2006, p. 92). Their contributions expanded the understanding of user experience within the literature, emphasizing that dimensions such as “pleasure,” “emotion,” and “aesthetic impact” should also constitute areas of inquiry [37].

### 3.4. Late 20th Century: From Functional Aesthetics to Emotional Aesthetics

The concept of emotional aesthetics centers on the notion that design objects should be evaluated based on their utility value and the emotions they evoke in the user. While the significance of emotions in aesthetic theory was historically contested by philosophers such as Baumgarten and Kant during the 18th and 19th centuries [48], the systematic examination of emotions within the realm of industrial design is a relatively recent innovation. From the mid-20th century onwards, psychology has begun to explore the association between emotions and cognitive processes, with psychologists such as Paul Ekman [49] and Robert Plutchik [50] categorizing basic emotions. This accumulation of knowledge within psychology established a foundational basis for research on user experience in design. In contemporary terms, the concept of emotions in product design began to take shape at the conclusion of the 1970s in Japan with the introduction of the Kansei Engineering approach. In the 1980s, Mitsuo Nagamachi integrated the concept of kansei, which translates to "emotion" or "sensitivity" in Japanese, with engineering, applying it to product development [51]. Nagamachi (1989) defined Kansei Engineering as the translation of consumer sentiments and perceptions concerning a product into design elements [51]. Consequently, the notion that emotional responses could be harnessed within the design process initially arose within engineering.

With the emergence of user-centered design during the 1980s and 1990s [52], the sensory and emotional impacts of products began to gain prominence. Following Donald A. Norman’s application of cognitive psychology principles to design challenges, by the late 1990s, design researchers started to expand the concept of user experience to encompass the emotional resonance of products. In 1999, the inaugural international “Design and Emotion” conference was organized, signifying the establishment of an academic community within this domain [53]. Norman further advanced this movement with his 2004 publication, Emotional Design [54]. In this work, Norman analyzes human-product interaction across three tiers: the visceral level (the emotional response upon initial observation, aesthetic appeal), the behavioral level (the pleasure or frustration experienced during usage), and the reflective level (assessing the relationship with the product over time, attributing meaning and value) [54]. Norman’s contributions instigated a discursive shift by underscoring the significance of an “emotion-focused” design approach in industrial design practice. Today, among the criteria for effective design, in addition to functionality, ergonomics, and usability, the user’s emotional response to the product is also recognized [54]. This transformation represented a notable departure from the modernist paradigm.

In conjunction with this transformation in design discourse, novel approaches have emerged in practice. Patrick W. Jordan, through the New Human Factors approach, identified four fundamental categories of pleasure in product design focused on user satisfaction: physiological pleasure (sensory enjoyment), sociological pleasure (satisfaction derived from social interaction and status), psychological pleasure (pleasure from cognitive and emotional responses), and ideological pleasure (satisfaction from the alignment of the product with the user’s values) [41]. Drawing inspiration from anthropologist Lionel

Tiger's theory of "four pleasures," Jordan [41] established this classification. He introduced the concept of "pleasurable design" into the discourse, extending beyond mere usability in industrial design [41]. In the early 2000s, researchers such as Pieter Desmet experimentally demonstrated that products could evoke specific emotions. They proposed the Product Emotion model, arguing that design can be strategically crafted to elicit particular emotions in users, including happiness, surprise, or pride [55]. During this era, user experience evolved to include emotional experience, and "design and emotion" themes began to be integrated into industrial design educational curricula [53]. This integration catalyzed a transformation in design pedagogy, prompting students to explore narrative structures, sensory engagement, and the symbolic meanings embedded in objects. Practically, designers began to employ advanced methods such as emotion mapping, storytelling, and co-creation techniques to strategically design for intended emotional responses [56]. Consequently, the purpose of design was redefined not only as achieving functional satisfaction but also as fostering an emotional connection and a positive user experience.

The design approach developed around emotional aesthetics is exemplified in numerous iconic products. For instance, the Juicy Salif lemon squeezer, created by Philippe Starck in 1990, diverged from the conventional typology of kitchen tools and transformed into an object that elicits surprise and delight through its sculptural form (see Figure 5). Starck's design achieved recognition not for its practicality. Still, for the emotional response and conversational value it evoked, it was selected as the cover image for Norman's book on Emotional Design [54]. This product serves as a pioneering and notable example of the intentional application of emotional aesthetics in industrial design, demonstrating a deliberate prioritization of emotional impact and symbolic value over purely utilitarian concerns —a tension often debated within design discourse.

***Figure 5.*** *Juicy Saliff – Philippe Starck – Source: Alessi [57]*

According to Heskett [24], this approach unlocks a landscape of limitless possibilities for generating ever-new forms that require little or no connection to purpose. It enables products to be drawn into fashion-driven cycles of change for the primary benefit of producers, turning design into a kind of fashion instrument across many industries. This attitude toward design was eagerly adopted by numerous companies—such as Alessi—that sought to add value to products with low profit margins [24]. As consumption shifted from merely meeting functional needs to addressing individual gratification through emotional design and identity construction, design became one of the driving forces of capitalist economies from the mid-20th century onward. It was precisely the ecological crisis triggered by this pleasure-oriented culture of consumption that laid the groundwork for the emergence of the sustainable design paradigm. Jonathan Chapman [58] introduces the concept of emotionally durable design. He argues that fostering emotional longevity between users and objects is critical from a sustainable design perspective. According to Chapman, emotional aesthetics should not merely be about fleeting pleasure but about creating long-term satisfaction and attachment, thereby potentially extending product lifespans and reducing waste [58]. This perspective suggests that the depth of emotional connection can be a key factor in more sustainable consumption patterns, a theme that resonates strongly with subsequent discussions on sustainable design.

### 3.5. Late 20th Century: Sustainable Design

The concept of sustainability is fundamentally rooted in the global rise in environmental awareness and the ecological movement that emerged during the latter half of the twentieth century. Significant developments, such as the oil crisis of the 1970s and the "Limits to Growth" report (1972), illuminated the fact that unlimited economic growth and consumption were unsustainable [59]. The first prominent use of the term "sustainability" was noted in the 1987 report "Our Common Future" issued by the United Nations World Commission on Environment and Development. This report brought the concept of sustainable development to the global agenda, defining it as the ability to meet the needs of the present without compromising the capability of future generations to meet their own needs [60]. Sustainability is inherently a multidisciplinary concept, grounded in the fields of ecology, environmental science, economics, and ethics. The origins of sustainability within industrial design can be traced back to the mid-twentieth century. In the 1960s, Buckminster Fuller drew attention to the Earth’s limited resources through his metaphor of "Spaceship Earth" [61]. Meanwhile, industrial design theorists, such as Victor Papanek, began to question the social and environmental responsibilities associated with design from the late 1960s onward. Victor Papanek is regarded as one of the pioneering figures emphasizing the ethical and ecological dimensions of the industrial design profession [62]. In the preface to his 1971 book "Design for the Real World," Papanek posited that industrial design was one of the most detrimental professions humanity might encounter [62] and paved the way for ethical and sustainable approaches to emerge in design education and practice following 1970 [63]. Even at that time, Papanek addressed issues such as manufacturing radios from recycled materials and designing low-cost products for individuals with disabilities and those of low income, presenting early instances of socially and environmentally conscious design [62]. Papanek's radical critique and proactive proposals had a profound impact on design philosophy, challenging the prevailing consumerist ethos and positing the designer as a responsible agent capable of addressing pressing global issues, particularly through the promotion of socially responsible and ecologically sensitive design approaches [62]. His work catalyzed a shift in design education, moving it towards the incorporation of ethics, social responsibility, and ecological literacy into curricula. It inspired practical approaches centered on appropriate technology, resource conservation, and designing for real human needs rather than manufactured desires. During this era, Manzini [64] emphasized the need to develop systematic strategies for reducing the environmental impact of industrial production. Dieter Rams (1987) bolstered this transformation by incorporating the principle of “environmental friendliness” into the criteria for good design. By the late 1970s and into the 1980s, terms such as environmental design, green design, eco-design, and cradle-to-cradle design began to permeate design terminology [65]. While until the 1990s the success of designers was predominantly assessed based on aesthetics and market performance, criteria such as a product’s carbon footprint, energy consumption, and material toxicity also began to be regarded as integral components of design quality during the 1990s and 2000s [66]. This shift catalyzed transformative changes in design practice, including the systematic adoption of tools such as Life Cycle Assessment (LCA), a heightened emphasis on materials science aimed at developing sustainable alternatives, and the formulation of strategies under the 'Design for Environment' (DfE) framework, encompassing principles like dematerialization, detoxification, and design for disassembly and recyclability [66].

Examples of products that embody sustainability principles span various periods in design history. A notable early example is the tin can radio prototype, developed in the 1970s by Victor Papanek and James Hennessey (see Figure 6) [67]. This radio, constructed using simple and recycled components, such as a tin can casing and a basic electronic circuit powered by candlelight, sought to address the communication needs of rural populations in developing countries at a minimal cost. This design represented a pioneering project that integrated the social dimension of sustainability, reflecting Papanek’s design philosophy.

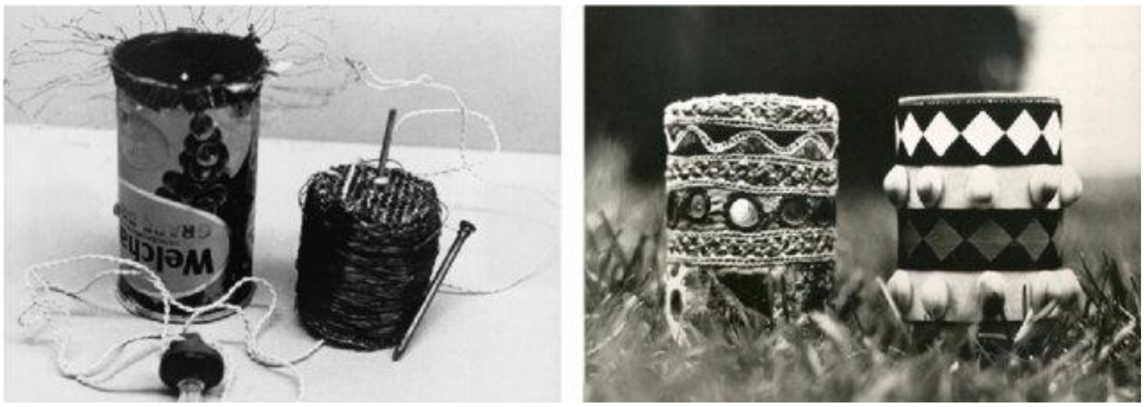

***Figure 6***. *Tin Can Radio (1962) by Victor Papanek and George Seegers, and the radio decorated by an Indonesian user (Marotta et al., 2021) [67]*

Another example previously referenced in the ergonomics section is the Aeron Chair, introduced by Herman Miller in 1994 (see Figure 3). This chair distinguishes itself not only through its ergonomic design but also because 94% of its components are recyclable and is characterized by a durable construction. Rather than utilizing foam and PVC, which are commonly found in traditional office chairs, the Aeron Chair incorporates a stretchable mesh material known as Pellicle. This innovation enhances user comfort while facilitating component replacement, and its design has become one of the first commercial furniture products to achieve Cradle to Cradle certification [68]. The evolution towards sustainable design, as exemplified by Papanek's activism and products like the Aeron Chair, not only redefined technical and material considerations but also underscored a broader shift in understanding the designer's role and responsibility within society. This growing awareness of design's far-reaching impacts naturally led to questions about who should be involved in making these critical design decisions, thereby fostering an environment conducive to the emergence of participatory design approaches where users and other stakeholders are actively engaged in shaping more equitable and sustainable futures.

### 3.6. Late 20th Century: Participatory Design

Participatory design is based on the principle that stakeholders actively and creatively engage in the design process. The origins of this concept can be traced back to the late 1960s and early 1970s, predominantly grounded in the democratic participation movements within Scandinavian nations. By the end of the 1960s, Scandinavian labor unions, in their pursuit of improved working conditions and the promotion of industrial democracy, expressed a desire to influence the implementation of new technologies within workplaces [69] [70]. Notably, in Norway during the early 1970s, the notion emerged that workers and unions should participate in decision-making processes when designing computer-supported work systems [70]. In this respect, the “Democratic Design” experiments in Norway can be regarded as among the first instances of participatory design [70]. Concurrently, during the same period in the United Kingdom, the Design Research Society convened a conference titled "Design Participation" in Manchester in 1971, thereby elevating the issue of user participation to a prominent position within the international design community [71]. These early developments underscored a fundamental philosophical shift: a move towards democratizing design processes and acknowledging the rights and expertise of those directly affected by design outcomes.

However, the comprehensive integration of participatory design into the industrial design discipline, both as a theoretical concept and a practical method, took place during the 1990s and 2000s [72]. Initially, the focus was predominantly on the collaborative design of information systems and software interfaces; however, participatory design gradually extended to encompass various scales and fields, including product design, service design, and public space design. By the 2000s, particularly in the United States and other nations, participatory design increasingly emerged as a method for innovation and the enhancement of user experience [73]. During this timeframe, large design consulting firms sought to mitigate product development risks and identify more accurate responses to user needs by incorporating end users into the design process. Liz Sanders articulated this trend as the “from user to design partner” paradigm, underscoring the necessity for authentic creative participation, which contrasts with traditional user research methods [74]. Nonetheless, it cannot be asserted that the fully realized participatory design process has been extensively reflected in design practice.

One of the most notable instances illustrating the impact of participatory design on practice is evident on the IKEA Hackers platform, where users modify products to meet their specific needs [75]. On these digital platforms, individuals creatively recombine IKEA furniture for diverse applications and share the innovative solutions they create with others, signifying a form of engagement not initially contemplated by the designer. Notably, in 2021, IKEA initiated the publication of official “hack” guides for select products, thereby integrating user creativity into the institutional design framework. The rise of participatory design, therefore, represents a culmination of many of the trends discussed previously – from a focus on the human user (ergonomics, usability, user experience) to an engagement with broader social and ethical responsibilities (sustainability). It signifies a maturation of the design discipline, where the definition of "designer" expands and the boundaries between producer and consumer become increasingly blurred. This ongoing evolution in industrial design terminology, reflecting a continuous redefinition of design's scope, purpose, and methods, sets the stage for a concluding discussion on the discipline's multifaceted and ever-transforming nature.

## 4. CONCLUSION

The process of forming industrial design terminology transcends the mere establishment of a linguistic structure isolated within the design discipline; instead, it constitutes a dynamic and multilayered framework influenced by numerous fields. As this study has clarified, this framework does not serve as a passive reflection of disciplinary evolution, but rather as an active arena for cross-disciplinary conceptual appropriation and recontextualization, wherein terms are borrowed, adapted, and infused with new meanings that redefine the evolving concerns and identity of design. Fields such as engineering, architecture, art, sociology, psychology, ergonomics, and marketing have significantly impacted both the conceptual framework and the practical implementation of industrial design. This interdisciplinary interaction has enriched the terminology and advanced its development through a cross-disciplinary understanding, illustrating that industrial design operates as a critical nexus where diverse intellectual traditions converge and are synthesized.

An examination of example terms reveals a distinct evolutionary trajectory: technical terminology appropriated from engineering predominantly emphasizes the functionality of the designed artifact, while concepts evolved from psychology and sociology place the human user at the center. Engineering-based approaches in industrial design focus on the functionality, manufacturability, and performance of products. In its early era, industrial design occupied a position of synthesizing art and engineering. As noted by the Industrial Designers Society of America (IDSA), “early industrial designers frequently worked on the border between artist and engineer, balancing aesthetics with function” [76]. Terms acquired from engineering—such as durability, cost, efficiency, modularity, and standardization—underscore the “industrial” dimension of design. From the 1950s onward, a significant shift occurred as the focus of industrial designers increasingly shifted toward the user. Within the concept of usability, terms such as perception and cognitive load, borrowed from psychology, have come into use. During this era, industrial designers also integrated human ergonomics, material innovations, and corporate branding into the design process [76]. This shift introduced psychological notions such as user experience, sensory design, and emotional attachment into the terminological repertoire. Consequently, terms such as cognitive ergonomics and user experience have become integral to the lexicon. While sociology and psychology introduced user behaviors and cultural contexts into the terminology, marketing contributed to the emergence of new concepts by emphasizing the product's economic value and its relationship with the consumer. This entire terminological progression is not merely an academic exercise; it reflects a fundamental transformation in industrial design's self-perception and societal role – from a primarily technically oriented profession focused on mass production to an increasingly human-centered, and later, experience-driven discipline concerned with meaning, interaction, and broader systemic impacts.

Sociology, anthropology, and marketing have contributed terminologies that underscore the societal significance of products and illuminate consumer behavior. Perspectives from social sciences have facilitated the development of concepts such as user research, cultural context, and social impact. Concurrently, the contributions from the marketing discipline reflect the direct commercial dimension of the field, enabling the integration of marketing terminologies such as product life cycle, brand identity, and target market into the terminology used in industrial design. The Industrial Designers Society of America (IDSA) also emphasizes that contemporary industrial designers take into account factors such as corporate branding and end-user benefits [76]. The amalgamation of these diverse terminologies signifies the maturation of industrial design beyond a purely product-centric focus, recognizing its profound embeddedness within, and reciprocal influence on, broader social, cultural, and economic systems.

Ultimately, the terminology of industrial design functions as a discursive instrument that articulates the multidimensional relationships among objects, users, society, and the marketplace. This highlights the inherently interdisciplinary nature and continuously evolving structure of industrial design. The interplay that underlies the formation of this terminology not only directly influences design processes by providing a conceptual scaffold for thought and action but also facilitates the establishment of a shared language for professional communication. In doing so, it actively constructs and negotiates the very identity and boundaries of the discipline. It offers a living and evolving conceptual infrastructure, enriched by the cumulative knowledge of diverse disciplines. Understanding this dynamic terminological landscape is, therefore, crucial not only for tracing the historical trajectory of industrial design but also for critically navigating its present complexities and anticipating its future directions. As new societal challenges and technological frontiers arise, the lexicon of design will undoubtedly continue to adapt and expand, reflecting the discipline's enduring capacity for critical reflection and transformative action.

Industrial design, a discipline that has historically evolved through close interaction with architecture, engineering, the arts, and the social sciences—and whose conceptual lexicon has accordingly broadened [77]—is expected to enter a new phase of transformation in the 21st century, particularly as artificial intelligence technologies become increasingly embedded in design processes. In this context, the trajectory of terminological evolution in industrial design is beginning to be shaped by emerging technologies such as artificial intelligence, digital fabrication, and computational design. The algorithmization of design tools has introduced a new conceptual vocabulary—encompassing terms like data-informed design, generative systems, and AI-mediated creativity—reflecting a shift in both the epistemological and methodological orientation of design practice. Such a shift reconfigures both the practical and conceptual dimensions of design, redefining the designer's role as that of a systemic mediator—one who constructs frameworks to navigate and structure the dynamic interplay among users, machines, and data flows. Within this framework, design emerges not solely as a process of creation, but as a critical practice involving ethical judgment and the construction of complex systems [78]. The integration of big data into design practice has catalyzed the development of novel epistemological frameworks, including data-informed and data-centric design methodologies [79]. The integration of AI into decision-making processes requires algorithms to be ethically accountable, which in turn has introduced new terminology such as transparency and algorithmic justice into the discourse [80].

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