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A Quest for Identity: Remembering Tehran Museum of Contemporary Art (TMoCA)

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Abstract

This article examines the historical background of the establishment and realization of the Tehran Museum of Contemporary Art (TMoCA), initiated through the vision and connections of Iran's former queen and architect Farah Pahlavi and designed by Iranian artist and architect Kamran Diba. The museum skillfully integrates traditional architectural elements with modern materials and forms, creating a bridge between historical traditions and contemporary sensibilities. Reflecting Diba's explorations of Iranian architectural identity in the late 1970s, the design respects Iran's cultural heritage while addressing the functional needs of modern society, serving as an intermediary space that functions as a cultural platform fostering social and artistic interactions in the city. Adopting a historical and biographical approach, this study situates the museum within the context of pre-revolutionary Iranian art and architecture, focusing on Pahlavi's vision for a Western-oriented contemporary art museum and Diba's reinterpretation of this vision through hybrid architectural forms. The research analyzes the dynamic relationship between the museum and its surroundings, particularly emphasizing its spatial dialogue with Laleh Park, one of Tehran's most significant public spaces. Drawing on international and Iranian literature, oral histories, and collective memory, this study explores the museum's legacy and future, offering a perspective on TMoCA's critical role at the intersection of art, architecture, and society.

1. INTRODUCTION

The Tehran Museum of Contemporary Art (TMoCA), inaugurated in 1977, has been a landmark of Iran's pre-revolutionary modernism and cultural aspirations. Conceived under the patronage of Shahbanu Farah Pahlavi and designed by the Iranian architect and planner Kamran Diba, TMoCA embodies a unique intersection of Iran's historical architectural heritage and the modernist ethos that shaped the late 20th century. Positioned on the edge of Laleh Park, one of Tehran's most significant urban public spaces, the museum offers not only a venue for art exhibitions but also an architectural narrative that engages with its sociopolitical and cultural milieu.

Diba's design for TMoCA reflects a deliberate negotiation between tradition and modernity. Drawing on Iranian vernacular forms and spatial configurations, such as courtyards and windcatchers, he reimagined them through modern materials and techniques. This synthesis mirrors broader efforts in the late 1970s to articulate an Iranian identity that resonates with both the past and contemporary global trends. Shahbanu Farah Pahlavi's vision of a contemporary art museum was similarly ambitious, aiming to place Iran at the forefront of the international scene of art and culture.

This study examines the intertwined narratives of TMoCA's architectural design, cultural positioning, and its broader historical and political context. It explores how the museum's spatial and symbolic gestures engage with its environment and community, acting as a cultural bridge between historical continuity and

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modern innovation. The study also considers TMoCA's enduring legacy and its place within ongoing discussions of heritage, memory, and contemporary Iranian identity.
The Tehran Museum of Contemporary Art (TMoCA), founded in 1977, at the turn of the Islamic revolution of 1979, remains one of Iran's most iconic cultural and architectural achievements of the 1970s. This project exemplifies a deliberate effort to harmonize traditional Iranian architectural elements with the ideals of global modernism, achieving a cohesive and innovative synthesis of the two.

Inspired by Iran's vernacular architecture, Diba integrated features such as windcatchers, central courtyards, and forms characteristic of desert structures to create a space that both honors Iran's cultural heritage and aligns with the aesthetic and functional demands of modern architecture. As Ardalan and Bakhtiar (1973) highlight in their seminal work *The Sense of Unity*, traditional Iranian architecture inherently embodies spiritual and unifying principles—a philosophy that resonates strongly in the design of the TMoCA.

Guided by traditional Iranian architectural principles such as the *hashti* [1] and *chaharsoo*[2], Kamran Diba crafted a space that invited visitors to engage with contemporary art while remaining deeply rooted in Iranian cultural heritage. These design elements have elevated the TMoCA into a symbol of the interplay between past and present, significantly contributing to Iran's cultural and social prominence. By seamlessly integrating tradition with modernity, the museum serves as a dynamic platform for contemporary audiences to connect with a revitalized expression of Iranian cultural identity.

TMoCA is among the rare architectural projects that successfully merge social and cultural concepts with modern aesthetics. In *Space and Place: The Perspective of Experience*, Yi-Fu Tuan (1977) underscores the importance of designing spaces that elevate human experience. Aligning with this principle, Kamran Diba incorporated open and flexible spaces into the museum's design, fostering an ideal environment for cultural and artistic interactions. With a deliberate focus on simplicity and innovative spatial organization in terms of the circulation, transparency and open spaces, Diba envisioned the museum not only as a center for art but also as a vibrant hub for cultural and social engagement.

The museum has undergone notable transformations, particularly in the tumultuous years following the 1979 Revolution. During the period from 1978 to 1980, architectural and cultural development were largely neglected as revolutionary ideals took precedence. Art was redefined through the lens of divine and revolutionary values, sidelining themes that did not align with this framework. As a result, the museum witnessed and was subject to substantial political and cultural shifts. Many Western artworks were removed from public display due to their perceived incongruity with revolutionary principles. Furthermore, the museum temporarily ceased its activities, with greater focus placed on Islamic and traditional Iranian art.
During the 1980-1988 Iran-Iraq War, the museum played an unconventional role, serving as a shelter for the families of its staff. Its valuable art collection was secured in the basement, while employees' families took refuge in a separate section. In 1999, the museum marked a pivotal moment in its history by hosting its first exhibition of Western art since the revolution. This pop art exhibition featured renowned artists such as David Hockney, Roy Lichtenstein, Robert Rauschenberg, and Andy Warhol, symbolizing a significant cultural shift and a re-engagement with global art.

This research examines the Tehran Museum of Contemporary Art as both an artistic and social hub within Iranian society, focusing on two significant figures in its realization: Farah Pahlavi and Kamran Diba. It

[1] *Heshti* refers to a space at the threshold and entrance of a building. This space is designed as a transitional and functional element in the main passageways.
[2] *Chaharsoo* refers to a spacious area with a circular arch at the intersection of two or more corridors.

highlights the museum's architectural evolution and the cultural impact it has generated throughout its history.

2. METHOD

This research adopts a historical, architectural, and biographical lens to analyze the Tehran Museum of Contemporary Art as both an artifact and a cultural phenomenon. The methodology integrates qualitative approaches, focusing on the following key dimensions: Primary and secondary sources are examined, including architectural drawings, and historical photographs related to TMoCA's foundation. Iranian and international publications from the late 20th century provided critical perspectives on the art and architectural scene of pre-revolutionary Iran. A detailed study of the museum's design elements, materials, spatial organization, and its relationship to Laleh Park is conducted. This analysis explores how Diba's architectural language mediates between local traditions and modernist aesthetics, reflecting broader cultural and spatial narratives.

The roles of Shahbanu Farah Pahlavi and Kamran Diba are analyzed through biographical accounts, interviews evident in the literature that documented their visions for the museum. This aspect highlights the interplay of political aspirations and artistic innovation in TMoCA's conception. The study incorporates oral histories, capturing personal recollections of those involved in the museum's establishment and its visitors. These narratives provide insight into the museum's social and cultural significance, both historically and in contemporary times.

This study aims to situate itself within existing scholarship on Iranian modernism, museum studies, and architectural history, synthesizing these fields to contextualize TMoCA within its broader cultural and historical framework. The research takes a commemorative stance, reflecting on the museum's legacy and its potential role in shaping Iran's cultural future. This approach underscores the importance of heritage preservation and the evolving dialogue between past and present. Drawing upon these methodological tools, this study aims to demonstrate a holistic understanding of TMoCA's significance as an architectural, cultural, and historical landmark. It aims to contribute to broader discussions on the intersections of architecture, politics, and identity in the context of Iran and beyond.

3. BETWEEN MODERNITY AND TRADITION: PRE-REVOLUTION IRAN IN CONTEXT

In contemporary Iranian history, the tension between tradition and modernity has emerged as a defining theme in architecture and urban planning. As Kenneth Frampton, in his seminal article "Towards a Critical Regionalism: Six Points for an Architecture of Resistance", quotes from the French thinker Paul Ricoeur, this challenge stems from a fundamental duality: the necessity of engaging with global civilization and scientific rationality while simultaneously preserving cultural and historical identity. Ricoeur encapsulates this paradox with the question: *"How to become modern and return to sources; How to revive an old, dormant civilization and take part in universal civilization."* (Ricoeur, 1965, as cited in Frampton, 1983) This duality is particularly pronounced in Iran's modern history, spanning over 150 years, and is especially evident in the architectural and urban development of Tehran. The city has served as a focal point where the confrontation and interaction between these contrasting forces have shaped its identity, reflecting broader societal struggles and aspirations.

Since the Qajar era (1789-1925), Tehran has served as the epicenter of architectural and urban transformations in Iran, embodying the coexistence of tradition and modernity. Initially, the city's urban fabric was rooted in traditional patterns, but the growing influence of Western lifestyles and architectural styles gradually introduced significant changes. This shift began during the reign of Naser al-Din Shah and intensified during the Pahlavi era, when modernization was often equated with the wholesale adoption of Western models. Under Reza Shah (Pahlavi I), Tehran underwent radical urban modernization, including the construction of railways, wide boulevards, and modern governmental buildings, which profoundly reshaped the urban landscape. These efforts aimed to project a modern image of Tehran but often marginalized its traditional elements, fostering the tension between preserving cultural heritage and advancing toward a more globalized, modern identity.

During the reign of Mohammad Reza Shah (Pahlavi II), Iran's urban planning and architecture experienced a period of transformation fueled by increased oil revenues and the contributions of domestic and international experts. Efforts during this era, including the Tehran Master Plan (1968) and various contemporary architectural projects, aimed to integrate global modernist principles with Iran's cultural heritage. However, these initiatives were often criticized for failing to adequately reflect the local social and cultural context, leading to a disconnect between modern architectural practices and Iranian identity.
In response to these challenges, which Iran exemplified, the theory of critical regionalism emerged as a potential solution for bridging the divide between tradition and modernity. Originally formulated by architectural theorists Alexander Tzonis and Liane Lefaivre in 1981 and subsequently developed further by Kenneth Frampton in 1983, critical regionalism provides an analytical framework aimed at harmonizing the universal principles of modernity with the cultural and contextual specificity of tradition. (Zoghi Hosseini, 2021, as cited in Frampton, 1983; Tzonis & Lefaivre, 1981)

Frampton's approach emphasizes the interplay of dualities such as "place versus space", "tectonics versus scenography", and the "local versus the global." Rather than framing tradition and modernity as oppositional forces, critical regionalism advocates for their interaction and redefinition, proposing a mediating approach that respects both global advancements and local identity. This theory provides a valuable perspective for understanding the challenges and opportunities in Iranian architecture and urban planning during this pivotal period.

Frampton argues that architecture should steer clear of both superficial imitation of historical forms and the erosion of identity brought about by globalization. As he states, "[c]ritical regionalism opposes the sentimental replication of local elements and instead seeks to redefine them. It may also draw those elements from external sources" (Frampton, 1983: 327).

In this context, critical regionalism redefines the concept of place by harmonizing cultural and historical elements with modern innovations. It emphasizes a thoughtful reinterpretation of local features, integrating them with contemporary advancements to create architecture that is both contextually rooted and globally relevant. This approach allows for the preservation of identity while embracing the opportunities presented by modernity.

The goal of critical regionalism is to develop architecture that integrates the distinct characteristics of each region with the innovations of modern architecture. This approach goes beyond the superficial use of visual or symbolic elements, focusing instead on the underlying concepts that shape architectural creation. By addressing regional architectural needs while reinterpreting traditional principles in a fresh and innovative way, critical regionalism ensures that each project preserves its local identity while adopting a modern expression. The result is architecture that harmonizes place-specific qualities with contemporary advancements, endowing each location with a unique and modern identity.

This theory provides a practical framework for addressing the "placelessness" often associated with modernity by fostering a dialogue between tradition and modernity. As Zoghi Hosseini (2021) explains, Kenneth Frampton extends the ideas of Zonis and Lefebvre in critical regionalism, emphasizing its urgent role in counteracting the uniformity of placelessness. Frampton (1983) elaborates on this issue in his article "Towards a Critical Regionalism: Six Points for an Architecture of Resistance". It seeks not only to revive historical authenticity but also to use modern tools to enhance it, creating a "space-in-between" as referred in this study, where tradition and modernity interact and find reconciliation.

Critical regionalism emerged in Iran during the 1960s and 1970s, a period marked by rapid modernization and globalization. During this time, the concept of the "space-in-between" gained traction as architects sought to bridge tradition and modernity cohesively and creatively. This movement, rooted in a deep contextual awareness, emphasized cultural continuity and resisted dominant globalized modes of spatial production while fostering international exchange and dialogue.

Pioneering architects like Houshang Seyhoun, Kamran Diba, Nader Ardalan, and Hossein Amanat advanced this approach. Their works—Seyhoun's Mausoleum of Avicenna, Diba's Tehran Museum of

Contemporary Art, and Amanat's Azadi Tower—demonstrate this synthesis by utilizing local materials and techniques, integrating modern forms with the geometry and principles of traditional Iranian architecture and prioritizing social needs and human interactions in spatial design.

Notably, while these architects innovatively fused tradition with modernity, they largely refrained from engaging with postmodern discourse. Ironically, the figures who influenced them, such as Louis Kahn and Mies van der Rohe, were rooted in modernist traditions or, in Kahn's case, represented critical evolutions within modernism.

4. THE QUEST FOR IDENTITY: KAMRAN DIBA AND HIS ARCHITECTURAL (DIS)POSITIONS

Kamran Diba, one of Iran's most prominent modernist architects with a historical perspective, has made a lasting impact through his significant contributions to architecture. Born in Tehran in 1934, Diba graduated in architecture from Harvard University in Washington, D.C., in 1964, and returned to Iran the following year. Between 1962 and 1970, he also served as a faculty member at the University of Tehran.

Figure 1. *The renowned Iranian architect and designer of the Tehran Museum of Contemporary Art*

Diba is best known for his innovative approach, which integrates modernist principles with Iran's cultural and historical context. His notable works include the design and execution of the Tehran Museum of Contemporary Art, Shafagh Park and Cultural Center, Niavaran Park and Cultural Center, the prayer hall adjacent to the Carpet Museum, Shushtar New Town, Jundi Shapur Mosque, and numerous projects in Iran, Europe, and the United States (Banimasoud, 2015: 313). These works highlight his commitment to creating spaces that balance tradition with modernity while addressing social and cultural needs.

Kamran Diba seamlessly bridged the realms of art and architecture, distinguishing himself not only as a painter and architect but also as a visionary who established cultural and artistic institutions to promote the arts and elevate the status of artists in Iran.

During his 12 years of practice in Iran, the intellectual and theoretical foundation of Diba's work reflected a profound commitment to the social dimensions of architecture, which he termed "humanistic architecture." This approach emphasized creating meaningful and socially engaged projects that served society and addressed the needs of the people.

Diba's passion for urban design, urban planning, and landscaping was deeply rooted in this humanistic ethos. Unlike many of his contemporaries, he showed little interest in private buildings, dedicating his efforts to public and cultural projects that had a broader social impact. In these endeavors, he often took on multiple roles, acting as both the conceptualizer and planner, ensuring that his vision extended from the initial idea to its realization. Through this holistic approach, Diba's work stands as a testament to architecture's potential to foster community engagement and cultural enrichment, demonstrating his unwavering dedication to the greater good.

Kamran Diba views architecture as fundamentally intertwined with human interaction, famously defining a building as *"a social event."* In his philosophy, the physical reality of a space is inseparable from the social dynamics it fosters. "I deliberately attempt to build an environment which multiplies and enhances the quality of interaction," he asserts (Diba, 1981: 8). For Diba, the role of the architect extends beyond addressing functional requirements. It includes the responsibility to design spaces that actively encourage and facilitate social engagement. He encapsulates this approach in what he terms the "human interaction intensification program," which focuses on "enhancing the quality and quantity of human interaction by means of physical and spatial organization" (Diba, 1981: 54).

This philosophy underscores Diba's dedication to creating environments that prioritize meaningful connections, aligning his work with broader social and cultural objectives. By designing spaces that go beyond utility, Diba emphasizes the potential of architecture to enrich human relationships and community life. Kamran Diba extends his architectural philosophy by emphasizing the importance of community over mere housing. He critiques modern housing projects for their incompatibility with the lifestyle of Muslim communities, advocating instead for a focus on "community development, rather than on housing" (Diba, 1980a: 40).

Despite his relatively brief career in Iran, Diba is recognized as a pivotal figure in contemporary Iranian architecture, leaving behind a legacy of valuable and memorable works. As a modernist architect deeply committed to regionalism and historicism, Diba's designs reflect his passion for Iranian architecture and culture, often evoking familiar concepts and forms rooted in Iran's architectural traditions.

Diba repeatedly highlighted the cultural responsibility of architecture, stating:
"The architecture of any era is always a response to the culture of its time. The role of architecture is to establish and enrich the culture of its era through innovation and the introduction of challenging ideas. This process allows architects and artists to document and preserve the state of their time for future generations." (Tabatabai Diba, 2006: 13).

While acknowledging the necessity of progress, Diba warned against blindly replicating past styles, instead advocating for learning from historical design principles, environmental awareness, and social practices. His vision extended beyond the creation of individual buildings to the cultivation of socially connected communities. He believed that merely scattering aesthetically pleasing buildings within a chaotic urban environment would not suffice. For Diba, true architectural success lies in fostering collective, socially vibrant spaces that reflect and advance the culture of their time.

One of the hallmarks of Kamran Diba's architectural approach is his authentic and innovative use of Iranian architectural patterns. Rather than relying on decorative motifs, Diba focuses on the underlying principles of spatial organization and typology inherent in traditional Iranian architecture. This is particularly evident in his emphasis on axial alignments, a recurring feature in both his urban planning projects and architectural designs. His work, most notably the Tehran Museum of Contemporary Art, showcases how enriching the spatial experience within a three-dimensional framework can enhance the interior's depth and appeal.

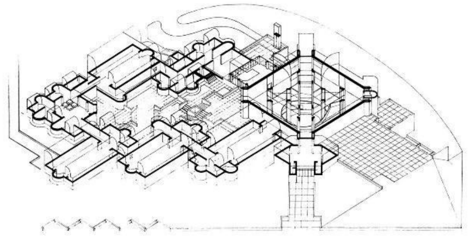

***Figure 2.** Spatial organization of traditional Iranian architecture - TMoCA.*

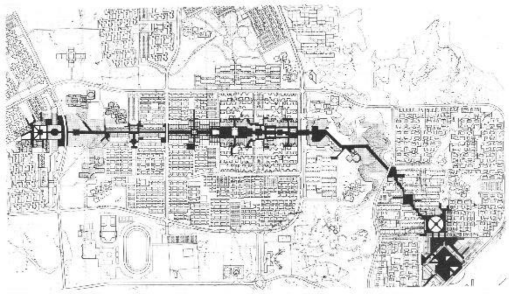

***Figure 3**. Emphasis on axes in Diba's architectural and urban planning designs- Original Master Plan of Shushtar New Town*

Diba occupies a unique position as both a proponent and a critic of modernism. While firmly rooted in its framework, he critiques it from within, offering a nuanced perspective that balances modernist ideals with cultural and historical awareness. His interpretations of history and tradition are distinctly modern, avoiding the semiotic, symbolic reinterpretations characteristic of postmodernism. Instead, Diba's work reflects a deeply contextual and forward-thinking approach, bridging the past and present in ways that are innovative yet respectful of Iran's architectural legacy.

In an interview with Mohammadreza Shirazi, Kamran Diba reflects on his engagement with postmodernism, noting that the movement caught his attention only after his professional career in Iran ended following the 1979 revolution. He emphasizes that his "search for identity" was fundamentally distinct from the superficial tendencies he observed in American postmodernism. This perspective was shaped in the mid-1970s during his tenure at Cornell University's Graduate School of Architecture, where he taught at the invitation of Mathias Ungers.

Diba observes that by the time postmodernism was taking hold, most of his major projects in Iran had already been completed. While he recognized that postmodernism broke the rigid constraints of modernism and offered a degree of liberation, he ultimately rejected it as a valid design approach. For Diba, its commercialization and superficiality undermined its potential, and he remained committed to a deeper, more meaningful exploration of identity and tradition within a modern architectural framework.

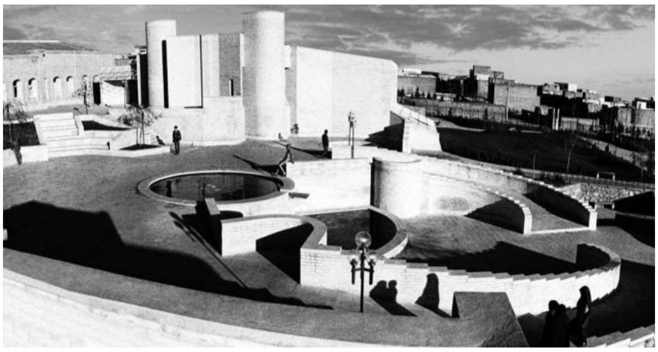

Figure 4. Park-e Shafagh (Garden of Yousef-Abad).

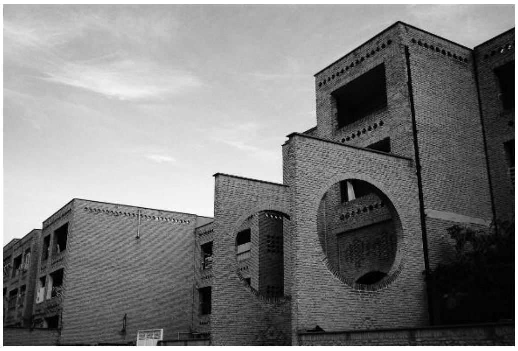

Figure 5. Shushtar New Town.

When asked if he identifies as an Iranian postmodernist, Kamran Diba responds unequivocally: "No, I don't consider myself anything. The truth was, I was in searching setting into context the national identity and, above all, making my personal mark." In response to comparisons with architects like Jørn Utzon, Henning Larsen, and the later Alvar Aalto—known for their sensitivity to the "specificity of place"—Diba candidly remarks: "Why not?" (Shirazi, 2018: 105).

Despite the brevity of his architectural career, Diba's body of work is remarkably diverse. His designs often feature simple yet sharply sculpted forms, characterized by prominent openings and robust columns that make bold architectural statements. This distinctive style draws from the traditions of Iranian architecture while reflecting the influence of English neo-Brutalism.

Diba's designs frequently incorporate traditional Iranian elements such as domes, windcatchers, courtyards, pools, and porticos, reinterpreted in innovative ways. Roofs play a pivotal role in his work, often defining the exterior form, as seen in the TMoCA. These elements are not mere ornamentation but are abstracted into volumetric features that evoke a metaphysical atmosphere, bridging the past and present while reflecting Diba's pursuit of a timeless and culturally resonant architectural language.

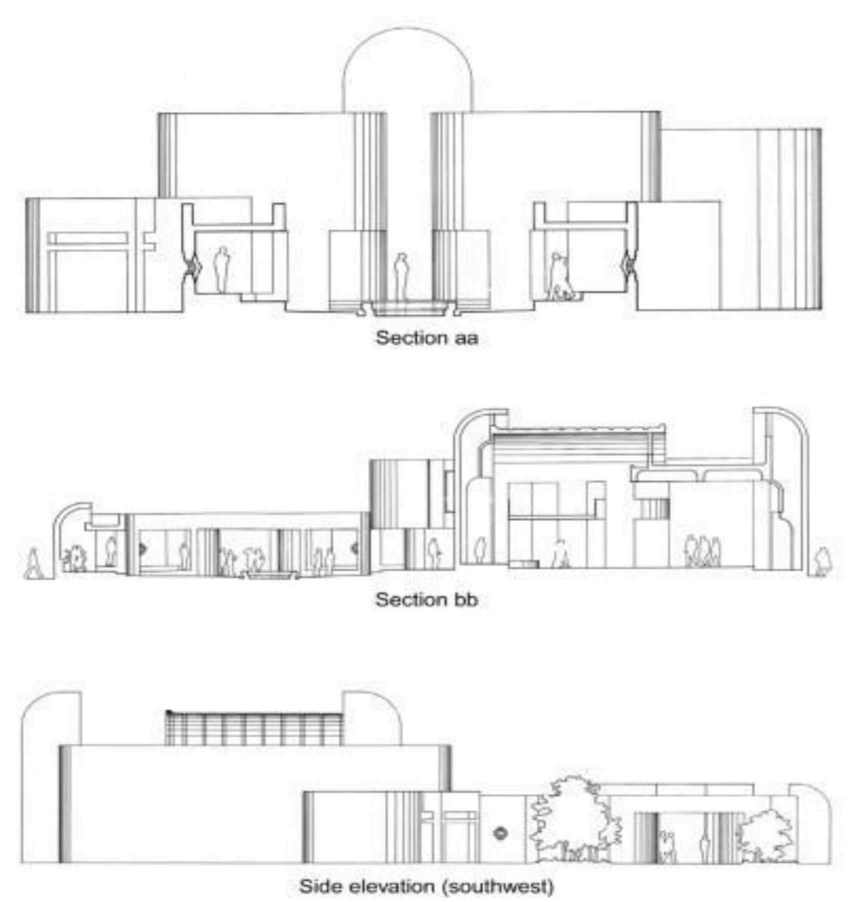

Figure 6. *The Role of Roofs and Traditional Iranian Architectural Elements in Shaping Form-Mosque of Shahid Chamran University.*

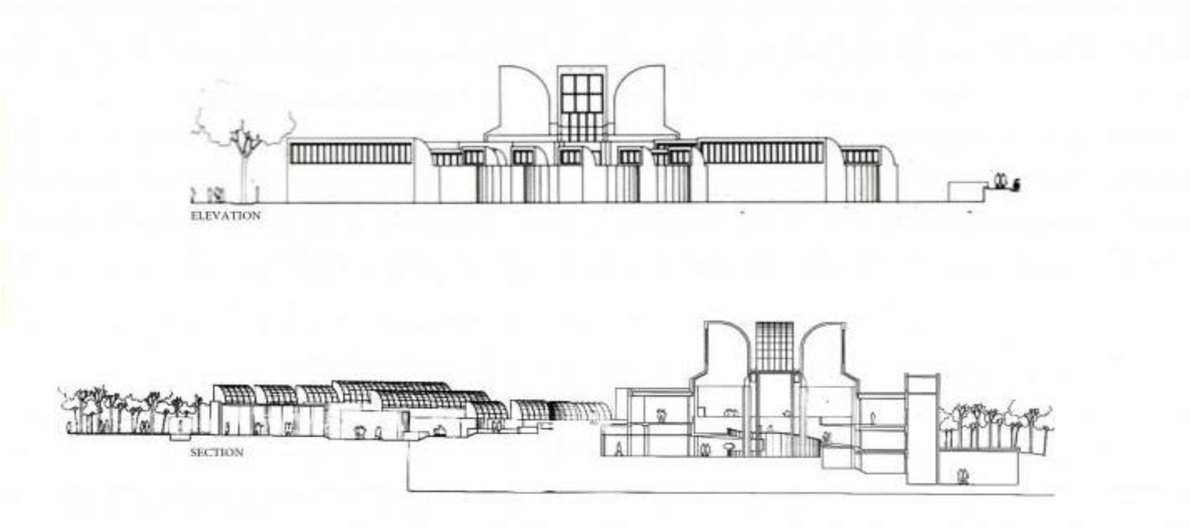

Figure 7. *The Role of Roofs and Traditional Iranian Architectural Elements in Shaping Form-TmoCA.*

In analyzing the architectural elements in Kamran Diba's works, light is not treated as unrestrained brightness but as a refined and deliberate presence. Natural light is controlled and filtered through architectural elements, creating a harmonious interaction with the built environment. A notable example is the skylights of the Tehran Museum of Contemporary Art, where the traditional windcatcher is reimagined as a skylight. These features allow light to enter the interior in a controlled manner, often diffused to interplay with shadows, amplifying the light's presence and imbuing the space with an air of mystery and ambiguity.

The wall is another defining element in Diba's architecture. In Diba's designs, walls transcend their functional role as mere barriers; they simultaneously embrace and exclude, keeping observers at a distance while inviting exploration. What sets Diba's walls apart is their unapologetic simplicity and their emphasis on "wall-ness." Free from ornamentation, they exist in their pure, tectonic form, as Diba himself emphasizes: *"*Walls do not dazzle; they create ambiguity" (Diba, 2010: 133). He praises the architectural potential of the wall, describing it as a meticulous creation:
"A simple wall embodies separation, character, security, and ownership. Ultimately, a wall is what orients us and prepares us to enter the realm of architecture. I'm crazy about building a simple wall!" (Diba, 2001: 22).

Through this approach, Diba elevates the wall from a structural necessity to an architectural statement, a vessel of both functionality and profound spatial meaning.

5. A SPACE-IN-BETWEEN: TEHRAN MUSEUM OF CONTEMPORARY ART (TMoCA)

5.1. Imagining A Contemporary Art Museum In Tehran: Farah Pahlavi And The Foundations Of TMoCA

Farah Diba (born October 24, 1938), the wife of Mohammad Reza Shah Pahlavi, served as the last Empress of Iran from December 20, 1959, to February 11, 1979. During her tenure, she played a pivotal role in advancing cultural and social initiatives, leaving a lasting impact on Iran's artistic and architectural landscape.

Figure 8. *Farah Pahlavi, the last Empress of Iran and wife of Mohammad Reza Shah Pahlavi.*

Before her marriage, Farah Pahlavi studied in Iran and pursued architecture in France, where she became fluent in English and French. It was during her studies abroad that she met Mohammad Reza Shah, marrying him on November 21, 1959. Following her coronation, she assumed the roles of Queen Consort and Vice-Regent of Iran, becoming an influential figure in the country's cultural affairs.

In the latter decades of the Pahlavi dynasty, Empress Farah prioritized the preservation and restoration of Iran's architectural and artistic heritage. Her efforts aimed to counter the effects of rapid urban modernization, which often resulted in the neglect or destruction of traditional and Islamic architecture. While figures like Jalal Al-e-Ahmad and Ali Shariati criticized excessive Westernization, emphasizing the need to safeguard Iran's national identity, Farah sought to create a balance by reviving traditional arts and architecture while embracing modernity.

Since Reza Shah's reign, urban development often came at the expense of historical structures, with a focus on pre-Islamic heritage while neglecting Islamic historical sites. In contrast, Empress Farah championed the restoration and conservation of Islamic and traditional architecture, emphasizing its importance in reflecting Iran's rich history and cultural identity. She believed that architecture should draw from the past while addressing climatic, geographical, and societal needs, asserting that it could serve as a powerful tool for improving quality of life and driving social and cultural reform. In her memoirs, she reflected on her vision: "I had such high hopes for the preservation of my country's heritage and Iran's emergence as a contemporary cultural force." (Stein, 2013, as cited in Tabibi, 2014, p. 113)

One of her most notable contributions was supporting the creation of the TMoCA. The concept of a venue for contemporary Iranian and international art was first proposed by Kamran Diba—an architect, painter, and Farah Pahlavi's cousin—during discussions with the Empress. Diba later recounted:

*"After returning from my studies abroad, I spoke with the Empress several times about this issue because, in my view, no institution in the country was seriously collecting art. [...] The idea took shape in 1966 (1345), but it took years to complete the project." (*Daftari & Diba, 2013: 80)

Farah Pahlavi remarked:
"Why couldn't Iran have a museum for [modern] art?" the shahbanu once indicated and continued, "I thought we should, and include it with Western art. We couldn't afford to go back to art from centuries before, so we focused more on the contemporary." (Ayad, 2011: 47)

Farah Pahlavi’s interest in modern art also shaped her cultural policies. She encouraged government agencies and private collectors to allocate more resources toward acquiring and exhibiting modern works, complementing the nation’s traditional art and emphasizing Iran’s presence in the global art scene.

During the 1970s, a dramatic surge in oil prices, culminating in 1975 (1354), brought unprecedented wealth to Iran’s treasury. Empress Farah Pahlavi sought to capitalize on this financial boom as part of the "Great Civilization" program, aiming to modernize Iran's cultural landscape and elevate its global standing. She first discussed the idea of building a museum for contemporary art with the Shah and then-Prime Minister Amir-Abbas Hoveyda, proposing that the country’s newfound wealth provided a unique opportunity to acquire a diverse collection of modern, traditional, and ancient artworks. This vision led to the decision to construct two museums in Farah Park (now Laleh Park): one for modern art—the Tehran Museum of Contemporary Art—and another for traditional Iranian handwoven artifacts—the Carpet Museum.

To expand the reach of these initiatives, Pahlavi also engaged Alvar Aalto, the famed Finnish architect, to design a branch of the Tehran Museum of Contemporary Art in Shiraz. Explaining this choice, the Empress stated:
“We chose Alvar Aalto as the architect, because he was such a famous international figure. We thought his building would be a work of art. He came to Iran and loved Shiraz where he chose a special site for the museum” Unfortunately, the project faced delays and remained incomplete due to the 1979 revolution. (Stein, 2013, as cited in Tabibi, 2014: 123)

These initiatives reflected her ambition to present Iran as a cultural and artistic powerhouse, blending its rich heritage with contemporary global influences. TMoCA, established in 1976, was the first and only institution created under the Farah Pahlavi Foundation. Its inception marked a turning point in the cultural policies of the Pahlavi era, symbolizing a shift in the management of art and culture from royal patronage to a more nationally oriented framework. The museum aimed to bridge Iran’s cultural heritage with the global contemporary art scene, reflecting the broader ambitions of the Pahlavi dynasty to modernize Iran’s cultural identity.

The TMoCA project was developed over four years under the leadership of Kamran Diba, with significant contributions from Iranian architect Nader Ardalan and foreign experts Anthony J. Major and Priyank Guptan. The museum was officially inaugurated on October 14, 1977, coinciding with Empress Farah Pahlavi’s 39th birthday. The event was attended by prominent figures, including Mohammad Reza Shah, Empress Farah, Nelson Aldrich Rockefeller (then Vice President of the United States), Thomas Messer (Director of the Guggenheim Museum), and Edy de Wilde (Director of the Stedelijk Museum in Amsterdam).

At the ceremony, Nelson Rockefeller praised the museum, describing it as “one of the most beautiful museums in the world” and likening it to an extension and completion of the Guggenheim Museum. (Daneshvar, 2010: 152) This international recognition underscored the museum’s importance as a cultural landmark, positioning it as a symbol of Iran’s aspirations to merge tradition with modernity on a global scale.

Figure 9. *Farah Pahlavi and Andy Warhol standing before Warhol's portraits, taken by Alain Nogues.*

5.2. Re-Imagining the Museum: Kamran Diba and Architecture of TMoCA

Before Tehran became overwhelmed by pollution and congestion, it held the potential to be a city shaped by thoughtful visual and environmental qualities, fostering meaningful interaction with its inhabitants. The architectural identity of Tehran relied on the construction of buildings designed and executed by architects—professionals whose concerns extended beyond mere functionality. Architecture, when detached from the prevailing artistic, cultural, and local contexts, risks becoming hollow. For construction to contribute meaningfully to a society's national and cultural identity, it must address practical needs while resonating with the emotions, beliefs, and spiritual understanding of a city's residents and a nation's people. In the 1960s (1340s SH), a series of iconic buildings emerged in Tehran, shaping the city's cultural character. Among these, the TMoCA stands as a beacon of cultural and artistic significance, attracting attention on an international scale. At its inception, the museum embodied the city's aspirations to engage with global art movements while preserving its local essence. Located on the western edge of Laleh Park along Amirabad Street, the museum also played a pivotal role in defining the identity of its surrounding neighborhood. However, it catered to a specific audience—those with interests beyond the routine of daily life. It appealed to a segment of society eager to explore the cultural and artistic essence of modern Iranian society, which was finding its voice and carving out a platform for expression in a rapidly changing world.

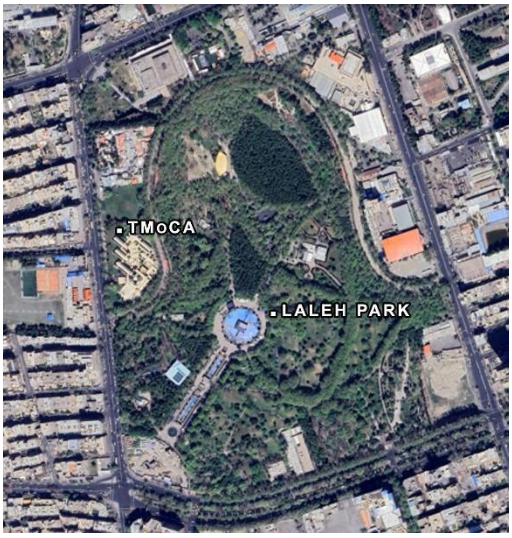

Figure 10. Location of Laleh Park and TmoCA.

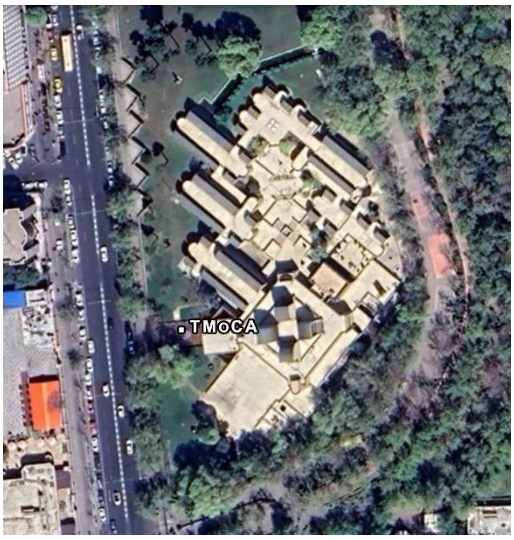

Figure 11. Tehran Museum of Contemporary Art.

The TMoCA, founded in 1977 (1356 SH), stands as one of the most distinguished cultural and artistic institutions in Iran and the Middle East. Dedicated to preserving and expanding its art collections, the museum hosts permanent and temporary exhibitions, intimate galleries, and curated aesthetic installations, catering to both the general public and specialized audiences (Nadalian, Ahmad, 8611).

The TMoCA, housing a rich collection of works by prominent global and Iranian artists, has secured a unique position in the art world. Its collection includes over 3,000 pieces by artists such as Pablo Picasso, Andy Warhol, Jackson Pollock, Francis Bacon, and Salvador Dalí. Additionally, works by renowned Iranian artists like Parviz Tanavoli, Bahman Mohasses, and Massoud Arabshahi are also featured in the museum's collection.

The TMoCA, located on North Kargar Street (Amirabad) near Laleh Park, is one of the key cultural and artistic hubs of Tehran. Positioned between Hejab Street and Keshavarz Boulevard, and adjacent to the Carpet Museum, its strategic location makes it one of the most attractive and accessible cultural destinations in the city. Amirabad Street, serving as a major thoroughfare in Tehran, connects various neighborhoods, while the proximity to the Tehran Carpet Museum and the bazaars around Laleh Park further enhances the appeal and visitor traffic of the Museum of Contemporary Art.

Laleh Park, spanning 35 hectares, is one of Tehran's largest parks, established in 1966 (1345 SH). Previously known as Jalalieh Garden, it was used for equestrian activities and military parades. The park features a variety of plant species, including plane trees, acacias, and pines. In addition to its green spaces and sports facilities such as basketball and volleyball courts, the park houses a puppet theater center, a library, and a mosque. The southeastern section of the park is designed in the style of Japanese gardens, complete with fountains and meandering streams.

Surrounded by dense trees, Laleh Park offers not only a serene and reflective atmosphere but also an artistic charm, enhanced by the presence of the TMoCA. Over the years, the museum's exhibitions, cultural events, and the movement of artists have lent a cultural identity to the area, imbuing the surrounding streets with a sense of significance and respect for art and creativity.

The vicinity of the museum has become a hub for art enthusiasts and students, where art serves as the defining theme. Informal gatherings often transform the space into a vibrant meeting point for sharing ideas, displaying works, and engaging in friendly critiques and discussions. These activities underscore the unique character of the area, which has been shaped by a community dedicated to fostering creativity and cultural exchange. This collective engagement has endowed the surroundings of the museum with a distinctive sense of prestige and identity, making it a focal point for Tehran's artistic community.

The combination of diverse public spaces and seamless pedestrian flow, coupled with the captivating architecture of the TMoCA, attracts a wide array of visitors.

In response to criticisms regarding insufficient interaction between the Tehran Museum of Contemporary Art and Laleh Park, Kamran Diba clarified that the museum was originally conceived with the park's environment and context in mind. He explained that the rooflines of the museum were intentionally sloped downward to establish a harmonious visual connection with the park's greenery, especially from the west and north sides. Diba emphasized that during the museum's construction, a deliberate functional and visual relationship between the building and the park was achieved. However, post-construction environmental changes and poor management disrupted this connection. (Shirazi, 2018: 106). Issues such as converting parts of the park into rest areas, picnic spots, and parking lots, as well as the loss of numerous original trees due to inadequate maintenance, undermined the visual and functional integration initially envisioned. Diba stressed that these problems emerged after the museum's completion and were unrelated to its design.

His explanation underscores that fostering interaction between the museum and Laleh Park was a fundamental goal of the project. The museum's architecture was thoughtfully planned to complement its surroundings, but subsequent alterations and neglect weakened the intended connection between the two spaces. This highlights the importance of consistent environmental stewardship to preserve the synergy between cultural institutions and their natural settings.

Art and architecture have always been pivotal in shaping identity and driving societal transformations, serving as powerful tools for conveying cultural messages and influencing communities. In the contemporary era, museum architecture has become a vital platform for connecting art and society, profoundly shaping cultural narratives and enriching human experience. Within this framework, the Tehran Museum of Contemporary Art, designed by the renowned architect Kamran Diba, stands as a remarkable example of the intricate relationship between art and contemporary architecture.

The museum is a quintessential representation of critical regionalism, making it one of the most distinguished examples of this architectural approach in Iran and the Middle East. Its design exemplifies the potential and relevance of critical regionalism, showcasing its ability to bridge cultural heritage with modernist innovation while affirming its feasibility and necessity.

This building offers an indirect yet profound interpretation of the past, weaving traditional elements into a modern composition. While the overall design is distinctly contemporary, it is deeply rooted in the geometry of Iranian architectural traditions. The light catchers reinterpret the traditional *badgirs* (windcatchers) of central Iran, while the use of exposed concrete and roof patterns evokes the monolithic textures of adobe bricks and roofing found in historic Iranian cities. At its core lies a central courtyard—a reimagined version of the archetypal Iranian courtyard—serving as the heart of the complex and organizing all surrounding spaces into an introverted microcosm, distinct from its external environment.

The building also highlights the craftsmanship of its construction. Exposed façades reveal the construction techniques, while the layered elevations showcase a hierarchy of materials, transitioning from stonework to concrete and glass. The structure engages the body and senses profoundly, encouraging visitors to experience its design through movement—walking through galleries, navigating ramps, and perceiving the subtle interplay of sound, texture, and light.

The spatial experience of this modern building, functioning as a gallery for contemporary art, propels visitors forward into a modern context while grounding them in a dialogue with tradition. It bridges the old and the new, demonstrating the enduring relevance of traditional architectural principles in a contemporary framework.

Having evident references to the works of renowned architects Louis Kahn, Le Corbusier, and Frank Lloyd Wright, with particular emphasis on Josep Lluís Sert,, these modernist influences are harmoniously blended with the traditional rooftop designs characteristic of Iran's desert cities, creating a unique architectural language. Diba describes its modern design as unparalleled in Arab and Muslim countries. The museum's layout and functional elements were also inspired by the Museum of Modern Art (MoMA) in New York, which informed its structure and organization. (Khani-Zadeh, 2013: 104)

The TMoCA has two entrances: the main entrance from Kargar Street and a secondary entrance from Laleh Park, which is designated for service purposes. The museum's layout includes a central hall, exhibition spaces, a meeting hall, a library, a bookshop, a dining area, as well as administrative and service sections. The museum is divided into two main areas: the enclosed spaces and the central courtyard. The enclosed area is designed in a circular layout with seven main spaces. The galleries are designed to ensure that visitors can engage with the artworks in the most effective way possible.

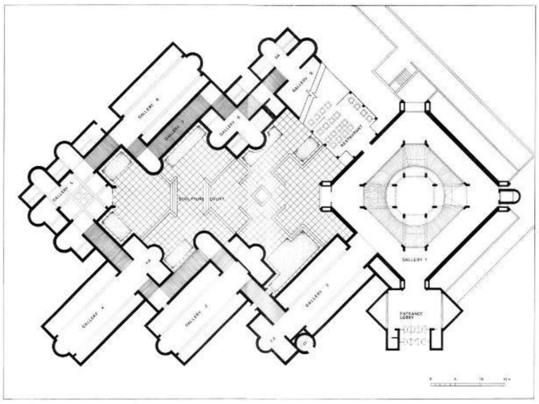

Figure 12. *Tehran Museum of Contemporary Art plan.*

The main hall of the museum, which serves as the starting and ending point for visitors, is octagonal and features a tall vaulted ceiling with large skylights. This hall is connected to various spaces within the museum, including the entrance, galleries, lower floor, library, restaurant, and other areas. At the center of the museum, at the lowest point, there is a space designed similar to traditional Iranian vestibules (hashtis), with a pool in the center, styled after Iranian courtyard ponds .

The central courtyard of the museum has an irregular shape and is connected to Galleries 1 and 5 through glass doors. At the end of the visitor route in the museum, there is a large, shining oil pool, which serves as the symbol of the TMoCA. This pool, a legacy of Japanese artist Noriyuki Haraguchi, is filled with 5,000 liters of used oil and has been permanently displayed in the museum since its opening in 1977 (1356 SH).

Over the years, it has become a symbolic element of the museum and a shared memory for all who visit. The design of the museum reflects a deep engagement with Iranian cultural traditions, offering a platform for continuous reinterpretation of the past through modern forms and methods. This approach fosters what can be described as a "dialectic of presence,"(Shirazi, 2018: 87) where elements of the old and new, the specific and the universal, and place and space coexist in a balanced and dynamic relationship.

Gallery One exemplifies this dialectic. Its design draws inspiration from the traditional Iranian *chaharsoo* (a four-sided bazaar intersection), creating a sense of movement and interaction akin to the flow of people in these historic spaces. By seamlessly blending cultural memory with contemporary design, the Tehran Museum of Contemporary Art serves as a space where tradition and innovation are harmoniously intertwined, inviting visitors to experience a dialogue between the past and the present.

In this dialectic, a continuous interaction unfolds between two opposing poles—tradition and modernity—neither of which fully dominates the other. Instead of fostering tension or passivity, the design creates a space for dialogue and active participation, inviting users to reflect and engage. This reconciliation generates a space-in-between" (Shirazi: 2018) that simultaneously preserves the memory of tradition while emphasizing the presence of contemporary elements in a fresh and innovative manner.

Diba describes this simultaneous presence as a dialectical process. He explains that his architecture consistently aims to merge tradition and modernism through a dynamic interaction (Diba, 2010: 68). According to Diba, tradition on its own risks stifling creativity, while unchecked progressivism threatens to sever ties with cultural roots. In Iran, he argues, the key is to harmonize these two modes of existence. The resulting fusion generates a dynamic tension between old and new, perceptible to visitors as they experience the memory of the past reimagined in a contemporary environment.

According to Diba, the interior spaces of the museum enhance the connection between humans and their activities. (Moieni, Roazbeh, Biglari & Peyhani, 2016: 4) The open spaces and corridors, which gently curve through the museum and lead to the galleries, have effectively created such an environment.

These concepts are also reflected in the museum's exterior and facade. The permanent collection of the TMoCA includes beautiful and unique sculptures in the Sculpture Garden, which attract the attention of visitors and art enthusiasts, sparking their curiosity. The Sculpture Garden features valuable and beautiful sculptures by contemporary artists such as Henry Moore, Alberto Giacometti, and Parviz Tanavoli, transforming the surrounding green space into a sculpture park.

Figure 14. *Tehran Museum of Contemporary Art(TMoCA)-1970.*

The form of the TMoCA is a blend of traditional and modern architecture, with a unique identity that creates a captivating and beautiful urban image in the viewer's mind. The museum building is designed at a 45-degree angle to the main street, and the skylights are oriented toward the northeast to reduce direct sunlight exposure. The design of the structure is inspired by traditional buildings from Iran’s hot and dry regions, with the skylights resembling Iranian wind catchers, and the building slightly recessed into the ground, showcasing a representation of Iran's desert architecture (Khani-Zadeh & Ehsani-Moayed, 2014: 96).

The materials used in the building's facade include rough-cut orange stones and light-colored concrete, which, in combination with the skylights, give the museum a traditional and solid appearance. These materials evoke the adobe architecture of Iran's desert regions. The choice of coarse stones and the use of circular forms in the facade are inspired by the works of prominent 20th-century architects such as Le Corbusier and Frank Lloyd Wright (Khani-Zadeh & Ehsani-Moayed, 2014: 98). Diba has aimed to create a balance between traditions and innovations that is both connected to Iranian identity and modernity.

Figure 15. Materials used in the TMoCA's façade.

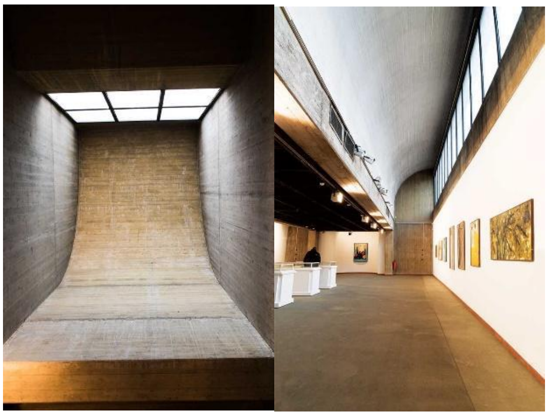

Figure 16. Skylights are oriented toward the northeast to reduce direct sunlight exposure-TmoCA.

The museum's short stairs are designed in accordance with the principles of Iranian architecture, with movement between them gradually guiding the viewer's gaze toward the ceiling and architectural details, creating harmony and proportions in the exterior space that convey a sense of grandeur and magnificence. Even the museum's exterior, with its sculpture garden and statues, promotes cultural and artistic values while attracting the attention of passersby.

The TMoCA has become a cultural and artistic space that introduces the audience to the history of Iranian architecture and contemporary global architecture, while also showcasing a sense of belonging to a space with Iranian identity (Khani-Zadeh & Ehsani-Moayed, 2014: 103).

The TMoCA, while recognized as one of the symbols of modern architecture in Iran, has faced criticism regarding the authenticity and creativity of its design. Some parts of the building, particularly the curved towers, resemble global modern architectural works more than they reflect traditional Iranian wind catchers.

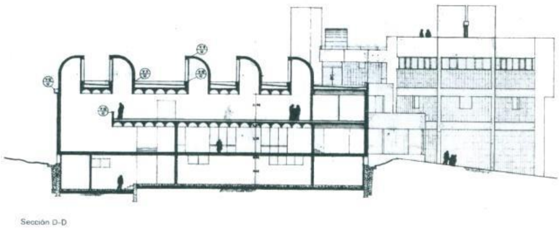

Figure 17. *Curved towers in TMoCA's section.*

These towers were primarily designed to provide natural light and, rather than functioning like wind catchers, they serve only as a poetic interpretation of them. Additionally, similarities can be observed between the design of this museum and famous works such as the Joan Miró Foundation in Barcelona and the Fondation Maeght in Nice, France, further highlighting the influence of global architectural trends.

While some traditional elements are visible in the museum's design, these efforts resemble more of a superficial symbolism rather than an innovative reinterpretation of traditional Iranian architecture. As a result, instead of creating a native architectural language, the building has become a version of global modern architecture with local influences.(Borbor,personal interview,April 22,2018)

Another criticism of the architecture during the Pahlavi era is the excessive focus on elites and the neglect of public needs. In the case of the TMoCA, the emphasis on elites seems logical, as the museum specifically focuses on showcasing modern art, and its design is intended to attract artists and a particular audience. However, this focus on a specific group of society may lead the general public to feel that the space is not for them, preventing them from fully benefiting from its cultural opportunities.

From a functional perspective, the TMoCA faces challenges that impact its exhibition and artistic interactions. One such challenge is the lack of flexibility in its interior space. The design of the space is not suitable for displaying modern and contemporary artworks with unconventional dimensions or large installations. Fixed walls and predetermined pathways create limitations in adjusting the space. The absence of modular or adaptable spaces, which are essential for experimental or multimedia exhibitions, is considered a functional weakness of the museum. Furthermore, the museum's architecture lacks sufficient space for social interaction. Today, creating spaces for social interaction, such as cafes and multipurpose halls, is essential in contemporary museums. In the TMoCA, these spaces are notably absent, which could reduce opportunities for idea exchange and interaction among visitors.

Regarding the choice of materials, the TMoCA is generally compatible with the climatic conditions of Iran, and its design aligns with the characteristics of modern art. However, the building's design could have embraced a more modern atmosphere by incorporating a greater use of newer materials or techniques. Such an approach could have been more in harmony with the nature of contemporary art and the museum's goal of showcasing this art, providing a more innovative appearance to the building.

Ultimately, despite all these criticisms, the TMoCA has managed to create a distinctive and influential space in the world of art as an important cultural and artistic center. With its unique approach, the museum has been able to meet modern requirements while maintaining loyalty to Iran's indigenous identity. However, in terms of functionality, there are still potential areas for improvement in certain aspects.

6. EPILOGUE

Contemporary Iranian architecture often navigates the delicate balance between tradition and modernity. While preserving cultural and historical identity remains a priority, meeting the evolving demands of modern society presents an ongoing challenge for architects and urban planners. In addressing this duality, concepts like "space-in-between" and the theory of critical regionalism offer valuable frameworks for creating architecture that harmonizes these contrasting needs.

TMoCA, envisioned by Farah Pahlavi and designed by Kamran Diba, exemplifies this approach. By establishing a symbolic connection between the past and present, the museum functions as a "space-in-between", inviting visitors and passersby to engage with the rich dimensions of Iranian culture alongside contemporary art.

The museum's strategic location and innovative design have established it as more than just a venue for contemporary art—it is a space that encourages social and cultural interaction. Serving as a "space-in-between," it exemplifies how architecture can be a powerful medium for redefining cultural identity in an increasingly globalized world. Through the principles of critical regionalism, Diba created a space where tradition and modernity engage in a meaningful dialogue, offering visitors a profound and multifaceted experience that blends nostalgia with renewal.

In recent decades, Iranian architecture and urban planning have faced challenges such as placelessness and a growing detachment from local identity. These issues highlight the critical need to revisit the concept of "place." Critical regionalism, with its focus on creatively reinterpreting local elements within a modern framework, still provides an effective response. Enhancing local and historical features while incorporating modern technologies intelligently offers a balanced approach to contemporary Iranian architecture. By avoiding the extremes of imitating traditional forms or unconditionally adopting modernism, this strategy creates spaces that address the needs of contemporary society while maintaining a strong connection to cultural and historical roots.

Despite challenges such as globalization and rapid social transformation, contemporary Iranian architectural heritage retains significant potential for creating "space-in-between." These spaces bridge the past and future, tradition and modernity, and the local and global, offering a renewed vision for Iranian design in the modern era.

TMoCA redefines cultural identity within a global framework. Recent restoration efforts have focused on preserving the building's architecture and safeguarding its invaluable collections, reflecting a commitment to Iran's cultural heritage. However, constraints such as limited budgets, management issues, and socio-political influences have occasionally disrupted the museum's programs.

The museum continues to reinforce its role as a bridge between Iranian and global art. The 2024 exhibition *Eye to Eye*, centered on portraiture in modern and contemporary art, is one prime example. Featuring over 120 works by renowned artists such as Francis Bacon, Toulouse-Lautrec, Picasso, and Andy Warhol alongside Iranian masters like Kamal-ol-Molk and Bahman Mohassess, the exhibition has drawn unprecedented interest, resulting in long queues and extended viewing dates.

With its rich history and unparalleled collection, the Tehran Museum of Contemporary Art holds immense potential to become a leading art hub in the Middle East. Through strategic planning, modern technologies, and global collaborations, the museum can further bridge traditional and contemporary Iranian art with the art of the wider world. By blending memory with inspiration, the museum creates a timeless dialogue that continues to inspire and connect diverse audiences, serving as a cultural and architectural landmark in Iran and beyond.

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Trends in City Resilience Research: Bibliometric Analysis with Rstudio and Biblioshiny

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Abstract

Given the increased frequency and severity of natural catastrophes in recent years, it is evident that city design, planning, and central and local government policies are crucial to urban resilience. Resilience has evolved as a fundamental foundation for effectively managing the functioning of vital systems in the face of unexpected shocks, stress, and disaster events. However, it is clear that there is room for improvement in the selection and standardization of resilience assessment frameworks identified in the research, and resilience should begin at the community level. As a result, in order to define the notion of resilience, an extensive literature research was done, and the data gathered were analyzed using the bibliometric analysis method. Within the purpose of this study, the Web of Science (WoS) database was used, and studies from 1975 to 2024 were examined. "Resilience" and "urban" were selected as keywords. The database search on November 1, 2024 yielded 419 documents. The first document study on architecture was undertaken in 2004. The data was processed with the "biblioshiny for bibliometrix" application. As a result, it was emphasized that in order to become a sustainable city, cities must have resilient critical infrastructures, the importance of building stock, resilience must begin at the community level, and local governments, as the closest unit to the community, must play an important role.

1. INTRODUCTION

Cities' critical systems are complex networks that collaborate with various transdisciplinary components to ensure their long-term viability [1]. These systems are designed to address the demands of society by providing essential services such as shelter, energy, water, heating, cooling, transportation, and communication while also protecting society's integrity and functionality [2]. Furthermore, these systems struggle to retain their biological structure in the face of a variety of dangers, including natural disasters, accidents, cyber assaults, terrorism, vandalism, criminal activity, and neglect. As a result, ensuring key system resilience through reliable assessments and presented frameworks is critical to societal survival and sustainability.

The notion of resilience in the built environment first appeared in the late 1990s and gained popularity following numerous disasters [3,4,5]. Resilience seeks to build more resilient, secure, and flexible systems [6,7,8,9]. The resilience strategy takes a hybrid approach to the physical and technological parts of the city's key systems, as well as the socio-ecological-technical aspects. It examines the social, environmental, and economic implications [10,11,12,13]. This concept shows that urban resilience is made up of complex, interrelated systems. Social activities such as societal harmony and social networks are critical in intervention and recovery, particularly following a tragedy [13,14,15]. Services and interventions for green infrastructure and ecosystem protection are important for urban resilience as they support the fight against climate change, water management and biodiversity. In addition, technological developments increase the robustness of the critical systems that make up the city, making monitoring, intervention and recovery processes more efficient [16,17,18]. By establishing the existing conditions for the preservation and continuity of resources, economic resilience promotes societal sustainability [13,19].

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A more thorough and successful resilience strategy is made possible by acknowledging and incorporating these intricate, interdependent, and highly interrelated networks, which guarantees that every facet of urban systems is taken into account and reinforced [13,20,14,15,19,21]. For instance, strong social networks can boost the efficacy of technical solutions, while technological advancements and innovations can enhance ecological monitoring and management. In addition to enhancing quick reactions to unexpected shocks and pressures, this all-encompassing and inclusive strategy supports the long-term sustainability and adaptation of urban ecosystems.

The ability of a city and its systems to prevent and recover from a negative consequence by reducing the time needed to eradicate a specific shock or threat is known as resilience [22,23,24,25,26]. Effectively and efficiently planning and adjusting the structural integrity and functions of all the fundamental systems that comprise a society can increase its resistance to unforeseen shocks and stressful situations. Critical systems should therefore be assessed before to, during, and following an unexpected outage [27,28,29]. By evaluating the system's resilience prior to disruption and putting the right preventive measures in place to manage the process, it becomes more resilient and even offers financial advantages by enhancing its functionality. Public health and the built environment are greatly impacted when one of the vital systems that comprise the city fails [5,30,31]. The issue of climate change has spread throughout the world. One of the most important systems in the city, agriculture, is directly impacted by rising temperatures, erratic precipitation, and catastrophic weather events. Consequently, this condition has a detrimental impact on food security, income from food, city livelihoods, and population distribution. Given the global impacts of climate change and its implications for the sustainability of natural resources, as well as the fact that by 2050, 70% of the world's population is predicted to reside in urban areas, developing nations in particular must create effective adaptation and mitigation plans to eradicate the negative effects and boost the resilience of the vital systems that comprise cities. The economic, environmental, and social aspects that make up sustainability should all be compatible with a resilient system, which incorporates sustainability principles [29,32]. It directly aligns with the United Nations-established Sustainable Development Goals 9 and 11, which went into effect in 2016.

Innovation, safe environments, inclusive and sustainable urbanization movements, resilient infrastructure, and resilient and sustainable cities are its main objectives [27,29]. By anticipating the vulnerabilities of cities and the dangers they are likely to face, the UN acknowledges the significance of lowering and eradicating the risk of failure of the vital systems that make up the city. It guarantees the creation of risk-reduction strategies to control and lessen the impact of any adverse consequences brought on by unexpected shocks and pressures [27,32]. Ensuring the long-term sustainability and resilience of the city's vital systems is crucial with this strategy. Numerous techniques, definitions, and measuring strategies have been established and defined in the literature on the evaluation of the resilience of key systems in urban areas. Examining the methodologies reveals that they comprise both qualitative and quantitative methods, as well as empirical methods based on data and assumptions [6,17,33,34,35]. Nevertheless, it is noted that these approaches have drawbacks, including assessing resilience using data and information already in existence, the subjectivity of the responses, and their exclusive focus on particular critical systems or likely occurrences, which restricts the methods' ability to be applied generally [9,34,35,36]. Multiple viewpoints should be considered, a thorough and in-depth assessment should be conducted, and complex dynamics that are interdependent and interconnected should be addressed when assessing the resilience of the city's vital systems [22,10,37]. Because a significant system failure might have a cascading effect on other systems.

This research study investigates the notion of urban resilience using bibliometric and scientific mapping studies. The relationships among scientific publications, research institutes, journals, countries, researchers, and keywords are examined. Furthermore, it seeks to uncover new patterns in resilience research, identify major contributors in terms of keywords, nations, authors, and journals, and provide ideas for future studies through co-authorship, co-creation, bibliographic linkage, and co-citation analysis. To attain these objectives, the essay covers crucial research concerns about performance analysis and the scientific mapping of resilience literature or research articles. It seeks to identify the most productive or influential authors, institutions, countries, and journals in resilience research, as well as to assess the current state of their work, using citation analysis, co-keyword formation, co-country authorship, institutional bibliographic linkage, and co-source citation patterns. In order to model and thoroughly assess the resilience of many important systems, a common resilience framework is necessary. In order to generate theories on resilience trends, future research must conduct a thorough analysis of the literature on the standards and criteria for evaluating urban critical systems. In order to direct future resilience research and policy activities, this research article attempts to identify important study topics, trends in recent publications, and gaps in the field.

2. RESILIENCE

According to historical analysis, the idea of resilience initially arose as ecological research intended to bolster ecological system shocks [17,18]. A more thorough analysis of risks and uncertainties is now possible thanks to recent developments in resilience studies that have extended to a variety of disciplines, including engineering, sociology, and economics [9,17,18,35,38]. One of these has been the ability of metropolitan areas, where the majority of human-nature interactions take place, to withstand the severe consequences of disasters [14,39,40]. Based on ecological resilience, which Holling first proposed in 1973, urban resilience is the ability of a system to withstand shocks, adapt, and carry on with its operations in the face of change [41]. Holling and Gunderson created the Panarchy Model, which outlines interdependent and interconnected hierarchical systems, to aid in the comprehension and resolution of challenging issues. By assessing these disturbances for a possible transformation, this model not only preserves critical functions in the case of a systemic disruption, but it also refocuses attention on resilient cities [14,15,40].

Holling's 1996 study highlighted that engineering resilience derived from ecological resilience is what determines the capacity and aptitude of urban infrastructure to withstand natural disasters [9,18]. In order to limit the ability, reaction, and loss of the desired function during system disruptions and to prevent dysfunction, engineering systems' resilience is closely related to the effectiveness of transformation and the robustness of urban infrastructure systems [14,15,40,42]. This idea has made it possible for planners, designers, implementers, and both municipal and federal legislators to concentrate on enhancing cities' resilience and the mechanisms that shield them from natural disasters. In order to better prepare for unforeseen shocks, stress, and disasters, urban resilience has emerged as a key concept in urban planning, design, and development [40,42,43,44]. The ability of an urban system, including its socio-ecological and socio-technical networks, to sustain or quickly sustain desired operations in the face of disruptions in various locations and at various times, to adjust to changes, and to quickly alter systems that impede the current or future system's adaptability is known as urban resilience [15,44,45,46]. This definition offers a foundation for enhancing urban systems' capacity to adapt, grow, and withstand changes and uncertainty. By increasing the transparency of the connections between the city's vital systems, it is portrayed as a significant factor influencing urban resilience [13,20,19,39,43,44].

Research has been done to better comprehend, spread, and increase public understanding of the idea of urban resilience on a global basis. In order to build sustainable communities, strategies are being put into place for urbanization, disaster management, climate change and global warming, sustainable development, and the economy. The OECD carried out one of these studies. To overcome, recover from, and get ready for possible or unanticipated disasters in cities, a resilience framework has been developed. The OECD's resilience framework is displayed in Figure 1 [47].

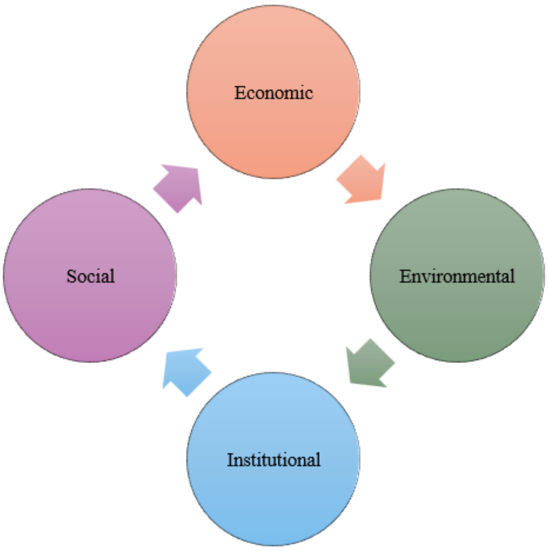

Figure 1. *Resilience Framework [47].*

According to the OECD's resilience framework, cities' critical systems need to be ready in four areas (social, environmental, institutional, and economic) and be able to react, adjust, and change in the event of an unexpected disruption.

Only then can their resilience capabilities become apparent. Urban resilience has been a popular notion in recent years, but when the evaluation methods are examined, they are applied narrowly and only address certain facets of the city's systems [39,40,43,44]. Given the ongoing and extensive effects of natural disasters and increasing urban growth, there is a need for a comprehensive resilience assessment that takes into account the interconnectedness of the city's systems, vulnerability levels, and capabilities [14,15,39,40,45]. Comprehensive approaches are required to establish acceptable time periods for studying disaster life cycles and developing effective intervention methods that take into account the relationship between humans and nature. The concept of resilience, as described in several disciplines, necessitates extensive planned evaluation approaches to increase understanding of urban ecosystems and dynamics. Figure 2 depicts the fields that use the concept of resilience.

Figure 2. *Disciplines Where the Concept of Resilience is Used.*

Given the negative repercussions of disasters, resilience is an important aspect of urban system design, planning, and decision-making by central and local governments. Examining urban resilience allows for a full assessment of disaster-related hazards as well as the city's vital systems' ability to withstand these difficulties [13,20,15,19,40,43,45]. Five important features explain the city's and its constituent systems' ability to prepare, absorb, improve, adapt, and transform at various phases of resilience [13,15,19,40,44]. Monitoring these features during the process provides insight into a system's resilience level and allows for the development of measures to increase its resilience structure. The preparation stage involves the ability to plan and prepare for potential or unforeseen disasters, which is required for decision-making based on the city's typical structure and vulnerable places prior to disasters [14,15,43,44]. The absorption stage refers to the ability to resist a disruption in the system, handle its consequences, and, if possible, preserve the operation of the process without deterioration. It highlights the potential of urban systems, including resilience, diversity, and redundancy [48,49,50]. The recovery stage tries to quickly recover from a system disturbance while also reorganizing and restoring functionality through rapid response mechanisms and self-directed efforts. Recovery entails not just fixing the city's physical infrastructure, but also maintaining social functionality [25,51,52,53]. The adaptation step involves reviewing the opportunities discovered during the process and providing long-term applications in response to changing situations in order to sustain the desired functionality. The transformation stage is the ability to create a fundamentally new system through significant changes in infrastructure, functions, and relationships when the existing economic, ecological, and social systems become untenable as a result of a disruption during the process [20,14,15,54,19,39,43,44]. Urban resilience and its assessment methodologies provide key studies in economics, ecology, and sociology. Understanding the links between these sectors is critical for developing strategies to improve urban system resilience [15,39,43]. Sharifi and Yamagata (2016) identified five fundamental parameters for assessing urban resilience [43]. Figure 3 shows these qualities.

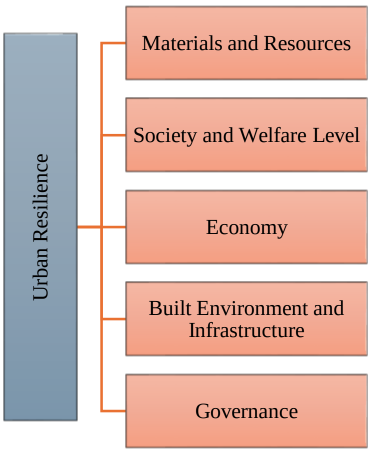

Figure 3. *Urban Resilience Characteristics (Adapted from Sharifi and Yamagata [56]).*

When evaluating Figure 3, materials and resources determine the availability and accessibility of clean and inexpensive resources required to survive natural disasters. Social capital, a sense of belonging, a secure society and spaces, equality, and an accessible distribution of learning processes all fall under the umbrella of society and wellbeing. A resilient economy is defined as the equitable distribution of resources required to recover from and eliminate system disturbances and the resulting situation. The built environment and infrastructure aspect reflects the fragility and efficiency of the infrastructure, ensuring the supply of necessary services in the city. Leadership, resource management, emergency planning, collaboration, and education are all aspects of governance that are required for urban system operations [39,43,44].

With the density of people and activity in metropolitan areas, city sustainability faces a number of challenges. These issues have brought the notion of social resilience in the built environment to the forefront in recent years among both scientists and central and municipal governments [43,55,56,57,58]. While acknowledging that risks to the social structure cannot be avoided, the growing interest in the notion of community resilience highlights the importance of measures for mitigating social structure disruption. Furthermore, resilience entails learning from negative results and employing adaptive and transformational measures to promote the system's slow, long-term evolution [43,44,46].

Research has been performed to establish several ways for assessing and developing the idea of community resilience. Community resilience assessment has been acknowledged as a critical component of resilience, particularly in recent years [13,15,19,59,40,46]. The growing emphasis on community resilience derives from a desire to better understand the negative effects of climate change in cities, determine the necessary budget for developing urban resilience, and track progress toward international risk reduction targets [48,56,57,60,61]. Assessing community resilience is critical for lowering catastrophe risk and preparing for both natural and man-made disasters. Community resilience is critical for understanding and improving urban resilience. As urban regions confront rising challenges from catastrophes and other risks, establishing and implementing community resilience assessments is critical for building sustainable communities [40,43,46,62,63].

3. RESEARCH AND METHOD

This research article uses bibliometric analysis. Bibliometric analysis was defined by Pritchard [64] as "the quantitative and qualitative analysis of published academic literature to monitor the development of a particular research area over a long period". A different definition is the analyses conducted to reveal the profile sequence and development of research conducted in a particular field [65]. The bibliometric analysis process consists of many processes that start with selecting any database, then obtaining the data as a result of scanning the selected database and transferring the data to the bibliometric software. According to the bibliometric analysis method used in the article, the Web of Science (WoS) database was selected to collect data in the determined study area. This database is prominent among scientific citation search and analytical information platforms [66]. The reason for choosing this database to obtain the data in the article is; the most effective and essential data in different fields of study are included in this database, and it contains comprehensive data that makes it easy to follow the development process of the data [67,68]. The data obtained from the Web of Science (WoS) database were evaluated using the "biblioshiny for bibliometrix" application running in the RStudio Version (4.4.1) program. This application is software developed by Massimo Aria and Corrado Cuccurullo (University of Naples Federico) [69]. This software analyses annual scientific production, the most productive authors, the most frequently used keywords, the most popular journal, and the co-authorship related to the selected research topic. This analysis helps to update the current status and the progress of the trending research topic. There are also different software for performing bibliometric analysis. The "biblioshiny for bibliometrix" software tool was selected for the article. Because data analysis is easier and faster, visualization and data can be read more clearly, and analysis can be done under many headings.

In order to reach resilience studies, which is an interdisciplinary concept in the Web of Science (WoS) database, a search was conducted on 01.11.2024 by writing "All Fields" in the search section and "resilience" in the keyword section, covering the years 1975-2024. As a result, 20.848 studies were obtained. In order to reach studies on resilience in the field of architecture, the search was narrowed down by adding "Architecture" to the category section. As a result of this narrowed-down search, 419 studies on resilience were reached in the architecture category. The data reached are in varying categories: article, report, book chapter, book, note to the editor, early view, essay, book review, art exhibition review, news, reprint and withdrawn publication. In this context, the analyses in this article are based on 419 documents obtained in the architecture category between 1975 and 2024, according to the scan conducted on 01.11.2024. The obtained data was transferred to Web of Science (WOS), and the "biblioshiny for bibliometrix" program for the analysis process began. While evaluating the data obtained as a result of the scan, the selected titles aimed to present the current status of the trends in resilience in the field of architecture; at the same time, they were selected in order to understand the development and direction of the process on the relevant subject and to create future scenarios. In this context, in order for the article to achieve its purpose, the following questions were answered within a general framework:

1. What are the results of the bibliometric analysis of publications on resilience in the field of architecture?
2. How many publications on resilience have been accessed? (Web of Science)

3. How have resilience research, citations, articles, keywords, countries producing articles, and country collaborations changed over the years in the field of architecture?

The flow diagram for the method used in the article is shown in Figure 4.

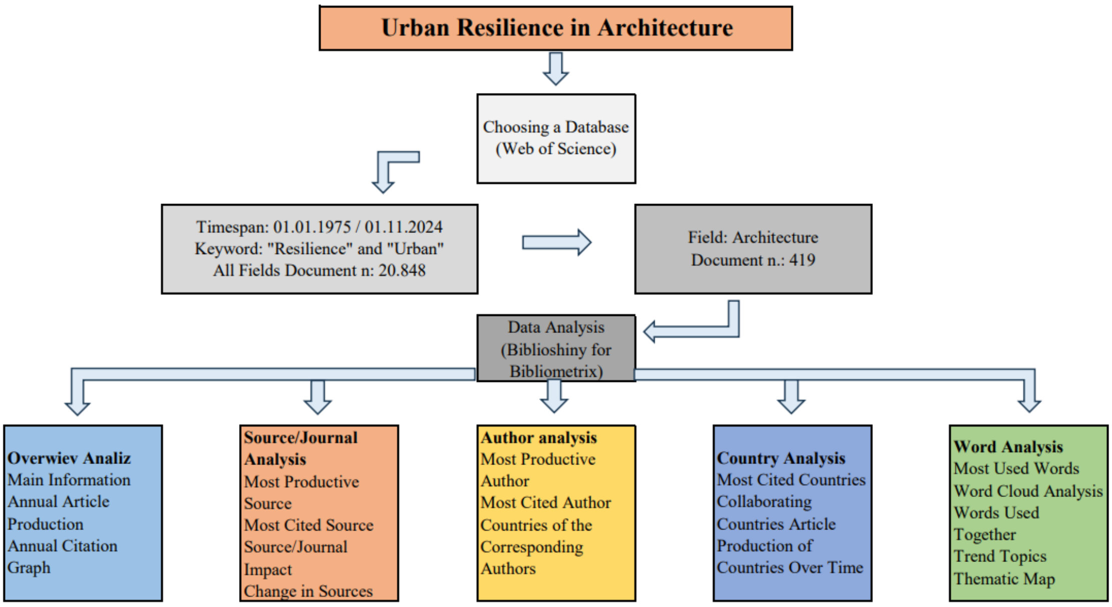

Figure 4. *Flow Diagram of The Method Used in the Article.*

4. FINDINGS

The data published on resilience in the field of architecture scanned and obtained from the Web of Science (WOS), are listed in Table 1. According to this table, it was determined that the first document on resilience in the field of architecture was conducted in 2004. In this context, it is seen that there are a total of 419 documents between 2004-2024. It was determined that 266 of these studies were articles, 20 were book chapters, 8 were early/previewed articles, 2 were proceedings papers, and 1 was withdrawn.

Table 1. *Data on Documents Between 2004-2024.*

Explanation	**Results**
Maın Informatıon About Data	
Timespan	2004:2024
Sources (Journals, Books, Etc)	118
Documents	419
Annual Growth Rate %	14,31
Document Average Age	6,08
Average Citations Per Document	3,695
References	12759
Document Cıntents	
Keywords Plus (ID)	357
Author's Keywords (DE)	1354
Authors	
Authors	934
Authors Of Single-Authored Docs	130
Document Types	
Article	266
Article; Book Chapter	20
Article; Early Access	8
Article; Proceedings Paper	2
Article; Retracted Publication	1
Book	1
Book Review	5
Editorial Material	15
Editorial Material; Book Chapter	3
News Item	1
Proceedings Paper	88
Reprint	1
Review	8

The analyses of the data transferred to the Biblioshiny for Bibliometrix program are shown in Figure 5.

Figure 5. *General Information.*

Figure 6 shows the distribution of studies and citations to studies over time according to the data obtained from the Web of Science (WOS). According to the Biblioshiny for Bibliometrix software data, the annual document production rate is 14.31%.

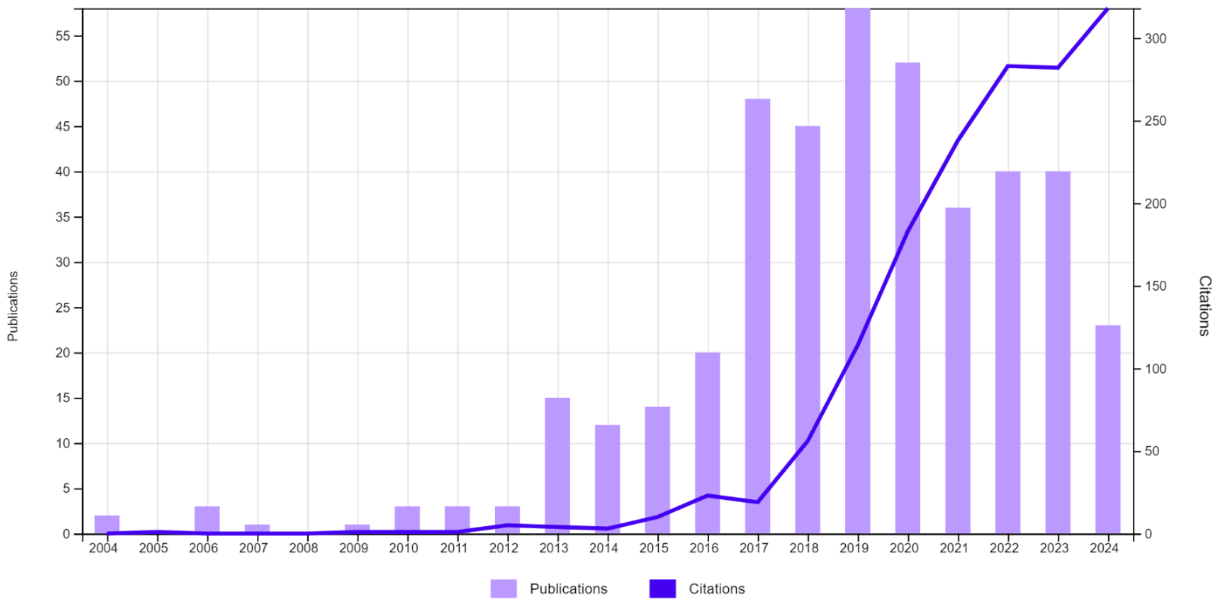

Figure 6. *Studies and Citations Produced Over Time.*

When Figure 6 is examined, the first documents was conducted in 2004. Interest in studies on resilience in the field of architecture increased after 2013 and reached its peak in 2019. Although it tended to decline in the following years, there was an increasing interest. The same situation is also seen in the annual average citation graph. The Sankey Diagram was used to measure the relationship between the authors of the obtained studies, the keywords they used, and the sources where the studies were published. In this way, the relationship was revealed with a triple-area graph. The diagram is shown in Figure 7.

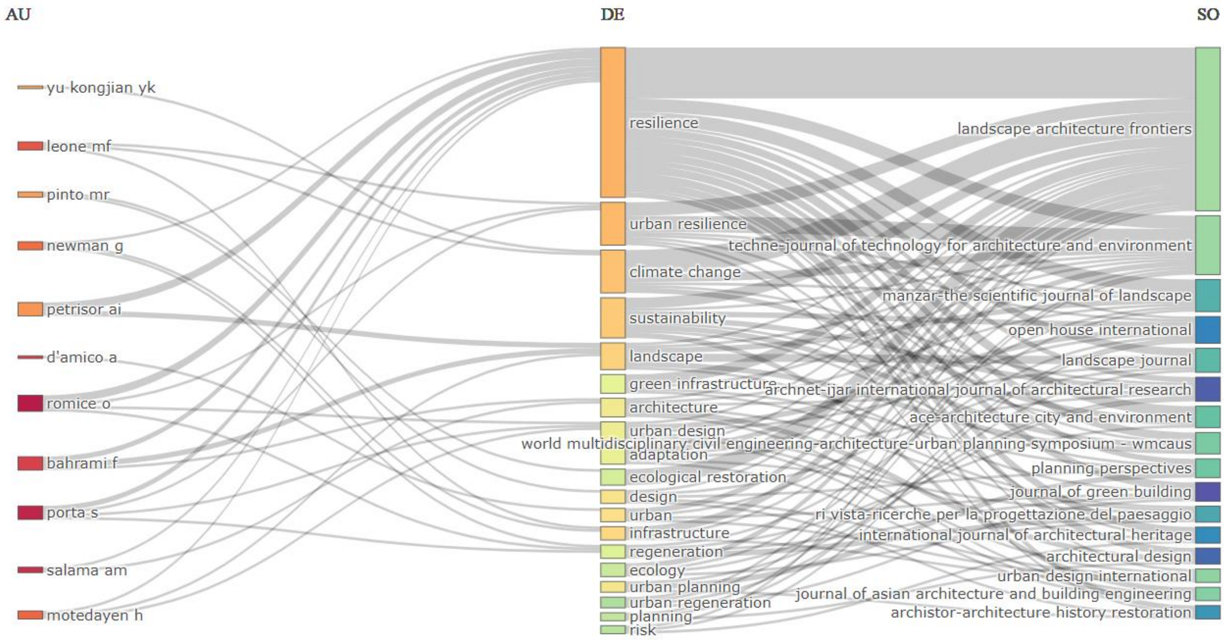

Figure 7. *Relationship Between Authors, Keywords Used and Published Sources.*

According to the Sankey Diagram in Figure 7, the sources where the studies on resilience in the field of architecture are mostly published, the authors whose work is included in these sources, and the keywords frequently used by the authors are included. The connection between these three selected titles is shown with gray lines. The thinness or thickness of the gray line provides information about the use density. In addition, the size of the rectangles in the diagram also shows the density related to the relevant title. Accordingly, the authors are located on the left of the diagram. The names of 11 different authors are listed here. The prominent authors are Petrisor A.I., Romice O. and Bahrami F. In the middle of the diagram, the authors frequently use 20 keywords. "Resilience" stands out among the keywords used. Then come the keywords “urban resilience”, “climate change”, “sustainability”, and “landscape”. When the keywords are examined, the frequent use of the keywords “resilience and "urban resilience" confirm that this research article, which examines trends in urban resilience research, serves its purpose. The sources of the studies are on the right side of the diagram. It is seen that the authors mostly prefer the source "Landscape Architecture Frontiers" for their studies on resilience in the field of architecture. Other sources are "Techne-Journal of Technology for Architecture and Environment", "Manzar-The Scientific Journal of Landscape", "Open House International", and "Landscape Journal". Figure 8 shows the most productive sources in studies on resilience in the field of architecture.

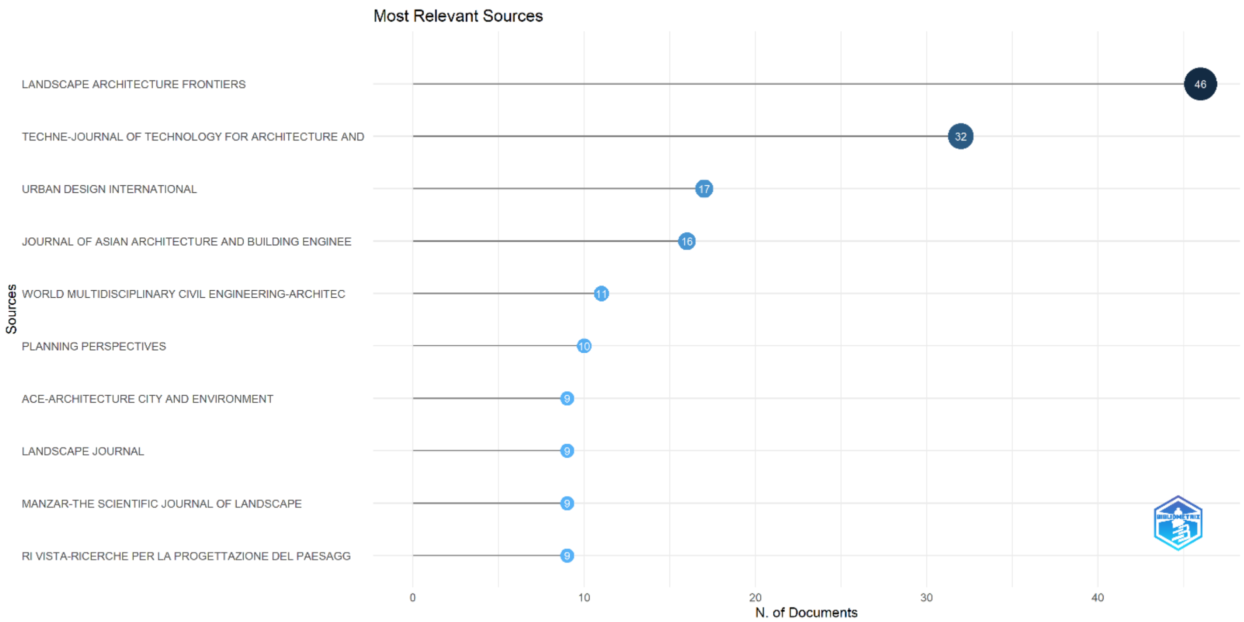

Figure 8. *The Most Productive Sources (Publishers).*

The number of publications increases as the circles in Figure 8 get more prominent and darker. Accordingly, Landscape Architecture Frontiers ranks first with 46 publications. Figure 9 shows the sources most cited by the authors. Accordingly, Landscape and Urban Planning stands out with 191 citations.

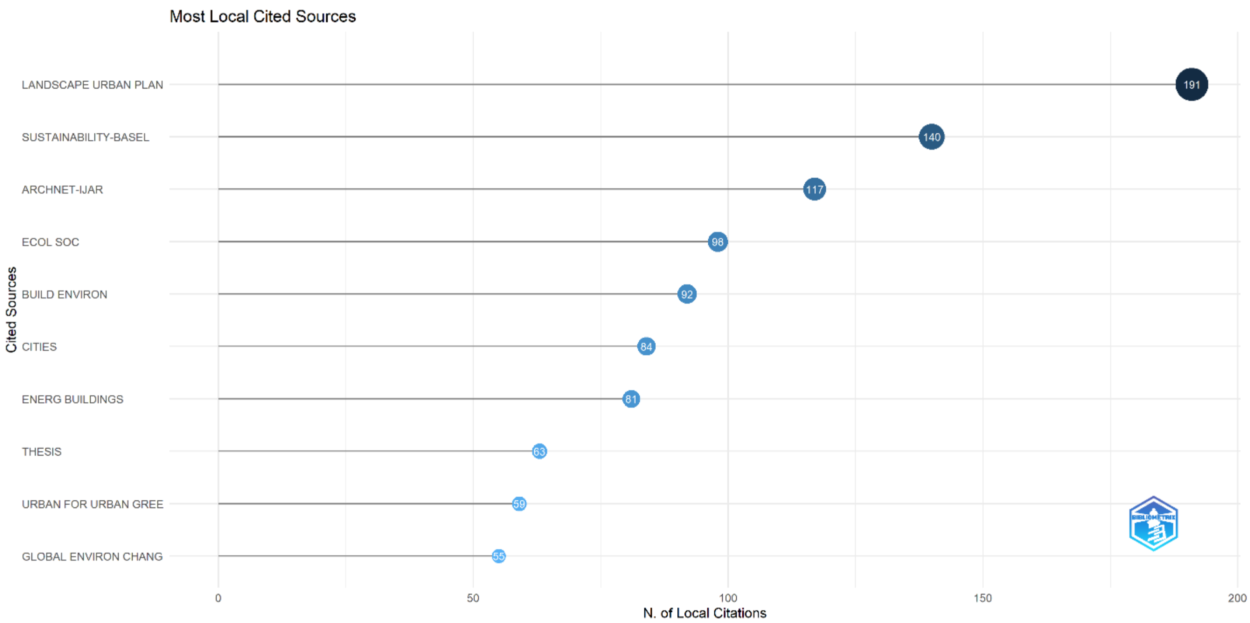

Figure 9. *Most Cited Sources.*

Figure 10 shows the H-index information of the journals in which studies on resilience in architecture are published. The magnitude of the H-index value shows that the source is influential. Accordingly, the "Landscape Journal" source ranks first with a value of 7.

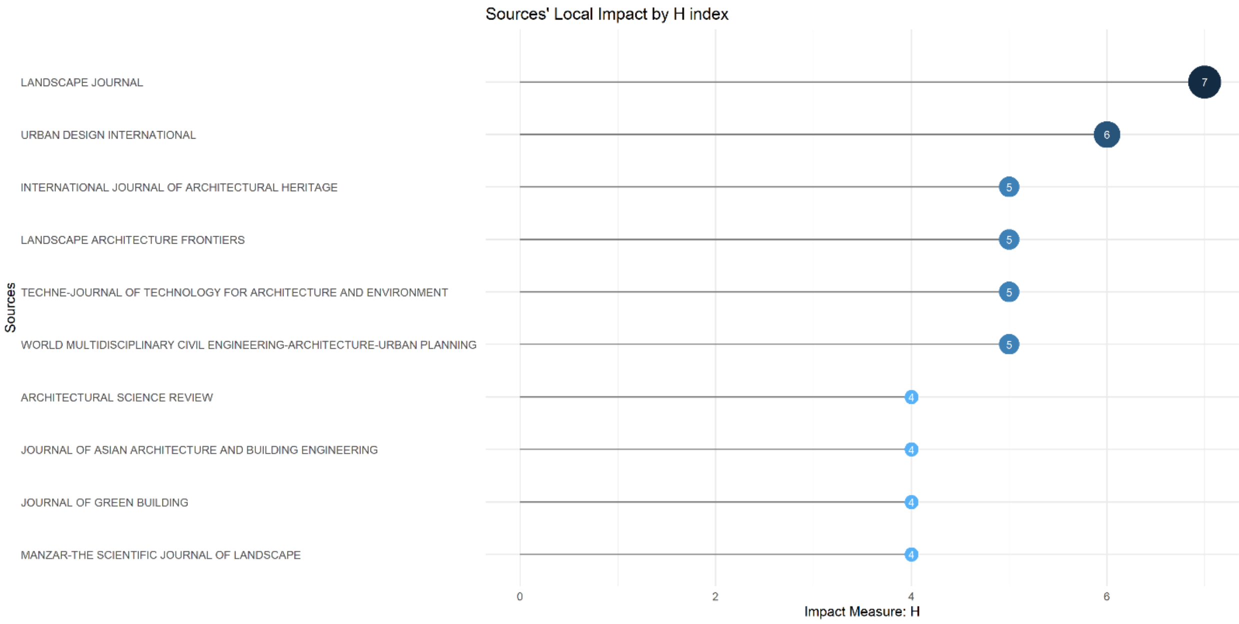

Figure 10. *The Most Influential Sources.*

Figure 11 shows the current status of the interest in the sources of resilience studies in the field of architecture throughout the historical process. Considering that the first document on resilience in the field of architecture was produced in 2004, it is seen that the interest in the subject has increased and that resilience is given more place in the sources than before. The negativities experienced in cities around the world can be shown in this. As indicated in Figure 11, the source that gives the most place to the subject of resilience is the "Landscape Architecture Frontiers".

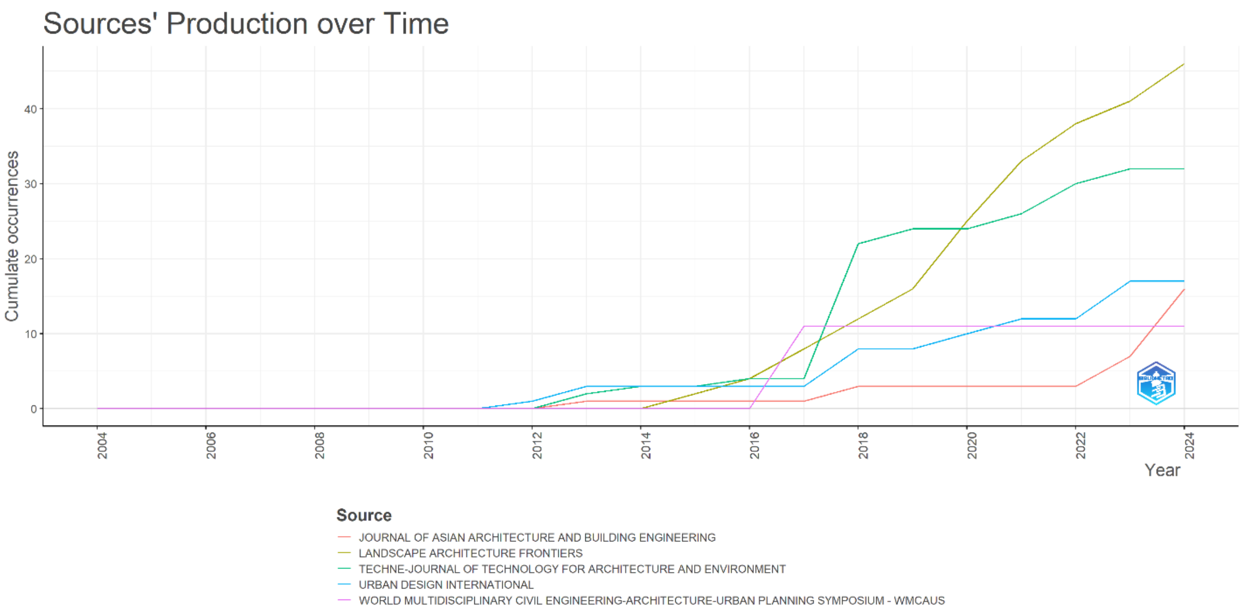

Figure 11. *Documents Production of Sources Over Time.*

In order to determine the authors who are most interested in the subject of resilience and produce studies on this subject, the data obtained from the Web of Science (WoS) database was analyzed with the "biblioshiny for bibliometrix" software tool. Accordingly, Kaewunruen S. stand out with 13 publications. Figure 12 lists the 10 most interested and productive authors on the subject of resilience in the field of architecture.

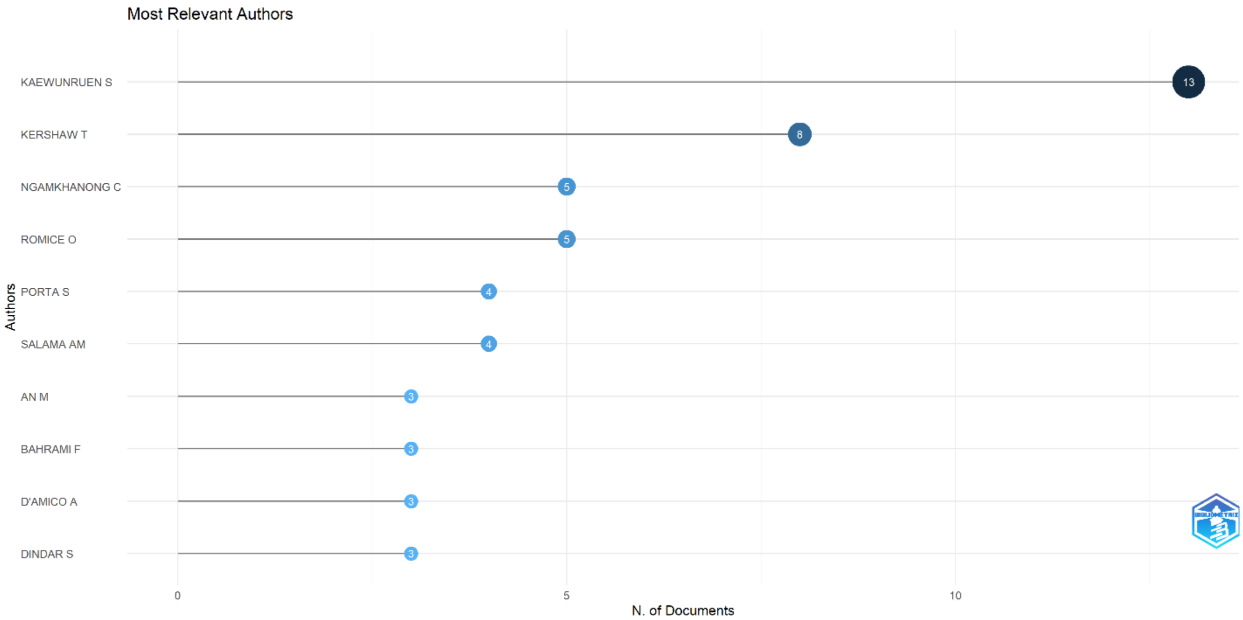

Figure 12. *The Most Productive Writers.*

Among the authors interested in the subject and producing documents, the most cited author is Bahrami F. with 4 citations. Figure 13 shows the top 10 most cited authors.

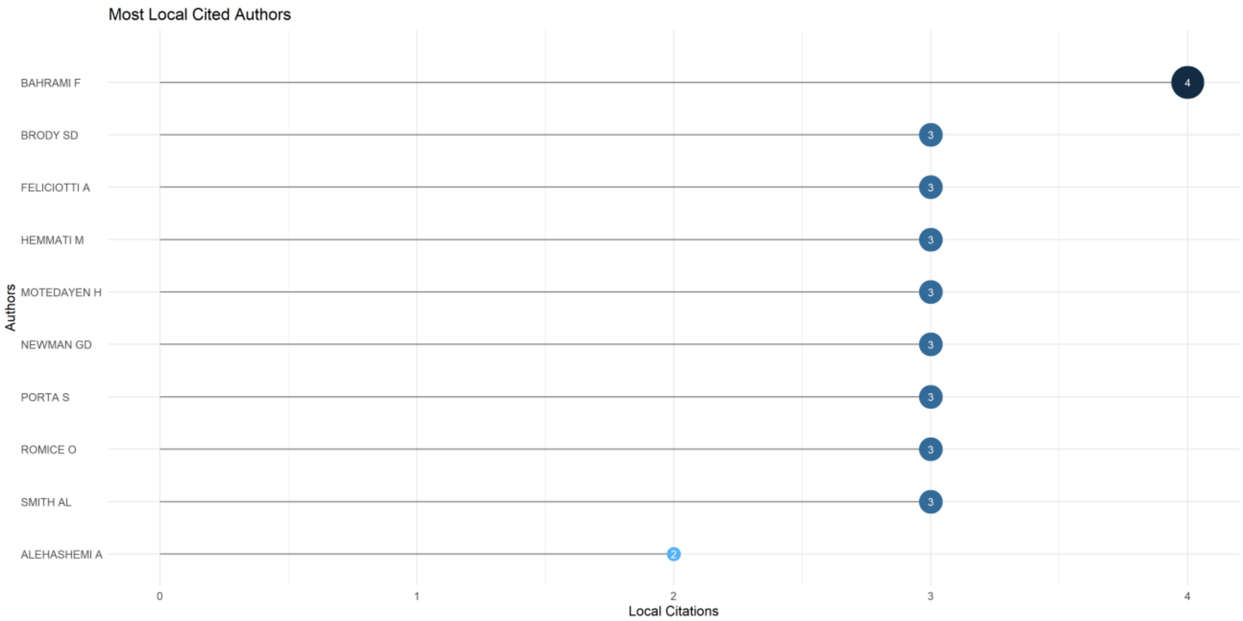

Figure 13. *Most Cited Authors.*

Figure 14 shows the 20 countries where studies on resilience in the field of architecture are produced and their responsible authors. It is seen that the distribution of studies produced by the country is between 0 and 100. In addition, two different colours are in the lines in the figure. Red color indicates publications produced with the participation of authors from more than one country, while Turquoise color indicates studies produced with the participation of authors from only one country. According to Figure 14, Italy stands out as the country that produces the most documents, and it is seen that the majority of this production is realized through single country collaborations (SCP). The USA and the United Kingdom are in second and third place respectively, and authors from these countries produce documents through both single country (SCP) and multi-country collaborations (MCP). Countries such as China, Spain, Poland and Canada have also made significant contributions and have achieved a certain level of multi-country collaborations. Figure 14 also shows that Turkey is also active in the field. When Figure 14 is analyzed, it is seen that Italy is the country that produces the most documents with 85 documents, but the MCP collaboration rate is only 8.2%. The Netherlands, which has 7 publications on the subject of “resilience” in the field of architecture, ranks first with a 42.9% MCP collaboration rate. While 9 of the 11 documents produced in Turkey were produced through single country collaborations (SCP), 2 were produced through multi-country collaborations (MCP). The multi-country collaboration (MCP) rate is 18.2%.

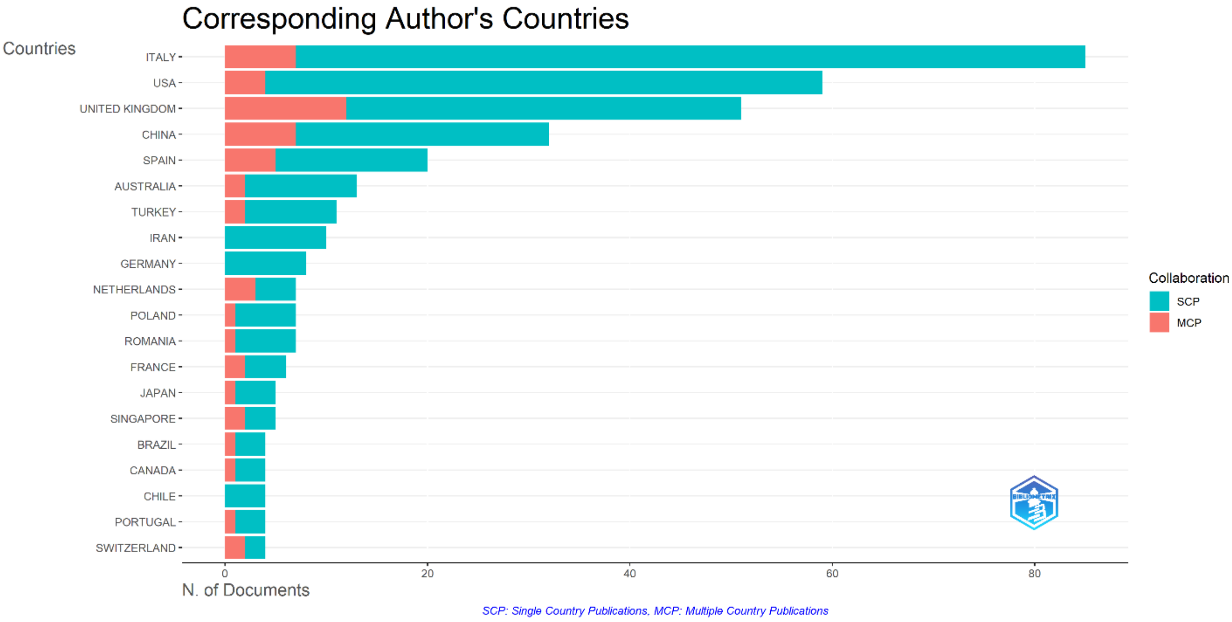

Figure 14. *Countries of Corresponding Authors (Single/Multiple).*

The top 20 most cited authors who produced documents on resilience in the field of architecture are shown in Table 2.

Table 2. *Top 20 most cited authors.*

Author	Year	Document Name	Source	Citation	Amaç Yöntem
Soltani, A and Sharifi, E	2017	Daily Variation of Urban Heat Island Effect And Its Correlations to Urban Greenery: A Case Study of Adelaide	Frontiers Of Architectural Research	118	A fieldwork was conducted to determine the surface temperature and urban heat island effects in the temperate city of Adelaide.
Boeing, G	2018	Measuring the Complexity of Urban Form And Design	Urban Design International	75	A typology of measures and indicators was developed to assess the physical complexity of the built environment at the urban design scale.
Feliciotti, A; Romice, O and Porta, S	2016	Design for Change: Five Proxies for Resilience in the Urban Form	Open House International	58	The concepts of urban morphology and resilience are combined under the headings of diversity, redundancy, modularity, connectivity and efficiency. The components and their interconnections are explained.
Feldhoff, T	2013	Shrinking Communities in Japan: Community Ownership of Assets As A Development Potential for Rural Japan?	Urban Design International	45	Current and future economic and socio-demographic challenges, population decline, and government policies facing shrinking communities in Japan are analyzed.
Hunter, M	2011	Emerging Landscapes Using Ecological Theory to Guide Urban Planting Design: An Adaptation Strategy for Climate Change Marycarol	Landscape Journal	33	Adaptation strategies have been developed to overcome the challenges of urban green space design in a changing climate.
Sterling, R and Nelson, P	2013	City Resiliency and Underground Space Use	13th World Conference of Associated-Research-Centers-for-the-Urban-Underground-	29	Examines the importance of understanding and improving the resilience of cities. Provides a general picture of the advantages and disadvantages of underground utilities in relation to various disaster events.

			Space (ACUUS)		
Fezi, BA	2020	Health Engaged Architecture in the Context Of Covid-19	Journal Of Green Buılding	28	In the context of COVID-19, this article demonstrates the potential of architecture and urbanism to play an active role in the prevention and control of epidemics and human health.
Cara, S; Aprile, A; (...); Roca, P	2018	Seismic Risk Assessment and Mitigation at Emergency Limit Condition of Historical Buildings along Strategic Urban Roadways. Application to the "Antiga Esquerra de L'Eixample" Neighborhood of Barcelona	International Journal Of Architectural Heritage	27	It provides a management tool for large-scale assessment and reduction of seismic risk of urban systems.
Newman, GD; Smith, AL and Brody, SD	2017	Repurposing Vacant Land through Landscape Connectivity	Landscape Journal	26	It describes the creation of a regional growth framework that balances the need to reuse vacant land with the provision of ecosystem services.
Ahern, J	2016	Novel Urban Ecosystems: Concepts, Defınıtıons and A Strategy to Support Urban Sustainability and Resilience	Landscape Architecture Frontiers	23	A new urban ecosystem strategy is presented to provide essential ecosystem services to support urban sustainability and resilience.
Marcus, L; Pont, MB and Barthel, S	2019	Towards A Socio-Ecological Spatial Morphology: Integrating Elements of Urban Morphology and Landscape Ecology	Urban Morphology	21	Strategies for developing an integrated socio-ecological urban morphology based on developments in each area are presented.
Putri, PW	2019	Sanitizing Jakarta: Decolonizing Planning and Kampung Imaginary	Planning Perspectives	19	This article provides a critical overview of the water and sanitation sector within the broader trajectory of Jakarta's spatial development and planning.
Feliciotti, A; Romice, O and Porta, S	2017	Urban Regeneration, Masterplans and Resilience: The Case of Gorbals, Glasgow	Urban Morphology	19	A 150-year study of the Gorbals borough of Glasgow explored the concept of resilience by comparing examples of nineteenth-century, modernist and recent masterplans.
Newman, G; Li, DY; (...); Ren, DD	2019	Resılıence through Regeneratıon: The Economıcs of Repurposıng Vacant Land wıth Green Infrastructure	Landscape Architecture Frontiers	18	Performance measurements were conducted to evaluate the economic and hydrological performance of green infrastructure renovation projects for three neighborhoods in Houston, Texas, USA.
Roberts, AR	2019	"Until the Lord Come Get Me, It Burn Down, Or the Next Storm Blow It Away" The Aesthetics of Freedom in African American Vernacular Homestead Preservation	Buıldings & Landscapes-Journal of the Vernacular Architecture Forum	17	It is argued that more attention should be paid to the preservation of rural grassroots homes.
Dindar, S; Kaewunruen, S; (...); Gigante-Barrera, A	2017	Derailment-based Fault Tree Analysis on Risk Management of Railway Turnout Systems	World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium (WMCAUS)	17	The aim is to identify product risks and defects in official accident reports and to analyze the impact of the possible process using Boolean algebra.
Brotas, L and Nicol, F	2017	Estimating Overheating in European Dwellings	Architectural Science Review	16	Energy performance and thermal comfort of residences were evaluated using transformed climates in 2020, 2050 and 2080 to assess overheating.
Chomicz-Kowalska, A; Mrugala, J and Maciejewski, K	2017	Evaluation of Foaming Performance of Bitumen Modified with the Addition of Surface Active Agent	World Multidisciplinary Civil Engineering-Architecture-Urban Planning Symposium (WMCAUS)	16	The article presents the analysis of the performance of foamed bitumen modified using surfactants.
Staniscia, S; Spacone, E and Fabietti, V	2017	Performance-Based Urban Planning: Framework and L'Aquila Historic City Center Case Study	International Journal of Architectural Heritage	16	Possible applications of seismic risk assessment are described in a sub-area of the historic centre of L'Aquila, considering only buildings, roads and open spaces.
Bobylev, N; Hunt, DVL; (...); Rogers,	2013	Sustainable Infrastructure for Resilient; An Environments	13th World Conference of Associated-Research-	16	The academic perspectives and progress to date of the Sustainable Infrastructure for Resilient Urban Environments research project, carried out at the

CDF	Centers-for-the-Urban-Underground-Space (ACUUS)	University of Birmingham, funded by the European Commission's 7th Framework programme between 2012 and 2014, are described.

The graph showing the interest of publication-producing countries in the field of resilience in architecture over the years is given in Figure 15. Accordingly, the Italy ranks first with 217 document, and it is seen that there has been an accelerated increase in production.

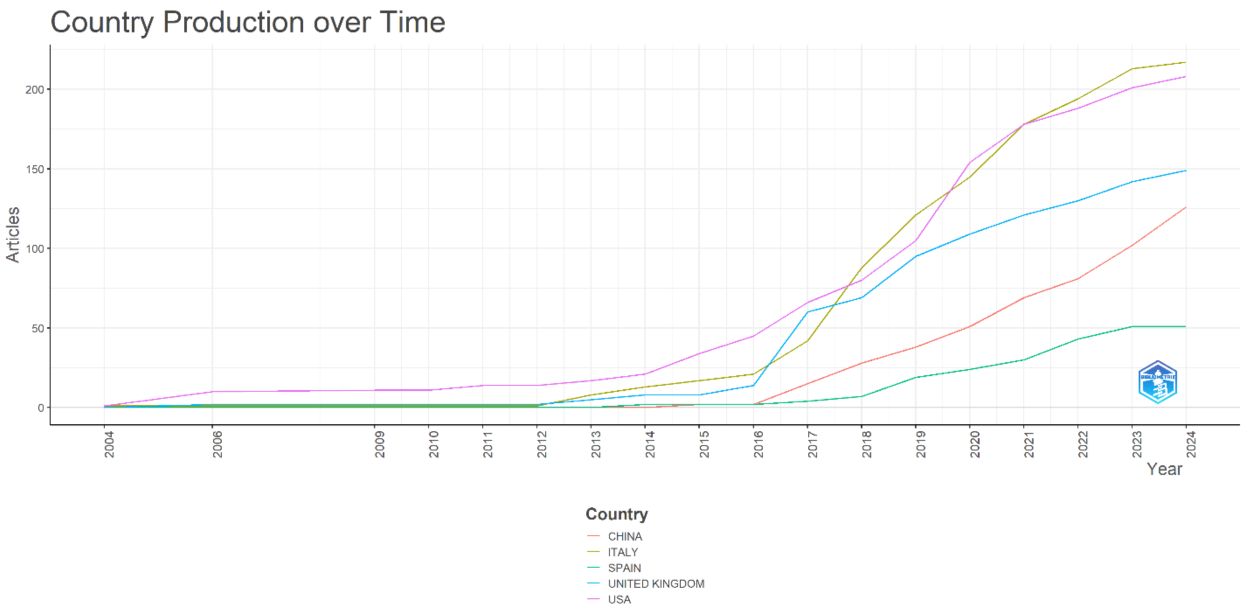

Figure 15. *Documents Production by Countries Over Time.*

Figure 16 shows the countries that receive the most citations among the publication-producing countries. Accordingly, the USA ranks first with 353 citations. United Kingdom ranks next with 223, Australia 172, Italy 162, and China 71 citations.

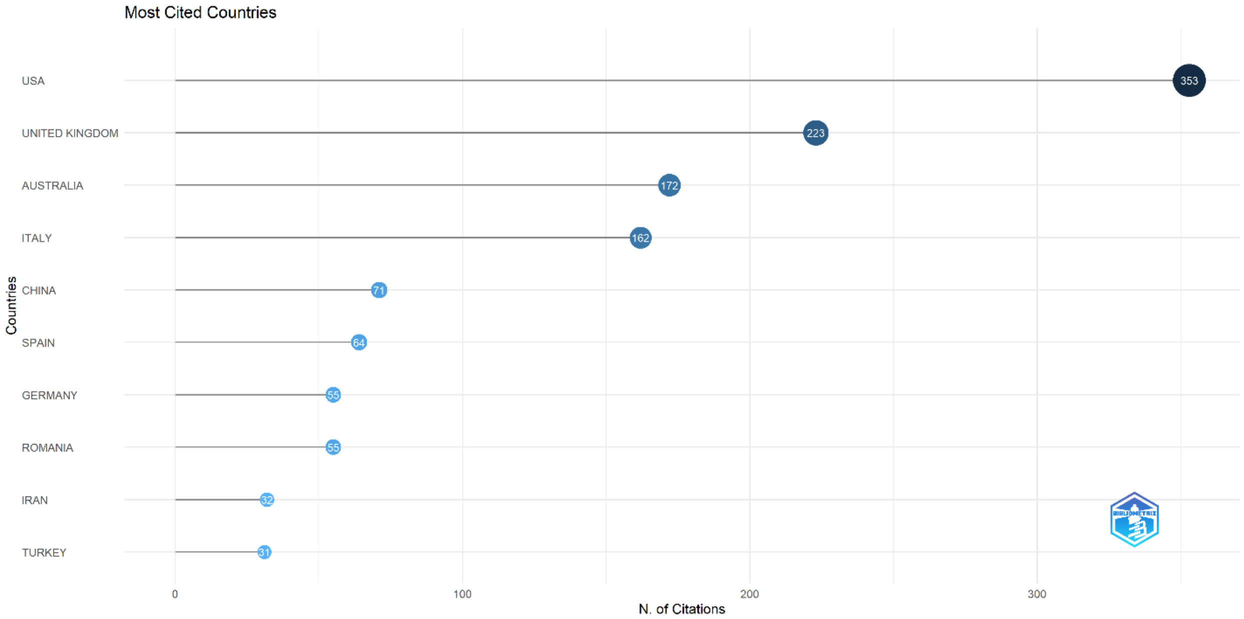

Figure 16. *Most Cited Countries.*

Figure 17 shows the countries that cooperate in document production. The world map uses the color blue, and the darker the blue, the more documents are produced. The thickness of the connection line between the countries also shows greater cooperation.

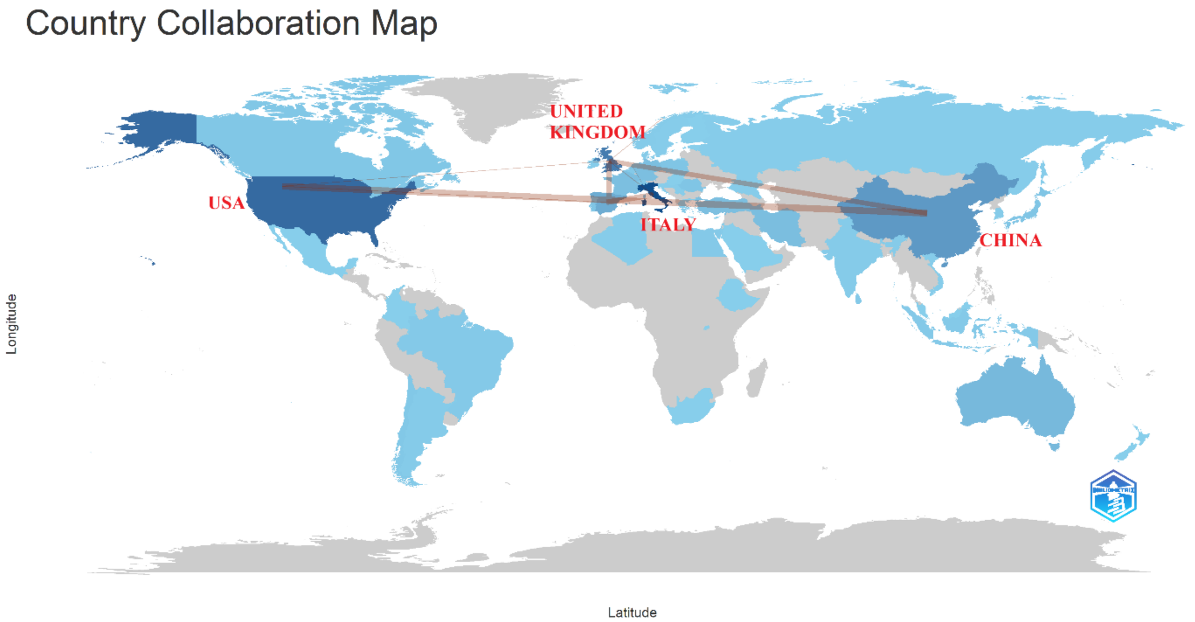

Figure 17. *Countries Collaborating in Document Production.*

A search of the Web of Science (WOS) database on 01.11.2024 to identify studies on resilience in architecture found 419 documents. The keywords used in these documents are listed in Figure 18.

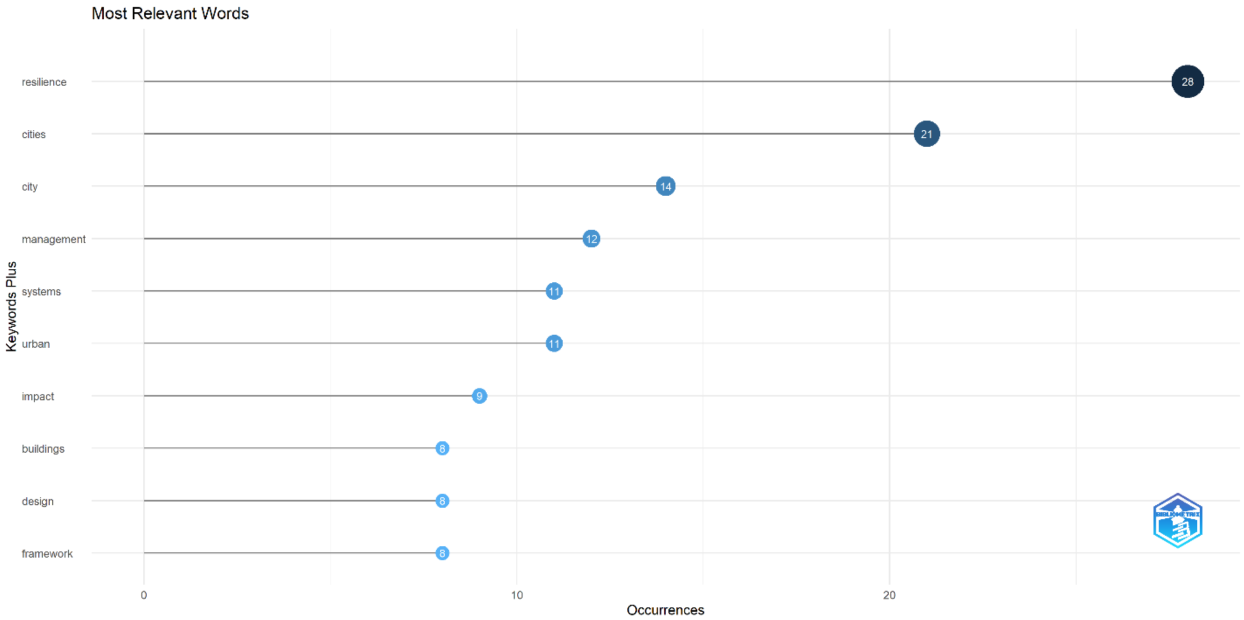

Figure 18. *Most Frequently Used Words.*

When Figure 18 is examined, “resilience”, also the subject of this research article, ranks first among the most frequently used words with 28 uses. “Cities” is used 21 times, “city” 14 times, and “management” 12 times in the documents. The authors' keywords (a), keywords plus (b), word clouds in titles (c) and abstracts (d) for keywords frequently used in studies on resilience in the field of architecture are shown in Figure 19.

Figure 19. *Word Clouds Related to Documents.*

A word cloud is a data visualisation technique used to represent the keywords of published documents, in which the size of each word indicates its frequency or importance. The term "author's keywords" is used to denote the topical and contextual inclinations of researchers in a given study [70, 71]. The "Keywords Plus" keyword structure is created by an automatic computer algorithm and consists of words that are frequently seen in the reference titles of a study [72]. It is worth noting that the keywords in the "Keywords Plus" structure do not necessarily have to be in the title of the study or in the keywords determined by the author. These keywords make it easier to capture the content of an article with more depth and variety [72]. Accordingly, it is seen that frequently used words are expressed in larger fonts than others, and the less frequently repeated words are expressed in smaller fonts. The word clouds are designed on the 50 most frequently repeated words in the studies produced. Word clouds with four different variables are shown in Figure 19. When Figure 19 (a) "authors' keywords" are evaluated, "resilience" (101) ranks first as a keyword in the studies on resilience in the field of architecture. It is then seen that the frequently used keywords are "urban resilience", "climate change", "sustainability" and "landscape". Figure 19 (b) "keywords plus" is evaluated, "resilience" is in the first rank with 28, and the keywords "cities", "city", "management" and "systems" are frequently used, respectively. Figure 19 (c) shows the keywords frequently used in the titles of the produced studies. Accordingly, "urban" is first (166), followed by "resilience" and "design". Figure 19 (d) shows which words are frequently used in the abstarcts of the produced documents. In this word cloud, the word "urban" is first (961) followed by "resilience", "design", and "city". As can be understood from these word clouds, city, sustainability, design and climate change are frequently used in urban resilience research. It is seen that the negativities experienced in cities due to climate change are also reflected in academic studies and that the city must have resilient systems on the path to sustainable development. Figure 20 shows the change and frequency of the words used in the field of architecture to describe resilience to the changing world and conditions, starting from the first study produced to the present day.

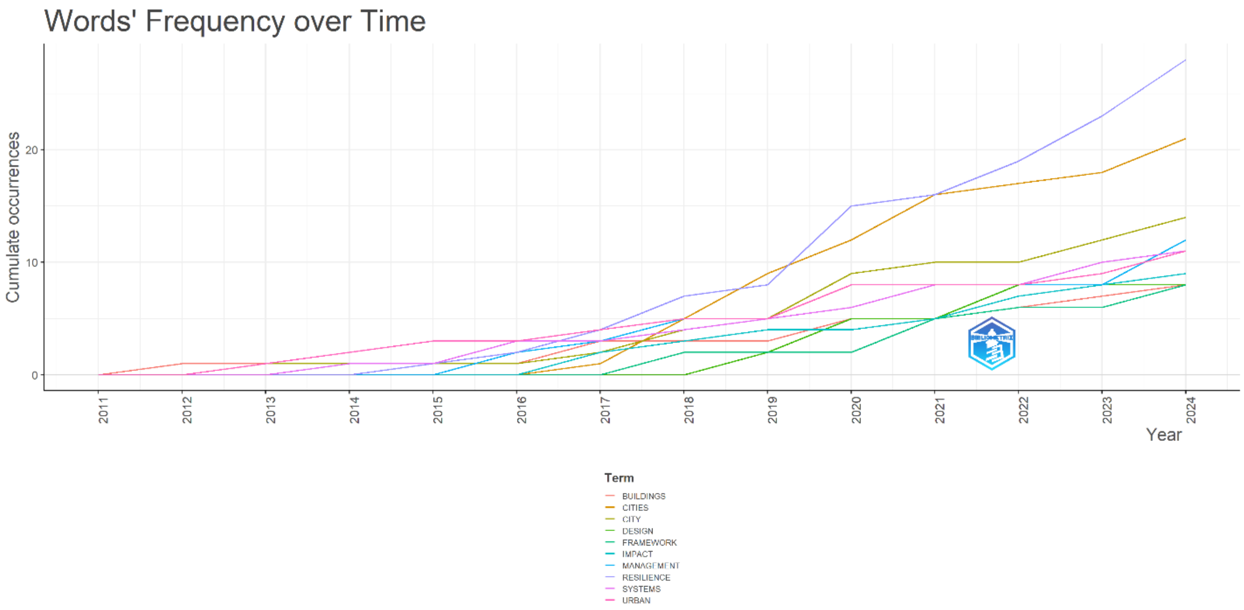

Figure 20. *Change in the Frequency of Use of Words Over Time.*

The trend status of the keywords used in the historical process is shown in Figure 21.

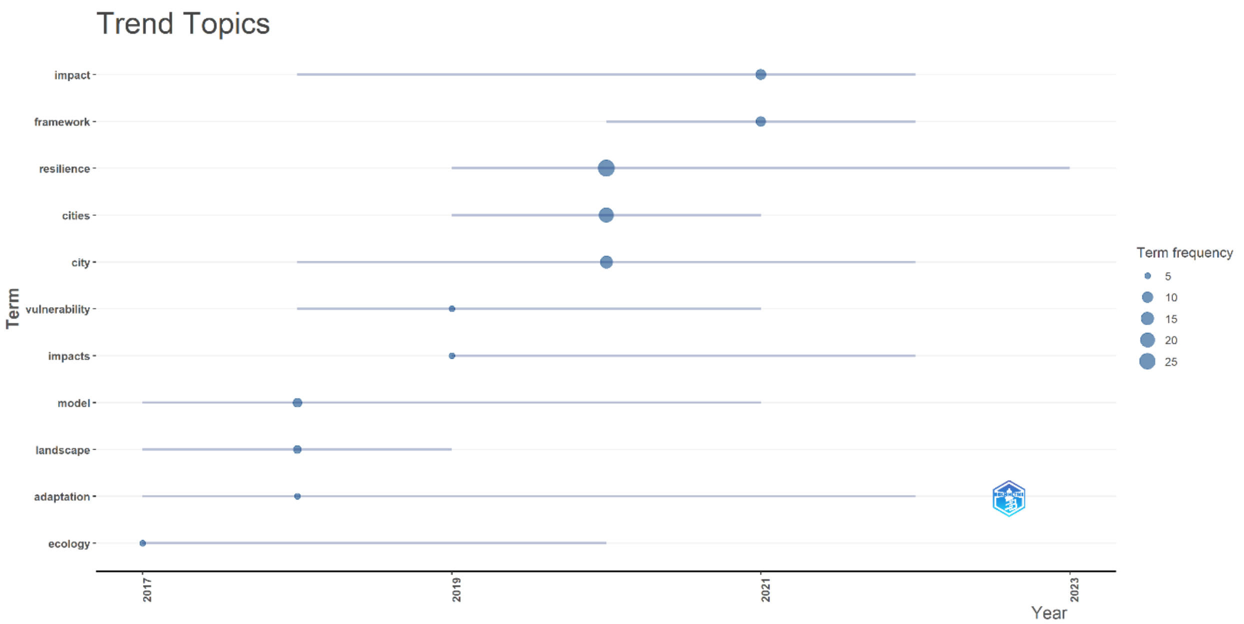

Figure 21. *Trend Keywords Over Time.*

The size of the circles in Figure 21 shows the frequency of use and the trend status. Accordingly, the word “resilience” became a trend in 2020. The network map in Figure 22 shows the frequently used and trending keywords as authors' keywords.

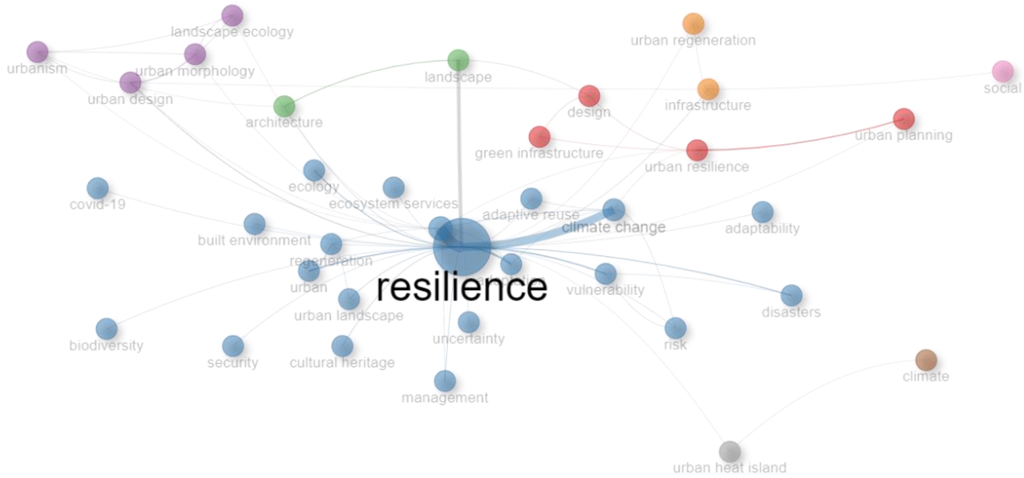

Figure 22. *Use of Keywords Together.*

When the use of authors' keywords are analyzed through the network map, it is seen that the word "resilience" is closely and directly related to keywords such as "climate change", "adaption", "urban" and indirectly related to words such as "design", "social", "urban regeneration" and "urban heat ısland". A Thematic map of the keywords used by the authors was created with the "biblioshiny for bibliometrix" software tool. Figure 23 shows the thematic map of the keywords used by the authors.

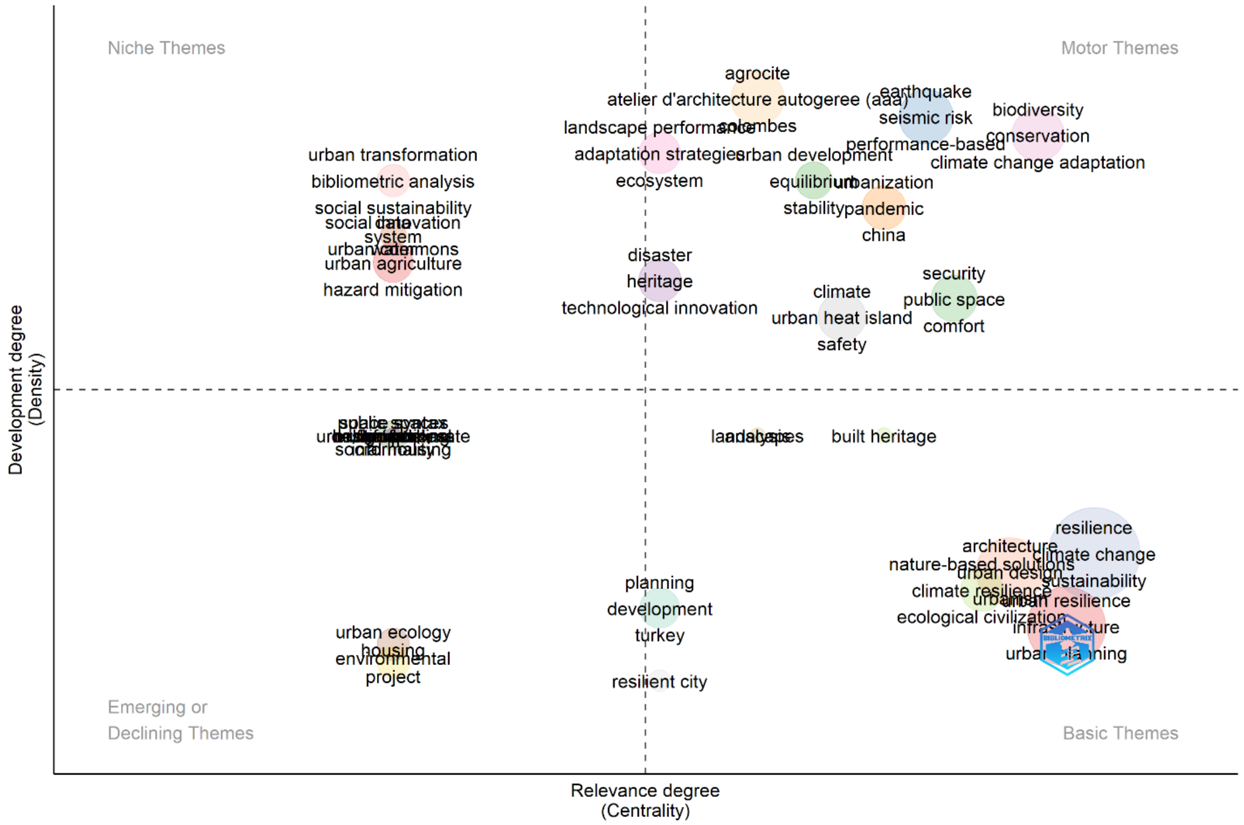

Figure 23. *Thematic Map Showing the Keywords Used by the Authors.*

Thematic map was used to analyze the importance and periodic development of the research theme. Thematic map was first used by Callon and his colleagues [73]. Thematic map is a coordinate system consisting of centrality (x-axis) and density (y-axis). Centrality measures the importance of the selected theme, and density measures the development of the selected theme [74, 70]. The centrality measure for a given cluster is the density of its connections to other clusters. The more and stronger these connections are, the more this cluster determines a series of research problems that are vital to the scientific or technological community [73]. Density characterizes the strength of the connections that connect the words that make up the cluster. The stronger these connections are, the more coherent and integrated the research problems corresponding to the cluster are. Therefore, a research topic can be classified into 4 quadrants according to these two values, each representing a specific theme module, and thus the research topic can analyze where the keyword is and display its bibliographic data with a relevant keyword. This method is a necessary method for interpreting the thematic map and therefore research topics [73, 75, 76]. The thematic map is divided into four quadrants [74, 70]. In this thematic map, the degree of centrality is shown on the horizontal axis, and the degree of density is shown on the vertical axis. Accordingly, those close to the centre represent the keywords most used in the documents included in the analysis. In terms of density, the higher the keyword is, the more it is used. The keywords in the Basic Themes section are the most used critical keywords in all studies. The Motor Themes section shows the trending keywords in the studies produced in recent years. The Emerging or Declining Themes section represents the keywords that are not used much in the studies produced or that have newly emerged. These keywords either disappear or progress towards becoming a trend over time. The Niche Themes section shows that more work needs to be done on the keywords in this theme in studies on resilience; in other words, there is a gap and potential in the literature. From this thematic map, it becomes clear that in studies on resilience in the field of architecture, the keywords in the Basic Themes section should be scanned, the trending keywords in the Motor Themes section should be used in the studies produced, and the potential of the keywords in the Niche Themes section should also be evaluated.

5. CONCLUSION

In this research article, a bibliometric analysis of studies on resilience in architecture was conducted using the Web of Science (WOS) database. The "biblioshiny for bibliometrix" software tool was selected for the bibliometric analysis of the data belonging to these documents. The data from the documents were transferred to this software tool, and the visuals belonging to the analysis were obtained. According to the results of the analysis, general information about the documents was given first. According to the data obtained within the scope of the article, the documents produced on resilience in architecture were analyzed under five headings. First, the overview analysis included general information, annual document production, annual citation count, and analysis using the Sankey Diagram and triple area graph. Secondly, in the Source/journals analysis, the most productive source, the most cited source, source/journals impact and the analysis of the change in document production of the sources over time were included. Thirdly, in the author analysis, the most productive author, the most cited author and the countries of the responsible author/authors of the documents were analyzed. Fourthly, the countries cited the most, the countries that cooperate in document production and the change in the document production of the countries over time, are shown in the country analysis. Finally, the fifth analysis, the word analysis, includes the most used keywords, word cloud, words together, the change in the words used over time, trend topics and thematic map. As a result of the analysis, it was determined that there were 419 documents, the first document on the subject in the relevant field was produced in 2004, and the annual documents production rate was 14.31%. Although document production peaked in 2019 and there was a partial decrease in the following years, the interest in the subject in the field is constantly increasing. The prominent authors are Petrisor A.I., Romice O. and Bahrami F., the keywords "resilience", "climate change", and "urban resilience" are frequently used; the source "Landscape Architecture Frontiers" is the most preferred, "Landscape and Urban Planning" stands out with its number of citations, and the source " Landscape Journal" has the highest H-index impact value. It is seen that Italy ranks first among countries with 85 publications and that the interest in publications on resilience in the field of architecture in the USA and Italy have increased over time. It is seen that the keyword “resilience” is the most used keyword with 28 uses and that it is closely and directly related to keywords such as “climate change”, “adaption”, “urban” and indirectly related to words such as “design”, “social”, “urban regeneration” and “urban heat ısland”. The keywords “cities”, “city”, “sustainability” and “management” are frequently used in urban resilience research. It is seen that the negativities experienced in cities due to climate change are also reflected in academic studies and that the city must have resilient systems on the path to sustainable development. When the studies produced on resilience in the field of architecture are analyzed, it is seen that there are only 11 documents from Turkey. Compared to other countries, it is seen that there has yet to be interest in resilience research in the field of architecture in Turkey. Increasing urban population and needs threaten critical systems in cities.

In some cases, these critical systems may be inadequate. With the increasing population, access to basic needs such as education and health, especially housing problems, becomes more difficult. Segregation in society, the stigma of poverty, isolation, low social harmony and dissatisfaction directly affect social sustainability. The negativities experienced due to climate change and global warming, the adverse effects of which are now more tangibly felt worldwide, directly and threaten cities. Cities are both the source of these negativities and also suffer from their consequences. The increase in urban population and the decrease in rural population lead to a food crisis, as agricultural production decreases. In this case, people migrate to cities more intensively to access food and employment. In this case, the building stock increases and global warming is experienced due to buildings. This spiral relationship continues in a cycle. Steps that will stop this cycle or reduce the intensity of the relationship should be taken by local governments and central government. Intensive migration is predicted only to occur if people are provided equal opportunities for employment and housing in their settlements. Local governments, the closest administrative unit to the people, should act with the principle of partnership and participation and include the individual in critical systems without separating from society. Since resilience is defined as the ability of critical systems in a city to respond to sudden shocks and stresses, the importance of the resilience of critical systems in a city becomes evident in a sudden disaster. These natural disasters have historically caused migrations, epidemics, housing problems and food crises. For this reason, for a city's critical systems to be sustainable, it must have a primarily resilient structure. Academically, more emphasis should be placed on resilience studies, especially in the field of architecture.

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An Approach for Solver Sensitivity Analysis Cfd Simulations for Natural Ventilating in a Middle-Scale Mosque

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Abstract

Energy-efficient building design is a goal achieved through efficiency in the calculations of energy consumption based on building simulations during the design phase. During the design phase, measures to reduce the building's energy consumption can be taken, and in existing structures, the potential for natural ventilation can be utilized through passive design principles without compromising comfort conditions. In addition, predicting the effectiveness of natural ventilation often leads to highly uncertain results compared to mechanical systems. Unlike the extensive mechanical system analyses found in the literature, there is uncertainty in the accuracy of appropriate CFD solution steps in natural ventilation studies. Different approaches are being tested in CFD solutions to increase the accuracy of simulation-based predictions. Among the approaches to predicting ventilation effectiveness in buildings, computational fluid dynamics (CFD) calculations are common. CFD analyses show varying results depending on solver settings, discretization schemes, turbulence models, mesh sensitivity, and time methods. This study investigates the necessary steps to simulate and predict the effectiveness of natural ventilation. It explores whether a different approach is needed in terms of the CFD calculation model compared to mechanical CFD examples to simulate the indoor with natural ventilating. This study tests different analytical approaches for certain opening configurations to analyze the effect of numerous uncertain variables on comfort parameters. The extent to which the results of the Coupled and SIMPLE solvers affect cross-ventilation and perpendicular ventilation cases is questioned. Differences between parameters such as CO_2 concentration as a pollutant gas value, air velocity, and temperature have been taken into account. While the air velocity parameter shows quite similar results for both solvers, the results for CO2 concentration and temperature parameters differ significantly. Whether the flow is in two-dimensional or 3D flow volume affects the solver settings. Since CO2 concentrations depend on the mass increase, they were found to be slightly affected by the solvent difference. Air velocity was found to be the most important factor affecting the flow pattern and the distribution of concentrations and temperature. When evaluating cross ventilation and perpendicular ventilation in terms of indoor air quality and thermal comfort, perpendicular ventilation tends to create a more negative indoor air quality situation.

1. INTRODUCTION

Natural ventilation can be a highly efficient energy strategy as an alternative to ventilation systems that impose a 9% energy load on end users [1]. For large spaces to benefit from energy-efficient strategies, the design of openings must appropriately utilize passive ventilation strategies based on their volume. When considering mechanical systems, system loads increase in proportion to the size of the space, leading to significant energy consumption for heating, cooling, and maintaining good air quality compared to other building types. Furthermore, it's known that buildings with large volumes significantly impact operational and maintenance burdens through decisions made during the design process, especially when considering investment costs. During the design process, carefully examining the requirements of the building and the benefits that can be gained from the passive strategy of natural ventilation ensures that the goal of an energy-efficient building throughout its life cycle is achieved.

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The mosque, as a structure made up of a large single volume, is a space where air stratifications and scent accumulations occur, similar to an atrium. Among the expectations of mosque users, hygiene within the structure is paramount. [21] While thermal comfort conditions are more related to the building envelope, the characteristics of indoor air quality are directly dependent on air movement within the volume. One feature that distinguishes this space in terms of user behavior from other buildings is that it is a carpeted area where shoes are not worn. This leads to the accumulation of gases causing unwanted odors, which negatively impact comfort conditions, especially under heavy use. Utilizing simulations that will influence the design of the new mosque structure will provide data for retrofit efforts in existing mosques and will also enlighten designers in choosing energy-efficient strategies. Therefore, research is planned to explore natural ventilation conditions to reduce unnecessary ventilation loads.

To fully examine the effectiveness of natural ventilation strategies, it's essential to conduct CFD analyses that are as close to reality as possible. However, due to the challenges and uncertainties of validating these through on-site measurements or wind tunnel experiments, CFD sensitivity analyses look into how decisions made in the analysis inputs affect the results. Many studies observe changes in findings by making literature-based modifications to CFD analysis decisions (Table 1). This observation questions the accuracy of decisions based on the fraction of results. CFD simulations can vary outcomes according to the effects of fluid properties, flow viscosity, turbulence models, and discretization choices.

The airflow distribution within a space was evaluated numerically through experimental data decades ago, but today, computational fluid dynamics tools are used. With the tools provided by advancing technology, ventilation simulations are conducted during the design phase. The study of fluid movement is based on the Eulerian control volume method in internal flows. As a control volume, the iterative calculations of continuity, velocity in the x, y, and z directions, energy, turbulence, and species equations are dependent on each cell of the flow volume. Additionally, the discretization schemes in the solution system of the equations and the calculation order (first order-second order) in each grid cell affect the accuracy of the results.

Literature-based natural ventilation CFD simulations include various approaches from calculating fluid movement based on the geometry of the space to the decisions involved (Table 1). Many of these studies focus on openings to assess ventilation under wind effects. Depending on the direction of the wind approaching the building facade, the pressure coefficient (Cp) increases as the distance between the openings in the wind direction increases [3]. To evaluate the effectiveness of the openings, air change ratio and pollution concentration values are assessed according to the ASHRAE 62.1 standard. Chang et al. (2020) studied CO concentration based on wind speed within a tunnel and reduced the air change duration by increasing the eddy events in their simulation model where they added a jet fan[4].

In the method of finite volumes, CFD analyses provide scientifically reliable solutions due to their precise results for determining air movement within a space. In this computational model, which considers all parameters of flow during the calculation steps, the primary factors that dictate fluid motion are flow velocity and, consequently, acceleration. The thermal distribution caused by fluid movement, concentrations of pollutant gases, and values of comfort parameters are secondary parameters that need to be evaluated based on the mutual effects of the fluid's speed and the sources of these values.

***Table 1.** CFD calculation decisions in large-volume geometries in the literature. (comp: computational, expr: experimental, num: numerical, meas:measurement)*

research	**building type**	**method**	**Strategies**				**induced by**		**scale**		**details of simulatio**
			stack effect	cross ventilation	single sided ventilation	two sided ventilation	buoyancy	wind	small	full	tubulence model
2018, Qinzi, L.	domain	expr. and comp.	√	√				√	√		RNG κ–ε
2018, Gong,J., Hang, J.	atrium	expr. and num.	√				√		√		
2011, Gao, C.F., Lee, W.L.	residentials	comp.	√					√			κ–ε
2005, Hunt,G., Linden, P.F.	domain	expr. and comp.	√	√	√	√	√	√	√		RNG κ–ε
2005, Cook, M., Li,Y., Hunt, G.	domain	expr. and num.	√			√	√	√			
2008, Fitzgerald, S.D., Woods, A.W.	domain	expr. and num.	√	√							
2013, Stavridou, A.D., Prinos, E.P.	domain	expr. and comp.		√			√	√	1		RNG κ–ε
2020, Chang,X. et al.	tunnel	num. and comp.		√		√		√		√	RNG κ–ε
2016, Daish, N.C. et al.	domain	expr. and comp.			√			√	1/25		
2011, Walker, C. et al.	model	expr. and num.	√				√		1/12		κ–ε
2021, Varela-Boydo,C.A. et al.	windcatcher	comp.				√		√	√		κ–ω
2010, Gan,G.	model	comp.		√			√	√		√	RNG κ–ε
2020, Sultansu,S. Ayhan,O.,	model	comp. and meas.									
2006, Asfour, O	religious	comp.		√		√		√	√	√	RNG κ–ε
2018, Mohammadmirzaei, M.	model	comp. and meas.	√	√				√			RNG κ–ε
2019, Gürhan, Ö.	historic	comp.		√				√		√	κ–ε
2019, Sapuram,N.,	tall building	comp.		√				√		√	
2009, Mouriki,E.	atrium	comp. and anly.	√					√			

In the literature, large structures with atriums, semi-open stadiums, indoor sports halls, and mosques have been the subject of experimental studies. For the atrium volume, when the openings are arranged vertically opposite each other, cross ventilation occurs and stratification can be observed at the levels above the air outlet opening [5].

The mosque architecture has been studied in terms of the effects of dome shapes and openings, as well as the impact of minarets on ventilation within the context of computational fluid dynamics. Different dome shapes and all wind angles (0°, 45°, and 90°) were analyzed at wind speeds of 1 and 3 m/s, revealing that 87.5% of the openings facilitate outward airflow [2]. It was also observed that outward flows increased at 0° and 90° wind angles, while inward flows increased at a 45° wind direction. When the minaret was positioned towards the side of the wind direction, it was noted to increase indoor air speeds [2]. Reda (2022) has analyzed a model involving users in his study. In the simulation studies of mechanical ventilation, they solved the steady-state condition analysis using a second-order discretization scheme [20].

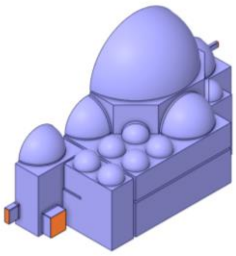
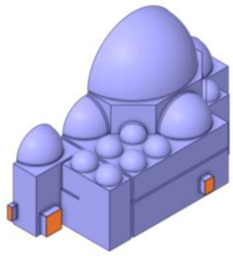
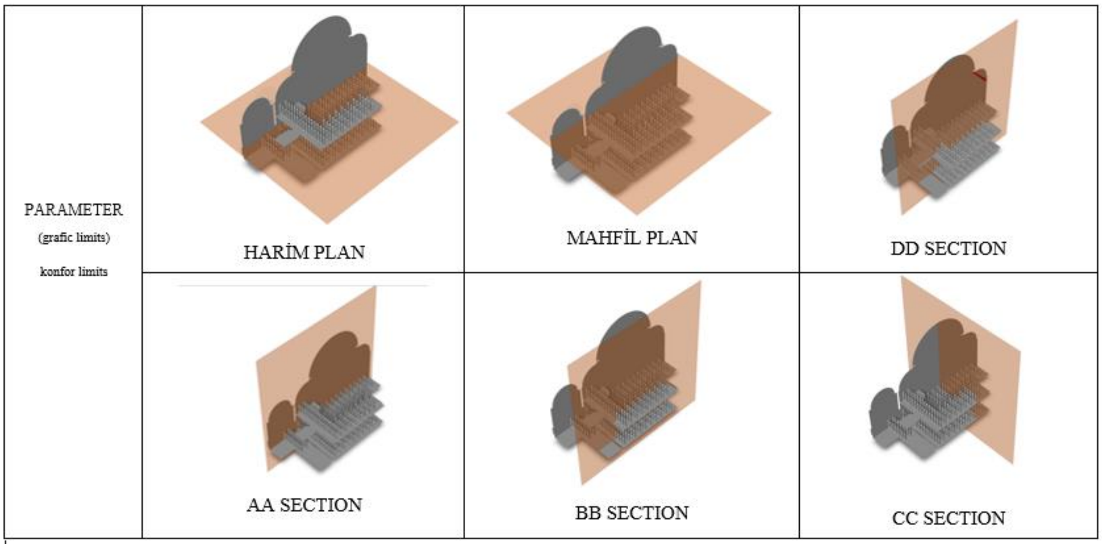
In the literature, experimental, computational, and measurement studies have been conducted on variables like spatial formation, the positioning of openings, the impact of heat sources, the effect of wind towers, wind and buoyancy effects, the influence of atriums on ventilation, and the connections between rooms. The aim of these studies is to investigate how architectural formation affects energy-efficient ventilation, and they have provided results in this direction. In the studies carried out, the turbulence calculation model used in the analysis approach varies from one to another. Essentially, when simulating the ventilation of a space, the results are entirely dependent on the calculation model. The calculation model, which expresses the mathematical computation of fluid movement, is based on a series of decisions, and at this stage, decisions are made based on properties like fluid, domain, and scale. The accuracy of the conducted studies requires a validated approach in architectural CFD analyses. The accuracy of the approach can be ensured by measurements, or it can be evaluated by looking at the systematic variation of parameters, convergence, and residual values. In this study, results were assessed by trying out two different solvers on two different geometries.

In this study, the differences in the results of analyses with various computational approaches were examined to determine air movement in mosque structures that are similar to atrium buildings in terms of volumetric properties. The aim of this study is to investigate whether a different approach is needed in terms of the CFD calculation model when simulating architectural spaces, compared to mechanical CFD examples. Defining the fluid domain and determining the calculation model in building simulations are crucial for the accuracy of the results. The findings of the SIMPLE and Coupled solver simulations conducted for cross geometry and perpendicular ventilation were compared.

2. METHOD

This study examines large-scale, heavily used religious buildings. Among these structures, mosques were selected as the type with the least area allocated per person (0.72-1.00 m^2). Considering the mosque forms applied in our country, the traditional style of mosque typology is commonly seen. Among the projects of the Directorate of Religious Affairs, the Type-7 project, known for its ease of construction and capacity, is chosen for the CFD study in this work. The Type-7 mosque project is a medium-sized mosque with a capacity of 473 people, featuring a half dome and a U-shaped balcony plan, combining the ground floor and balcony level.

Table 2. *CFD models and evaluation planes and lines.*

CV2D0S0 model	PV12D0S0 model
	
Inlet: vent1 (120 x 160 cm)	Inlet: vent1 (120 x 160 cm)
Outlet: vent3 (80 x 100 cm)	Outlet: vent7 (120 x 160 cm)
	

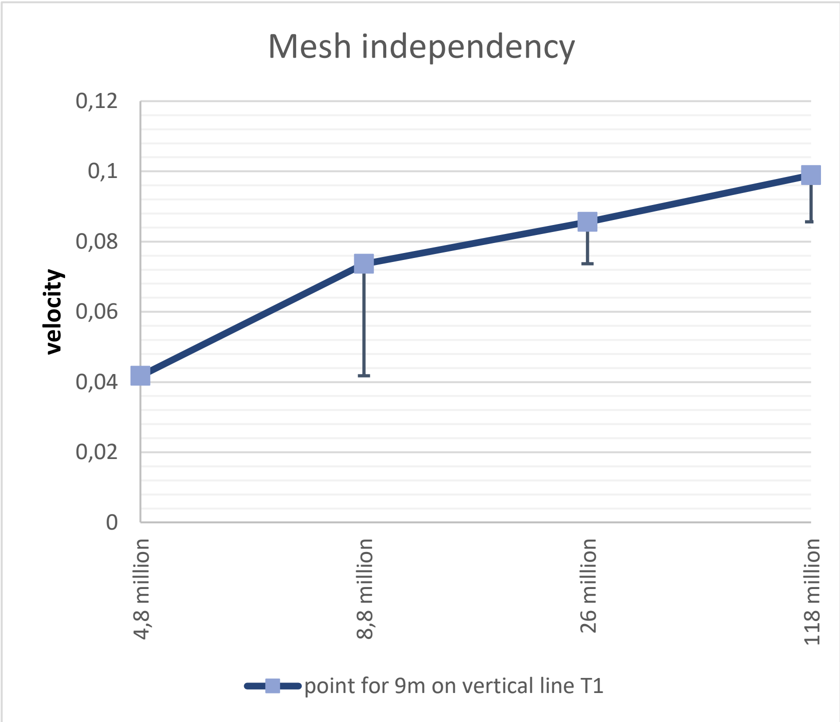
The geometric model created for the CFD analysis is symmetrical. Users and shoe racks have been calculated as fully loaded to capacity. A cylindrical model represents the user, and for CO_2 entry, a circular opening has been made, while a square prism represents the cabinets.

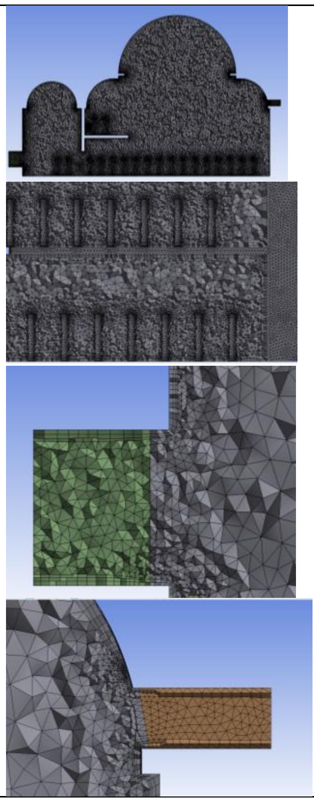
The ANSYS Fluent 2022 program was used for CFD analysis. A mesh grid was created using tetrahedral elements, suitable for CFD analysis of complex geometries. The minimum element height was set to 5 cm for the boundary layer. To ensure the flow reaches a stable regime before the vents, an external volume was created at a distance of 1 m outside the window.

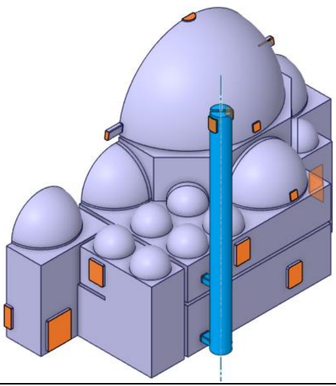
For cross ventilation and perpendicular ventilation, the inlet dimension (vent1) is 1.2 x 1.6 m, and the outlet dimension (vent3) is 0.8 x 1 m. For perpendicular ventilation, the inlet dimension (vent1) is 1.2 x 1.6 m, and the outlet dimension (vent 7) is 1.2 x 1.6 m.

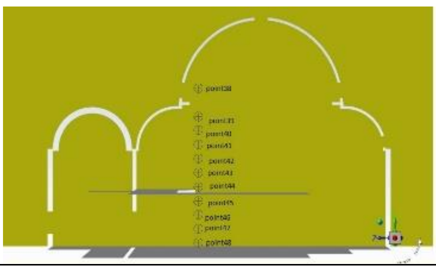
The parameters for evaluating CFD cases are temperature, ambient velocity, CO_2 concentration, PMV, PPD, and Draught rate. While PMV and PPD are indicators related to thermal conditions, according to the ISO 7730 standard, the Draught rate is a comfort indicator that depends on air velocity and thermal conditions.

***Tablo 3**. Mesh properties and mesh independence.*









Note: Steady-state velocity values are utilized for mesh independence. All windows are open. The mesh versions were determined so that each cell size was three times larger than the previous one.

To ensure that the analysis results are independent of mesh size, a mesh grid was selected based on the steady analyses performed with 4.8 million, 8.8 million, and 26 million mesh counts, as there was no significant difference found between the results with 8.8 million and 4.8 million mesh cells.

2.1. Boundary Conditions

Despite the selected project type having been implemented in many parts of the country, this study considers the climatic and geographical features of Ankara. The average outdoor air conditions for the winter months are taken from the TMY (1991) data for Ankara. The ambient pressure is based on the pressure at an elevation of 800 m above sea level, and the fluid behaves like an ideal gas. The outdoor CO_2 concentration is assumed to be 400 ppm. Considering that the building is in a fully occupied state, heat input, and CO_2 inlet have been defined from the modeled users. The building is accepted to be adiabatic, and heat losses/gains from the building envelope and radiation sources are neglected.

Due to the type of mosque layout, the building has been modeled symmetrically. On the entrance facade, a window is defined as an inlet, and on another facade, an opening is marked as an outlet, allowing for the analysis of cross and perpendicular natural ventilation. It has also been assumed that the door is continuously open. All the walls are made of gypsum material, and the transparency of other windows is ignored. A full occupancy situation has been analyzed in the building, and CO_2 and heat sources have been identified from the users. Heat sources have been defined from the floor and belongings. To evaluate odor problems that affect the perception of hygiene in mosques, ammonia (NH3) gas is used as a representative gas, considered as an emission source from shoe cups. Fluid materials are assumed to behave as ideal gases. The turbulence intensity for inlets and outlets is set at 20%. Turbulence kinetic energy and turbulence dissipation rate are referred to as K and epsilon, respectively.

Tablo 4. *Boundary condition of cases.*

	CV2D0S0-SIMPLE	CV2D0S0-Coupled	PV12D0S0-SIMPLE	PV12D0S0-Coupled
vent3 (60 x 80)	91723 Pa	91723 Pa		
vent7(120 x 160)			91863 Pa	91863 Pa
solver	SIMPLE	Coupled	SIMPLE	Coupled
door (200 x 230)	0,50 m/s			
vent1 (120 x 160)	0,52 m/s			
heat-source (floor)	120 W/m2, gypsum			
heat-source (body)	48,83 W/m2, wood			
outdoor temperature	1.6 °C			
indoor initial temperature	21 °C			
pollution source body	0.002553435 kg/s CO2			
pollution source shoe cup	4.19075e-6 kg/m3-s NH3			

In this study, the results of two measurements were analyzed using ANSYS Fluent software. CFD calculations require careful definition of boundary conditions when simulating natural ventilation conditions. In the literature, studies on ventilation influenced by wind have examined the inputs for large building samples, which change depending on wind speed and opening size, despite the selected solver and energy dissipation. (Table 1) Due to the flow being natural, turbulent flow equations were chosen. A relaxation factor of 1 was set for the convergence of the solution. All pressure, velocity, and turbulence discretization schemes are second-order discretization.

The model used tetrahedral cells to create a mesh network, which provides the highest quality mesh depending on the complexity of the geometry. Convergence was achieved at a level of 10^{-3} for continuity and x-y-z velocity and at a level of 10^{-7} for energy residual. Time integration uses the explicit method, with a time step of 2 seconds. Fluent analyses ran for 5 minutes.

3. RESULTS

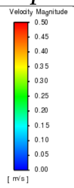
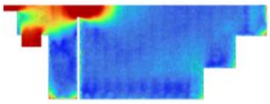
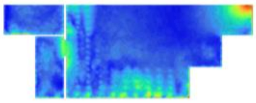
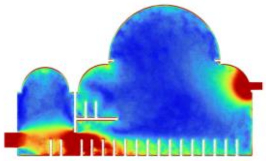
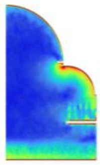
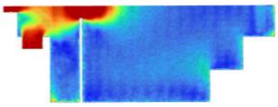
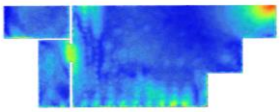
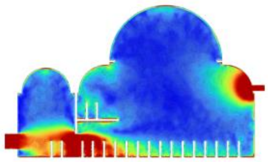
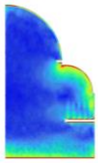
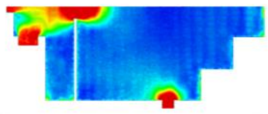
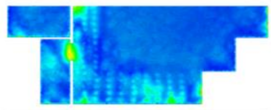
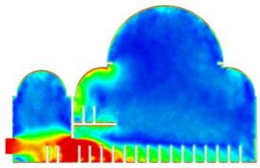
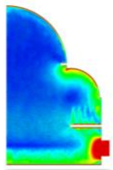
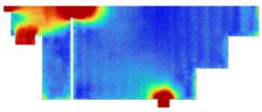
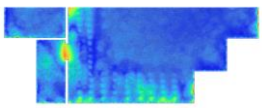
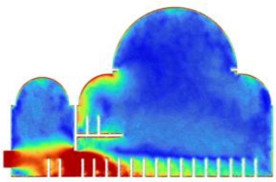
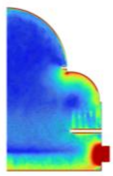
Cross-ventilation and perpendicular-ventilation situations are simulated with SIMPLE and Coupled solvers. Cross-ventilation cases occur through a fluid but perpendicular-ventilation cases occur rotational fluid pattern. According to the coupled solver, three components of the velocity vector are taken into consideration. Consequently, perpendicular cases differ from others for the coupled solver.

Tablo 5. *Velocity, temperature, and CO_2 concentration on central vertical three lines, for CV2D0S0 and PV12D0S0 cases.*

For both geometries, it's expected that the trends of the evaluation parameters on the central vertical lines show parallelism and have similar values to a certain extent. On the central three vertical lines, the CV2D0S0 velocity trendline is anti-parallel to the PV12D0S0 velocity trendline. Similarly, the CV2D0S0 temperature values differ from the PV12D0S0 temperature values over time. In the occupant zone, the CO2 concentration trendline is the same, but the CO_2 concentration values are distinct from the PV12D0S CO_2 concentration values over time.

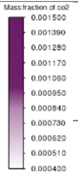
Coupled solver cases and SIMPLE solver cases are distinguished from each other because the geometries are 3D in both cases. The velocity value, which is the most important parameter that ensures the flow, differs between the coupled and SIMPLE solvers, and this is crucial for the accuracy of the results.

Table 6. *Velocity for cases CV2D0S0-SIMPLE, CVD0S0-Coupled, PV12D0S0-SIMPLE, PV12D0S0-Coupled. (Colormap 0-0,5 m/s and comfort max limit 0,5 m/s according to ISO 7730)*

	Velocity, m/s (comfort limits 0-0,2 m/s)			
	HARİM PLAN	MAHFİL PLAN	AA SECTION	CC SECTION
CV2D0S0-SIMPLE (ACH:5,68)				
CV2D0S0-Coupled (ACH:5,66)				
PV12D0S0-SIMPLE (ACH:5,62)				
PV12D0S0-Coupled (ACH:5,57)				

In the SIMPLE solver results for both geometries, the air velocity value is observed at high speeds in a wider region within the volume. In terms of ACH (Air change per hour), it is seen that the SIMPLE solver has a higher value depending on the air velocity values in the vents. The fact that the opening is close to the areas where the users are located creates unfavorable conditions in terms of comfort conditions.

Table 7. *CO_2 concentrations for cases CV2D0S0-SIMPLE, CV2D0S0-Coupled, PV12D0S0-SIMPLE, PV12D0S0-Coupled. (Colormap: 400 ppm – 1500 ppm and comfort max limit 1000ppm according to ASHRAE and TS 16798-1)*

	CO_2 concentration-ppm (comfort limits max 1000 ppm)			
	HARİM PLAN	MAHFİL PLAN	AA SECTION	CC SECTION
CV2D0S0-SIMPLE (ACH:5,68)				
CV2D0S0-Coupled (ACH:5,66)				
PV12D0S0-SIMPLE (ACH:5,62)				
PV12D0S0-Coupled (ACH:5,57)				

In the SIMPLE solver results where the air velocity values are higher, it is understood that in the CV2D0S0 analysis, the air flow exits from the outlet without reducing the concentration in the space due to the mutual location of the openings. However, for PV12D0S0 case, CO_2 concentration is lower in SIMPLE solver results where ACH and velocity values are higher. The fact that the airflow is perpendicular, not linear, and has a perpendicular direction has led to a lower CO_2 concentration inside the structure.

For CO_2 concentrations, the difference between the results for the two solvents increases over time, and for longer periods of use, such as 20 minutes, the final CO_2 concentration value will be quite different.

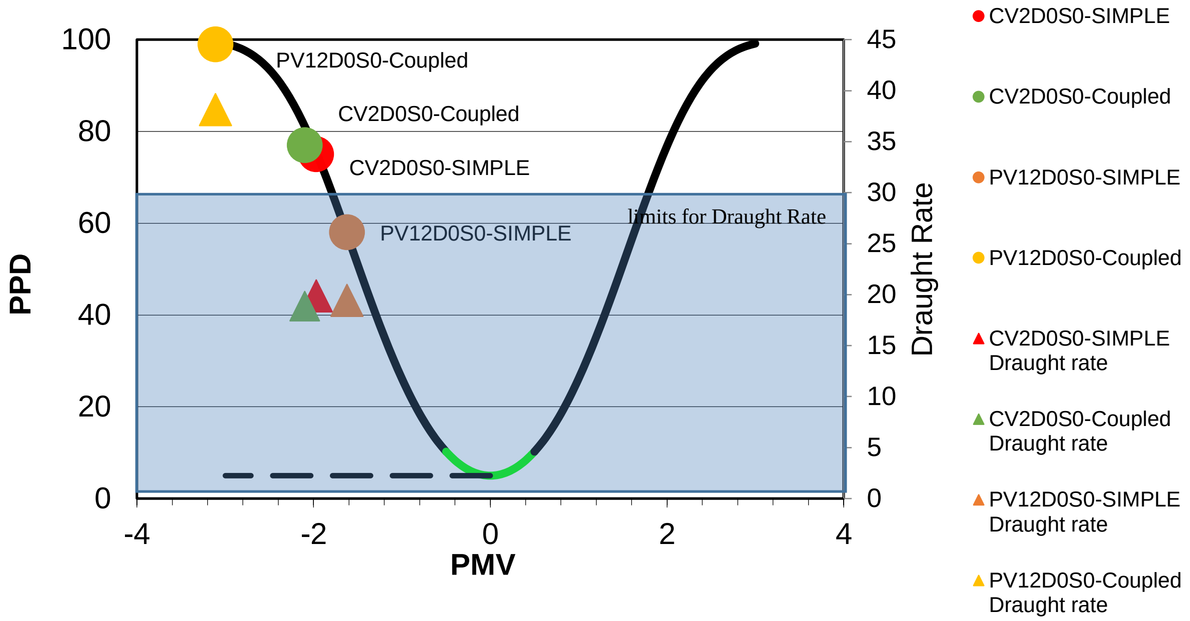


Figure 1. *PMV, PPD, and Draught rate (According to ISO 7730)*

In the analysis conducted for winter conditions in Ankara, using a boundary condition of 1.6°C as the average for the winter months from TMY (1991) resulted in PMV and PPD values being far from comfort conditions. Additionally, the Draught rate value for the CV2D0S0 Coupled and SIMPLE cases meets comfort conditions, whereas the PV12D0S0-Coupled case has a high draught rate. The high draught rate in the PV12D0S0-Coupled case is due to the parameters it depends on temperature and air speed.

Draught rate (DR) indicates the airflow rate in the environment and is a type of air movement that is particularly bothersome for people standing near windows in communal areas. Defined in ISO 7730, this parameter is calculated based on the air speed, turbulence intensity, and ambient temperature, and it tends to have a value that contrasts with thermal comfort (PMV) during winter conditions. As the natural airflow increases, the ambient temperature decreases. The PV12D0S0-Coupled case represents the most unfavorable example in terms of DR and PMV. Other examples have a DR value below the 30% limit.

4. DISCUSSION

The varying appearance of results dependent on the solver variable highlights the need for careful decision-making regarding the computational model in CFD analyses. When looking at the average values of three vertical lines within the space in Table 5, both the Coupled solver and the SIMPLE solver are consistent in terms of the trend of CO_2 concentration. The difference in trend between the velocity and temperature values, as well as the fluctuation in the velocity value at the 2nd minute, indicates that the SIMPLE solver is not stable. In the case of CV2D0S0, an irregular graph for the velocity value is observed, while in the PV12D0S0 case, fluctuations are noted in the temperature value. In CFD literature, achieving convergence and stabilization throughout repeated solutions reflects the appropriateness of the computational settings. However, the SIMPLE solver does not show stable results in the examples presented in this study.

In Table 6, the case with the lowest air change rate is the PV12D0S0-Coupled case. Comparing the air change rate with CO_2 concentration values in Table 5, the lowest example of ACH corresponds to the highest CO_2 concentration in Table 7.

Stavridou and Prinos, in their 2013 study, demonstrated that air layering occurs at the elevations above the outlet. The results of this study show that in areas where the airflow is minimal, meaning where the air speed is low, there is a buildup of CO_2. In this study, the CV0D0S0 case outlet is located above the 1st floor, while the PV12D0S0 case outlet is at the ground floor. For the CV0D0S case, when the inlet and outlet are chosen at different levels and in opposing locations, the flow pattern within the volume becomes linear. In the PV12D0S0 case, since the inlet and outlet are on the same floor but on perpendicular facades, the flow cannot facilitate the exchange of air in the upper levels, resulting in a high CO_2 concentration. Therefore, alongside the heights of the inlet and outlet, the flow pattern is significant. Especially in large volumes, areas that the flow cannot reach may create unfavorable environments regarding indoor air quality (IAQ) and thermal comfort.

In Figure 1, there isn't a relationship between the DR and PMV values, but both are indoor comfort parameters and are conversely positioned regarding comfort limits for samples. Under winter conditions, when the airspeed and turbulence are increased, as seen in the example PV12D0S0, the DR rate rises significantly while the PMV thermal comfort drops drastically.

5. CONCLUSION

The results showed that Solver settings play an important role in the prediction of the fluid patterns. As seen in the two examples where the fluid motion is linear and rotates in the 3D volume, there are significant differences, especially in the air velocity parameter. Although the parallelism of the results for temperature and CO_2 concentration is understood as the similarity of these two solvents, the most important parameter in indoor flow pattern determination is the velocity value. In CFD analysis, solver settings depend on the properties of the geometric model. Whether the flow is in two-dimensional or 3D flow volume affects the solver settings.

The reason for these differences is that in 3D geometries, the vectors of the flow vector in three directions in the Cartesian coordinate system affect the acceleration in all three directions. The use of the Coupled solver, which takes into account the effects of these vectorial values on each other in the calculations, will affect the accuracy of the results. With the Coupled solver, the residual graphs show a more stable trend.

Depending on the temperature, both PMV and PPD values and draught rate values are outside the comfort limits at the end of 20 minutes. It is seen that natural ventilation does not provide comfort limits in winter conditions, but it is thought that the expected standards can be met when the outdoor air temperature is close to the comfort temperature.

The CO_2 concentration was found to be slightly affected by the solvent difference, as it increases in the space due to each user, as a constituent in the fluid, due to the mass increase.

In each case in this study, the air velocity in the area close to the opening is higher than the comfort level and users in this area may experience negative space comfort due to drafts.

Air velocity was found to be the most important factor affecting the flow pattern and the distribution of concentrations and temperature.

The fact that the evaluation parameters have opposing effects necessitates conducting a significantly higher number of simulations and diversifying the variables to achieve optimal conditions. In this study, in order to further advance the investigations related to opening position and the solver, it is essential to determine suitable and accurate approaches for CFD solutions by conducting research based on variations in opening sizes, air velocities, and climate temperatures. Additionally, turbulence approaches, which have been extensively studied in the literature, need to be evaluated in the context of large volumes and differing opening positions. As a result, if CFD analyses are applied carefully in spaces, with a thorough examination of computational models and accurate interpretation according to the characteristics of the problem, they can be considered a reliable prediction for natural ventilation.

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PART B: ART, HUMANITIES, DESIGN AND PLANNING

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Cultural Transmission through Industrial Heritage Architecture: Van Nellefabriek

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Abstract

Today, many industrial structures are out of use for various reasons such as automation, changing demands of the market and consumers, insufficient infrastructure and architectural traits. Some of these structures are considered industrial heritage and are protected. Industrial heritage sheds light on the developments of societies in certain periods and has an impact on their culture. Therefore, they are unique representators.

The protection of various heritage structures and ensuring their use by conservation and restoration of them appropriately are important in terms of both reflecting and transmitting the culture of the time to which the structure belongs. This study aims to investigate whether the Van Nelle factory, listed as a heritage structure by UNESCO, encourages cultural transfer. During the research process, the issues of industrial heritage and culture and the transfer of culture through physical spaces were examined in detail. The Van Nelle factory is included in the research as a case study.

Inspection of the intertwined relationship between cultural transmission and the conservation of historic buildings is another aspect of the study. The impact of effective and reversible interventions has been tried to discover.

1. INTRODUCTION

The Industrial Revolution, which began in the eighteenth century, brought about great changes in many areas of society. Many branches of industry have developed based on the needs arising in production and cities have been shaped with the impact of these developments (Uysal & Manav, 2024). Since the industrial revolution modern societies have started to develop and change, this metamorphosis occurred in every portion of civilization. It is only natural to see the outcomes of this tidal wave in architecture and space planning. Building types, forms, and scales have been drastically changed. One of these buildings' forms are industrial facility. Although they existed before the Industrial Revolution, the revolution marked a transformative leap in scale, efficiency, and economic impact. In time, some factors lead to a decrease in the need for facilities like this such as the growth of international trade networks, outsourcing materials, technological advances like automation, environmental and health concerns, and urbanization. Eventually, most of these buildings were abandoned without any sufficient usage or solution to enhance their desirability once again.

Culture is a definite norm for human existence. Every individual in a society acts upon their own culture. These particular cultural systems are created by the individual's environment. Gradually, with the contributions of old and new generations, cultural entities are transferred. This transfer process is called cultural transmission, which is the essence of cultural continuity and, from a greater spectrum, of humanity. We may define many cultural elements, even group them as tangible and intangible. Tangible cultural elements include architectural productions as well. The relationship between building and the builder has two ways, both influence one another. Buildings stabilize social life. They give structure to social institutions, durability to social networks, persistence to behavior patterns. What we build solidifies the

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society against time and its incessant forces for change (Gieryn, 2002). Naturally, construction and design are culturally infused.

Remnants of the past hold great importance for cultures. Since architecture and culture are inseparable, buildings, especially heritage buildings, may be considered strong cultural transmission tools. They influence local and global culture by articulating the way of life of the prior members of the community. Thus, they need utter protection. Successful protection would help create a long-lasting cultural landmark.

2. METHOD

This study aims to explore the relationship between cultural transmission and built heritage, specifically focusing on architectural heritage. Architectural heritage encompasses structures of various sizes and functions. For this research industrial heritage category had been selected. Industrial heritage includes a diverse range of structures, effectively showcasing the materials used, construction techniques, and architectural styles of their respective periods. Therefore, these types of structures have been chosen as the focus of this study.

A qualitative case study approach held to examine the relationship between cultural transmission and industrial heritage. This method considered suitable for analyzing how conservation facilitates cultural transmission within historical contexts. Van Nellefabriek factory had been chosen as a case example. The primary reason for selecting this particular building is its designation as a UNESCO World Heritage Site, which has been recognized since 2014. Information and resources about the building were gathered from UNESCO's official website dedicated to the Van Nellefabriek. The restoration project of the Van Nelle factory was examined as a case study at the Technical University of Delft in the Netherlands, under the instruction of Wessel de Jonge. Data and visual materials were collected from the TU Delft case study as well as from a video describing Jonge's project.

Two key factors were considered in assessing the relationship between structure and cultural transmission: authenticity and integrity. These evaluation criteria were supported by the ICOMOS report of listed buildings for Van Nelle. This report provides detailed information about the original factory compound, the restoration process and the factors influencing its listing, serving as a valuable resource. Artifacts from the report regarding authenticity and integrity were used to create two tables. These tables serve as supportive elements in determining whether the factory can be recognized as a cultural transmitter.

3. INDUSTRIAL HERITAGE AND CULTURE

The Nizhny Tagil Charter (2003) defines Industrial Heritage as follows: 'Industrial heritage consists of the remains of industrial culture which are of historical, technological, social, architectural or scientific value. These remains consist of buildings and machinery, workshops, mills and factories, mines and sites for processing and refining, warehouses and stores, places where energy is generated, transmitted, and used, transport and all its infrastructure, as well as places used for social activities related to industry such as housing, religious worship or education.' Based on this definition, it is possible to state that industrial heritage has a broad spectrum of artifacts to consider.

Industrial heritage is deeply connected to industrial archeology. While industrial heritage covers built or tangible elements, industrial archeology is responsible for researching, discovering, and recording heritage materials. Both co-exist except archeology is a little more comprehensive concept. As Richard Stinshoff (2013) emphasizes, practitioners of this discipline, from the beginning, used to refer to the physical remains of the industrial past by the collective term ‘industrial heritage’ as a legacy for whose protection and understanding Industrial Archaeology’s stewardship would be crucial.

The roots of industrial heritage go back to the 1940's. The United Kingdom might be seen as a pioneer in defining and protecting industrial heritage. According to British historian Barrie Trinder (1981), around 1940’s British people changed their perspectives on industrial vestiges and transformed their understanding from ugly to a valuable asset. This change was achieved and supported by the author L.T.C. Roth. Roth's efforts and works were in a local state. Recognition of industrial assets as heritage at a global level did not occur until the 1970's. The First International Congress on the Conservation of Industrial Monuments (FICCIM) gathered in 1973 at Ironbridge, United Kingdom. This congress marks the first international step to the protection of industrial heritage. Followed by the second congress (SICCIM) in 1975 and the third one in 1978 total of 15 congresses listed on the official TICCIH website. The third one marks a name change from Industrial Monuments to Industrial Heritage (Saner, 2012).

With the influence of conferences, specifically the first and second, the need for an official organization focused on industrial heritage arose. Thus, The International Committee for the Conservation of the Industrial Heritage (TICCIH) was founded on July 4, 1978. TICCIH is the first international organization established solely interested in industrial heritage. Regarding heritage and protection of related artifacts, ICOMOS should be addressed as the most influential and extensive organization. On November 10, 2014, a Memorandum of Understanding was signed (TICCIH, Memorandum of Understanding, 2014) between TICCIH and ICOMOS which helped TICCIH to be more influential.

There is a general intersection point in the relationship between culture and all types of heritage. This point is memory. Without memory, a sense of self, identity, culture, and heritage is lost (McDowell, 2008). Thus, the existence of heritage is a form of security for memory and culture. Heritage also has the power to create its own cultural landscape. In terms of this creation industrial entities play an important role in particular. It is common to find regional or urban settlements located closely or centered around those structures. By studying an industrial heritage, the site it had built on and its surroundings could narrate crucial details about the former citizens of that specific region. Information gathered this way presents a groundwork for understanding cultural accumulation.

Integrating industrial heritage into modern urban settlements creates a multi-dimensional cultural area. As Luis Torres (2018) emphasizes cities are by far the largest creation of humanity. Cultural entities that contain representations from the past, via the present, to the future, running through the entire cultural evolution of the 'city as object'. Proper integration may create cultural transaction areas where heritage building undertakes the role of the conveyor. Keeping heritage buildings in use with different purposes will contribute to sustainability in both environmental and cultural dimensions.

4. CULTURAL TRANSMISSION THROUGH PHYSICAL SPACES

Knowledge since the start of humanity is conveyed from one generation to the other with the intent of creating the ultimate network of information which is the basis of the everyday lives of people. Conveyed cumulative knowledge has different aspects, and culture is one of these. Naturally, culture has a unique transfer mechanism. Bissin and Verdier (2008) explain this as follows: 'Preferences, beliefs, and norms that govern human behaviour are partly formed as the result of genetic evolution, and partly transmitted through generations and acquired by learning and other forms of social interaction. The transmission of preferences, beliefs and norms of behaviour which is the result of social interactions across and within generations is called cultural transmission.' Cultural transmission is substantial for the continuity of diversity.

Cultural transmission is a method of learning, and a theory has been developed to explain how it occurs, known as cultural transmission. Generally, there are three types of cultural transmission: vertical, oblique, and horizontal. Taylor & Thoth (2011) explain vertical transmission as passing on cultural elements from parent or caregiver to children, horizontal as similar to peer learning because transmission occurs between members of the same generation, and oblique as a more diffuse system due to unrelated individuals from one generation pass on culture to the next. The transmission type and the conveyor are also important factors in the process.

Clifford Geertz (1973) explains culture concept as a pattern of historically transmitted meanings manifested in symbols, a system of inherited concepts expressed in symbolic forms through which humans communicate, preserve, and develop their knowledge of life and attitudes toward life. The symbols, systems, and concepts mentioned above are all abstract forms of information. Intangible knowledge becomes concrete when embodied by an artifact. This embodiment also represents a transmission. Any object, document, or material could be a transmitter. Once they are protected and properly preserved, they can facilitate communication between generations, transcending the barriers of time.

Human life is centered around daily routines and activities, shaped by their combination. Daily life differs across societies due to unique habits, and this variation can also be observed at a regional level. Individuals spend most of their time in defined spaces. These areas are usually reserved and designed for a specific activity such as education, work, or healthcare. Space has an important role in strengthening cultural change, because the expected behavior patterns within a particular space reflects the specific cultural values (Ettehad, Karimi, & Kari, 2014). This is where architecture comes forward. By defining, designing and building places architecture helps to create meaningful context areas for culture flourishment and transfer. Therefore, it is a crucial component of culture in more than many aspects. In his research Ashadi (2020) demonstrates the relationship between culture and architecture as shown in Table 1.

Table 1. *The model of the relationship between culture and architecture*

Architecture and culture	Architecture	Scope of culture
Functional	As a result of social components interaction	Sociology
Conceptual	As an artistic product that includes an end elevation of the mind	Aesthetics
Functional Conceptual	As a matter of human's life and includes and effective on actions	Anthropology
Perceptual	As a result of mental attitude to the surrounding built environment	Psychology

Buildings incorporate culture in many ways. In architectural design projects, culture can be embodied in appearance, materials, spatial layout and decoration (Wang, Atipattayakul, & Sengna, 2024). Interior and exterior cultures are cultivated in a unified manner. Regarding appearance, the facade serves as the first impression of every structure and conveys the cultural elements directly through observation. Material selection is another aspect. Specific material choices and sources of materials also represent the cultural values of societies. The intersection of material and culture can be observed through building techniques and craftsmanship. Spatial layout and decoration directly relate to habitants' lifestyles, manners, and activities. These aspects form culture. Thus, spatial planning and decoration might be considered the most culturally specific areas of a building.

Several researchers tried to uncover the connection between cultural transmission and architecture. Voogt, Maillot, Lang, and Eerkens focused on architectural traits' transmission in the Near East and the Meroitic Kingdom while Bill Hillier explored modern European constructions to find meaningful connections. Both studies are good examples, proving that buildings and culture influence each other. Regional differences might affect the way of transmission but it occurs anyhow.

For heritage structures to effectively serve as a medium for cultural transmission, their original components must be visible and functional. When assessed from an interior perspective, the structure's integrity—considering its dimensions, layout, materials, and decorative elements—is crucial for understanding and conveying its cultural values. This is where building preservation becomes essential. As Milligan (2007) suggests, historic preservation presents an avenue for studying how the built environment, specifically the historic built environment, is given meaning and the processes through which it shapes and constrains interaction. Therefore, heritage protection highly contributes building's role as a transmitter. Culture, architecture, and conservation share mutual roots which make them inseparable in many ways. As The Australia ICOMOS Burra Charter, 2013 states: 'Cultural significance is embodied in the place itself, its fabric, setting, use, associations, meanings, records, related places and related objects. Preservation and conversation of these cultural entities can create a bridge for transmission.

5. VAN NELLEFABRIEK

The original Van Nelle factory, known in Dutch as the Van Nellefabriek, was designed by architects Johannes Brinkman and Van der Vlugt between 1925 and 1931 in Rotterdam, Netherlands (Figure 1). Commonly referred to as a 'sunlight factory' due to its predominantly transparent glass façade, it is regarded as one of the most modern manufacturing facilities in the country. As Wessel de Jonge (2021) describes, prior factory constructions were limited in terms of the allowance of natural light in the interior spaces. This emphasizes Van Nelle's uniqueness and importance. The factory had a separate administration block that showed the same transparency (Bergeijk, 2012). The design also incorporates concrete in its construction, a clear representation of the influence of the Modern Movement in architecture.

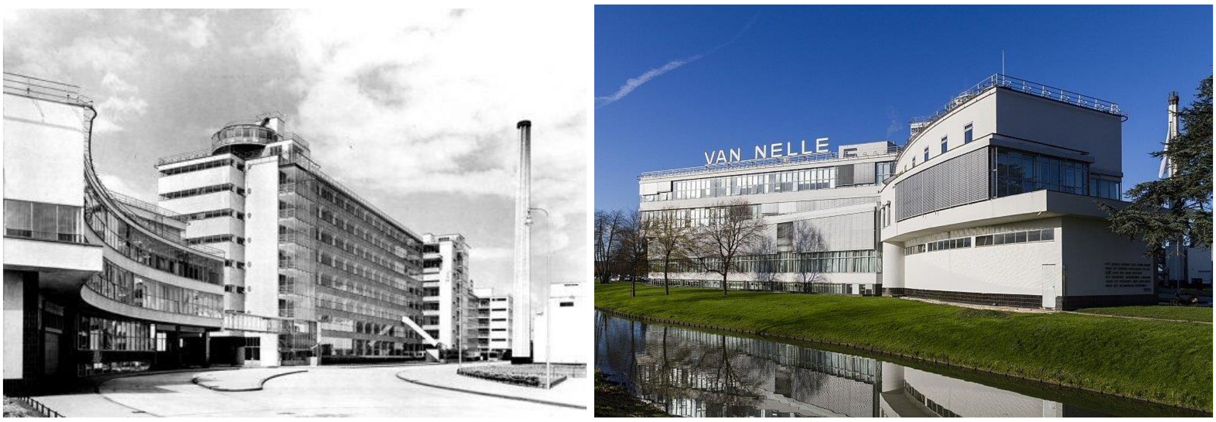

Figure 1. *Van Nellefabriek Exterior Views [22], [25]*

The factory produced tea, coffee, and tobacco products. There are three factory buildings on the site. Essentially, the factory consists of three different buildings. The largest and tallest of them, the tobacco factory (1926-1929), is in the centre. To the north of it is the coffee factory (1928-1930), which is slightly less tall, followed by the tea factory (1928-1929), whose height is in turn lower. To the south, the alignment of the curtain wall facades is continued by the office building (1928-1930) which forms a concave line in the perspective. The run of glass curtain walls is some 220 m long. It is dominated by horizontal lines, which are punctuated by three vertical stair well blocks, the tallest of which culminates in the rotunda-shaped tea room (1926-1929), which provides a panoramic view of the factory and the surrounding area (Figure 2).

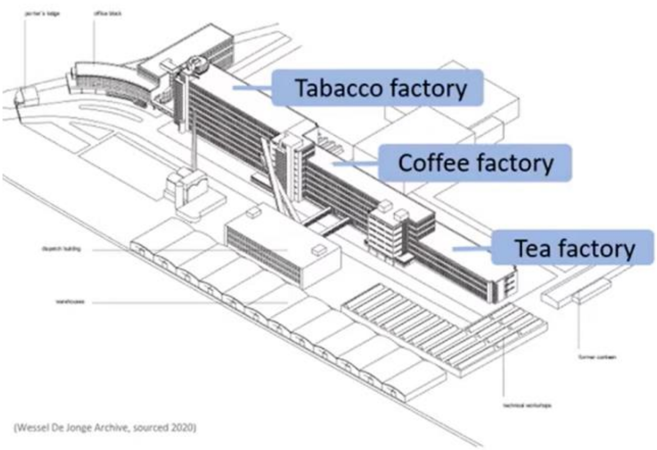

Figure 2. *Van Nelle Factory building distribution [26]*

Opposite the main architectural ensemble and the series of glass curtain walls, there is a series of functional buildings along the other side of the internal street: the boiler house and its lofty chimney (1927-1929), the large dispatching hall (1929-1930) with five overhead bridges linking it to the factories, the warehouses (1942-1943 and 1967), and finally along the canal and closing off the space to the north, the workshop building (1929-1930) (ICOMOS, 2014). Along with the curtain wall, the most important architectural feature of the building is the octagonal 'mushroom' columns (Figure 3).

Figure 3. *Mushroom Columns, Van Nellefabriek Interior [27]*

Van Nelle's compound exemplifies numerous architectural traits representing a pivotal era in terms of design, construction techniques, and usage of new materials. Thus in 2014, Van Nellefabriek was recognized as a 'World Heritage' and listed in the heritage buildings list by UNESCO.

5.1. Restoration Process

Architect Wessel de Jonge carried out Van Nelle's restoration project. The redevelopment project, involving the conservation and adaptive reuse of all ten buildings and the outdoor space, started in late 1998. As conceived by its spiritual father, Eric Gude (1953-2018), this endeavor aimed to create a hub for the creative industry of Rotterdam: the 'Van Nelle Ontwerp Fabriek' (Design Factory) (van Hevele & de Jonge, 2024).

According to video explaining the renovation story on the TU Delft case website (2020), the architect created a strategy code for Van Nelle's restoration project. He named this approach as CRASH. C stands for Conservation, R for Reuse, A for architecture, S for Sustainability, and H for Heritage. He also color-coded every aspect. There are two colors used for coding: blue and green. Based on Wessel de Jonge's explanations, code Blue could be considered for mostly successful and highly protected aspects whereas code Green is awarded for the aspects where there is some degree of sacrifice in terms of conservation (Table 2).

Table 2. *Wessel de Jonge CRASH color codes*

INTERVENTION - COLOR CODE TABLE		
CRASH CODE	COLOR	
INTERVENTION TYPE	BLUE	GREEN
CONSERVATION		
REUSE		
ARCHITECTURE		
SUSTAINABILITY		
HERITAGE		

For the Conservation he awarded it as blue and stated '*Almost all that was still there has been retained and conserved, minor missing elements were restored and completely missing elements were not reconstructed*'. Reuse was also awarded blue by the architect. He explains this '*From an obsolete and empty building into a well-used workspace. The new use is quite compatible with the old building.*' For the architecture, de Jonge considered green: '*The volumetry, transparency, sight lines, nocturnal image, etc., and the modern architectural spirit of the factory has been carefully kept and conserved. At least from the outside.*' To figure out an effective use in terms of new function, interior spaces of the factory building had been installed with partially glazed partition walls that separated and divided interiors (Figure 4), (Delft, 2020).

Figure 4. *Office spaces divided by partitions [28]*

Restaurant area (Figure 5) and ground floor event spaces are kept without much intervention with the aim of visitors should understand and perceive the original place. One important aspect regarding the interventions is that de Jonge states were largely reversible except for flooring (Figure 6), (Delft, 2020).

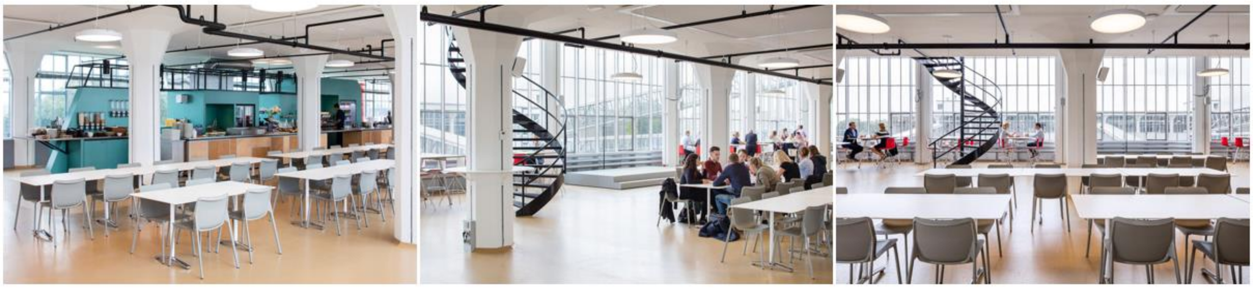

Figure 5. *Van Nelle Restaurant area interior [29]*

Again, for sustainability he awarded green. Both energy efficiency and conservation are secured by a double-skinned façade. However, he admits that in terms of sustainability, a lot more could be done, even with the 1999 standards. As for the last aspect Heritage, he was awarded as green. De Jonge explains this aspect: '*Intervention has little negative impact on the heritage like significance. Even opening up the premises made the heritage values more available to the public at large the interior spaces have largely been altered though in a sensitive way. Because we left some spaces relatively untouched you can still tour and enjoy the building as it originally was.'*, (Delft, 2020).

Figure 6. *Van Nelle Factory flooring before renovation [30]*

Once the restoration works were completed, the Van Nelle Factory started operating as an office and event venue. Users can rent office spaces of different sizes. This marks a complete change in function, allowing Van Nelle to continue its operations.

5.2. ICOMOS Evaluation and Listing

Van Nellefabriek was listed as a heritage building in 2014. Wessel de Jonge notes that the factory was listed after all the restoration project interventions were completed (Delft, 2020). The report regarding the listing contains justification for inscription, integrity, and authenticity. This chapter explains the reason behind Van Nelle's nomination as a heritage building based on a comparative analysis made by the State Party. Five aspects are listed related to the nomination of the building (Table 3). ICOMOS considers that this justification is for the most part appropriate, and that the Van Nellefabriek is indeed an icon of Modernism in industrial architecture (ICOMOS, 2014).

Table 3. *ICOMOS articles for justification of outstanding universal value.*

ICOMOS	
JUSTIFICATION OF OUTSTANDING UNIVERSAL VALUE	
NUMBER	VALUE
1	It is an example of industrial urban planning, constructed in an open polder area, close to a canal, roads and the railway; the urban planning, and the architectural choices, represent the combined achievement of the humanistic entrepreneur who commissioned the factory and a team of architects and engineers taking their inspiration from Modernism.
2	Through its industrial urban planning approach, and its architecture which is open both in spatial terms and in terms of admitting daylight, the Van Nellefabriek quickly became an icon of Modernism. It is considered to be a particularly accomplished and coherent example of the way an industrial complex can be integrated with its environment.
3	The facades make systematic and large-scale use of curtain walls, consisting of continuous windows in metal frames, giving them a specific tone which is both sober and bright.
4	The general architectural choices reflect outstanding use of verticality and horizontality, to maximise the functionality of the space and its overall aesthetics.
5	It reflects an open and progressive design of the interior spaces based on the rationalisation of the processing of food products (tea, coffee and tobacco) and adaptability to changes in industrial processes.

Another important aspect of the report is the three criteria related to the building's cultural importance (Table 4).

Table 4. *ICOMOS cultural criteria which inscription proposed*

ICOMOS			
CULTURAL CRITERIA			
CRITERION		ICOMOS' EXPLANATION	ICOMOS' CONSIDERATION
(i)	Represent a masterpiece of human creative genius	ICOMOS considers that the Van Nellefabriek is one of the most accomplished industrial installations of the inter-war years, in terms of modernism in the industrial world and functionalism in architecture. The synthesis that it represents however brings together trends in architecture and in the planning of industrial areas that considerably pre-date the Van Nellefabriek, and the values advanced here are explicitly recognised under criteria (ii) and (iv).	ICOMOS considers that this criterion has not been justified.
(ii)	Exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design	ICOMOS considers that the Van Nellefabriek embodies the bringing together and use of technical and architectural ideas that were born in various parts of Europe and North America, just before World War One and in the years that followed. It is successful in terms of its location with its harmonious functional relationship with its environment, and its accomplished architectural realisation. It became one of the great international icons, in Europe and the Americas, of Modernism in the industrial field, and constitutes an exemplary contribution by the Netherlands to this movement. It illustrates the long-established importance of the port of Rotterdam in the international food product trade.	ICOMOS considers that this criterion has been justified.
(iv)	Be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history	ICOMOS considers that the Van Nellefabriek is technically one of the most accomplished industrial complexes ever built, and one of the great aesthetic successes of Modernism and Functionalism in architecture during the inter-war period. In terms of industrial architecture, it is an eminent example which illustrates the values of the relationship with the environment, particularly with the canals and transport networks, of rational organisation of production and mechanical handling flows, and of maximum use of daylight through the large-scale use of a curtain wall of glass reinforced with iron. It expresses the values of clarity, fluidity and the opening up of industry to the outside world.	ICOMOS considers that this criterion has been justified.

Two suggested criteria were accepted as justified by ICOMOS, while one was rejected. As the report describes, even though Van Nelle is a good and strong example of an industrial heritage other buildings that also reflect the same architectural traits traced back to the same period. The assessment concludes with the statement 'ICOMOS considers that the nominated property meets the conditions of integrity and -authenticity, and meets criteria (ii) and (iv).'

ICOMOS's report presents a largely positive outlook for the restoration project. The only noted downside is the building's resemblance to other examples of industrial architecture. The echoes of modernist architecture and industrialism could be observed all across the European continent. Thus, Van Nelle's similarity with other architectural examples can be considered a natural outcome.

6. CONCLUSION

Van Nelle's restoration and cultural transmission connection could be evaluated using two criteria: protection of authenticity and unique features of the building after interventions in other words integrity. The evaluation is supported by the ICOMOS report on Van Nelle.

The listing happened after restoration. Thus, it could be determined as a successful intervention process. Here, it can be thought that authenticity and integrity are intertwined at some level. Integrity can be interpreted as no apparent loss of any part of the structure. On the other hand, authenticity is a concept that includes the preservation of special and unique parts of the structure. It can be thought that authenticity will also be preserved under conditions where integrity is achieved. However, this is not always the case. While all parts of the structure are physically preserved, in other words, they are not demolished, fragmented, or destroyed, interventions carried out on a superficial scale will prevent the original texture from being seen and might damage authenticity.

For both integrity and authenticity, the Report (2014) finds the building intact. The following phrases supports this outcome:

- ICOMOS considers that the conditions of integrity, in terms of urban composition (locations of buildings and organisation of territory, functional relationships, panoramic views, etc.) and architectural terms, from the various exterior and interior aspects, are satisfactory.
- ICOMOS considers that the restructuring/restoration of the property undertaken for economic reasons between 2000 and 2006 has been well integrated into a property that has been generally well maintained, and which has undergone no major reconstruction or alteration since it was first

> built. The work has been conducted with great care, in a model works project which is today considered to be a benchmark. The various aspects of authenticity of the property have thus been satisfactorily maintained, and this authenticity is clearly visible to the Van Nellefabriek's visitors and users.

Based on the elaborations and explanations provided by the ICOMOS, it is possible to consider Van Nelle factory as a good and solid example of a cultural transmitter.

However, a few remarks can be emphasized. As the architect described, the only loss of identity occurred for the flooring. Protection of the original flooring could be a positive contribution in terms of culture. Original flooring would reflect the period's unique material selection and construction techniques. Like most of the industrial buildings, Van Nelle had an uninterrupted interior space in terms of mass, volume and spacing. Re-designing the interior spaces for the new function to work out smoothly is a right path to follow. Dividing some areas with partitions may also created some loss. But this intervention did not apply for all the interior spaces and it is reversible which eventually makes it a positive approach. Even with these two factors, Van Nelle could be experienced by the users an almost completely original structure. This interaction would create cultural transmission. As a strong example of modern industrial complex with open-plan interior, the Van Nelle Factory serves as an exemplary case for the adaptive reuse of large-scale industrial buildings, particularly in their transformation into public or mixed-used spaces.

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AI-Driven Tools for Advancing the Industrial Design Process – A Literature Review

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Abstract

The integration of artificial intelligence (AI) into industrial design is revolutionizing traditional methods, particularly in areas such as generative design, sustainable material selection, and predictive analytics by using rapid prototypes. This study systematically reviews existing literature and presents empirical findings on the practical applications of AI in industrial design. The findings indicate that AI-assisted workflows can significantly reduce prototyping time and increase the number of design iterations, demonstrating its ability to accelerate innovation. Additionally, qualitative insights highlight AI's role in overcoming creative blockages and refining complex design elements. However, limitations exist, including an over-reliance on AI-generated outputs and challenges in integrating AI tools with traditional design intuition.

By synthesizing current research, this article provides a comprehensive evaluation of AI's role in industrial design, discussing its benefits and limitations. It also proposes future research directions, such as improving AI-human collaboration in ideation and refining AI's adaptability to non-traditional design aesthetics.

1. INTRODUCTION

The field of industrial design has traditionally relied on iterative processes, often requiring multiple rounds of prototyping, testing, and refinement before achieving final products. However, the advent of artificial intelligence (AI) is reshaping these methods, providing designers with tools that can accelerate workflows, reduce resource waste, and support innovative and sustainable decision-making[1]. AI's potential to enhance industrial design is evident in various stages, from concept generation to production, where algorithms are used to generate and test countless design iterations, simulate real-world conditions, and even predict user interactions[2]. The impact of AI is most notable in areas such as generative design, sustainable material selection, data-driven personalization, and predictive analytics and rapid prototyping, offering both speed and accuracy in the design-to-market cycle[3]. Feng et.al. [4]state that areas such as rapid prototyping which require product properties to be listed in precise data files such as 3d models have an advantage to take part in AI driven design and later prototyping-manufacturing processes.

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Figure 1. *CAD rendering and the prototypes of a table clock product concept (designed and built by the author).*

Therefore, one of the most transformative applications of AI in industrial design is in rapid prototyping as shown in Figure 1. AI-driven generative design and simulation tools allow designers to create virtual models that mimic physical prototypes, drastically reducing the need for physical tests. Recent advancements in AI simulation have enabled designers to predict wear and tear, ergonomics, and usability without producing multiple physical prototypes, leading to significant cost and time savings[5]. This trend aligns with the broader industrial shift towards digital twins - virtual replicas that serve as test beds for physical products - enabling a more efficient design process[6]

Sustainable material selection is another critical area where AI plays a key role. As environmental concerns grow, designers are increasingly tasked with balancing aesthetics, durability, and eco-friendliness. AI algorithms can analyze vast datasets on material properties, such as environmental impact, durability, and cost, assisting designers in making informed choices that minimize environmental impact while maintaining product integrity[7]. For instance, AI can predict the environmental footprint of specific materials, allowing designers to select eco-friendly alternatives without compromising on quality or aesthetics[8].

AI's ability to personalize mass production and enhance interdisciplinary collaboration marks a new era in industrial design. By analyzing user data, AI can tailor designs to individual preferences, thus enabling more personalized yet scalable solutions[9].

With these properties, AI is becoming a central tool for cross-functional collaboration among designers, engineers, and product managers, streamlining the design process through real-time feedback and iteration loops[10].

The purpose of this study is to examine the role of AI in industrial design by analyzing its applications, benefits, and limitations. This research is framed within the conceptual phase of the industrial design process. By reviewing existing literature, the study aims to assess how AI enhances key design phases, from ideation to prototyping and final product development.

To achieve this purpose, a systematic literature review is conducted on empirical and theoretical studies on AI applications in industrial design. The research follows a qualitative approach, analyzing case studies and experimental findings from various industries, including consumer electronics, automotive, and sustainable product design. The central research question guiding this study is: "How do AI-driven tools contribute to the efficiency, sustainability, and innovation of the industrial design process?" Through this analysis, the study aims to provide a comprehensive understanding of AI's impact on industrial design while identifying challenges and opportunities for future advancements.

2. ARTIFICIAL INTELLIGENCE TOOLS FOR INDUSTRIAL DESIGN

In industrial product design, several artificial intelligence (AI) tools can be useful to optimize workflows, improve design quality, enhance customer satisfaction, and streamline production processes[11].

Current design tools, such as Autodesk Generative Design, Siemens NX, and Fusion 360, utilize AI algorithms to generate a wide range of design alternatives based on parameters like material, weight, and manufacturing methods[12]. These tools often create unconventional, but highly optimized designs that meet performance, cost, or durability requirements. Machine learning applications, such as IBM Watson, DataRobot, and TensorFlow, enable predictive analytics that can identify potential failures early, optimize maintenance schedules, and refine designs based on data from prototypes or existing products[13].

Digital twins, implemented through platforms like Siemens MindSphere, GE Predix, and Microsoft Azure, create digital replicas of physical products or systems. This allows designers to simulate and test models virtually, reducing the need for physical prototypes and enabling more efficient product development[14]. Computer vision tools, including Google Cloud Vision, Amazon Recognition, and OpenCV-based custom solutions, are used for quality control, detecting defects early in the manufacturing process and improving design feedback loops[15].

Natural language processing (NLP) technologies like Google NLP API, Amazon Comprehend, and IBM Watson's NLP tools analyze customer feedback from various sources—such as reviews, surveys, and social media—helping designers tailor products to better meet user needs. Robotic process automation (RPA) tools, such as UiPath, Blue Prism, and Automation Anywhere, automate routine design and administrative tasks like data entry, document creation, and design file management, allowing designers to focus more on creative and strategic aspects[16].

AI-driven optimization platforms, including MATLAB, Ansys, and Altair HyperWorks, allow designers to run complex simulations and optimizations, gaining deeper insights into product behavior under different conditions[17]. Similarly, voice and speech recognition tools like Microsoft Azure Speech Services and Google Speech-to-Text facilitate hands-free design adjustments, improving process speed and accessibility[18]. Virtual and augmented reality (VR/AR) platforms, such as Unity, Unreal Engine, Vuforia, and PTC Creo, incorporate AI to provide immersive 3D visualization, allowing designers to evaluate and refine products before they are physically created, fostering better design choices and collaboration[19].

Lastly, deep learning libraries such as PyTorch, Keras, and TensorFlow are used to create customized models that can optimize component shapes, materials, and assembly processes, helping tailor designs based on extensive datasets from past products[20].

The next chapter will explain our methodology to explore current research literature on how industrial product designers can leverage selected AI tools to drive innovation, accelerate time to market, enhance product quality, and develop more efficient and optimized products.

3. METHODOLOGY

This article employs a systematic literature review to explore the applications and impacts of artificial intelligence (AI) in industrial design. The methodology focuses on analyzing recent scholarly research, industry reports, and case studies mostly published in the last five years, capturing insights into how AI is transforming processes such as rapid prototyping, sustainable material selection, data-driven personalization, predictive analytics, and interdisciplinary collaboration.

To ensure a comprehensive overview, the literature selection targeted studies from multiple industries-including automotive, manufacturing, consumer goods, and packaging-that highlight AI’s role across diverse industrial design contexts. The criteria for including each study were based on relevance to these specific themes and each source’s contribution to understanding AI’s role in enhancing the design process.

The review process involved the following steps:

Literature Search and Selection: Scholarly databases, including IEEE Xplore, ScienceDirect, and Google Scholar, were searched using keywords such as "AI in industrial design," "rapid prototyping with AI," "sustainable materials selection," and "generative design." To capture recent developments, the search mainly focused on articles from 2019 to 2025. These searches resulted in more than 500 papers initially being considered. The next step involved reading the abstracts and, when necessary, the full text of the papers to ensure relevance. Notes were taken to extract key insights, methods, and findings from each source

Categorization of Findings: The content was analyzed for recurring themes and trends in AI applications in industrial design, such as rapid prototyping, material selection, personalization, collaboration, generative design and such. This categorization enabled a structured analysis of AI applications across different stages of the industrial design process. The final dataset consisted of 45 research articles, 10 reports, and 12 case studies, which were deemed suitable for the systematic review. After final checks against repetitive subjects, study areas, industries etc., 60 studies took place in this article.

Thematic Analysis was used to systematically extract key insights, trends, and implications from the studies about how AI reshapes industrial design. This analysis focused on comparing the goals, methodologies, and results of the studies to identify common patterns and themes. Key aspects like AI's role in optimizing design performance, improving sustainability, and enhancing customization were highlighted, with an emphasis on how AI technologies such as generative design, predictive analytics, and digital twins are being implemented. This comparative approach revealed AI's transformative impact on design workflows, making them more efficient, sustainable, and responsive to user needs.

Synthesis and Reporting: Findings were synthesized to provide a cohesive narrative on AI’s impact, challenges, and emerging trends in industrial design. This synthesis highlights the breadth of AI applications, from supporting faster, more efficient workflows to advancing sustainability and personalization, offering a clear picture of AI's transformative potential in this field.

Timeline: The study was carried out over a period of three months. The first month was dedicated to gathering and screening relevant materials, while the second month was used for a detailed analysis, categorization, and coding of the findings. The final month involved synthesizing the results, identifying gaps in the current literature, and preparing the final report. For added rigor, the methodology drew upon foundational literature on systematic reviews, such as Webster and Watson’s guidance on structuring reviews through categorization and synthesis, which informed the overall research process[21]. Additionally, numerous studies such as those listed in the following section in the areas of AI-driven rapid prototyping, digital twins, sustainable material selection, data-driven personalization, and generative design provided insights into each specific theme. Collectively, these sources provide a comprehensive foundation for analyzing the current implementations of AI in industrial design and assessing its future potential.

4. FINDINGS

Research on the integration of artificial intelligence (AI) in industrial design has surged in recent years, driven by advances in AI technology and the increasing demand for efficient, sustainable, and personalized design processes[22]. The integration of AI into industrial design is revolutionizing how products are conceived, developed, and optimized[23]. With AI's ability to accelerate the design process, increase material efficiency, personalize products, and facilitate real-time collaboration, the industry is experiencing significant transformations[24]. In this section, we delve into key areas where AI is reshaping industrial design, providing quantitative and qualitative data and real-world examples to illustrate these changes. In the following paragraphs, recent studies that examine AI's applications across various stages of the industrial design cycle, such as conceptual design, material selection, data-driven personalization, and interdisciplinary collaboration, rapid prototyping are presented, their methods and findings are summarized.

4.1. Use of AI in the Industrial Design Process

Elal and Özsoy [25]offered a perspective on the use of artificial intelligence tools in the conceptual phase of the design process. To gain their insights they performed a field study with the participation of industrial design students divided into two groups, one using AI tools and the other using traditional ID methods to design coffee makers (Figure 2). The two groups produced their version of the selected product, which were methodically evaluated afterwards according to selected criteria by using AHP method. Based on experience gained with this study they listed the pros and cons of AI use in design and stated that it is necessary to work methodically to increase the effectiveness of AI as a tool and prevent issues such as idea fixation.

Figure 2. *Four different coffee machine design concepts produced by MidJourney AI[25]*

4.2. AI in Rapid Prototyping

Ghorbani[1] explored the potential of AI-driven virtual prototyping tools to replace traditional physical prototypes. His study focused on generative design and simulation technologies, which enable designers to create and test virtual models that closely resemble physical products. Ghorbani's research aimed to reduce the time and cost associated with physical prototyping by implementing AI to simulate real-world conditions, such as wear and tear or environmental effects. The study found that these AI tools could reduce the need for physical prototypes by up to 50%, enabling faster design iterations and lowering resource usage.

Marrone [26]states that traditional design tools often rely on physical prototypes, which are time-consuming and costly to produce. AI-powered tools, including generative design and simulation-based prototyping, significantly reduce the need for physical prototypes by allowing designers to test and refine ideas in virtual spaces.

Li et al. [27] found that AI-based virtual prototyping reduced the time spent on iterative testing compared to traditional methods. For example, an automotive manufacturer using AI for generative design in the production of new car parts was able to achieve a 25% reduction in weight without sacrificing durability, while simultaneously reducing material use by 30%. These improvements led to a 15% reduction in manufacturing costs. Furthermore, the use of digital twin technology helps simulate real-world conditions, reducing the failure rate of prototypes by up to 35%, thus saving substantial testing time and costs.

According to Clainche et.al. [28], AI's potential for improving prototyping is not limited to cost and time reduction. For example, AI simulations used in the aerospace sector helped optimize aircraft wing design. The result was a 20% reduction in fuel consumption due to the improved aerodynamics of the wing shape, based on AI’s prediction of airflow and performance under varying conditions.

4.3. Digital Twins and AI-Driven Efficiencies

Quian et al. [29] have investigated the use of digital twin technology in industrial design, which leverages AI to create virtual replicas of physical products. Their study aimed to understand how digital twins, combined with AI simulations, enhance product testing and design processes. They focused on architectural manufacturing, where the physical testing of prototypes is costly and time intensive. Their findings show that digital twins not only streamline testing but also enable real-time feedback loops that improve product quality and reduce the time to market.

Hao et al. [30] have contributed to industrial product design by examining how artificial intelligence (AI) can enhance digital twin technology, which is used to create dynamic digital models of physical systems. Their paper systematically reviewed AI applications, particularly machine learning models like neural networks and deep generative models in digital twin deployment across sectors such as industry, healthcare, and urban planning. They addressed challenges that often hinder digital twin effectiveness, such as data quality, availability, and interoperability. Their study shows how AI can provide scalable solutions for design and operational performance in industrial applications and proposed future research directions for improving digital twin functionality.

4.4. Sustainable Material Selection with AI

The environmental impact of design has driven a significant amount of research into sustainable material selection. Rane et al. [23] have examined AI’s role in analyzing vast materials databases to identify sustainable alternatives. Their study focused on evaluating materials based on factors like durability, cost, and environmental footprint, aiming to guide designers toward choices that balance aesthetics and sustainability. They found that AI-based material analysis could reduce carbon footprint of products by up to 30% when compared to traditional materials, highlighting the importance of AI in promoting eco-friendly practices in architectural design.

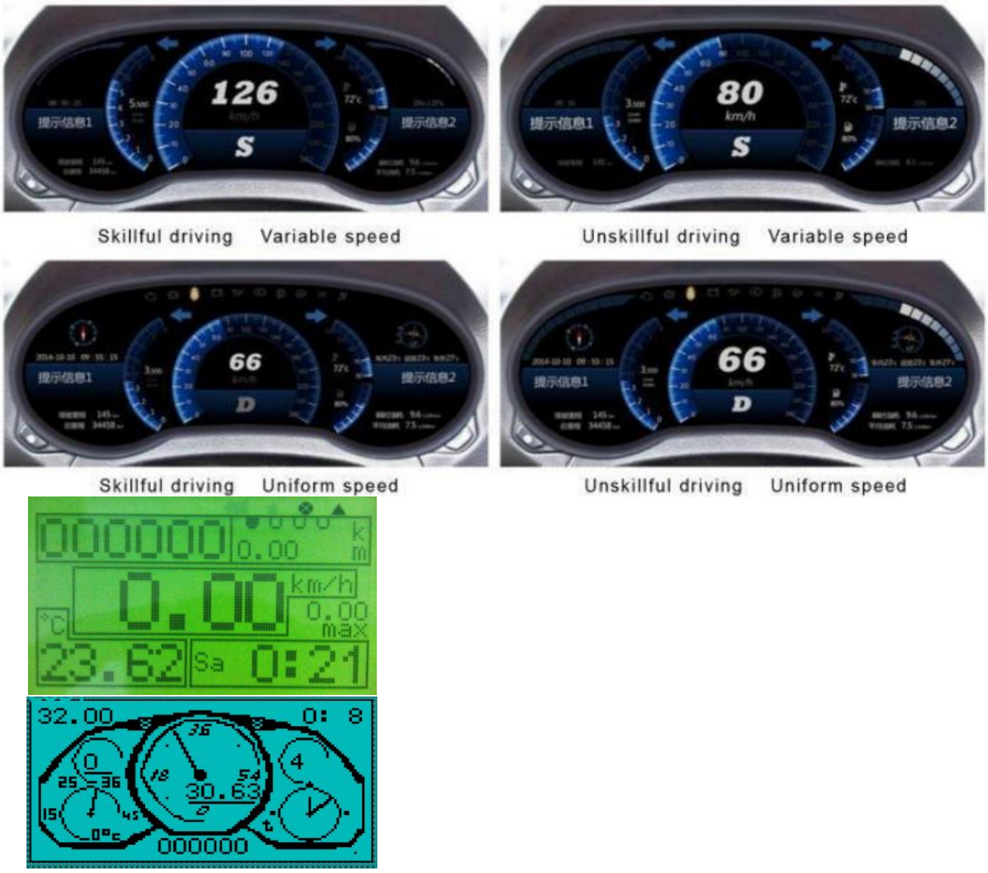
4.5. AI and Data-Driven Personalization in Industrial Design

Personalization is one of the most valuable applications of AI in industrial design. AI enables designers to customize products on a scale, creating designs that meet individual preferences without compromising efficiency or cost-effectiveness[22].

Quan et al. [31] have conducted a study on AI's ability to personalize mass production. Their research focused on analyzing user data to create products that meet individual preferences, while still maintaining the scalability and cost-effectiveness of mass production. They found that AI-enabled personalization allows companies to tailor designs to match user-specific needs, such as ergonomic preferences or aesthetic tastes, without incurring prohibitive production costs. This approach represents a shift towards user-centric design that is both efficient and adaptable at scale.

Ding et al. [32] explored how AI-driven customization tools enabled the production of personalized furniture based on customer preferences for material choice, design style, and size. In one instance, a furniture company using AI to personalize sofa designs saw a 22% increase in customer satisfaction, as users were able to choose specific fabric types, colors, and configurations to match their interior decor. This personalized approach led to a 30% increase in sales, as customers valued the customization options, which increased their attachment to the product.

In the automotive industry, AI-driven customization tools have helped manufacturers to offer tailored interiors based on customer preferences[33]. An example from a major automotive brand showed that AI integration into the design of various automotive parts such as dashboards as shown in Figure 3, which adjusts itself according to user's driving style resulted in an increase in customer satisfaction and a boost in sales for the customized vehicle models[34].



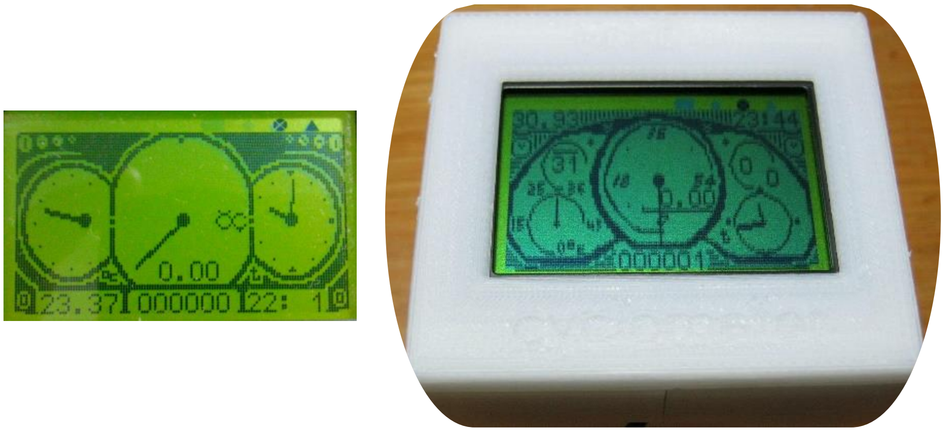


Figure 3. *Various dashboard interface designs for different driving styles[34] and our implementation's 2d design phase and on an actual product we designed (a bicycle computer).*

Customers were able to personalize their vehicles' arrangements, such as adjusting for their height, body shape, and comfort preferences, leading to a more engaging and user-centric product experience[35]. Some vehicle sample parts can be seen in Figure 4.

Figure 4. *AI generated vehicle parts to fit user or technical needs[35].*

Moreover, AI can optimize mass personalization by analyzing user data, such as ergonomic needs and aesthetic preferences, to create personalized yet mass-produced items. For instance, a company producing athletic wear used AI to design shoes that fit each user's foot structure, gait, and running style. This personalized shoe design shown in Figure 5 led to an increase in sales and an improvement in customer retention, demonstrating the significant impact of personalization on consumer behavior[36].

Figure 5: *Different AI models produced with changing parameters [36].*

4.6. Generative Design for Industrial Design Innovation

Generative design, powered by AI, is affecting the product development process by enabling the creation of optimized, innovative solutions. As demonstrated from one of our experiments in Figure 6, AI algorithms generate multiple design alternatives based on a set of input parameters, allowing designers to explore thousands of possible configurations in a fraction of the time it would take using traditional methods[37].

Figure 6. *Three groups of coffee machine designs generated from literal depictions emphasizing color, simplicity and retro design features consecutively (produced by the Author).*

Gayam [38] explored the role of AI-driven generative design in industrial innovation, focusing on how AI algorithms can create multiple design variations based on specified parameters. Gayam's study aimed to assess the effectiveness of generative design in enhancing creativity and speeding up the ideation phase. Gayam found that AI-enabled generative design tools not only expanded designers' creative possibilities but also reduced initial design times. This research underscores AI's potential to support creative exploration in industrial design.

McClelland [39] found that generative design tools reduced the duration of ideation and refinement phases of product development. For example, an AI platform used in the aerospace industry generated a lightweight, high-strength design for an aircraft component that reduced material usage by over 50% and improved its strength-to-weight ratio by 13%. This will eventually lead to cheaper manufacturing along with reduced fuel consumptions of the aircraft due to less weight being carried during flight, showcasing the potential of generative design to enhance both performance and economy.

Generative design is particularly valuable in industries requiring highly optimized, complex structures. In the case of a new drone frame seen in Figure 7 [40], AI-generated designs reduced the frame's weight by 30% while maintaining structural integrity. This not only improved the drone's flight time but also contributed to a 12% reduction in manufacturing costs.

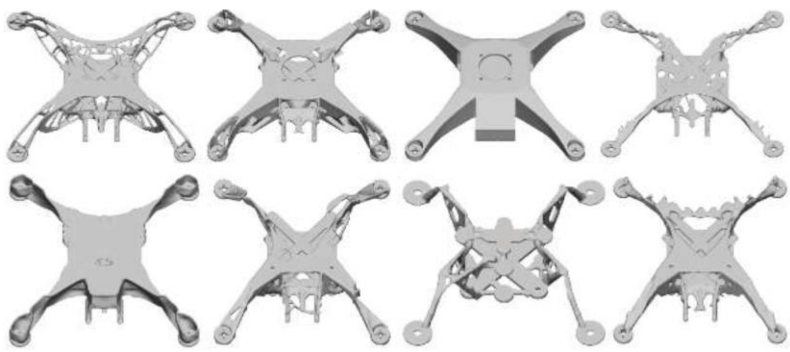


Figure 7. *Various drone chassis designs produced by giving different parameters to AI[40].*

Figure 8 shows the results of one of our own experiments, in which AI was used to design an ergonomic workstation for medical environments conforming to given literal cues and images of coffee machine images we previously created by using AI shown in Figure 6. Although this fun experiment seemingly generated irrelevant results, it might be considered as a nice example of thinking out of the box, enabling the designer to improve the design, in an unexpected way.

Figure 8. *AI generated medical workstations (produced by the Author)*

4.7. Sustainable Material Choices and AI's Role in Green Design

Lodhi et al. [41] have examined how AI can improve the selection of sustainable materials in the context of green design. Their study aimed to identify the specific ways AI assists in evaluating and choosing materials based on sustainability metrics, such as recyclability and carbon footprint. Focusing on applications in packaging and consumer goods, the researchers found that AI-driven material selection could lower waste by enabling a more precise match between material properties and product requirements. Their study reinforced AI's critical role in advancing eco-friendly design choices.

Sustainability in industrial design is crucial, and AI is playing a significant role on sustainability by means of optimizing material selection. Designers traditionally rely on material databases and personal experience when choosing materials, but AI's ability to process vast datasets allows for more informed decisions, considering environmental impact, performance, and cost[42]. Biometric structures form datasets which are used as the basis for generation algorithms as shown in Figure 9[43].

Lodhi et al. [41] reports that AI-driven material selection tools can reduce carbon emissions in manufacturing by 20-30%. For instance, an AI system used in the design of a footwear product helped select a biodegradable plastic that performed similarly to conventional petroleum-based plastics but reduced carbon emissions during production by 28%.

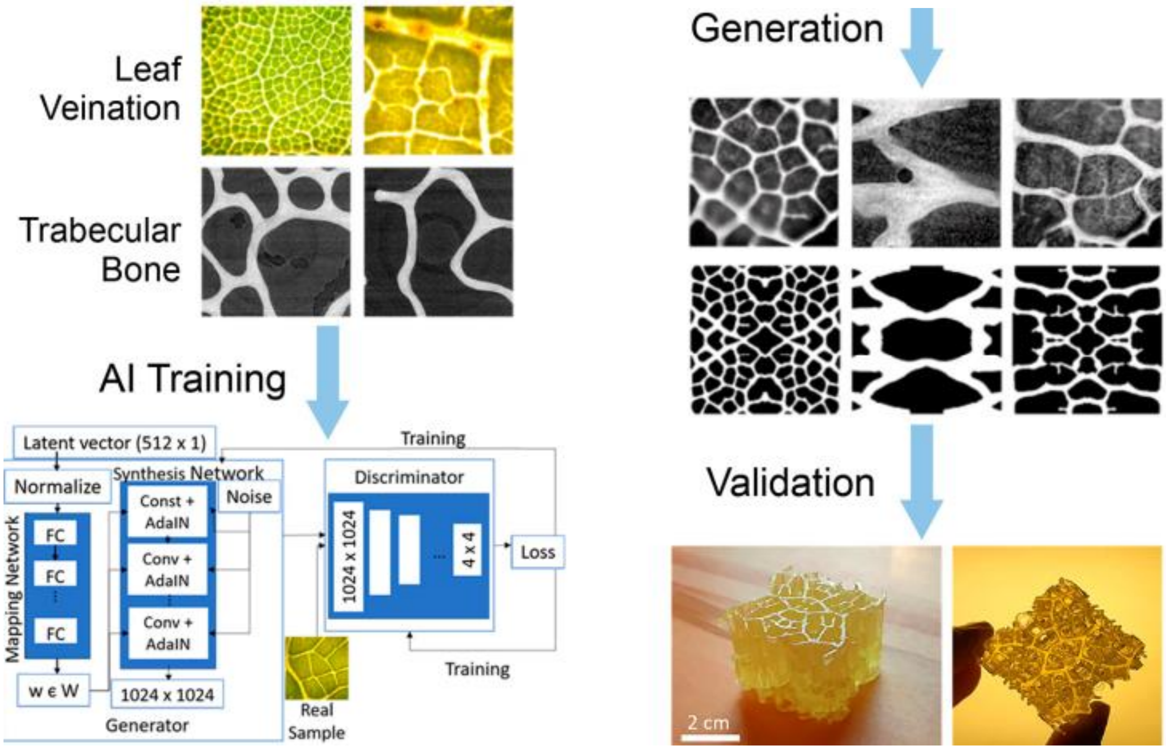


Figure 9. *AI analyzed microtextured natural surfaces and material structures generated by using the analysis results[43].*

AI's role in sustainability extends to reducing material waste. By investigating the related literature Sah et al. [44] found that using AI to optimize supply chain processes for wood and metal in manufacturing led to a 12% reduction in material waste.

AI also helps identify new, sustainable materials. For instance, AI-assisted simulations in various industries led to the discovery of a new recyclable composite material that reduced the weight of product parts while providing increased durability. This shift to lighter, more durable materials also reduced energy consumption during manufacturing, contributing to a reduction in the carbon footprint of the product line[45].

4.8. AI and Interdisciplinary Collaboration in Design

AI plays a vital role in fostering collaboration between designers, engineers, and manufacturers. In traditional industrial design, communication barriers between these groups can lead to delays and inefficiencies. AI-powered collaborative platforms improve coordination, ensuring that all stakeholders are aligned throughout the design and manufacturing process[46].

Tsang and Lee [22] have investigated AI as a collaborative tool in industrial design, focusing on its use for real-time feedback loops among designers, engineers, and product managers. Their research aimed to assess whether AI-driven tools could facilitate more effective communication across teams, reducing design-to-market timelines and enhancing product quality. The findings revealed that AI-powered platforms improve cross-functional collaboration, enabling quicker iteration cycles and fostering an agile design process illustrating AI's potential to streamline collaboration in complex design projects.

Singh and Lata [47] found that AI-based collaborative tools considerably reduced decision-making time in the design phase of product development. In one of their studies, they investigated a global design team which used an AI platform to collaborate on a product for the consumer electronics market. The AI system facilitated real-time feedback and helped resolve design issues before physical prototypes were created, reducing development costs by 20%. Furthermore, the system provided predictive analytics that helped design teams identify potential flaws early in the process, preventing costly redesigns later.

Real-time collaboration is especially valuable in industries where time-to-market is critical. In the fashion industry, AI-assisted design platforms enabled a design team to reduce the turnaround time from concept to production by 25%. This rapid prototyping allowed for quicker product launches, meeting market demand while keeping production costs under control. Similarly, in the automotive industry, AI helped coordinate communication between design, engineering, and manufacturing teams, reducing production errors by 15% and cutting development time by 10%[48].

5. INTERPRETATINON OF THE CURRENT RESEARCH FINDINGS

The findings from the reviewed studies show several key insights, each reflecting the broad-reaching impact of AI across various stages of industrial design. These findings can be interpreted to highlight the ways in which AI not only optimizes traditional practices but also introduces novel methodologies that push the boundaries of what is possible in design, manufacturing, and sustainability.

5.1. Acceleration of Prototyping and Design Processes

The findings regarding AI in rapid prototyping demonstrate that AI significantly reduces the time and costs associated with the iterative process of design. It is reported that there is a 40% reduction in time spent on virtual prototyping compared to traditional methods[49]. This time reduction directly correlates with lower costs, both in terms of material and labor. The example of aerospace companies considerably reducing the weight of parts without compromising durability, while also cutting material usage[39], or automotive companies working hard to improve their vehicles' efficiency by every possible way including AI tools[50] indicates that AI does not merely speed up design processes but enhances the quality and resource efficiency of the final product.

AI's ability to simulate and test design options virtually, as seen with the use of generative design algorithms, represents a paradigm shift from physical testing to data-driven optimization. The ability to generate and test thousands of design alternatives allows for higher precision in product development, providing companies with the flexibility to explore solutions that might have been overlooked in traditional approaches[51].

5.2. Advancing Sustainability in Design

The role of AI in promoting sustainability is another major takeaway from the findings. AI's ability to guide material selection and optimize manufacturing processes is helping companies to reduce their environmental footprint[52]. As Maroun has found out [53], AI-assisted material selection could reduce carbon emissions by up to 30%, underscoring the potential of AI to promote more sustainable manufacturing practices. This is particularly important in industries such as electronics, construction, and automotive[50], where the environmental impact of material sourcing and production is substantial.

The ability to reduce material waste further supports AI's role in creating more sustainable production practices. By optimizing cutting patterns, AI helps minimize leftover materials, reducing both waste and costs. This ability to make processes more sustainable without compromising performance demonstrates AI's ability to integrate environmental considerations into the core of design processes.

Moreover, the development of new, sustainable materials through AI highlights AI's potential to not only optimize existing materials but also discover innovative material solutions that improve both performance and sustainability, thus contributing to the global economy.

5.3. Personalization and Consumer-Centric Design

Personalization, facilitated by AI, is a transformative aspect of industrial design. AI's ability to analyze user preferences and data allows for the creation of customized products on a scale, which traditional manufacturing processes could not achieve efficiently[54]. Wan et al. [55] shows that AI-driven product customization increased customer satisfaction, indicating that personalized products are more appealing to consumers and lead to higher sales. This highlights the importance of aligning product design with consumer preferences, which not only improves customer loyalty but also boosts sales.

Yan et.al. [56] report that AI's ability to extend products' personalization spreads beyond just aesthetics or comfort. In their AI-assisted garments customization study, they gathered a large amount of data related to the bodies of selected persons and processed them by AI to create personalized wearable products, with high performance figures specifically tailored to those individuals therefore much better than standard mass-produced garments. This approach improves customer experience by providing them with products that much better meet their needs and in the case of, for instance, professional sport garments, can also create millions of dollars of additional value.

5.4. Collaboration and Communication Enhancement

The findings regarding AI in collaborative design underscore its potential to streamline communication between design teams, engineers, and manufacturers. Zhang et al. [57]have found that AI-driven platforms reduced decision-making time by 30%, which is a significant improvement that enables faster product development. In industries where time-to-market is critical AI-driven collaboration tools can significantly shorten development cycles, allowing companies to launch products faster and respond more swiftly to market demands.

Real-time feedback and predictive analytics also help prevent costly mistakes. For instance, AI systems that provide automatic corrections or identify design flaws early on, reduce the likelihood of expensive redesigns. This collaborative efficiency is especially valuable in global teams, where time zone differences and physical distances can hinder effective communication. AI tools that provide instant feedback allow teams to stay aligned and optimize the design process.

5.5. Generative Design and Innovation

Various uses of generative design in literature have shown that AI can not only optimize existing designs but also generate entirely new ones that might not have been conceived by human designers. For example, the structure used in the stool design shown in Figure 10 is created using innovative algorithms that optimize the necessary structural specifications while minimizing material use [58]. The resulting design has a natural, organic look that enhances its visual appeal. Trautmann [59]found that generative design reduced the ideation phase by 40%, enabling companies to explore a broader range of solutions in a shorter time frame. This approach leads to more innovative and efficient products.

Figure 10. *Stool that combines AI generated solid and Voronoi-based sections[58].*

Generative design's potential for innovation is exemplified by its application in the automotive and aerospace industries, where it has resulted in the creation of lighter, stronger parts that improve fuel efficiency and reduce operational costs. AI-generated designs for an aircraft component that reduced material use highlights AI's ability to create technical designs as well that are both resource-efficient and high-performing[59]. AI's ability to think outside the conventional design constraints can lead to breakthroughs in product design, making generative design an invaluable tool for companies seeking to stay competitive in industries where performance, cost, and sustainability are key drivers[60].

6. CONCLUSIONS

The general findings and results of the literature studies investigated in our research summarize that AI-driven tools offer significant advantages in enhancing efficiency, sustainability, and innovation of the industrial design process. By automating routine tasks, AI tools help streamline workflows, reduce human error, and enable designers to focus on more complex and creative aspects of their work. These tools also facilitate faster decision-making by analyzing data and trends, enabling designers to quickly adapt to changing consumer needs and market demands. In terms of sustainability, AI assists in selecting eco-friendly materials and optimizing the use of resources, minimizing waste throughout the design process, and supporting the creation of more sustainable products.

Innovation is fostered through AI's capabilities in generative design, which allows designers to explore a wider range of design possibilities that might be missed in traditional approaches. AI-powered generative tools enable designers to push the boundaries of creativity, producing complex, highly efficient, and often unexpected solutions that would be difficult to achieve by traditional methods. Moreover, AI's ability to enable interdisciplinary collaboration enhances the potential for breakthrough innovations by integrating expertise from various fields. Personalized design generation, driven by AI, also helps create products tailored to individual user needs, improving customer satisfaction and usability while maintaining cost-efficiency.

However, despite these benefits, the integration of AI into industrial design also poses certain risks and challenges. One possible negative consequence is the potential loss of jobs in certain areas of design, as AI tools could replace manual tasks previously performed by people. This could result in economic disruptions, particularly in traditional design roles, and may exacerbate inequality in the workforce. Furthermore, singlehanded reliance on AI tools could lead to a reduction in the diversity of design ideas, as these systems often use pre-existing data and patterns. Accepting their creations without question could inadvertently stifle creativity and lead to designs that are limited within AI patterns and forms, lacking human originality therefore failing to achieve the rapidly improving needs of people and industry.

AI's emphasis on efficiency and cost-effectiveness may sometimes lead to designs that prioritize function over aesthetics or human-centered considerations. This could undermine the artistic and emotional aspects of industrial design, which are often integral to a product's appeal and user experience. Moreover, the complexity of AI tools and their reliance on vast datasets can create challenges in ensuring that the tools are accessible and understandable to all designers, particularly those in smaller firms or with less technical expertise.

Looking ahead, future research could address several critical areas. One focus could be on refining AI tools to better balance creativity with efficiency, ensuring that the potential for innovation is not decreased by overly data-driven approaches. Research could also explore the broader societal impacts of AI in industrial design, particularly the implications for labor markets and the potential need for reskilling in the workforce. Additionally, studies could investigate the long-term environmental benefits of AI’s role in promoting sustainable design practices and its contribution to a global circular economy. Lastly, further exploration into AI's potential to democratize the design process, particularly by making advanced tools more accessible to smaller businesses and independent designers, could help foster more inclusive innovation in the industry.

Thus, while AI presents transformative possibilities for industrial design, it is essential to be mindful of the potential downsides. As AI tools evolve, ongoing research and thoughtful integration into design practices will be key to ensuring that the benefits are maximized while mitigating the risks associated with their widespread adoption.

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Architectural Design for Active Shooter Preparedness: A Simulation-Based Systematic Review

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Abstract

Active shooter incidents (ASIs) pose a grave threat to occupant safety in built environments. This systematic review methodically examines research on building design strategies to mitigate ASI risks and enhance occupant safety, with a particular emphasis on studies utilizing simulation modeling. Employing the PRISMA framework, we analyzed 75 relevant studies published since 2000. The review synthesizes findings across key themes, including: the impact of exit design and spatial configuration on evacuation efficiency; the effectiveness of security features such as access control, surveillance systems, and bullet-resistant materials; and the role of communication systems in facilitating information sharing and emergency response. We critically evaluate the strengths and limitations of different simulation modeling approaches, highlighting their contributions to understanding human behavior dynamics and informing evidence-based design strategies. The review also identifies knowledge gaps and future research directions for optimizing building design to enhance occupant safety and resilience during ASIs.

1. INTRODUCTION

Active shooter incidents (ASIs), characterized by individuals using firearms to inflict harm in populated areas, pose a growing and substantial threat to public safety worldwide [1, 2]. These incidents, tragically, have become more frequent and deadly in recent years, generating widespread fear and prompting urgent calls for enhanced prevention and preparedness strategies [3–5] While ASIs can occur in various settings, built environments—including schools, workplaces, healthcare facilities, and public spaces—have become increasingly common targets [3, 6, 7]. This alarming trend and the inherent vulnerability of occupants within these confined spaces underscores the critical need to examine how architectural design can contribute to occupant safety during these unpredictable and often rapidly unfolding events.

The design of buildings themselves, beyond conventional security measures like access control systems, surveillance technologies, and armed guards [8, 9], plays a pivotal role in shaping occupant behavior and influencing safety outcomes during ASIs. Research has shown that specific architectural features can either hinder or support effective evacuation and response. For example, exits' number, location, and visibility influence evacuation time and pedestrian flow [10–12]. Studies have demonstrated that strategic placement of exits, clear signage, and well-lit escape routes can significantly reduce congestion and facilitate faster evacuation [13, 14]. Similarly, corridor width and layout directly impact pedestrian flow rates and potential bottlenecks or crowd-crushing during emergencies [15, 16]. Wider corridors, thoughtfully planned circulation paths, and strategically placing obstacles to guide movement can improve pedestrian flow and enhance safety [17, 18]. Furthermore, the availability of secure spaces or well-concealed hiding places within rooms can offer occupants temporary refuge and increase their chances of survival [8, 19].

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Recognizing the complex interplay between human behavior, spatial configuration, and the dynamics of ASI events, researchers have increasingly turned to simulation modeling as a powerful tool for evaluating the effectiveness of different building design strategies [20–22]. Simulation modeling allows for creating virtual environments where various ASI scenarios can be tested, incorporating a range of factors such as attacker behavior, occupant characteristics, and building features [23, 24]. By simulating different evacuation and response strategies, researchers can gain data-driven insights into how design variations impact occupant safety outcomes, such as evacuation time, casualty rates, and the likelihood of survival [10, 23, 25].

This systematic review aims to thoroughly examine the growing body of research on building design strategies for mitigating ASI risks, emphasizing studies utilizing simulation modeling to evaluate the efficacy of different design approaches. By synthesizing findings from diverse simulation studies across various building types and occupant populations, we seek to provide a comprehensive overview of current knowledge and identify evidence-based design strategies for enhancing occupant safety during ASIs. The review will also address the strengths and limitations of different simulation modeling techniques, highlight key knowledge gaps, and propose future research directions for advancing the field of active shooter preparedness from an architectural design perspective. Ultimately, this review seeks to contribute to developing safer and more resilient built environments that can effectively protect occupants in the face of this evolving threat.

2. RESEARCH PROCESS AND METHODOLOGY

This systematic review embraced a systematic and meticulous approach, adhering to the well-established Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Systematic Reviews (PRISMA) framework [26]. This framework, specifically tailored for systematic reviews, provides a transparent and structured methodology for conducting and reporting research, ultimately enhancing the reliability and reproducibility of the findings. This commitment to a rigorous methodology ensured a comprehensive and unbiased exploration of the complex relationship between building design and occupant safety during active shooter incidents (ASIs).

The research process began with an extensive search for relevant studies, spanning multiple databases to capture diverse perspectives and research approaches. This multi-database approach recognized that knowledge on ASI preparedness is dispersed across various disciplines, including safety science, engineering, architecture, social psychology, criminology, and computer science. Specialized databases dedicated to safety science, such as SafetyLit and Transportation Research International Documentation (TRID), provided a focused lens on studies addressing building design for emergency preparedness and risk management [27]. In parallel, searches were conducted in databases specific to engineering and architecture, including Compendex and the Avery Index to Architectural Periodicals, capturing research on building design, construction, and technology that could potentially be applied to ASI mitigation [13, 28]. To further broaden the scope, multidisciplinary databases like Web of Science, Scopus, and Google Scholar were also included, encompassing research from diverse fields that could offer valuable insights into human behavior during emergencies and the effectiveness of simulation modeling for evaluating design strategies [29].

The search was deliberately limited to peer-reviewed journal articles, conference papers, and relevant book chapters published in English, prioritizing research that had undergone rigorous academic scrutiny and scholarly evaluation. This emphasis on peer-reviewed literature ensured the inclusion of high-quality research with robust methodologies and credible findings. Moreover, the search was conducted with a specific temporal focus, encompassing publications from January 1, 2000, to the present. This timeframe captured the significant advancements in ASI research and building design strategies that have emerged in recent years, reflecting the growing awareness of this threat and the increasing urgency to develop effective mitigation measures.

A carefully constructed keyword strategy was employed to refine the search further and identify the most pertinent studies within this vast body of literature. This strategy utilized Boolean operators (AND, OR, NOT) to effectively combine search terms and pinpoint studies focusing on the intersection of building design, simulation modeling, and ASI preparedness. General keywords, such as "active shooter," "mass shooting," "architectural design," "building design," "evacuation," "simulation," "security," and "safety," were combined with more specific terms, such as "exit design," "corridor width," "access control," "surveillance systems," "bullet resistant," "emergency notification," "real-time communication," "information sharing," and "occupant behavior." This multi-layered keyword strategy allowed for identifying studies that explored both broad concepts and specific design features, technologies, and behavioral considerations relevant to mitigating ASI risks. For instance, searches combined general terms like "active shooter" or "mass shooting" with specific terms like "exit design" and "evacuation time" to identify studies examining the impact of exit design on occupant safety during ASIs.

The next crucial stage involved a systematic screening process to select studies that met predefined inclusion and exclusion criteria. This rigorous screening process ensured that only the most relevant and methodologically sound studies were chosen for inclusion in the systematic review. Studies were carefully evaluated based on their focus, publication type, language, and publication date. To be included, studies had to explicitly examine building design strategies for ASI preparedness, either using simulation modeling or through empirical studies of occupant behavior during actual or simulated ASI scenarios. Furthermore, they had to be published as peer-reviewed journal articles, conference papers, or relevant book chapters in English from January 1, 2000, to the present.

Studies were excluded from the review if they focused solely on other types of emergencies, such as fire or earthquake, without a clear and explicit connection to ASIs. While these studies might offer valuable insights into general emergency preparedness and evacuation behavior, their relevance to the specific context of ASIs was deemed insufficient for inclusion. Additionally, opinions, editorials, news articles, and other publications lacking empirical data or a systematic analysis of building design strategies for ASI preparedness were excluded. This ensured that the review prioritized research grounded in empirical evidence and rigorous methodologies.

Once the relevant studies were selected, a standardized data extraction form was meticulously employed to gather pertinent information from each paper. This form captured essential details about the study, including the author(s), year of publication, study design, building type, occupant population, simulation modeling approach (if applicable), and key findings related to building design and occupant safety. This structured data extraction process ensured consistency and facilitated subsequent thematic analysis. Following data extraction, the collected information underwent a thorough thematic analysis to identify recurring concepts and patterns across the literature. Themes emerged inductively, based on the frequency and significance of specific findings related to building design strategies for ASI preparedness. This thematic approach allowed for a comprehensive and organized research synthesis, highlighting key areas of consensus, identifying knowledge gaps for future exploration, and revealing the overall landscape of knowledge on how architectural design can contribute to occupant safety during ASIs.

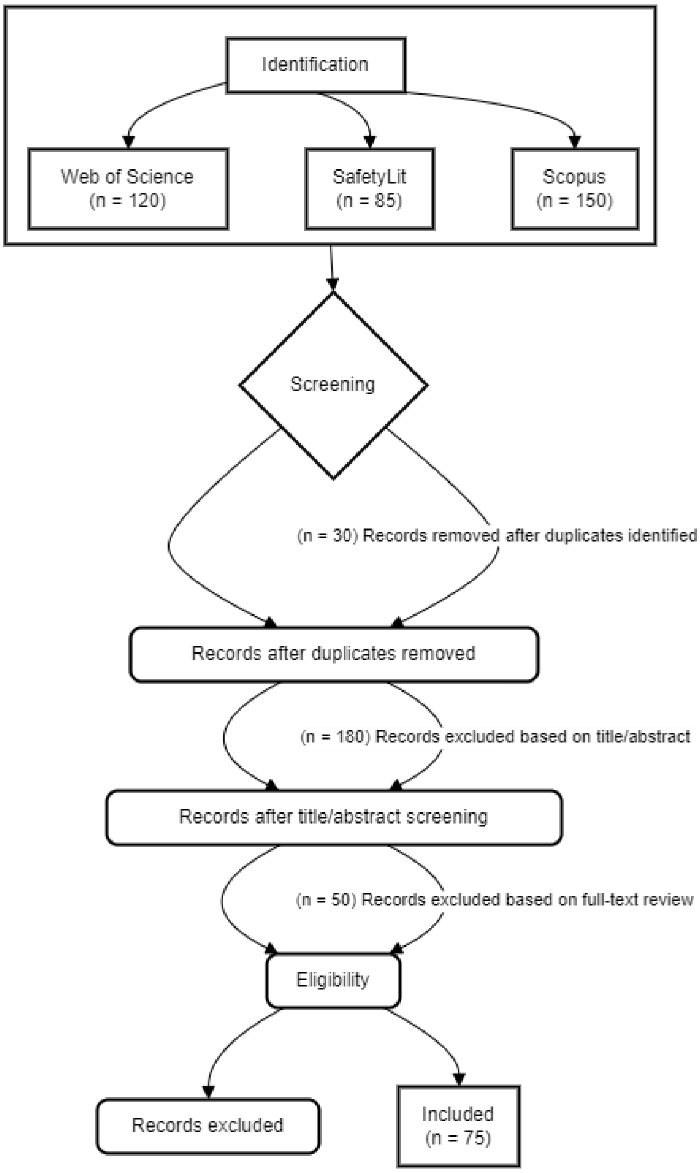

Figure 1. *PRISMA Flow Diagram for the Systematic Review*

This systematic and rigorous methodology, guided by the PRISMA framework, provides a robust foundation for exploring the multifaceted role of building design in enhancing occupant safety during active shooter incidents. By carefully selecting and analyzing relevant literature, this systematic review aims to contribute valuable insights to the field of ASI preparedness and inform the development of safer and more resilient built environments that can effectively protect occupants in the face of this evolving threat.

3. RESULTS AND THEMATIC ANALYSIS

The systematic search and screening process identified 75 studies meeting the inclusion criteria for this systematic review. These studies, spanning from 2000 to 2024, represent a diverse range of research approaches, building types, and occupant populations, reflecting the growing interest in understanding the role of architectural design in ASI preparedness. As illustrated in Table 1, simulation modeling has emerged as a dominant methodology, with agent-based modeling (ABM), social force models (SFM), and cellular automata (CA) being frequently employed to evaluate the effectiveness of different building design strategies.

Table 1. *Characteristics of Included Studies (see the whole Table in Appendix-A)*

Author(s)	*Year*	*Study Design*	*Building Type*	*Occupant Population*	*Simulation Model*	*Key Findings*
Arteaga & Park	2020	Simulation Study (Agent-Based Modeling)	School-like building	Students	Agent-Based Model (ABM)	Increasing hall and door widths improved evacuation efficiency and reduced casualties; narrower halls were more sensitive to higher occupant densities.
Zhu, Lucas, & Southers	2020	Qualitative Study (Focus Groups)	Various (schools, offices, hospitals)	Occupants	N/A	Security countermeasures must consider occupant behavior and trade-offs between security, cost, aesthetics, and daily operations; training and practice are crucial for effectiveness.
Doss & Shepherd	2015	Literature Review, Practical Guidance (Book Chapter)	Commercial buildings	Employees	N/A	Multiple communication platforms, clear message content, accessibility for diverse populations, and pre-scripted messages are essential for effective communication during ASIs.
Kellom & Nubani	2018	Simulation Study (Visibility Graph Analysis)	University classrooms	Faculty	Visibility Graph Analysis (VGA)	VGA measures predicted faculty preparedness levels and police response efficiency; visibility was crucial for both occupant safety and police response.
Shih, Lin, & Yang	2000	Simulation Study (Virtual Reality)	Metro Station	Passengers	Virtual Reality Simulation	VR simulations revealed discrepancies between traditional evacuation calculations and actual occupant behavior; exit signage and layout significantly influenced evacuation time.
Jin, Jiang, & Liu	2021	Empirical Experiment (Controlled Walking Trials)	Corridor	Pedestrians	N/A	Wider corridors improved pedestrian flow rates in both unidirectional and bidirectional movement; different corridor widths affected lane formation patterns.
Li & Xu	2020	Simulation Study	Limited-Space Building	Pedestrians	Social Force Model (SFM)	Exit width of 1.1m optimized evacuation time and construction costs; inward-opening doors were more efficient than outward-opening doors.
Lei, Li, & Gao	2013	Simulation Study (FDS + Evac)	Dormitory	Students	FDS + Evac	Corridor width of 3m and exit width of 2.5-3m were optimal for the dormitory; occupant density significantly influenced walking speed; evacuation time was not proportional to evacuation distance.
Hassanpour, González, & Cabrera-Guerrero	2024	Simulation Study (ABM)	University building	Students, Faculty	Agent-Based Model (ABM)	Integrating earthquake damage assessment into evacuation simulations informed the design of safe spaces and architectural layouts for post-earthquake evacuation.

Analysis of the included studies revealed several recurring themes related to building design for enhancing occupant safety during ASIs. These themes highlight the interconnectedness of architectural features, security systems, communication strategies, and human behavior in shaping safety outcomes during these critical events.

3.1 Exit Design and Spatial Configuration: Optimizing Egress and Movement

Exit design and spatial configuration are paramount considerations in ASI preparedness, as they directly influence evacuation efficiency and the potential for casualties. Effective exit design aims to minimize the time required for occupants to safely egress a building during an ASI, reducing their exposure to the threat and minimizing the risk of injury or death. Simulation studies have consistently demonstrated that the number, location, visibility, and design of exits significantly impact pedestrian flow, evacuation time, and the likelihood of successful escape [10–12].

Studies utilizing ABM and SFM have shown that increasing the number of exits, strategically placing them for optimal accessibility, and ensuring clear visibility and signage can considerably reduce congestion and facilitate faster evacuation [13, 14, 30]. These models allow researchers to explore how occupants navigate complex building layouts and make decisions about exit routes during emergencies.

For instance, research has shown that wider corridors and strategically placed doorways can create smoother pedestrian flows and reduce crowding [15, 16, 31]. Simulation studies have also demonstrated that the strategic placement of obstacles within corridors can, counterintuitively, improve pedestrian flow by directing movement and preventing congestion [17, 18].

Moreover, the availability of safe spaces or designated hiding places within rooms, offering temporary refuge from the threat, has emerged as a crucial design consideration, potentially increasing occupant survival rates [8, 19]. These spaces, ideally designed to be easily accessible, well-concealed, and resistant to forced entry, can provide occupants with a layer of protection while awaiting the arrival of law enforcement. Research has also highlighted the importance of integrating architectural design with emergency response protocols and occupant training programs [32]. By incorporating features that support lockdown procedures, such as reinforced doors and communication systems, buildings can be designed to facilitate a more coordinated and effective response to ASIs.

3.2 Security Features: Enhancing Protection and Delaying Access

Beyond exit design and spatial configuration, the incorporation of security features into building design is crucial for deterring attackers, delaying their access, and creating layers of protection for occupants. The goal is to create a "layered defense" [33], making it more difficult for attackers to reach their intended targets and providing occupants with additional time to evacuate or seek shelter. Studies have explored the effectiveness of various security features, including access control systems, surveillance technologies, and bullet-resistant materials, highlighting their potential to enhance building security and occupant safety.

Access control systems, such as locked doors, security checkpoints, and controlled entry points, have been shown to be effective in delaying or preventing attacker access [8, 34]. Research suggests that even relatively simple measures, such as requiring keycard access to enter buildings or individual rooms, can significantly increase the time it takes for an attacker to reach their targets, providing occupants with valuable minutes to escape or implement lockdown procedures [8]. However, it's crucial to balance security with accessibility and functionality, ensuring that security measures do not impede daily operations, create excessive inconvenience for occupants, or hinder emergency response efforts [8, 35].

Surveillance systems, including CCTV and other monitoring technologies, can play a vital role in enhancing situational awareness during ASIs, enabling faster detection of threats and supporting more effective response strategies [23, 36–38]. Strategically placed cameras, coupled with real-time monitoring systems, can provide security personnel with valuable information about the attacker's location, movements, and actions, allowing for a more informed and coordinated response [23]. Moreover, the integration of AI and machine learning into surveillance systems offers the potential for automated threat detection, identifying suspicious behavior and alerting security personnel to potential risks before an ASI occurs [39, 40]. This proactive approach to security, leveraging advanced technologies to identify and respond to threats early, could significantly reduce the likelihood of ASIs occurring and mitigate the severity of those that do.

Incorporating bullet-resistant materials into building construction, particularly in areas with high visibility or vulnerability, can offer an additional layer of protection for occupants, reducing the risk of injury or death from gunfire [41]. Research has examined the effectiveness of laminated glass, reinforced concrete, and composite materials in resisting ballistic impact, demonstrating their potential applications in building components such as windows, doors, and walls. However, while bullet-resistant materials offer enhanced protection, the cost-benefit analysis of implementing them must be carefully considered, considering factors such as building type, occupancy, perceived risk level, and budgetary constraints.

3.3 Communication Systems: A Lifeline for Information Sharing and Emergency Response

Effective communication systems are not merely technological tools; they are lifelines for occupant safety during active shooter incidents (ASIs), facilitating rapid information sharing, coordinated responses, and ultimately, saving lives. These systems play a critical role in mitigating the chaos and uncertainty inherent in ASIs, empowering occupants to make informed decisions and take appropriate actions, even in the face of extreme stress and fear. Research has repeatedly demonstrated the crucial role of communication in enhancing situational awareness, guiding evacuation, and supporting a swift and coordinated response from both occupants and emergency personnel [42, 43].

Emergency notification systems (ENS) serve as the foundation for effective communication during ASIs, acting as a central nervous system for disseminating critical information rapidly and widely [42]. These systems leverage diverse communication channels to reach occupants quickly and effectively, ensuring message redundancy and maximizing reach. Traditional methods, such as public address systems and audible alarms, remain vital for broad, immediate alerts within a building, particularly when power outages or internet disruptions may affect digital communication [44]. However, the digital age has expanded the communication toolbox significantly, incorporating SMS messages, emails, mobile alerts, social media platforms, and digital signage into the ENS repertoire [43, 45, 46]. This multi-channel approach, strategically combining traditional and digital methods, increases the likelihood of reaching occupants and creates redundancy, ensuring message delivery even if one or more channels fail [47].

While reaching occupants quickly is paramount, the effectiveness of ENS hinges on the messages' clarity, conciseness, and actionable nature [48]. Research has shown that vague or ambiguous messages can lead to confusion, hesitation, and inappropriate responses, potentially increasing the risk of harm to occupants [49, 50]. Therefore, emergency notifications must be carefully crafted, providing clear and specific instructions, location-based details (e.g., the location of the attacker, safe evacuation routes, designated safe spaces), and guidance on appropriate actions, such as evacuation procedures, lockdown protocols, or, as a last resort, defensive tactics [48, 51]. Furthermore, effective communication extends beyond initial alerts. Real-time communication and information sharing systems, utilizing mobile devices, two-way radios, and interactive digital displays, can further enhance occupant safety during ASIs [52, 53]. These systems create a dynamic information loop, providing ongoing updates about the situation, enabling two-way communication between occupants and first responders, and fostering a sense of shared awareness [23]. By knowing the attacker’s location, movements, and actions, occupants can make more informed decisions about evacuation routes, hiding places, or whether to engage in defensive actions [54, 55].

Integrating these real-time communication systems with building design is crucial for maximizing their effectiveness [23, 55]. Strategically placed communication hubs, incorporating two-way radios or internet-connected devices, can provide occupants with access to critical information and enable them to communicate with authorities even if cellular networks are disrupted [55]. Interactive digital displays, strategically positioned throughout the building, can provide real-time updates, evacuation maps, and safety instructions, supplementing audible alerts and enhancing situational awareness [23]. Furthermore, incorporating communication systems into building automation systems can enable automated responses, such as locking doors, activating alarms, or adjusting lighting to guide evacuation [56].

While technology plays a crucial role in facilitating communication during ASIs, it's paramount to acknowledge the profound influence of human factors. Occupants’ responses to emergency notifications are shaped by their perceptions of risk, trust in information sources, and the social dynamics unfolding around them. Research has shown that individuals in crisis situations often prioritize information from their peers and social networks, even if it is unverified or inaccurate [49, 57]. This "social contagion" [58] can rapidly spread misinformation, hindering effective response and potentially increasing the risk of harm. Therefore, building design and communication strategies should consider these social influences, promoting a culture of preparedness that fosters trust in official information channels and encourages occupants to verify information before sharing it. Regular drills, educational programs, and clear communication protocols can help build occupant confidence in emergency procedures and enhance their ability to act decisively and responsibly during ASIs [59].

3.4 Human-Building Interactions and Behavioral Aspects: A Complex Interplay of Design, Stress, and Social Dynamics

While well-designed exits, robust security features, and sophisticated communication systems form the physical and technological foundation of ASI preparedness, understanding and incorporating human behavior is paramount. Occupants are not simply passive entities moving through a building; they are active agents, making decisions, reacting to their surroundings, and influencing the dynamics of the event in profound ways. Research in crowd dynamics, social psychology, and human factors has revealed a complex interplay between individual characteristics, social influences, environmental cues, and the inherent stressors of ASI situations. Ignoring these human factors in building design and emergency planning risks creating environments that, despite technological sophistication, may fail to protect occupants effectively during these critical events.

One of the most challenging aspects of modeling occupant behavior during ASIs is the profound influence of panic and anxiety on human cognition and decision-making [60, 61]. Confronted with the sudden and unexpected threat of an active shooter, individuals may experience a cascade of physiological and psychological responses, including elevated heart rate, rapid breathing, hypervigilance, fear, and a sense of overwhelming dread [62, 63]. These stress responses, while evolutionarily adaptive for preparing the body to fight or flee, can significantly impair cognitive function, leading to delayed reactions, poor judgment, and an increased likelihood of making irrational or counterproductive choices [64, 65].

Studies have shown that under extreme stress, individuals may experience tunnel vision, auditory exclusion, time distortion, and a decline in fine motor skills [66, 67]. These stress-induced impairments can hinder occupants' ability to perceive information accurately, process instructions, locate exits, or effectively implement learned safety protocols [29]. Therefore, simulation models used to evaluate building designs must account for these psychological effects, incorporating realistic representations of human decision-making under stress to accurately predict evacuation patterns, identify potential bottlenecks, and guide the development of design strategies that can mitigate the negative impacts of panic [14, 30].

Furthermore, occupant behavior is significantly influenced by social factors, such as group dynamics, herd behavior, and information-sharing patterns. Research has consistently shown that individuals in emergencies often look to others for cues on how to behave, particularly when faced with ambiguity or uncertainty [68]. This "social proof" or "herd behavior" can be amplified during ASIs, as the chaotic and unpredictable nature of the event creates a heightened sense of urgency and a need for immediate action [69]. The tendency to follow the crowd can rapidly spread helpful and harmful behaviors, impacting evacuation efficiency, potentially contributing to congestion or panic, and hindering effective responses [58].

For example, research has shown that in crowded environments, the behavior of a few individuals can quickly cascade through the crowd, leading to mass movements towards exits, even if those exits are blocked or unsafe [70]. Simulation models can be powerful tools for incorporating these social dynamics, allowing researchers to explore how group behavior, leadership roles, and information sharing patterns influence exit choice, evacuation route selection, and overall crowd movement patterns during ASIs [22, 70]. By simulating different crowd compositions, social network structures, and communication strategies, researchers can gain insights into optimizing building design and emergency protocols to mitigate the negative impacts of herd behavior and promote more orderly evacuations.

Beyond social dynamics, building design itself can profoundly influence occupant behavior during ASIs. The arrangement of space, the visibility of exits, the clarity of signage, and the overall spatial configuration can either guide or hinder wayfinding, impact decision-making, and affect the perceived level of safety [8, 71]. Studies have demonstrated that well-lit corridors, clear signage indicating exit routes, and open spaces that provide a sense of visibility and control can reduce anxiety, improve wayfinding, and facilitate more efficient evacuation [8, 13, 71]. These design features can create a sense of predictability and control within the environment, supporting occupants' ability to make rational decisions and follow established safety protocols. Conversely, poorly lit areas, confusing layouts, narrow corridors, obstructed exits, and limited visual access can exacerbate panic, lead to poor decision-making, and increase the risk of congestion, bottlenecks, and injury [10, 16].

Finally, the effectiveness of training programs and emergency preparedness measures is intrinsically linked to occupant behavior and human-building interaction. Research on evacuation drills, active shooter training, and other preparedness initiatives has highlighted the importance of considering human factors, individual differences, and social dynamics in developing and implementing effective training programs [20, 32]. Traditional "lockdown" drills, while intended to enhance safety, have been found to increase anxiety and stress among participants, particularly children, without necessarily improving their ability to respond effectively during an actual ASI [72]. Therefore, there is a growing need to develop training programs that are not only informative but also psychologically sensitive, incorporating strategies for stress management, empowering occupants with a sense of agency, and addressing the diverse needs of different populations, such as children, individuals with disabilities, and those with pre-existing mental health conditions [73, 74].

Simulation models can be invaluable tools for evaluating the impact of different training strategies on occupant behavior, identifying areas for improvement, and informing the design of more effective preparedness measures [32]. By simulating occupants' cognitive and emotional responses during ASIs, researchers can assess the effectiveness of different training scenarios, communication methods, and building design features in supporting a calm and coordinated response [75].

By recognizing and integrating the multifaceted nature of human behavior into building design and ASI preparedness strategies, we can move beyond a purely technological approach and create built environments that are truly safer and more resilient for occupants. By considering the impact of stress, social dynamics, and the interplay between occupants and their surroundings, we can design buildings that facilitate swift evacuation and empower occupants to respond effectively, mitigate panic, and ultimately, increase their chances of survival.

4. DISCUSSION: SYNTHESIZING INSIGHTS, BRIDGING GAPS, AND SHAPING FUTURE DIRECTIONS

This systematic review, by systematically examining the burgeoning body of research on building design strategies for mitigating ASI risks, offers valuable insights into the complex interplay between architectural design, security features, communication systems, and human behavior. It unveils a landscape of knowledge where technological advancements intersect with human vulnerabilities, requiring a nuanced understanding of how people perceive and respond to threats within the built environment. While the review highlights promising avenues for enhancing occupant safety through informed design, it also unveils critical knowledge gaps. It underscores the need for further research to address the multifaceted challenges of ASI preparedness.

4.1 Connecting the Threads: A Holistic Perspective on Design for Safety

Synthesizing findings across the thematic categories reveals a clear and undeniable interconnectedness between the various aspects of building design for ASI preparedness. Effective mitigation requires a holistic approach, recognizing that exit design, security features, communication systems, and occupant behavior are not isolated elements but intricately interwoven components of a comprehensive safety strategy. This interconnectedness demands that architects, engineers, security professionals, and policymakers collaborate to create built environments that are physically secure and support informed decision-making, rapid response, and psychological resilience during ASIs. The need for this integrated approach is further amplified by the inherent unpredictability of ASIs, requiring buildings to be adaptable and responsive to a range of potential scenarios.

For instance, optimizing exit design for ASI preparedness extends far beyond simply providing sufficient exits and adhering to building codes [76, 77]. It necessitates a deep understanding of how occupants, under the extreme stress of an ASI, will perceive their environment, navigate complex building layouts, and make decisions about evacuation routes. Simulation modeling, particularly using approaches like ABM and SFM, allows researchers to explore these dynamics, considering factors such as exit visibility, signage clarity, corridor width, bottleneck potential, and the psychological and social influences on occupant behavior [10, 11, 16]. Research has shown that strategic placement of exits, ensuring their visibility from multiple vantage points, providing clear and intuitive signage, and designing wide and well-lit escape routes can significantly reduce congestion and facilitate faster evacuation [13, 14, 30]. Moreover, exit design must be carefully integrated with security measures to ensure that locked doors, security checkpoints, or other access control systems do not create unintended bottlenecks, trap occupants, or hinder emergency responders from accessing the building [8, 35]. This integration requires a nuanced understanding of how security features might alter occupant movement patterns during an ASI, necessitating a collaborative approach between security professionals and building designers.

As highlighted throughout this review, communication systems play a vital role in supporting a coordinated and effective response to ASIs. Beyond their function in quickly alerting occupants to the threat, these systems can provide real-time information about the attacker's location, guide occupants towards safe exits or designated safe spaces, and facilitate communication between occupants and first responders [42, 43, 52]. However, implementing effective communication systems requires more than just installing technology; it demands careful consideration of message content, delivery methods, accessibility for diverse populations, and the social dynamics of information sharing during emergencies [49, 50, 57, 78].

For instance, research has shown that emergency messages' clarity, conciseness, and actionability significantly influence occupant behavior [48, 51]. Vague or ambiguous messages can lead to confusion, hesitation, and inappropriate actions, potentially putting occupants at greater risk. Moreover, messages should be tailored to the specific context, audience, and communication channels being used, considering factors like language, cultural norms, literacy levels, and the potential for misinformation to spread through social networks [49, 78].

4.2 Simulation Modeling: A Lens into Complex Interactions, But Not a Crystal Ball

Simulation modeling has emerged as a powerful tool for exploring the complex interplay of factors influencing occupant safety during ASIs. These models allow researchers to create virtual environments, incorporating diverse building designs, occupant characteristics, attacker behaviors, and emergency response strategies [22–24]. By manipulating these variables and running multiple simulations, researchers can gain valuable insights into how different design choices impact occupant outcomes, such as evacuation time, casualty rates, and the likelihood of survival [10, 23, 25]. This data-driven approach offers a unique lens into the complex dynamics of human movement, decision-making, and social interaction within the built environment, providing valuable information for evidence-based design.

However, while simulation modeling offers a powerful approach to exploring ASI preparedness, it's essential to acknowledge its inherent limitations and critically evaluate the validity of simulation findings. As with any model, simulations simplify reality, based on assumptions and generalizations about human behavior, environmental conditions, and the unpredictable nature of ASI events. Oversimplifying these complex factors or relying on inaccurate assumptions can lead to misleading predictions, potentially misinforming design decisions, and creating a false sense of security [79]. Therefore, researchers utilizing simulation modeling must be transparent about the limitations of their models, clearly articulate the assumptions made, and strive to validate their findings through empirical data, real-world observations, or expert input whenever possible [79].

For example, many existing simulation models excel at capturing the physical aspects of evacuation, such as pedestrian flow rates, density distributions, and congestion patterns. Approaches like the Social Force Model (SFM) and Cellular Automata (CA) have been successfully used to simulate crowd movement, identify bottlenecks, and evaluate the impact of different exit designs on evacuation time [30, 80, 81]. However, accurately representing the psychological and social dimensions of human behavior during

ASIs remains a significant challenge [79]. While some models incorporate basic behavioral rules, such as following the shortest path to an exit or avoiding collisions with others, these rules often fail to capture the nuances of human decision-making under extreme stress, social dynamics' influence, and communication's impact on occupant behavior.

Models that fail to adequately account for the impacts of stress, panic, fear, herd behavior, social influence, information-sharing patterns, and individual decision-making biases may produce inaccurate results, particularly in high-stress, chaotic scenarios [49]. For instance, research has shown that occupants under stress may exhibit "freezing" behavior, delaying their evacuation or hindering their ability to make rational decisions. Social contagion can lead to the rapid spread of misinformation or panic through a crowd, influencing exit choices and evacuation routes in unpredictable ways [49, 58]. These findings underscore the need for ongoing research to develop more sophisticated simulation models incorporating a richer understanding of human cognition, emotion, and social dynamics, drawing on insights from psychology, sociology, and human factors research [82].

Furthermore, validating simulation models by comparing their results with empirical data from real-world events or controlled experiments is crucial for ensuring the accuracy and reliability of these models [83, 84]. Field observations of evacuations post-incident analyses of ASI events, controlled evacuation drills, and virtual reality experiments can provide valuable data for calibrating model parameters, testing the predictive power of simulations, and identifying areas where model refinements are needed [32, 85]. By grounding simulation models in real-world data, researchers can enhance their credibility and improve their ability to inform effective building design strategies.

4.3 A Holistic Framework for Building Resilience

While specifically focused on the urgent issue of Active Shooter Incidents (ASIs), this systematic review underscores the crucial need to connect its findings to the broader principles and frameworks of safety science. By integrating concepts such as human factors, risk assessment, control measures, and safety culture, we can transcend a purely event-specific approach and foster the creation of built environments that are not only prepared for ASIs but also inherently safer and more resilient in the face of diverse threats. This holistic perspective acknowledges that safety is not merely about reacting to specific hazards but about proactively designing and managing a system that anticipates, mitigates, and responds to risks across a spectrum of scenarios.

Human Factors: Weaving Human Behavior into the Fabric of Design

Human factors engineering, a discipline dedicated to understanding and optimizing the interaction between people, systems, and their environment, provides a crucial lens for examining building design for ASI preparedness [86]. Recognizing that occupants are not simply passive recipients of design but active agents interacting with their surroundings is essential for creating effective safety strategies. This requires going beyond compliance with building codes and prescriptive measures, delving into the complexities of human perception, cognition, decision-making, physical capabilities, and social behavior [29, 87]. Moreover, designers must understand how these human factors are influenced by the acute stress, anxiety, and fear inherent in ASI situations, recognizing that occupants under duress may not always behave rationally or follow established protocols.

For instance, research has shown that during emergencies, individuals may experience tunnel vision, auditory exclusion, time distortion, and a decline in fine motor skills, impacting their ability to perceive critical information, process instructions, locate exits, or effectively implement learned safety protocols [29, 66, 67]. These stress-induced impairments underscore the need for exit design that is not only compliant with building codes but also intuitive and easily navigable under duress. Clear lines of sight, strategically placed and well-lit signage, and wide, unobstructed evacuation routes can significantly reduce confusion and facilitate faster, more orderly egress [8, 11, 71, 88, 89].

Similarly, integrating security features must be carefully balanced with considerations for usability, accessibility, and the potential psychological impact on occupants [8, 35]. While locked doors, security checkpoints, and surveillance systems can deter attackers and enhance physical security, they can also create a sense of confinement, amplify anxiety among occupants, or even deter individuals from reporting suspicious activity if they feel intimidated or overly monitored [90]. The challenge lies in creating a secure environment without fostering a culture of fear or compromising the building's functionality and aesthetic appeal. Simulation modeling, incorporating realistic representations of human behavior under stress, can be a valuable tool for evaluating the impact of security features on occupant behavior and identifying potential unintended consequences.

Risk Assessment: Informing Design with Data and Foresight

A fundamental principle of safety science is the need for a systematic and data-driven approach to risk assessment. In the context of ASIs, this involves a multi-faceted process of identifying potential threats, analyzing vulnerabilities within the built environment, and quantifying both the likelihood and potential consequences of different ASI scenarios. Risk assessment should extend beyond a simple checklist of potential hazards, considering the interplay of factors such as building type, occupancy patterns, the profile of potential attackers, local crime rates, the accessibility of firearms, and the existing security measures in place [4, 91, 92]. This comprehensive approach provides a more nuanced understanding of ASI risks, allowing for the prioritization of mitigation strategies, the effective allocation of resources, and the development of informed design decisions.

Simulation modeling can be a powerful tool for supporting risk assessment, enabling researchers to explore various ASI scenarios and test the effectiveness of different design choices in mitigating risk [91, 93]. By incorporating data on building occupancy, attacker profiles, weapon characteristics, and potential escape routes, simulations can estimate potential casualties, predict evacuation times, and identify areas of vulnerability within a building [23, 24]. However, using simulation models judiciously is crucial, recognizing their inherent limitations and ensuring that the assumptions made align with real-world conditions and the complexities of human behavior [79].

Moreover, integrating real-time data from building systems, such as occupancy sensors, access control systems, and surveillance technologies, can significantly enhance situational awareness and support dynamic risk management [23, 94]. By continuously monitoring factors such as occupant density, movement patterns, access control breaches, and environmental conditions, intelligent systems can detect emerging threats, identify anomalies, adjust security protocols in real-time, and provide occupants with more targeted and timely information during an ASI. This dynamic risk management approach allows buildings to adapt to changing conditions and respond more effectively to evolving threats.

Control Measures: A Work of Design, Technology, and Human Action

Safety science emphasizes implementing control measures to prevent, mitigate, and respond to hazards. In the context of ASIs, building design strategies can be viewed as a set of architectural control measures orchestrated to minimize risks and enhance occupant safety. These measures encompass diverse approaches, blending physical design elements, technological systems, and administrative protocols to create a multi-layered defense against active shooter threats. However, these control measures' effectiveness hinges on their thoughtful design, meticulous implementation, and seamless integration with other safety systems and emergency protocols.

- **Engineering Controls:** These controls involve physical environmental modifications to reduce risk. Examples abound within the scope of this review, showcasing how architectural design features can act as robust control measures. Strategically designing effective exit routes, incorporating security features like access control systems and bullet-resistant materials, and implementing intelligent communication systems that enhance situational awareness and guide evacuation are all examples of engineering controls with the potential to significantly improve occupant safety during ASIs [8, 10, 42].

- **Administrative Controls:** These controls focus on policies, procedures, and training programs to manage human behavior and promote a culture of preparedness. They address the crucial human element in safety, recognizing that technology and design alone are insufficient without a well-trained and informed occupant population. Developing comprehensive emergency response plans, conducting regular and psychologically sensitive drills, providing active shooter training that empowers occupants with a sense of agency, and establishing clear communication protocols are all examples of administrative controls that can significantly enhance ASI preparedness [32, 50].
- **Personal Protective Equipment (PPE):** While not typically considered within the realm of architectural design, PPE can play a role in specific high-risk settings or for designated occupant groups. Security personnel, for example, might be equipped with bulletproof vests or helmets to enhance their personal protection during an ASI. In certain contexts, such as schools or government buildings, providing designated areas with readily accessible PPE for occupants could be considered as part of a comprehensive safety strategy.

As illustrated throughout this review, the effectiveness of control measures depends on their individual merits and careful integration and coordination. For instance, access control systems, while valuable for delaying attacker entry, must be designed to avoid creating unintended bottlenecks during evacuation or hindering first responders' access. This requires close collaboration between security professionals and building designers, using simulation modeling and real-world data to test the functionality of access control systems under various ASI scenarios [8].

Similarly, surveillance systems should be strategically placed while enhancing situational awareness to maximize coverage of vulnerable areas while minimizing privacy concerns [95, 96]. Integrating surveillance data with real-time communication systems can enable more targeted and timely information dissemination to occupants, guiding them toward safety based on the evolving situation. As highlighted earlier, emergency notification systems are only as effective as the messages they convey. Clear, concise, and actionable instructions, delivered through multiple channels and tailored to the audience's specific needs, are essential for minimizing confusion, reducing panic, and promoting a swift and coordinated response [42, 49].

4.4 Cultivating a Safety Culture: Empowering Occupants and Fostering Resilience

A truly resilient built environment goes beyond design's physical and technological dimensions, encompassing a deeper understanding of human behavior, social dynamics, and the importance of cultivating a proactive safety culture. A safety culture, as defined by the International Atomic Energy Agency (IAEA), is "the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance". This concept, readily applicable to ASI preparedness, emphasizes that safety is not merely a set of rules or procedures but a collective mindset, a shared responsibility, and a commitment to continuous improvement.

Cultivating a safety culture within a building or organization involves fostering a shared awareness of potential risks, empowering occupants to take ownership of their safety, and creating a climate of trust and communication. This requires a multi-faceted approach, encompassing:

- **Education and Training:** Regular training programs, such as active shooter drills, emergency preparedness workshops, and educational materials on safety protocols, can enhance occupant knowledge, build confidence in responding to ASIs, and mitigate the negative impacts of stress and panic [32, 50]. However, these programs must be designed with sensitivity to the psychological impact of ASIs, particularly on vulnerable populations like children or individuals with pre-existing mental health conditions [72, 97]. Utilizing simulation modeling and virtual reality technologies can create more immersive and engaging training experiences while allowing occupants to practice different response strategies in a safe environment [20, 75].
- **Clear Communication and Information Sharing:** Establishing open and transparent communication channels is vital for fostering trust and ensuring that occupants receive accurate

and timely information during an ASI [78]. This includes providing clear instructions, addressing concerns promptly, and actively countering misinformation or rumors that may spread through social networks [49, 57]. Building design can support effective communication by incorporating features like strategically placed digital displays, interactive maps, and communication hubs that provide access to real-time information [23, 55].

- **Empowerment and Shared Responsibility:** A strong safety culture empowers occupants to take ownership of their safety, recognizing that everyone has a role to play in preventing, mitigating, and responding to ASIs [98]. This can be achieved by encouraging occupants to report suspicious activity, participate in training programs, familiarize themselves with emergency procedures, and build evacuation routes. Building design can support empowerment by creating intuitive environments, providing clear lines of sight, and minimizing the sense of confinement or vulnerability [8, 13].
- **Continuous Improvement and Evaluation:** A safety culture is not static but continuously evolving, requiring ongoing assessment, feedback, and adaptation to ensure its effectiveness [99]. Regularly evaluating emergency plans, conducting post-incident analyses, and soliciting feedback from occupants can identify areas for improvement and inform the design of more effective safety strategies. Simulation modeling can play a valuable role in this process, allowing for testing new protocols, evaluating design modifications, and exploring different scenarios to identify potential vulnerabilities or areas for optimization [32].

By fostering a proactive safety culture, we can create built environments that are not only equipped to respond to ASIs but also cultivate a shared commitment to safety, empower occupants to act decisively and responsibly, and enhance the community's overall resilience in the face of this evolving threat.

5. CONCLUSIONS: SHAPING A FUTURE OF SAFER AND MORE RESILIENT BUILDINGS

This systematic review highlights the critical role of architectural design in mitigating active shooter incidents (ASIs) and enhancing occupant safety. By synthesizing findings from 75 studies, we have identified key strategies related to exit design, security features, communication systems, and human behavior modeling. Our analysis underscores the necessity of integrating these elements into a cohesive design approach that balances security, functionality, and occupant well-being.

A key takeaway from this review is that no single design intervention can fully eliminate the risks associated with ASIs. Instead, a multilayered approach—combining strategic spatial planning, access control, surveillance, and effective communication systems—offers the most robust defense. Additionally, simulation modeling has proven valuable in assessing design effectiveness, though future advancements must better incorporate real-world behavioral dynamics under stress.

While our review provides a comprehensive synthesis, several gaps remain. Future research should explore cost-effective security implementations, the psychological impact of security measures on occupants, and the development of adaptable design strategies for diverse building types. Furthermore, validating simulation models with empirical data will strengthen their predictive capabilities.

Ultimately, integrating evidence-based design principles with evolving technological solutions can help create safer, more resilient built environments. Addressing these challenges will require continued collaboration among architects, security professionals, policymakers, and researchers to ensure that safety remains a foundational consideration in building design and management.

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Appendix A: Comprehensive Version of Table 1 (Sorted by Year)

Author(s)	*Year*	*Study Design*	*Building Type*	*Occupant Population*	*Simulation Model (if applicable)*	*Key Findings*
Shih et al.	2000	Simulation Study (Virtual Reality)	Metro Station	Passengers	Virtual Reality Simulation	VR simulations revealed discrepancies between traditional evacuation calculations and actual occupant behavior; exit signage and layout significantly influenced evacuation time.
Purser & Bensilum	2001	Evacuation Experiments, Incident Investigations	Various Building Types	Occupants	N/A	Quantified pre-movement time during evacuations and provided strategies for applying behavioral data to design standards and escape time calculations.
Saloma et al.	2003	Empirical Study	N/A	Pedestrians	N/A	Investigated self-organized queuing and scale-free behavior in real escape panic, demonstrating the rapid spread of behavior patterns through a crowd.
Seeger et al.	2003	Textbook	N/A	N/A	N/A	Provided a comprehensive overview of communication and organizational crisis, emphasizing the importance of effective communication strategies, rumor management, and stakeholder engagement.
Mawson	2005	Literature Review	Various	N/A	N/A	Provided a comprehensive overview of mass panic and collective responses to threats and disasters, emphasizing the need to understand human behavior in emergencies.
Parisi & Dorso	2005	Simulation Study (Social Force Model)	Single Room with Exit	Pedestrians	Social Force Model (SFM)	Showcased the benefits of SFM for capturing contact forces and pedestrian parameters, finding that increasing exit size reduced the probability of blockages.
Pinizzotto, Davis, & Miller	2006	Qualitative Study (Interviews)	N/A	Police Officers	N/A	Investigated police officers' experiences during violent encounters, documenting physiological and psychological responses to stress and their impact on performance.
Moussaid et al.	2010	Experimental Study	N/A	Pedestrians	N/A	Demonstrated the impact of social groups on crowd dynamics, finding that groups can facilitate lane formation and improve flow in bidirectional streams.
Sattler et al.	2011	Experimental Study (Text & Email Messages)	University Campus	Students	N/A	Evaluated the effectiveness of text and email warning messages during simulated ASIs, finding them effective in providing clear instructions and promoting appropriate responses.
Lei, Li, & Gao	2013	Simulation Study (FDS + Evac)	Dormitory	Students	FDS + Evac	Corridor width of 3m and exit width of 2.5-3m were optimal for the dormitory; occupant density significantly influenced walking speed; evacuation time was not proportional to evacuation distance.
Stephens et al.	2013	Empirical Study	University Campus	Students	N/A	Examined the use of multiple channels for emergency communication during crises, emphasizing the need to combat noise and capture attention through diverse communication sources.
Zarrinmehr et al.	2013	Simulation Study (Agent-Based Modeling, Genetic Algorithm)	Building (General)	Pedestrians	Social Force Model (SFM), Genetic Algorithm	Optimized building layout to minimize danger during evacuations, demonstrating the potential of combining SFM with optimization techniques.
Jungert, Hallberg, & Wadströmer	2014	Short Communication	Critical Infrastructure	N/A	Surveillance System	Proposed a system design for surveillance systems protecting critical infrastructures, offering insights into principles of integration with emergency response.
Lang	2014	Case Study	University Campus	Students, Staff	N/A	Described a layered approach to emergency notifications and crisis response, emphasizing empowerment and a four-module training program for crisis coordinators.
Layne	2014	Practical Guidance (Book Chapter)	Cultural Properties	Visitors, Staff	N/A	Emphasized the importance of workplace violence prevention strategies, including access control, employee training, and collaboration with emergency responders.
Doss & Shepherd	2015	Literature Review, Practical Guidance (Book Chapter)	Commercial buildings	Employees	N/A	Multiple communication platforms, clear message content, accessibility for diverse populations, and pre-scripted messages are essential for effective communication during ASIs.
Jungert & Chang	2015	Research Article	Critical Infrastructure	N/A	Surveillance System	Described a surveillance system for incident handling using a situation-based Recommendations Handbook, providing insights into how surveillance data can inform decision-making during

						emergencies.
Zhou et al.	2015	Simulation Study	Hall	Pedestrians	Fuzzy Logic Model	Investigated pedestrian evacuation under the influence of attackers, using a fuzzy logic approach to model avoidance and escape behaviors.
Ahn, Kim, & Lee	2016	Simulation Study (Agent-Based Modeling)	Complex Shopping Center	Shoppers, Employees	Agent-Based Model (ABM)	Human conflict and spatial design significantly influenced evacuation time; wider exits near high-density areas improved evacuation efficiency.
Malekitabar, Ardeshir, & Stouffs	2016	Risk Analysis (BIM-Based)	Construction Sites	Construction Workers	Building Information Modeling (BIM)	Identified safety risk drivers detectable during the design phase, advocating for BIM-based risk assessment tools to prevent construction accidents.
Jones et al.	2017	Survey, Twitter Data Analysis	University Campus	Students	N/A	Conflicting information and reliance on social media for updates during a campus lockdown increased acute stress; highlighted the need for reliable, timely communication.
Kaji & Inohara	2017	Simulation Study (Cellular Automata)	Corridor	Pedestrians	Cellular Automata (CA)	Simulated pedestrian flow in a corridor, reproducing the velocity profile of Hagen-Poiseuille flow, demonstrating the applicability of CA for studying pedestrian dynamics in specific architectural settings.
Douma	2018	Discussion, Case Study	Public Spaces (general)	N/A	Automated Video Surveillance, Machine Learning	Highlighted the potential of using existing surveillance infrastructure and machine learning for real-time detection of emergencies and activating response.
Kellom & Nubani	2018	Simulation Study (Visibility Graph Analysis)	University classrooms	Faculty	Visibility Graph Analysis (VGA)	VGA measures predicted faculty preparedness levels and police response efficiency; visibility was crucial for both occupant safety and police response.
Kim & Han	2018	Simulation Study	Virtual Environment	Occupants	Active Route Choice Model	Developed an active route choice model for crowd evacuation, incorporating human characteristics and communication between occupants for realistic evacuation simulations.
Liu	2018	Simulation Study (Social Force Model)	Public Building (General)	Pedestrians	Social Force Model (SFM)	Dedicated exits for different pedestrian groups (e.g., those with mobility limitations) can improve evacuation efficiency, highlighting the need for inclusive design strategies.
Munn et al.	2018	Methodological Guidance	N/A	N/A	N/A	Provided guidance on choosing between systematic and scoping review approaches, emphasizing the importance of aligning the review methodology with the research question.
Payne et al.	2018	Interviews	Schools (K-12)	School Administrators, Crisis Teams	N/A	Identified communication challenges faced by schools during crises, emphasizing the need for media plans, relationship building with media outlets, and strategies for communicating reassurance and reunification.
Tordeux et al.	2018	Simulation Study	Urban Area	Pedestrians	Mesoscopic Model	Developed a mesoscopic pedestrian model for large-scale simulations, describing movement using aggregate density-flow relationships and capturing population heterogeneity and behavioral variability.
Trivedi & Rao	2018	Simulation Study (Agent-Based Modeling)	Building (General)	Occupants	Agent-Based Model (ABM)	Investigated the influence of door placement on evacuation efficiency, finding that doors located in the middle of walls rather than corners improved evacuation times.
Cho et al.	2019	Simulation Study (Agent-Based Modeling)	Indoor Building (general)	Occupants	Agent-Based Model (ABM)	Even low levels of real-time location tracking of the shooter can improve evacuation safety and reduce casualties.
Nissen et al.	2019	Longitudinal Study	Workplace	Employees	N/A	Employee perception of safety after a terrorist attack was influenced by security measures and evacuation procedures; highlighted the need for employer prioritization of security and clear communication.
Pilkington & Zhang	2019	Literature Review	N/A	N/A	N/A	Examined research trends and challenges in pedestrian and evacuation dynamics, emphasizing the need for data-driven models that incorporate social and behavioral factors.
Purpura	2019	Textbook	Various Buildings	N/A	N/A	Covered principles of life safety, fire protection, and emergency preparedness in various building contexts, emphasizing the need for a multi-faceted approach to safety.
Ronchi et al.	2019	Review Article	N/A	N/A	N/A	Examined the use of simulation modeling for evaluating evacuation

						performance in tunnel fires, highlighting the importance of model validation and the need for multi-model approaches to address uncertainties.
Zhu et al.	2019	Simulation Study (Virtual Reality)	Office Building	Occupants	Virtual Reality (VR)	Identified information requirements for virtual environments to study human-building interactions during ASIs, highlighting the potential of VR for research and training.
Arteaga & Park	2020	Simulation Study (Agent-Based Modeling)	School-like building	Students	Agent-Based Model (ABM)	Increasing hall and door widths improved evacuation efficiency and reduced casualties; narrower halls were more sensitive to higher occupant densities.
Gao, Medjdoub, & Sheng	2020	Simulation Study	Museums	Visitors	Constraint-Based Model, Branch and Bound Algorithm	Proposed a constraint-based design approach to optimize evacuation door positions for minimizing escape route length and evacuation time.
Gwynne, Amos, & Ronchi	2020	Review Article	Various Buildings	Occupants	N/A	Explored the limitations of traditional evacuation drills and proposed a framework for assessing and enhancing evacuee performance using emerging technologies, advocating for evidence-based approaches.
Li & Xu	2020	Simulation Study	Limited-Space Building	Pedestrians	Social Force Model (SFM)	Exit width of 1.1m optimized evacuation time and construction costs; inward-opening doors were more efficient than outward-opening doors.
Lu et al.	2020	Simulation Study (Agent-Based Modeling)	Public Square	Civilians, Attackers	Agent-Based Model (ABM)	More exits and diverse exit distributions reduced casualties during simulated terrorist attacks; highlighted the importance of public facility design for crowd management.
Moore-Petinak et al.	2020	Survey (National)	Schools (K-12)	Students	N/A	Active shooter drills were found to have negative impacts on student emotional health, raising concerns about their effectiveness and the need for less traumatic alternatives.
Schildkraut & Nickerson	2020	Review Article	Schools	Students, Staff	N/A	Examined the effects of lockdown drills and training on school emergency preparedness, emphasizing the need for clearly defined procedures and best practices.
Schonfeld et al.	2020	Policy Statement	Schools (K-12)	Children, Adolescents	N/A	Outlined considerations for involving children in live crisis drills, emphasizing the need to eliminate high-intensity drills, prohibit deception, and ensure appropriate accommodations.
Wang, Liu, & Wang	2020	Questionnaire Survey	Ro-Ro Passenger Ship	Passengers	Multinomial Logistic Regression	Analyzed passengers' likely behaviors during emergency evacuations, finding demographic differences in responses to alarms, instructions, and social influences.
Zhu et al.	2020	Qualitative Study (Focus Groups)	Various (schools, offices, hospitals)	Occupants	N/A	Security countermeasures must consider occupant behavior and trade-offs between security, cost, aesthetics, and daily operations; training and practice are crucial for effectiveness.
Bonaretti & Fischer-Preßler	2021	Survey, Analysis of SMS Warning Systems	University Campus	Students	N/A	SMS warnings often lack sufficient spatial awareness, hindering occupant comprehension and compliance; recommendations for improving message design provided.
Jin, Jiang, & Liu	2021	Empirical Experiment (Controlled Walking Trials)	Corridor	Pedestrians	N/A	Wider corridors improved pedestrian flow rates in both unidirectional and bidirectional movement; different corridor widths affected lane formation patterns.
Menn, Payne-Purvis, & Chaney	2021	Data Article (Survey Data)	University Campus	Students	N/A	Provided an open-access dataset on university emergency notification systems, including student perceptions and experiences, offering insights into communication effectiveness and areas for improvement.
NFPA	2021	Building Code	Various Buildings	N/A	N/A	Established life safety codes and standards for building design, including requirements for exits, fire protection, and emergency egress.
Omilion-Hodges & Edwards	2021	Experimental Study	University Campus	Students	N/A	Students acted as information responders during a simulated ASI, highlighting their role in crisis communication and the need for universities to engage with students as partners in emergency preparedness.
Rusho et al.	2021	Social Media Analysis (Twitter)	N/A	General Public	N/A	Analyzed social media responses to active shootings, revealing initial panic

						followed by informed public responses; demonstrated the evolving influence of social media on crisis communication.
Sadri, Ukkusuri, & Ahmed	2021	Review Article	N/A	N/A	N/A	Examined social influence in crisis communication and evacuation decision-making during extreme weather events, highlighting the role of social networks in information dissemination and behavioral influence.
Scott, Andersen, & Kobayashi	2021	Survey (Questionnaire)	Private University	Undergraduate Students	N/A	Explored student perceptions of safety and preparedness for ASIs, finding that participation in emergency preparedness activities increased awareness of susceptibility and preparedness and enhanced perceptions of safety.
Shi et al.	2021	Experimental Study, Model Validation	Controlled Environment	Pedestrians	Social Force Model (SFM)	Verified the applicability of SFM in simulating crowd egress at exits, highlighting limitations in reproducing emergency conditions and the need for further research.
Tang, Zhao, & Li	2021	Simulation Study	Passenger Terminal Building (Ro-Pax Terminal)	Passengers	Simulation Models (SM-PTO & SM-PE)	Developed a framework for evaluating evacuation performance in passenger terminals, simulating operation processes and passenger movement to identify bottlenecks and optimize design for emergency evacuation.
Zhuang et al.	2021	Simulation Study (Cellular Automata)	Public Space (General)	Pedestrians	Cellular Automata (CA)	Investigated self-organized queuing behavior at bottlenecks, finding that moderate orderliness can improve evacuation efficiency.
Fu et al.	2022	Controlled Experiment	Corridor	Pedestrians (incl. simulated disabilities)	N/A	Examined bidirectional flow with individuals simulating disabilities; helping behavior improved movement efficiency; congestion levels were higher at low densities compared to crowds without disabilities.
Saini, Kalra, & Sood	2022	Simulation Study	Smart Building	Occupants	IoT, Fog Computing, Cloud Computing	Developed an intelligent evacuation system using IoT, fog computing, and cloud services, demonstrating its efficiency in guiding occupants to safety during simulated emergencies.
Haghani	2023	Review Article	N/A	N/A	N/A	Differentiated crowd experiments based on purpose and critically assessed their validity; argued for a balance between controllability and realism in experiment design.
Jin et al.	2023	Simulation Study (Modified Social Force Model)	Ring Road, Straight Corridor	Pedestrians	Modified Social Force Model (SFM)	Addressed limitations of the traditional SFM in simulating bidirectional flow at high densities, successfully capturing lane formation even at high densities.
Lancel, Chapurlat, & Martin	2023	Behavioral Experiments, Computer Simulations	Supermarket	Shoppers	Agent-Based Model (ABM)	Active guidance (flashing lights at emergency exits) influenced exit choice during a simulated terrorist attack; demonstrated the impact of environmental cues on decision-making in emergencies.
Liu et al.	2023	Experimental Study	Office Building	Occupants	Virtual Reality (VR), Video	VR-based training improved response performance and perceived preparedness for ASIs compared to traditional video-based training; immersion and interactivity were key factors in VR training effectiveness.
Lu et al.	2023	Simulation Study (Agent-Based Modeling)	Bar	Civilians, Police, Attacker	Agent-Based Model (ABM)	Modeled ASI scenarios with police intervention, identifying optimal police force size and response times for minimizing civilian and police casualties.
Lyu, Wang, & Wang	2023	Evacuation Experiment, Model Validation	Large Underground Railway Station Plaza	Occupants	EVACNET 4, Composite Occupant Evacuation Model	Validated evacuation models using real-world data; direct access to outdoor exits significantly reduced evacuation time; highlighted the importance of accurate models for predicting evacuation performance.
Mirzaei-Zohan, Gheibi, & Behzadian	2023	Simulation Study (BIM-Based)	Multi-Story Commercial Building	Occupants	Revit, MassMotion	Different stair designs significantly impacted evacuation efficiency; two individual stairs per floor were optimal; identified key factors influencing evacuation performance (density, visibility, agent count).
Ray	2023	Review Article	N/A	N/A	N/A	Explored the background, applications, and limitations of ChatGPT, highlighting ethical concerns, data biases, and safety issues associated with AI technologies.
Templeton, Nash, & Spearpoint	2023	Qualitative Study (Focus Groups)	High-Rise Residential Buildings	Residents	N/A	Explored information sharing and support among residents during fire incidents, highlighting the influence of social dynamics, collective self-

						organization, and trust in peer information during evacuations.
Yakhou, Thompson, & Ronchi	2023	Framework Development, Prototype System	Various Buildings	N/A	Revit, Pathfinder (Evac4BIM)	Proposed a framework for integrating fire evacuation models into BIM, enabling comprehensive assessment of building designs and evacuation data; demonstrated the benefits of two-way data flow between BIM and evacuation tools.
Yang & Ding	2023	Experimental Study, Machine Learning Model	Classroom	Students	Random Forest, SHAP	Identified key factors influencing evacuation outcomes in classroom attacks, emphasizing distance from the attacker, preparation time, and seating position.
Barten, Janssen, & Mortelmans	2024	Cross-sectional Survey (Questionnaire)	Hospitals	Hospital Staff	N/A	Assessed threat awareness and counter-terrorism preparedness, highlighting potential vulnerabilities and security practices in healthcare settings.
Di & Gong	2024	Development of AI-Based Approach	School Buildings	N/A	AI, Point Cloud Data	Proposed an AI-powered method for creating spatial inventories of safety-related features, including access control points, to identify vulnerabilities and enhance response planning.
Hassanpour et al.	2024	Simulation Study (Agent-Based Modeling)	University building	Students, Faculty	Agent-Based Model (ABM)	Integrating earthquake damage assessment into evacuation simulations informed the design of safe spaces and architectural layouts for post-earthquake evacuation.
Lin & Zhou	2024	Simulation Study (Pathfinder)	Geriatric Hospital High-Rise	Elderly Patients, Staff	Pathfinder	Hierarchical crowd organization, vertical functional zoning, and congestion mitigation strategies reduced evacuation time; proposed an integrated evacuation strategy.
Menzemer, Vad Karsten, & Ronchi	2024	Survey, Semi-Structured Interviews	N/A	General Public	N/A	Investigated public perceptions and attitudes towards fire evacuation training, highlighting the importance of early-age education and the need for realistic and engaging training scenarios.

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From Austria to Türkiye: Guidelines for Sustainable Communities

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Abstract

This study outlines critical guidelines for developing and presenting sustainable alternative living drawing from Austrian experiences to communicate sustainable visions and strategies effectively. It emphasizes the need for comprehensive content encompassing data analysis, future projections, and impact assessments to guide informed decision-making and eco- planning. As the first study in Austria to focus on ecovillages within the Global Ecovillage Network (GEN), it highlights their role as experimental hubs for fostering local resilience during 2023-2024. Additionally, the research examines the Transition Towns (TT) Movement, which advocates for low-carbon, socially equitable futures through resilient communities and participatory approaches. These networks, with their innovative responses to peak oil and climate change, provide Austrian models for Turkish eco-towns exploring alternative, sustainable lifestyles. The guidelines are derived from in-depth interviews, site visits, observations, and surveys of case studies, including Vienna, Lower Austria, Cambium GEN ecovillage near Fehring and the Eggenlend Food Neighborhood supported by TT Graz in Styria, Austria. The study employs a ranking system to prioritize themes and topics, offering a structured framework for advancing sustainable alternative initiatives.

1. INTRODUCTION

The content, planning, design, and display of a resilient eco-communities are critical for effectively communicating the vision and strategies for a sustainable future. These guidelines, derived from Austrian experiences, emphasize the importance of comprehensive content, including data analysis, future projections, and potential impacts, to inform decision-making and strategic planning. This empirical study is the pioneer in Austria to explore ecovillages within the Global Ecovillage Network (GEN), highlighting their role as living laboratories for developing innovative solutions for local resilience in 2023-2024 [1]. It also examines the Transition Towns (TT) Movement, which strives for a low carbon, socially just future with resilient communities and increased societal participation. Both networks, with their innovative approaches to peak oil and climate change, serve as Austrian role models for Turkish eco-towns seeking alternative lifestyles. The overarching bilateral approach for this empirical study was a one-year collaborative effort in the interdisciplinary work group on Sustainable Urban Regions (SUUREG) at the Austrian Academy of Sciences. This effort included shared discussion, reflection and investigation of case studies, themes and stakeholder contacts in the field of sustainable settlement development; and not least mutual learning about the Austrian and Turkish planning systems with the aim of enabling a transnational travelling of planning ideas [2].

2. METHOD

Methodologically, the following guidelines are structured based on main themes from interviews, site visits, observations, and surveys of case studies- Vienna, Lower Austria, Cambium GEN eco-village near Fehring and Eggenlend Food Neighborhood supported by TT Graz in Styria-Austria [3,4,5], with a ranking system from (a) to (l) reflecting the importance and sequence of each topic as verified through joint interpretation in the work group of SUUREG. The summarized interviews were analyzed using ChatGPT to identify

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common themes and codes for qualitative analysis. All interview texts were input into ChatGPT, which identified recurring themes, ranked them highlighting topics from community building (a) and common ownership to collaborations and networks (l). This process demonstrates the advanced capabilities of machine learning, as AI like ChatGPT can analyze large datasets, understand human-made texts, and generate insights closely aligned with human cognition [6]. Study approach is to analyze transparency, bottom-up participation and collaboration. Transition Towns and Global Ecovillage Network are in the focus of the research for bottom-up participation for local resilience. Shared discussion, reflection and investigation of case studies, themes and stakeholder contacts were used for as methods to collect data from citizens and a platform to meet/collaborate with citizens. A collaborative approach helped the team composed of researchers, analysts and pioneers work smarter, more creatively and more effectively (Figure 1).

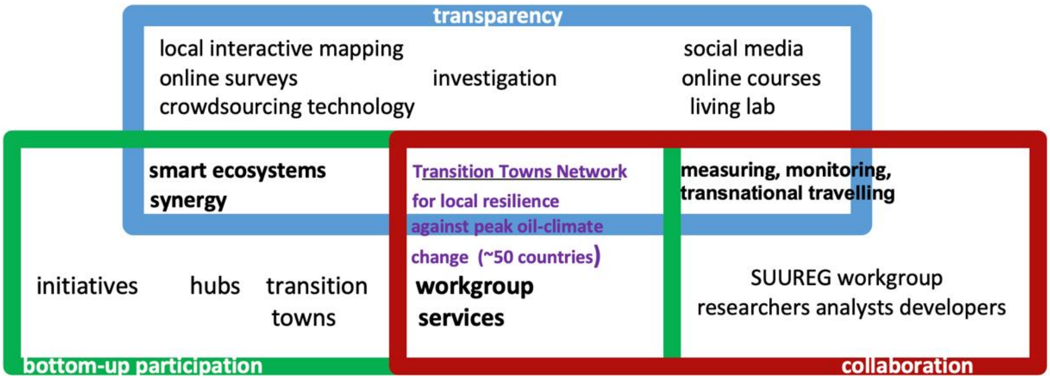

Figure 1. *Study Approach*

3. THEORETICAL FRAMEWORK

a) Community Building and Common Ownership:

The significance of trust and clear hierarchy in community advancement is evident in thriving societies, where seamless coordination and decision-making are keys. Shared ownership models enhance cooperation and unity, as seen in successful initiatives.

Cambium is a fully developed eco-village that has thrived for 9 years near Fehring, Graz, guided by the Dragon Dreaming method to align common dreams and create a vision [7].

Eggenlend neighborhood in Graz is a newer, lighter intentional community supported by TT Graz, focusing on sustainable food and community gardens. It is expected to grow as it continues its initiatives.

b) Motivation and Vision for Change:

The pursuit of ecological initiatives and sustainable community practices is driven by awareness of environmental threats, grassroots advocacy, and the recognition of conservation's long-term benefits. Progressive movements for social justice focus on personal liberty, equitable resource distribution, and empowerment to ensure fairness and equal opportunities.

Cambium community exemplifies these values with its eco-village, fostering openness, freedom, and interconnectedness among its residents. Their approach encourages trust and growth for all members, both adults and children.

Eggenlend community is motivated by a vision of providing healthy and affordable food for everyone, demonstrating their commitment to fairness and readiness for change in their neighborhood.

c) Dragon Dreaming and Vision Creation:

The Dragon Dreaming project management methodology is applied to project development with a holistic approach that enhances community engagement and sustainable outcomes, benefiting both people and the planet. This method supports integrating diverse groups by promoting dialogue, empathy, and a shared commitment to common goals while respecting individual differences.

For instance, Cambium adopted Dragon Dreaming in 2015, using it to shape their vision and foster their eco-village's growth. Similarly, the Eggenlend food community, starting in 2023, utilized Dragon Dreaming to coordinate their food project, clarifying their communal dreams, objectives, tasks, and vision. This approach underscores the transformative power of collaboration, innovation, and holistic thinking in achieving collective goals.

d) Sociocracy Impact on Decision-Making & Implementation:

Sociocracy and Dragon Dreaming enhance decision-making and community interactions by fostering trust, collaboration, and ownership. Sociocracy, which uses consent-based decision-making in circles, and Dragon Dreaming, with its structured yet flexible approach, improve cohesive action, problem-solving, and resilience by aligning decisions with shared values and diverse input. Challenges in implementing sociocracy across different levels-grassroots to governmental-underscore the need for adaptable frameworks, transparent communication, and continuous education. Addressing varying organizational cultures and power dynamics is crucial. Overall, sociocracy's potential to democratize decision-making and promote inclusivity can lead to more resilient and equitable communities, with effective training, feedback [8].

Cambium has benefited from professional guidance in sociocracy and community development, using interconnected circles instead of a hierarchical structure to facilitate autonomy and collaboration. Similarly, for Eggenlend food community, adopting sociocracy and working in circles could strengthen their decision-making processes and support their sustainability.

e) Financial Structure and Asset Pool:

Investigating asset pooling and autonomously managed financial systems highlights their potential to enhance investment performance, minimize risk, and ensure transparency and accountability. Effective financial decision-making requires balancing factors such as risk tolerance, investment objectives, time horizon, and market conditions, while aligning with sustainability goals. Barriers to collaboration, awareness-raising, and securing foundational funding stress the need for strategic partnerships, education, and innovative funding mechanisms. Cambium's financial model, operational since 2019, exemplifies these principles with a dynamic asset pool where community investors contribute and withdraw funds, supporting sustainability projects like photovoltaic installations and building renovations. Similarly, Eggenlend can leverage asset pooling and fundraising to build infrastructure, purchase equipment, and make long-term investments. Additionally, adopting a participatory budget model in Graz, where communities influence how funds are allocated for public amenities, could strengthen connections between private developers and local residents.

f) Knowledge of Transition Towns and Global Eco-Village Network:

Recognizing best practices in Austria and Europe highlights the need for thorough research and knowledge-sharing to adapt successful models to local contexts and address gaps in sustainable transitions. Collaborating with various initiatives is crucial for leveraging expertise and resources, fostering innovation, and tackling challenges through partnerships and cross-sector collaboration. Building positive relationships and identifying success factors require trust, open communication, and respect among stakeholders, with a focus on community engagement, leadership, inclusivity, and sustainability for effective transition efforts. GEN Austria offers eco-village design courses and organizes events through the Podium online series with partners. TT Austria is currently inactive due to the lead's health issues, while TT Graz is struggling with a heavy workload on one leader. Ideally, a dedicated team would help address its goals. The Eggenlend community center supports both food neighborhood projects and TT Graz, enhancing collaboration.

g) Sustainability: Eco-Initiatives & Spatial Characteristics of Settlements

Incorporating sociocracy into sustainability efforts involves applying participatory decision-making, transparency, and distributed authority to enhance effectiveness, inclusivity, and adaptability in sustainability goals. Sociocratic principles align with ecological values like collaboration and stewardship, strengthening community and ecosystem resilience. Proximity and interaction within eco-initiatives build community and collective action, improving communication, collaboration, and resource-sharing for environmental and sustainable living issues. Research and collaborations within sociocratic communities show that sociocracy fosters trust, empowerment, and innovation, leading to better organizational resilience and sustainability outcomes.

Interviews have identified several successful eco-initiatives that showcase effective practices for sustainable urban development. Notable examples include TT Graz, Circular Wien, and the Sociocracy Center and Wohnprojekt Wien, which integrate community-led sustainability, circular economy principles, and democratic governance models. The Cambium Eco-village, TT Austria, and DorfUni highlight intentional communities and educational programs fostering resilience and sustainable living. The Auenweideproject [9], Klimaaktivprogram, BOKU's SoneC project, and Initiative Gemeinsam Bauen und Wohnen further contribute to sustainable development through co-housing, climate action, and collaborative initiatives [10].

Superblocks- traffic calmed neighborhoods like Vienna's Supergrätzl, reduce car traffic and prioritize walking, cycling, and public transport [11], helping ease congestion in areas like Graz's Eggenlend neighborhood. The 15-minute city concept promotes density and accessibility, creating greener, more vibrant neighborhoods with close-knit communities. To encourage active transportation, create safe, dedicated paths for pedestrians and cyclists, ensure connectivity and accessibility, and integrate these paths with public transit and urban planning. Community involvement and regular maintenance are essential. Implementing these principles in Eggenlend can improve public health, reduce congestion, lower emissions, and foster sustainable communities.

h) Urban Planning and Governance:

Urban planning and governance are essential for creating sustainable, resilient, and thriving communities in transition towns and eco-villages. Effective planning integrates sustainable practices like mixed land use, pedestrian-friendly design, green spaces, and efficient transportation to improve quality of life and reduce environmental impact. Mixed-use developments and compact, clustered designs, such as those at Cambium campus, support diverse, inclusive communities and enhance energy efficiency.

Effective governance in these communities involves democratic, transparent, and inclusive processes. Participatory decision-making, clear roles, and conflict resolution empower residents to shape their future and address challenges. Community-led initiatives, such as those in Austria, enhance public amenities and foster vibrant communities. The Eggenlend community center plays a crucial role in co-creation events and urban gardening, driving physical, cultural, and social changes.

i) Co-Housing and Sustainable and Affordable Construction:

Co-housing involves citizens collaborating to create and manage their own homes through means such as land trusts, associations, cooperatives, or co-housing units. This approach can reduce costs and provide personalized, locally appropriate solutions, complementing traditional housing methods. Co-housing initiatives promote sustainable practices, resource-sharing, and decision-making, reducing ecological footprints and enhancing social cohesion and resilience.

Near Vienna, projects like Wohnprojekt Wien, Bikes&Rails, Gleis21, and Auenweide serve as models for community-led housing. These can be replicated in Eggenlend, offering affordable housing for refugees, immigrants, low-income individuals, and young people in sustainable buildings. Children in co-housing and eco-villages develop holistically through nature connection, community involvement, and sustainable living skills, supported by environments like Cambium Eco-Village and Auenweide Co-Housing.

Sustainable building techniques, including passive solar design, renewable materials, and energy-efficient appliances, reduce environmental impact and improve indoor air quality. Modular construction can enhance urban density and feasibility for projects, such as affordable housing, training facilities, and commercial spaces, in places like Eggenlend and Cambium.

j) Local Farming / Permaculture and Food Cooperatives

Local farming in intentional communities boosts sustainability, reduces carbon emissions, and strengthens community bonds through shared work and food culture. It supports local economies, promotes biodiversity, and encourages healthy eating. Initiatives like "eat and buy local" and "Made in Graz" enhance local product distribution and job preparedness. Urban green spaces, such as "Edible Streets," improve rainwater management, biodiversity, and community well-being by transforming hard surfaces into natural environments. Cambium eco-village is mostly food self-sufficient, growing most vegetables and buying local bulk items. They prioritize organic food, sourcing items like olive oil from a Greek cooperative and collectively purchasing around 70-80 essential food items. In Eggenlend, the community center initiated a seed exchange and started building raised beds with neighbors to ensure access to healthy, affordable food.

k) Renewable Energy and Carbon Footprint

Renewable energy is essential for intentional communities in a post-carbon future. It promotes sustainability, reduces emissions and pollution, enhances resilience, and supports self-sufficiency. Economic benefits include job creation and long-term cost savings. Additionally, it fosters community engagement and equity. Cambium eco-village, repurposing an abandoned building, exemplifies low carbon impact with innovative eco-tech installations, attracting visits from mayors. Smart City Graz's project explores solar modules, cooling, urban solar power, integrated façades, mini-CHP facilities, and smart heat grids, moving towards a Zero Emission City with 100% renewable urban energy. Integrating industrial waste heat into district heating and the BIG Solar Graz feasibility study show that 500,000 square meters of solar collectors could meet 20% of local heating demand [12]. These initiatives could significantly benefit Eggenlend.

l) Collaborations and Networks:

Engaging with networks like GEN and TTs provides intentional communities access to global knowledge, resources, and support, facilitating the sharing of best practices and collaboration on sustainability projects. These partnerships amplify community impact and support broader sustainability and social justice efforts. Connecting with local governments is crucial for navigating regulations, accessing funding, and leveraging infrastructure. Building trust through open communication, aligning on shared goals, and demonstrating the value of community initiatives can overcome collaboration challenges. Involving diverse stakeholders in decision-making and advocating for policy changes and funding are essential for successful community-government partnerships.

Cambium eco-village has been featured on the GEN website since 2018. TT Graz engages with Eggenlend community center activities and aims to strengthen its initiatives through collaborations and expanding its team.

3. THE RESEARCH FINDINGS

Based on the Austrian experience, potential networks in Türkiye can be established by adapting strategic principles to fit the Turkish social structure, human relations, and legal infrastructure. Key insights include assessing Türkiye's socio-economic context to identify suitable sustainable community models, fostering a culture of cooperation and trust, and encouraging the creation of a unified vision for development. Promoting active participation and inclusivity in decision-making processes will enhance community engagement, while emphasizing collective efforts in developing sustainable infrastructure will build a resilient community framework. By adopting these principles, Türkiye can enhance its sustainable community development, leveraging successful strategies from Austria.

a) Community Building and Common Ownership:

In Turkey, interpersonal relationships emphasize mutual tolerance and support due to strong family ties. There are about 322,000 NGOs, with 2.1% focusing on environmental issues, including notable organizations like TEMA and WWF-Türkiye. Turkish property law allows various ownership types, and associations can buy or sell real estate with board approval. Eco-villages/farms are relatively rare and often face budget and adaptation challenges [13]. Successful projects need to integrate with global networks like GEN and TT.

b) Motivation and Vision for Change:

Eco-village initiatives in Türkiye, which began gaining momentum in the 2000s, are mainly found in the Aegean and Mediterranean regions. These initiatives face challenges such as social and economic issues, social security concerns, healthcare deficiencies, and neglect of agriculture, impacting their effectiveness. The Cambium eco-village is noted for its success, with a focus on personal development and community bonds. Similarly, the Eggenlend community's commitment to providing healthy and affordable food is highlighted as a model for Turkish eco-village initiatives.

In Türkiye, about 10 Community Supported Agriculture (CSA) and Slow Food communities exist, with notable ones being the Buğday Association Cumhuriyetköy Bahçe project and Güneşköy Bahçemiz. While there's no formal CSA network, informal efforts by organizations like Buğday Association and Çamtepe Ecological Life Center support around 1,000 people [14]. Local citizen council workgroups are active but not linked to larger networks like TT or GEN.

c) Dragon Dreaming and Vision Creation:

It sounds like Dragon Dreaming (DD) has proven quite effective in articulating and aligning communal visions. It is interesting that despite its limited use in Türkiye, it has been valuable in Cambium and Eggenlend. Integrating DD at the beginning of a project can indeed help in clearly defining goals and organizing tasks. It could be a great opportunity to revisit and apply those techniques to new projects.

d) Sociocracy Impact on Decision-Making & Implementation:

Introducing sociocracy into Türkiye's intentional communities could indeed be a game-changer, especially in addressing intra-group conflicts and enhancing decision-making processes. The idea of setting up a Sociocracy Institute and providing ongoing training aligns well with the successes seen in other regions like Vienna and Cambium. By implementing socioratic decision-making, communities in Türkiye could benefit from more structured and effective governance, leading to greater continuity and success. It sounds like a promising path forward for improving community dynamics and project outcomes.

e) Financial Structure and Asset Pool:

Crowdfunding, including equity-based (EBCF) and debt-based (DBCF) methods, provides an alternative to traditional funding sources and is regulated in Turkey under specific laws. Participation Banks, limited in operations and unable to directly gather deposits, rely on profit and loss participation accounts. Çanakkale Municipality's participatory budgeting project in 2007 successfully funded local initiatives through community involvement [15]. Although asset pooling systems are unregulated in Turkey, they have potential for renewable energy, food cooperatives, and building cooperatives, with successful examples from Auenweide co-housing project and the Cambium eco-village demonstrating their viability.

f) Knowledge of Transition Towns and Global Eco-Village Network:

The GEN network is relatively unknown in Türkiye. Güneşköy, a GEN-Europe member since 2010, struggled with sustainability due to a lack of permanent residents. Transforming existing or abandoned villages into eco-villages could be more successful, though state support is often required. The Ecovillage Design Education (EDE) program, developed by GAIA Education, has been offered in Türkiye at METU (2007-2008), Abant İzzet Baysal University, and İstanbul (2015) [16]. In İstanbul, established by the İstanbul Permaculture Collective in 2018, appears inactive. Roof Farm, focusing on urban rooftop farms, is another notable initiative. Grassroots civil LA21 networks in Türkiye, evolving into volunteer citizen councils by 2006, align with municipalities. Promoting the TT movement is crucial for urban sustainability in Türkiye, especially post-Covid-19.

g) Sustainability: Eco-Initiatives & Spatial Characteristics of Settlements:

Establishing a Sociocracy Institute in Türkiye is a key recommendation for eco-initiatives. Promoting the TT Movement and exploring 24-hour eco-towns are essential. Urgent action is needed for energy-efficient solutions, sociocratic neighborhood projects, and constructing energy-certified model neighborhoods. Introducing co-housing and affordable housing for students, the elderly, refugees, and other vulnerable groups is also crucial.

Turkish cities need to improve transport and mobility strategies. Despite progress in traffic calming and bike/pedestrian-friendly planning, many cities still prioritize car-centric infrastructure. Immediate action is needed to implement superblocks, continuous bike lanes, pedestrian-priority areas, and expand light rail, metro networks, and bus connectivity.

Historically, old Turkish neighborhoods featured 15-minute urban environments, promoting pedestrian mobility and vibrant street life [17]. Post-Covid-19, embracing this model will create sustainable urban spaces, reduce accidents, and enhance safety, especially for children [18].

h) Urban Planning and Governance:

For sustainable urban development in TT's, it's crucial to promote compact urban forms, preserve open spaces, and reduce automobile reliance by encouraging public transit, walking, and cycling [19]. Effective waste and pollution reduction through reuse and recycling is also essential. Democratic governance and inclusive decision-making enhance community well-being, while affordable housing and social equity are key to cohesion. Austrian cities like Vienna and Graz exemplify these principles with their compact urban forms, open space preservation, and reduced car use. They serve as models for Turkish settlements, demonstrating effective planning and community engagement. In Türkiye, spatial planning should focus on permaculture zoning, infrastructure, and eco-villages with sustainable design and participatory governance.

i) Co-Housing and Sustainable and Affordable Construction:

In Türkiye, co-housing typically includes dormitories, elder care homes, and student hostels with private bedrooms and shared facilities, focusing on economic benefits and social interaction [20]. Unlike Austria's diverse co-housing examples, Türkiye's projects are more limited in scope.

Children in eco-villages and co-housing communities gain from a strong connection to nature, a sense of belonging, and flexible educational approaches. Austrian eco-villages like Cambium and Auenweide co-housing project offer environments rich in nature, community, and holistic education, promoting environmental stewardship and personal growth. Developing co-housing in Türkiye could provide similar benefits for child development.

Sustainable building techniques for affordable eco-housing focus on energy efficiency and environmental friendliness. Austrian methods include proper insulation, energy-efficient windows, passive solar design, renewable energy, and water conservation. In earthquake-prone areas of Türkiye, co-housing should incorporate reinforced construction, seismic design, and durable, lightweight materials. Key features include energy efficiency, water conservation, waste reduction, and modular designs for easier recovery. Community involvement ensures the buildings address local needs while promoting environmental sustainability and safety.

j) Local Farming / Permaculture and Food Cooperatives:

In Türkiye, food cooperatives, associations, and networks are key for sustainable food practices and community engagement. Cooperatives focus on collective purchasing, associations address food security and waste, and networks strengthen local food systems. These initiatives have gained recognition since the Covid-19 pandemic (Table 1).

Table 1. *Food cooperatives, associations, and networks* [21,22,23]

Associations:	Food Coops:	Food Communities and Networks:
Keçi Derneği	Ovacık Doğal Kooperatifi	Açık Gıda Ağı
TADYA/DBB/ Dört Mevsim Ekolojik Yaşam Derneği	İstanbul Temiz Hasat Tüketim Koop	Beyoğlu Gıda Topluluğu,
Muğla Çevre ve Arı Koruma Derneği (ÇARIK)	Kocaeli Yeryüzü Koop.	Etsiz Pazartesi
Buğday Derneği	Güneşköy Kooperatifi	Antalya Gıda Topluluğu
EKODER-Ekolojik Yaşam Derneği	İstanbul Yeryüzü Kooperatifi	Doğu Antalya Gıda Topluluğu
Ekoloji Kolektifi Derneği	Muğla İmece Evi Kooperatif Girişimi	İzmir Ege Üniversitesi Doğa ve İnsan Dostu Gıda Topluluğu
	İstanbul Kadıköy Kooperatifi	Zehirsiz Sofralar Ağı,
	İstanbul Boğaziçi Mensupları Tüketim Kooperatifi (BUKOOP)	Eskişehir Gıda Topluluğu
	Çanakkale Belediyesi Üretim ve Pazarlama Kooperatifi	Ekoloji Birliği
	Nilüfer Tarımsal Kalkınma Kooperatifi	SAKÜDA
	Anadolu'da Yaşam Tüketim Kooperatifi	İzmir Gıda Toplulukları (BİTOT, Güzelbahçe)
	Apikoop	Nilüfer Belediyesi Gıda Topluluğu,
	Beşiktaş Kooperatifi	Slow Food Halfeti

Most environmental efforts are focused within İstanbul, Çanakkale, İzmir, and the Western Mediterranean region. On the map, there are 29 marked green locations identified as eco-settlements, primarily consisting of local farms or residential properties (Figure 2).

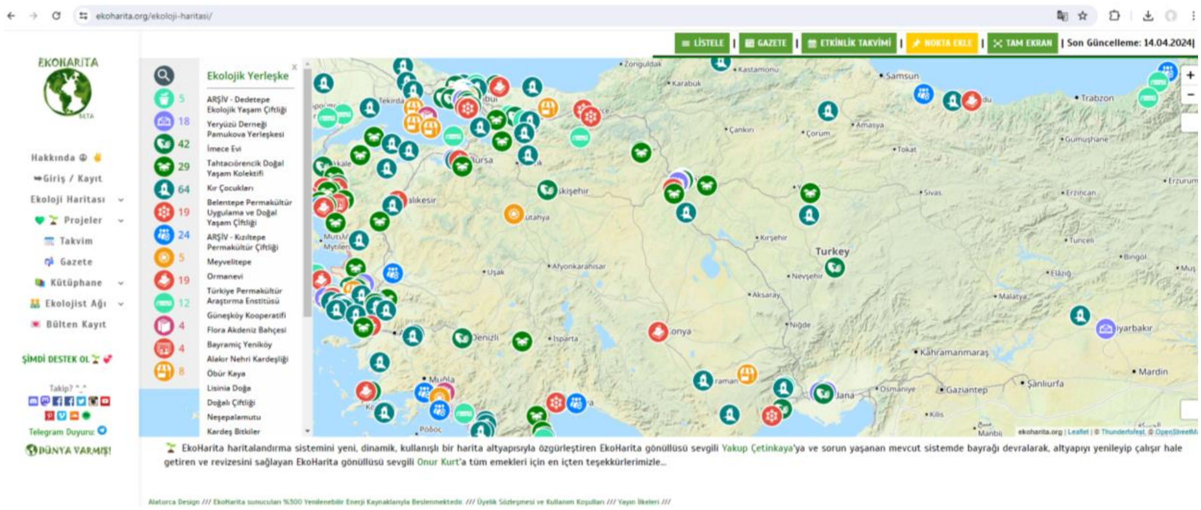

Figure 2. *Eco-initiatives in Türkiye,* [23]

The following tables Table 2 and 3 outline various types and scales of strategic interventions for an energy descent post-carbon transition scenario in Turkish context. Most efforts concentrate on culture, planning, and adaptation, with infrastructure and buildings forming the next category. In terms of scale, there are more interventions in the middle category, while small and large interventions have an equal number. Good governance is essential in this context. The objective is to bring more people together to raise awareness of the TT and GEN networks, and to implement changes in both cities and villages.

Table 2. *Fields of interventions*

Themes	*Culture*	*Policy*	*Adaptation*	*Planning*	*Infrastructure*	*Buildings*	*Financing*	*Education*
Community Building and Common Ownership	■	■	■					
Motivation and Vision for Change	■	■	■					
Dragon Dreaming and Vision Creation	■	■	■					
Sociocracy Impact on Decision-Making	■	■	■					
Financial Structure and Asset Pool	■	■		■	■	■	■	■
TT and GEN	■	■						■
Sustainability and Eco-initiatives			■	■	■			
Urban Planning and Governance				■	■	■		
Co-housing and Affordable Construction				■		■	■	
Local Farming-Permaculture		■			■	■		
Renewable Energy and Carbon Footprint		■		■	■			
Collaborations and Networks	■	■						■

Table 3. *Scale of interventions*

Themes	*Small*	*Medium*	*Large*
Community Building and Common Ownership		■	
Motivation and Vision for Change	■		
Dragon Dreaming and Vision Creation		■	
Sociocracy Impact on Decision-Making			■
Financial Structure and Asset Pool		■	
TT and GEN		■	
Sustainability and Eco-initiatives		■	
Urban Planning and Governance			■
Co-housing and Affordable Construction		■	
Local Farming-Permaculture	■		
Renewable Energy and Carbon Footprint			■
Collaborations and Networks	■		

k) Renewable Energy and Carbon Footprint

Since January 1, 2023, Turkish regulations require buildings over 5,000 square meters to achieve a minimum energy performance rating of "B" and use at least 5% renewable energy. Solar collectors are common, but solar panels remain costly. Collective heating is prevalent in the Aegean Region. While over 15 metropolitan municipalities have climate action plans, reducing residential carbon footprints needs more focus. Increased financial incentives, training, and adopting zero-emission smart city projects like those in Graz, along with carbon footprint measurements, are crucial for Turkish cities.

l) Collaborations and Networks:

In Türkiye, cities and municipalities are involved in EU projects and working with universities, with networks like Healthy Cities and the CittaSlow Movement leading city branding. However, the TT concept is largely unknown, and the Global Ecovillage Network (GEN) lacks visibility without a 24-hour eco-town example. Developing initiatives connected to these networks could enhance sustainable settlements and public participation.

WWOOF Türkiye, evolving from the TaTuTa project with UNDP support, is now part of the global WWOOF movement. Ecological Farm Visits are crucial for promoting sustainable practices such as food cultivation, composting, and renewable energy, with 66 hosts in Türkiye offering these educational programs (Figure 3).

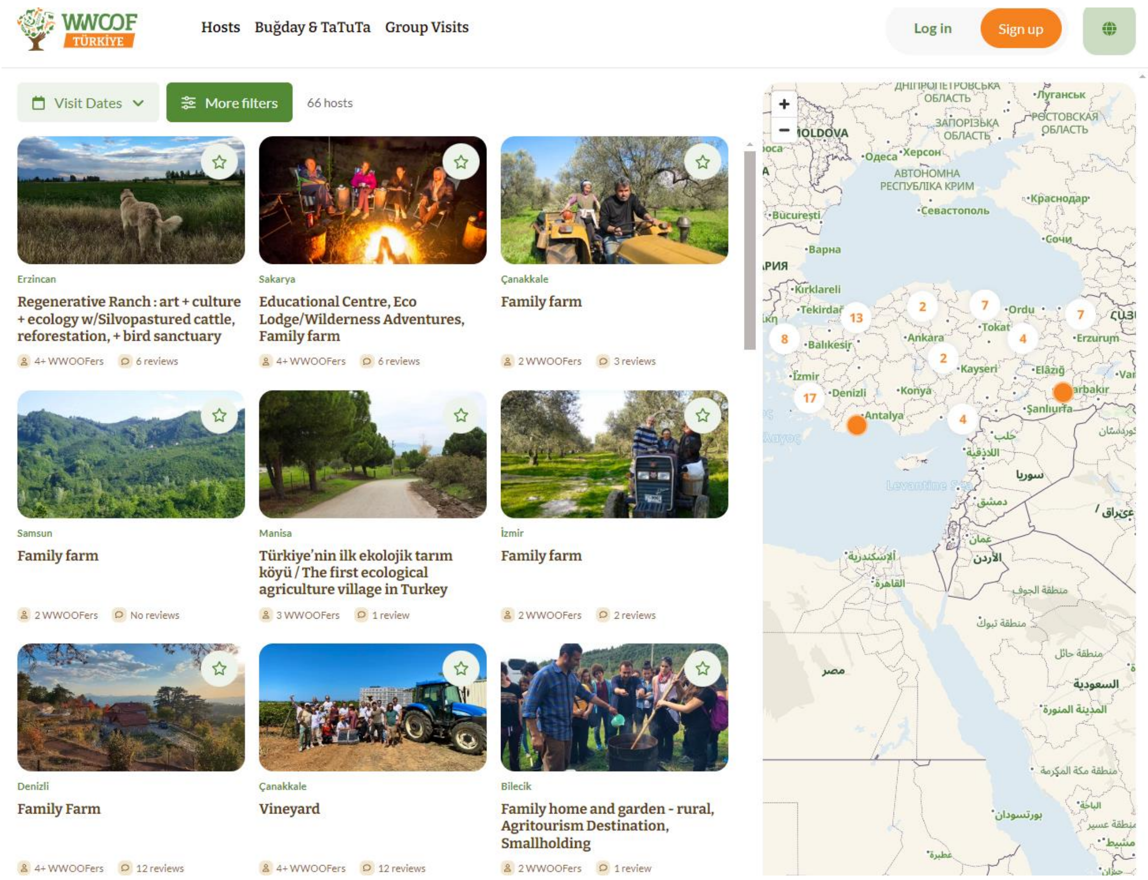

Figure 3. *WWOOF Türkiye host database,* [24]

4. CONCLUSION

The question arises: Do settlements connected to the TTs and Global Ecovillages networks represent resilient models and support the transition to low-carbon communities? Austrian examples suggest that co-housing projects act as mini-villages within cities. TT initiatives in urban areas like Graz focus on thematic projects and network connections rather than specific locations, fostering sustainable food collaborations across neighborhoods. The Cambium eco-village near Fehring is a successful intentional community, benefiting from expert support in community building, moderation, and sociocracy. Sociocracy, a key aspect of these projects, decentralizes decision-making, enhancing resilience and sustainability. Austrian co-housing and ecovillage projects also utilize the Dragon Dreaming method for initial vision building and sociocracy for governance. They serve resilient role models for transition.

In Türkiye, the primary challenge for intentional communities is not financial but a lack of clear vision and effective governance. Many are unaware of Dragon Dreaming, which could enhance community planning and development. Sociocracy is crucial for resolving intra-community conflicts and sustaining low-carbon communities. The success of Austrian projects highlights the importance of these methodologies.

Another critical factor is asset pooling, a financing method involving contributions from multiple individuals to support co-housing or eco-village investments. While Austrian laws facilitate asset pooling, it remains underutilized in Türkiye due to concerns about misuse and trust issues. Properly implemented, asset pooling could lead to successful outcomes similar to those seen in Austrian projects like Cambium and Auenweide.

Austrian initiatives, such as the 15-minute city concept, SuperGräztl design with participatory planning, and sociocratic neighborhoods, inspire local resilience against peak oil and climate change [25,26]. These strategies, crucial for establishing TT communities, emphasize food-related themes and participatory planning. They highlight key elements missing in the planning and design of Turkish cities. In line with

Healey [2], we should not expect to transfer these relevant ideas in identical shape from the Austrian towards the Turkish planning system, but we recommend and are confident that the core ideas found in Austria can work in adjusted way in Türkiye towards an overall more sustainable community development. “The move towards more localized energy efficient and productive living arrangements is an inevitable direction for humanity” [27].

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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