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Resilient Urbanism: Architecture, Equity & Innovation

Editors: Mojdeh Nikoofam
Abdollah Mobaraki

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Resilient Urbanism: Architecture, Equity & Innovation

Mojdeh Nikoofam
Abdollah Mobaraki
Editors

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Preface

Resilient Urbanism: Architecture, Equity & Innovation
As cities grapple with crises, environmental pressures, and shifting socio-cultural landscapes, the integration of heritage, technology, and equity becomes essential. *Urban Resilience & Design Futures* brings together twelve peer-reviewed chapters that explore spatial justice, architectural identity, and innovation in urban practice.

This edited volume is organised into two complementary parts. **Part I – *Architectural Identity, Heritage, and Adaptive Design*:** This section examines the intersections of tradition, memory, and innovation in the built environment. Chapter 1 explores how healthcare spaces and public realms were reimagined during crises. Chapter 2 delves into sacred geometry in Ottoman architecture, decoding its enduring language. The historical continuity of architectural ideas is revisited in Chapter 3 through analytical methods. Chapter 4 investigates local identity in high-rise façades in Bahrain, while Chapter 5 aligns energy retrofitting strategies in retail design with SDG 7. These contributions offer frameworks for blending the past with forward-looking sustainability goals.
Part II – *Urban Morphologies, Systems, and Equitable Transitions:* The second part shifts focus to city-scale dynamics, urban systems, and inclusive transformations. Chapter 6 critiques the patterns and consequences of urban sprawl. Chapter 7 highlights spatial exclusion and educational disparities in Phnom Penh's low-income areas. Chapter 8 offers design strategies for responsive and sustainable urban living. Chapter 9 introduces parametric approaches for shaping energy-efficient urban morphologies. Chapter 10 examines the influence of planning policies on housing layouts and market trends. Chapter 11 explores placemaking strategies in Bahrain that prioritise inclusivity and cultural expression. Concluding the volume, Chapter 12 presents a VISSIM-based simulation for enhancing mobility along Cairo's Salah Salem corridor.
Collectively, these chapters underscore that resilience in architecture and urbanism necessitates a synthesis of contextual sensitivity and adaptive capacity. The volume presents theoretical frameworks, methodological tools, and empirical case studies that demonstrate how cities can evolve and respond to emerging challenges without compromising their cultural identity—effectively bridging the continuity of heritage with the demands of innovation in the face of future uncertainties.
We encourage readers to critically engage with the insights presented, contextualise them within their own disciplinary and geographic frameworks, and in doing so, contribute to the shaping of urban environments that respect historical continuity while proactively addressing future uncertainties.

May 2025
Mojdeh Nikoofam
Abdollah Mobaraki
Editors

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PART I
Architectural Identity, Heritage, and Adaptive Design

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Chapter 1

Synthesizing Healthcare and Public Realms During Crisis

* Zerin Tasnim Promee, Md. Rahat Shahriar, Farhana Rahman Jhumu

Introduction

No matter the crisis—conflict, contagion, or catastrophe—healthcare facilities endure as the frontlines of human service and survival. Over the years, with advancements in technology and medicine, we assumed that well-funded and modern healthcare facilities were prepared to handle major health crises. However, the COVID-19 pandemic exposed a critical flaw in the preparedness and adaptability of healthcare infrastructure worldwide in moments of emergency and health crisis. As the crisis appeared, even nations with well-funded healthcare systems struggled. Hospitals reached capacity, supply chains failed, and they paused their essential services. Makeshift hospitals—established in the parks, parking lots, stadiums, and even in airports —became symbols of improvisation rather than planning. This exposed an alarming reality: this revealed not only a logistical failure, but also an architectural one. Despite technological and operational advancements, healthcare architecture was never ready to scale swiftly in acute need and bend under pressure. Healthcare facilities stood rigid while the cities around them fractured.

This revelation underscores an urgent need to reimagine healthcare infrastructure as an essential dimension of the urban system. Under the thematic lens of **Resilient Heritage & Adaptive Urbanism**, this chapter proposes a new theoretical framework for integrating healthcare facilities into the public realm to enhance cities' response to different health crises. Centered on Miami, Florida—a city vulnerable to hurricanes, flooding, and health emergencies—the study employs comprehensive site analysis, a 5x5 risk matrix, and scenario planning to design adaptable small-scale healthcare infrastructure. The proposed solution connects healthcare facilities to elevated MRT transit systems and evacuation centers, ensuring accessibility for vulnerable populations. By leveraging public transit networks, the proposed design connects healthcare hubs to underserved communities and evacuation centers.

Simulation outcomes from Miami's Civic Center Station demonstrated that elevating healthcare functions within MRT-linked modules maintains continuous service delivery even during severe flooding. By connecting healthcare facilities to public spaces, the design ensures seamless emergency services while supporting sustainable and adaptable layouts for crisis-specific needs and enhanced accessibility for underserved populations. The findings highlight the role of architecture as a systematic process of converting public places into a crisis management mode, merging healthcare in mitigating urban vulnerabilities and improving disaster response through flexibility and functionality under various crisis scenarios.

Looking globally, Dhaka, Bangladesh, offers a critical parallel context, reflecting similar vulnerabilities—dense urban fabric, flooding, and severe traffic congestion. Inspired by historical precedents such as the Bhopal Gas Tragedy, where train stations became vital emergency hospitals when trains were used, this study suggests adapting Dhaka's developing MRT network to function as modular healthcare units in the event of an emergency. Shahbagh, a major node in Dhaka, close to major hospitals, can act as a key emergency hub that can connect the adjacent major hospitals to other MRT stations during a time of crisis. Ultimately, this chapter argues that architecture should evolve from passive, rigid structures into active, flexible, and embedded systems capable of adapting to unpredictable urban challenges.

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Modern Healthcare Facilities: Limitation, Urban Isolation, and Present Strategies

Limitations of Traditional Health Infrastructure

Time and again, we see the same response when crisis strikes: build fast, serve a purpose, then dismantle. Temporary field hospitals erected during the COVID-19 pandemic are prime examples. Some, like the one in New York's tennis center (Figure 1), cost millions but barely served a hundred patients. Others were shut down due to staffing shortages or improvements in conditions (Hamis et al. , 2023).

Figure 1. The Tennis Court at Queens, which turned into a field hospital, served 79 patients (Source: The New York Times, July 2020)

Meanwhile, permanent hospitals built during the pandemic now face reduced demand, making their rigid forms and high costs questionable. Historically, this is not new. Once repurposed from a private estate to treat tuberculosis patients, Louisville's Waverly Hills Sanatorium (Figure 2) now stands abandoned, more a tourist attraction than a healthcare legacy. These examples expose a critical flaw: our crisis-built infrastructure rarely survives beyond the crisis. We keep building structures without thinking about their second life.

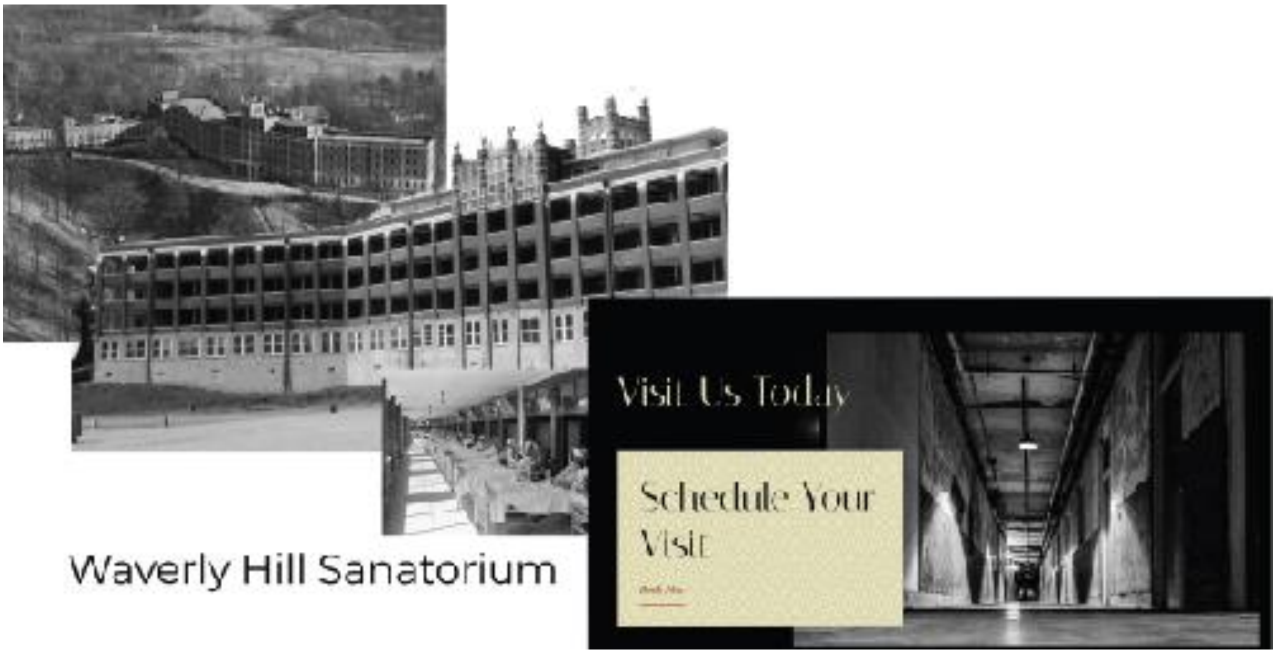


Figure 2. Louisville's Waverly Hills Sanatorium (Developed by Author)

Healthcare design today remains overly dependent on static, isolated hospital models that lack agility and integration with community systems. These buildings often fail to meet the needs of vulnerable populations during emergencies. They aren't built to adapt, move, or scale with changing demands. Instead, they reinforce spatial inequity. Research by OMA (Figure 3) shows that many modern hospitals have the shortest life spans in healthcare history. If our solutions during crises continue to rely on inflexible design, we'll keep repeating the cycle—build, use, abandon.

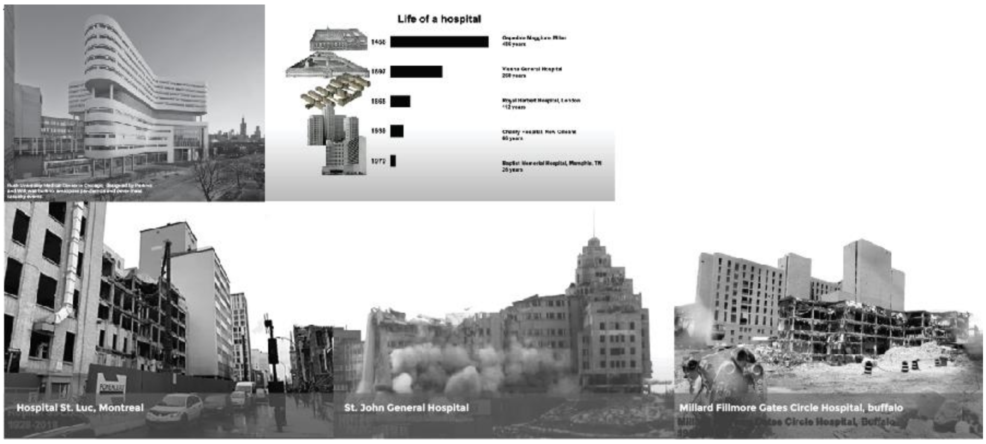


Figure 3. OMA's Study on Rigid Healthcare Facilities (Developed by OMA)

The Role of Architecture in Health Emergencies

Architecture has the potential to go far beyond sheltering medical functions in healthcare facilities—it can act as a proactive system for public health resilience and more prepared cities. Back in 19th-century New York, during the tuberculosis outbreak, city planners created Central Park not just for recreation, but to clean the air and give people room to breathe. Hospitals around it adapted too, adding balconies so patients could rest outside, close to the trees and fresh air. Years later, that same park helped again—during the World Wars, and most recently, during the COVID-19 pandemic (Figure 4) (Fink, 2020). It shows how public spaces often become something more during a crisis—they become part of the care system. But what if that wasn't just a coincidence? What if public spaces were designed to anticipate those moments? OMA's research raises this very question, critiquing the fortress-like isolation of modern hospitals and proposing horizontally expandable, automated healthcare environments. Their vision—where the public realm and healthcare facilities merge—challenges conventional models and opens new questions: Should we build more hospitals or reimagine our parks, metros, and civic infrastructure as flexible extensions of care? What if we redefined the boundary between the public realm and healthcare, allowing them to coexist rather than collide?

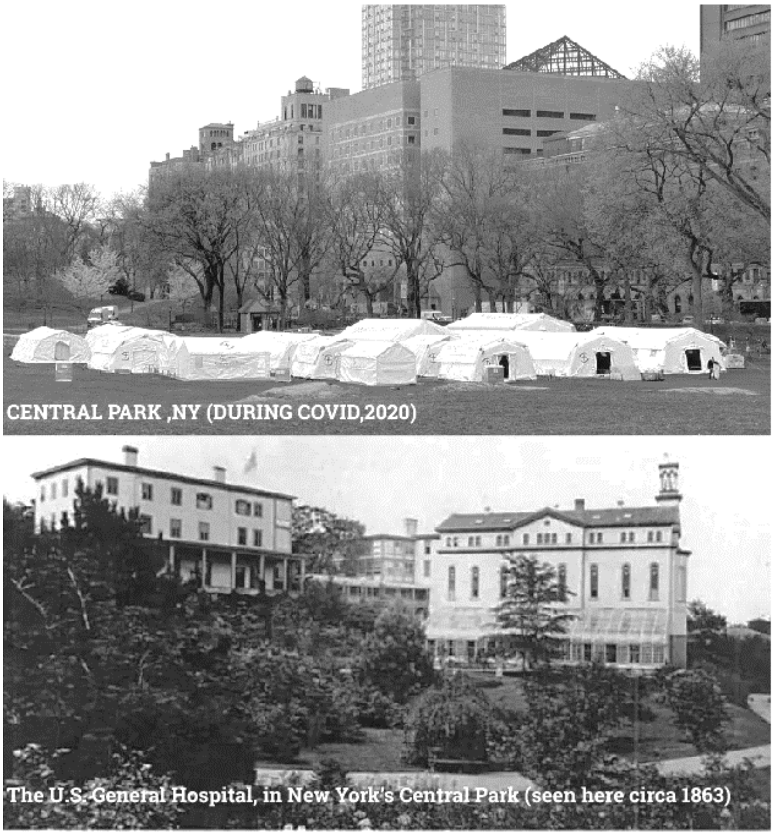


Figure 4. The adaptive use of Central Park over the centuries

Research Gap and Study Objectives

This research responds to a critical gap in both urban and healthcare planning: the disconnect between health services and the spatial and mobility logic of cities. Public spaces are typically designed for recreation, while transit systems prioritize movement and efficiency—yet neither is optimized for delivering care in times of crisis. The question arises: what if these spaces could be reimagined to provide adaptable, mobile healthcare systems embedded in daily urban life?

Focusing on Miami, a city highly susceptible to both public health emergencies and environmental threats, this study explores the integration of modular healthcare units into the elevated MRT network. Through this approach, the research sets out to explore three key goals: to understand how mobile, modular health units can boost emergency responsiveness; to analyze Miami's spatial vulnerabilities and the unique risks faced by different communities; and to develop a design model that can be adapted and scaled in other urban contexts to connect transit and healthcare delivery. At the same time, contemporary healthcare experts are raising vital questions about the role of public engagement in shaping health infrastructure. Should communities have a say in the design of the very facilities that serve them? And more importantly, can these communities take part in maintaining and sustaining these facilities during crises? (Figure 5)

Figure 5. Healthcare facilities and design approach proposed by OMA (Developed by Author)

This thesis argues that during times of public emergency, healthcare facilities must transcend their conventional role. They must become extensions of the public realm—approachable, accessible, and deeply embedded within the community (Fisher, 2022). Instead of viewing hospitals as isolated entities that only encroach into the public realm during a crisis, this research proposes a regenerative, two-way system. By intentionally linking healthcare facilities with civic infrastructure, we can design spaces that not only treat illness but also restore and support the community in moments of need.

Structure of the Paper

The paper unfolds through five key sections, beginning with an introduction that contextualizes the global healthcare breakdown in the time of COVID-19, highlighting the vulnerabilities of existing infrastructure. It moves on to describe the materials and methods used, focusing on Miami as the study site, supported by spatial analysis and architectural precedents. The results section showcases the design solution—MRT-integrated mobile health units—while drawing parallels to the urban context of Dhaka. This is followed by a discussion on the broader implications of architecture in crisis, examining both strengths and challenges of such integrated models. The final section concludes with key insights and lays out directions for future urban-health design strategies.

Materials and Methods

The initial phase began by identifying the nature of the crisis the design intends to respond to—primarily pandemic-related challenges—and how architecture can play a proactive role in health emergency management. The hypothesis driving this study is that healthcare infrastructure, even in well-funded systems like that of the U.S., has proven inadequate in times of crisis due to its rigid, centralized structure. A comparative review of national and global responses to past pandemics supports this claim.

The research method is segmented into four key steps (Table 1):

Table 1. Research Methodology.

	Methodological Step	**Purpose**	**Output**
1	Literature Analysis and Case Study	Establish theoretical foundation and precedent strategies using literature and global case studies.	Flexible, modular design principles and strategic insights for health-integrated public space.
2	Comparison and Typological Mapping	Categorize and evaluate case studies based on adaptability, context, and crisis responsiveness.	Typological matrix for comparative evaluation of healthcare infrastructure.
3	Contextual Sorting	Filter relevant case studies to align with Miami's demographic, infrastructural, and environmental needs.	Site-specific case study selection and relevance mapping.
4	Scenario Building and Prototyping	Develop design interventions through crisis scenario analysis, site modeling, and contextual validation.	Crisis-responsive design prototypes and context-sensitive architectural models

Literature Analysis and Case Study

This study is grounded in an evolving body of literature that addresses healthcare capacity building, crisis-responsive architecture, and adaptive spatial systems. Although the idea of flexible and modular architecture in emergency contexts is not new, recent global events—particularly the COVID-19 pandemic—have dramatically shifted its urgency and application. A range of literature was reviewed, from theoretical frameworks to precedent case studies, with an emphasis on spatial resilience, modular healthcare deployment, and public integration.

Key texts include Rethink Design Guide: Architecture for a Post-Pandemic World (RIBA Publishing), which provides a comprehensive strategy to reconfigure public and healthcare spaces in response to COVID-19. Thomas Fisher's Space, Structures and Design in a Post-Pandemic World further explores how design norms must evolve in everyday architecture. Meanwhile, The Pandemic Effect by Blaine Brownell compiles insights from ninety global experts on how cities and buildings must transform to withstand future crises.

Flexibility as a design principle was also central to this research. David and Robert Kronenberg's Flexible: Architecture that Responds to Change outlines historical and conceptual perspectives on adaptability, proposing that buildings must be capable of adapting, transforming, moving, and interacting with their context. Their insights reinforce the architectural argument for modularity, particularly in health infrastructure, where rigid typologies often fail during crises.

This research also drew from global case studies that redefine the relationship between hospitals and public infrastructure. OMA's Al Daayan Health District in Qatar, for instance, proposed a horizontally expandable hospital system with modular components, including prefabricated nursing units and 3D-printed corridors. The design integrates open courtyards not only for healing but also for medicinal plant cultivation, turning healthcare infrastructure into part of the ecological and social fabric (Stouhi, D., 2022).

Le Corbusier's unbuilt Venice Hospital offered another provocative model. Based on the mat-building concept, it dissolved the boundaries between hospital and city through interconnected courtyards and clustered room arrangements. Rather than enforcing sterile separation, it invited openness, air, and community into the healthcare experience, blurring the institutional edges (Yoon, E., & Lim, Y. , 2020).

Archigram's Plug-In City imagined architecture as a living system—mobile, responsive, and reconfigurable—offering a visionary approach that informed this study's emphasis on modularity and prefabrication at the urban scale. Similarly, Cedric Price's Thinkbelt proposed using obsolete rail infrastructure for a network of movable learning and healthcare modules. Both projects emphasize adaptability as a civic quality, suggesting that flexibility must be embedded in infrastructure, not retrofitted into it. (Aureli, P. V., 2011) (Cook, P., 1999)

Collectively, these studies helped frame the architectural strategy of this paper: to design modular healthcare nodes connected to public transit that could operate across emergency and non-emergency conditions. The literature offers both the rationale and reference models for thinking of healthcare not as a destination, but as a distributed, mobile, and embedded civic function.

Contextual Sorting Scenario Building and Prototyping

Selected case studies were categorized based on flexibility, modularity, response time, context relevance, and crisis scale. This comparative matrix allowed for identifying typologies of effective healthcare responses during COVID-19 and similar emergencies.

Case studies were filtered and refined to match the specific site conditions of Miami. The goal was to select precedents that align with the local demographic, environmental, and infrastructural challenges.

Design interventions were proposed by analyzing crisis scenarios and site-specific data. Using diagrams and modeling tools, the research visualized potential architectural outcomes, ranging from portable mobile healthcare units to hybrid public-health spaces that operate between hospitals and civic environments. The design process included site analysis, problem definition, scenario development, and design evaluation. Final solutions were tested against sociocultural context and community needs to ensure validity and responsiveness.

Study Area and Site Justification

The guiding question behind this research is how healthcare facilities can be expanded or reimagined to respond effectively during the next major health crisis. The initial phase of the study involved mapping U.S. cities most susceptible to future health crises, environmental threats, and demographic stressors. A vulnerability index, incorporating metrics like population density, healthcare infrastructure, and senior population rates, was used to evaluate potential sites. Among these, Miami, Florida, surfaced as a high-priority zone for both its critical exposure and intervention prospects. (Figure 6)

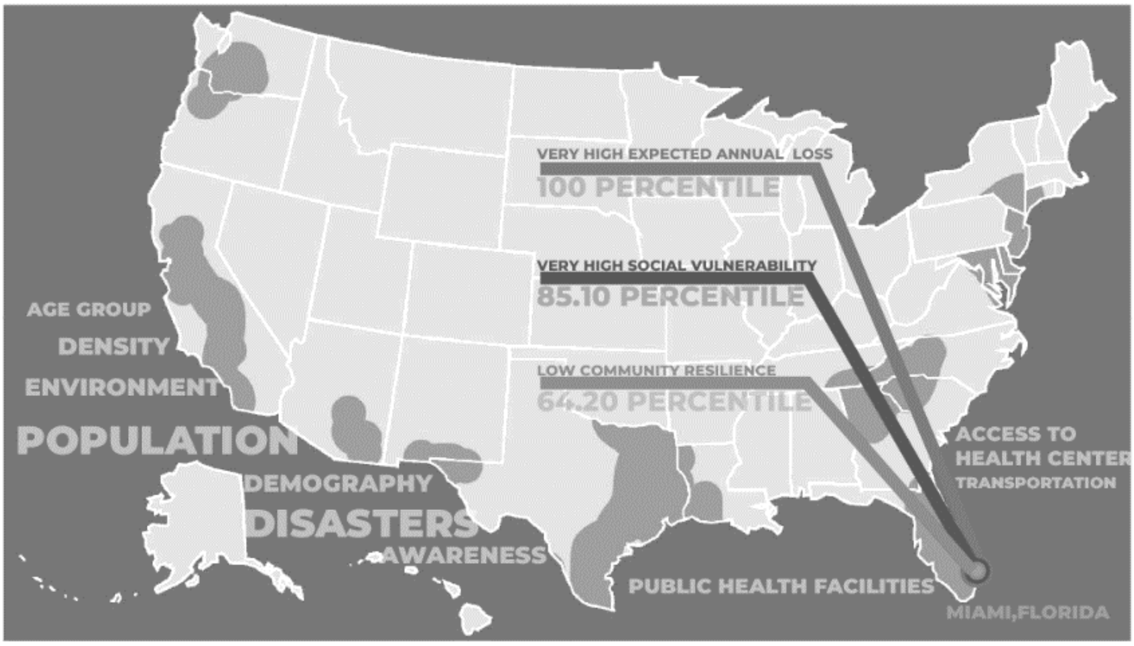


Figure 6. Site Selection Parameters (Developed by Author)

Though this research looks toward scalable, global outcomes, the U.S. provided a clear context where public health, mobility, and environmental challenges meet. Miami quickly rose as a fitting site—one where the urgency of the problem is matched by the infrastructure to test new ideas. Coastal and aging, the city is increasingly exposed to hurricanes, sea-level rise, and the realities of an older population. These conditions don't just threaten infrastructure—they affect people's lives, especially during a health emergency. The presence of one of the nation's largest medical hubs—the Miami Health District (Figure 7) —further strengthens its case as a launch point for new healthcare design interventions that are resilient, inclusive, and forward-thinking.

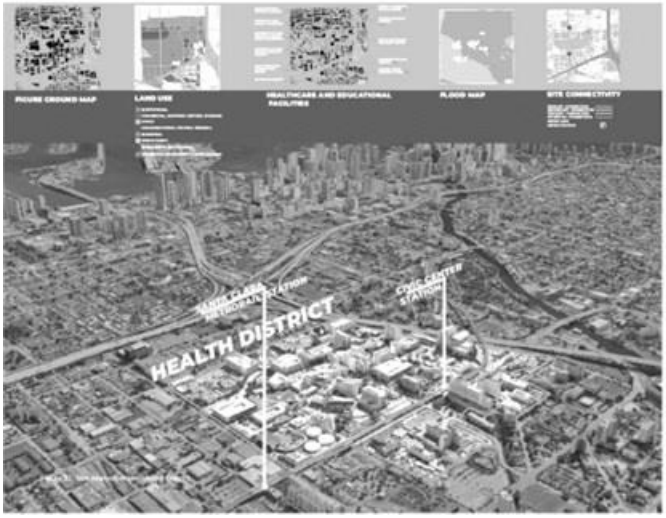


Figure 7. Site Analysis: Miami Health District (Developed by Author)

To better understand Miami's readiness, the research examined its current crisis management framework and assessed its strengths and limitations in dealing with public health emergencies. A hypothetical yet contextually grounded scenario envisions Miami being struck by a Category 5 hurricane in 2025, with wind speeds reaching 205 mph and leaving the city devastated. Though speculative, this projection mirrors the growing intensity of climate-related events already impacting the region.

Figure 8. Miami Elevated Metro Rail (Source: Miami Herald)

Given this backdrop, the study applies a layered analysis to evaluate how a city like Miami could adapt its infrastructure to withstand and respond to dual crises—climate and health. By understanding the city's demographic makeup, geographic exposure, and healthcare network (Figure 9), the research positions Miami as a laboratory for testing a scalable, modular, and mobility-integrated healthcare solution. Ultimately, the selection of Miami is not only driven by its risks but by its potential. The integration of mobile healthcare hubs with the city's Metrorail (MRT) system offers a pathway toward more distributed, accessible, and responsive emergency care, especially for underserved or immobile populations. This site-based approach anchors the conceptual design in real-world urgency, where architecture must engage both infrastructure and community in shaping a resilient future (Staletovich et al., 2022).

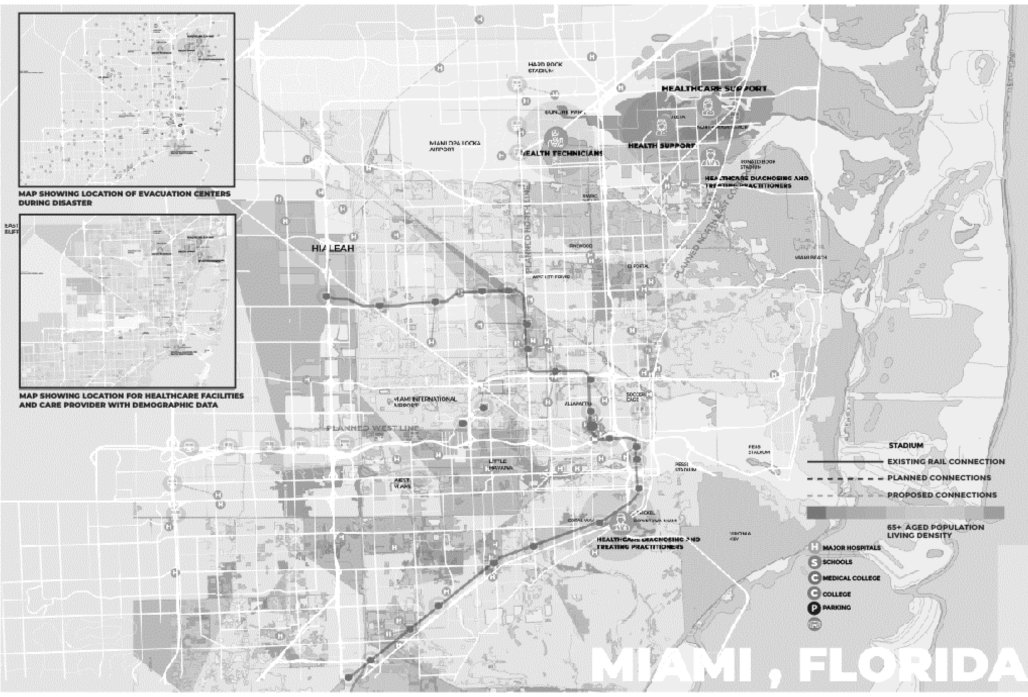


Figure 9. Site Analysis for Miami, Florida, based on the residence of healthcare providers and facilities, and connection to the MRT (Developed by Author)

Risk Mapping and Urban Vulnerability Assessment

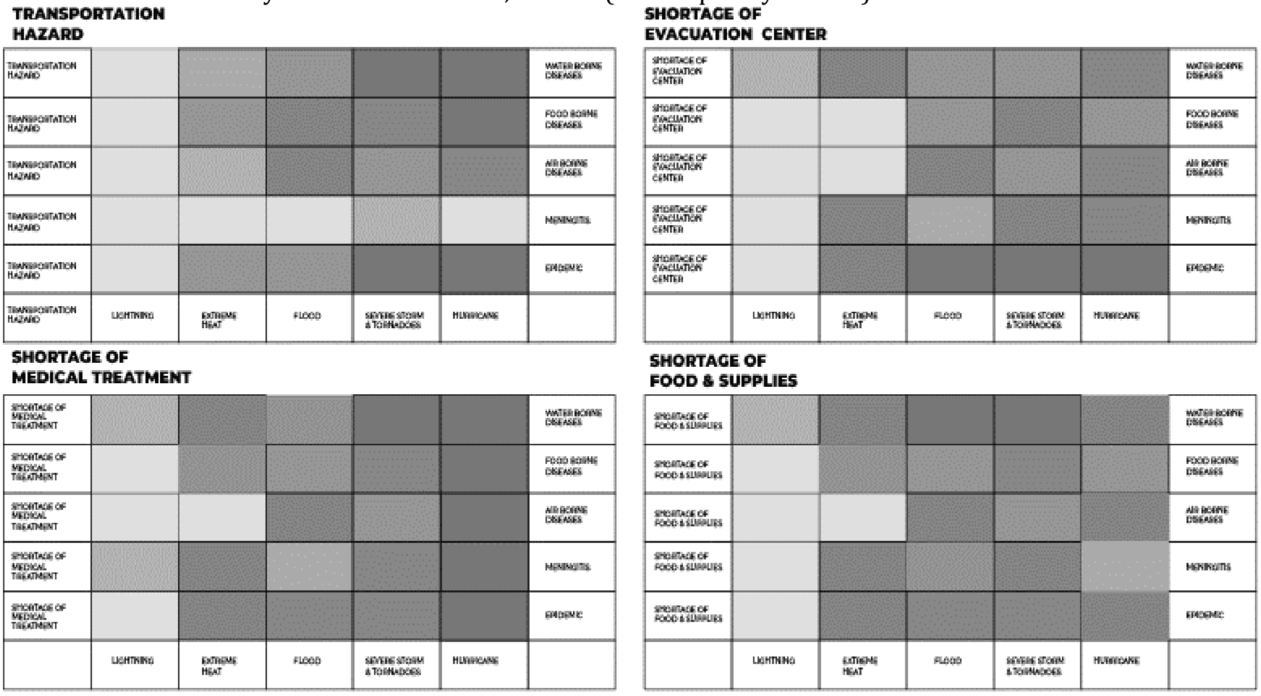
This study explored Miami's vulnerabilities to rising seas, climate-related disasters, and pandemics through the structured lens of the 5x5 risk matrix from the Department of Defense. This matrix guided the evaluation of Miami's crisis response across health, transportation, disaster management, evacuation, and healthcare capacity (RiskFactor, 2024).

Figure 10. Analysis of Miami's Flood Scenario

Two central scenarios anchored this analysis, both emphasizing Miami's elderly population, a group increasingly at risk (Figure 10). First, during floods or hurricanes, how could elderly residents safely access distant evacuation centers or hospitals? Second, in a health emergency, how could essential medical staff living far from healthcare facilities quickly reach their workplaces?

By concentrating specifically on Miami's Health District—one of the largest medical and research hubs in the United States—the study explored new ways to integrate healthcare facilities with public spaces and transit networks. A detailed analysis of demographic patterns, flood risk zones, and transportation infrastructure revealed critical gaps and opportunities. These insights positioned Miami as an ideal testing ground for innovative architectural solutions that enhance adaptability, accessibility, and community resilience during future crises.

Table 2. 5X5 Risk Analysis Matrix for Miami, Florida (Developed by Author)



From Research to Design: Scenario Testing and Modular Prototypes

This chapter translates the theoretical groundwork and site-specific research into tangible architectural proposals, emphasizing modularity, adaptability, and scenario responsiveness. The goal is to create an innovative healthcare infrastructure that operates seamlessly across everyday and crises, bridging the gap between healthcare facilities and the public realm.

At its core, the design explores creating a dynamic and transformable spatial system, situated between healthcare facilities and public spaces. This intermediary environment serves multiple roles, easily shifting functions according to community needs or crisis conditions. (Gow, 2022) The design is built around three interchangeable programmatic scenarios (Figure 11):

Table 3. Conceptual Framework of Proposal Idea

Conceptual Framework		
A Space for Community Engagement	**A Space for Crisis Preparation**	**A Space for Crisis Management**
Initially, this area functions as a vibrant public space—imagine a gym, community park, or cultural center. It is intentionally flexible and adaptable, encouraging community interaction and public health awareness. It integrates complementary healthcare activities such as counseling and rehabilitation, which have social value beyond medical treatment. During non-crisis periods, it is essentially a civic space where public engagement and preventative health activities flourish. (AMA,2019)	When a crisis looms, the flexibility embedded within the design enables rapid transformation of the community-focused space into a crucial support hub for nearby healthcare facilities. At this stage, the space expands healthcare capacity by serving as patient care units, quarantine zones, additional staff accommodation, or even storage areas for medical equipment and emergency supplies. The key strength here is modularity: the facility can swiftly adjust according to immediate needs, effectively expanding the healthcare infrastructure before the full impact of the crisis.	In extreme situations, such as severe pandemics or major natural disasters, the facility transitions fully into an emergency care unit. Here, the space's modular nature is pushed to its full capacity, providing critical care services tailored specifically to the crisis at hand. It becomes an integrated part of the healthcare infrastructure, operating as an essential medical resource directly responding to the severity and urgency of the situation.

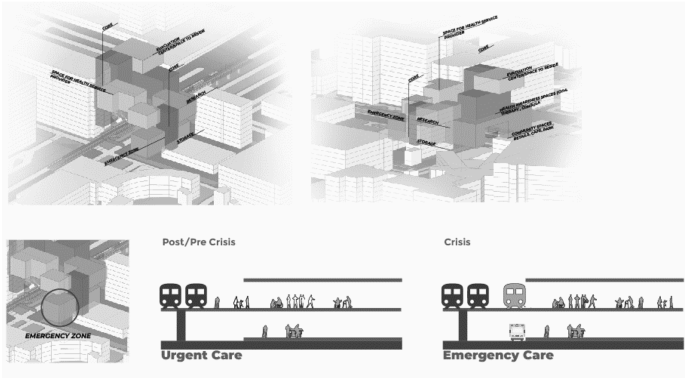


Figure 11. Initial Site-Specific Conceptual Development for the design

Recognizing Miami's vulnerability to flooding, the scenario considers the facility's physical and operational resilience during severe weather events. The core design strategy integrates elevated rail (MRT) infrastructure, ensuring continued operation even in flood conditions. By situating critical healthcare services at elevated levels, the design ensures uninterrupted medical care during floods, preserving critical connectivity between healthcare facilities and transportation nodes. Given the increasing risk of sea-level rise in Miami's health district, the design incorporates a strategy for relocating facilities inland, leveraging existing elevated rail infrastructure and replicating this resilient healthcare network throughout vulnerable urban areas.

Results

Urban Challenges in Miami: Aging Populations and Service Gaps

Miami presents a unique combination of urban vulnerabilities, primarily driven by two interconnected factors: an increasingly elderly population and growing environmental risks due to climate change. As more retirees continue to settle in Miami, the city's healthcare system faces growing demands. For elderly residents living far from main hospitals and medical hubs, accessing timely care becomes even harder, particularly during crises.

Our detailed demographic mapping revealed that these vulnerable populations are primarily concentrated in zones with limited transportation and high exposure to flooding and hurricanes. Miami's existing healthcare infrastructure, while robust in some central areas such as the Health District, does not adequately reach these peripheral communities, leaving them underserved precisely when help is most critically needed. (Figure 12)

Figure 12. Hypothetical Scenario Analysis: Miami Flood Scenario and Its Impact on the Aging Population's Access to Health Facilities, and an Alternative Solution Using Health Facilities. (Source: Prepared by Author)

Replicable Healthcare Units Linked to MRT Infrastructure

To directly address these identified challenges, we developed an architectural proposal involving modular healthcare units strategically integrated into Miami's existing elevated Metrorail (MRT) infrastructure. These modular units offer transformative capabilities, rapidly converting public spaces at MRT stations into temporary healthcare hubs. During non-crisis periods, these spaces serve as community engagement centers, offering services such as rehabilitation, preventive care, and health education.

During emergencies, these same spaces transform seamlessly into patient care units, quarantine centers, medical supply hubs, and temporary shelters for healthcare workers. Their integration with the MRT system ensures critical connectivity, enabling quick mobilization of medical resources and personnel across the city. This modular and transit-oriented design significantly closes the existing gap between healthcare facilities and underserved communities, allowing rapid, targeted response in crises.

Simulation Outcomes: Flood-Resilient, Transit-Ready Design

Simulation scenarios specifically considered the dual threats of hurricanes and severe flooding events, common to Miami. Using Miami's Civic Center Station as a primary testing site, we explored design solutions to maintain operational resilience under extreme conditions. Our scenario testing validated that elevating healthcare functions within MRT-linked modules ensures continuous service delivery, even when lower-lying areas become inaccessible due to floods.

The simulations highlighted several benefits, including accessibility, operational resilience, and community Integration. MRT-linked modules facilitated rapid evacuation and the timely arrival of medical personnel, and elevated healthcare modules remained functional during flood events, ensuring uninterrupted critical care. In non-crisis times, units effectively served community wellness, enhancing public health outreach. This design methodology demonstrates a robust, flexible, and scalable model of healthcare infrastructure, uniquely capable of adapting dynamically to changing environmental and urban conditions.

Dhaka as a Parallel Context: Health Infrastructure in the Global South

Dhaka represents a reality familiar to many cities in the Global South: crowded neighborhoods, frequent flooding, and severe traffic congestion that can make even routine healthcare access a challenge. During emergencies, these challenges become dangerous obstacles, significantly delaying critical medical responses and endangering lives. By examining Dhaka alongside Miami, we aimed to ensure our design was not only innovative but genuinely meaningful and responsive to communities around the globe.

Drawing inspiration from historical precedents, such as the Bhopal Gas Tragedy (Figure 13)—where trains became crucial lifelines in emergency healthcare delivery—we propose leveraging Dhaka's newly developing MRT infrastructure for modular healthcare deployment. (Broughton, 2005)

Figure 13. Historical Link: Bhopal Crisis & Railway-Based Medical. The 1984 Bhopal Gas Tragedy saw Indian Railways used to deliver emergency medical aid, turning train platforms into makeshift hospitals. (Image by Bhopal Medical Appeal, Martin Stott)

Stations like Shahbagh, strategically located near major hospitals, could become essential emergency healthcare nodes. Modular healthcare units positioned at these MRT stations could provide immediate crisis care, rapidly deployed and operationalized (Figure 14). This approach dramatically reduces response times, enhances patient accessibility, and strengthens urban resilience.

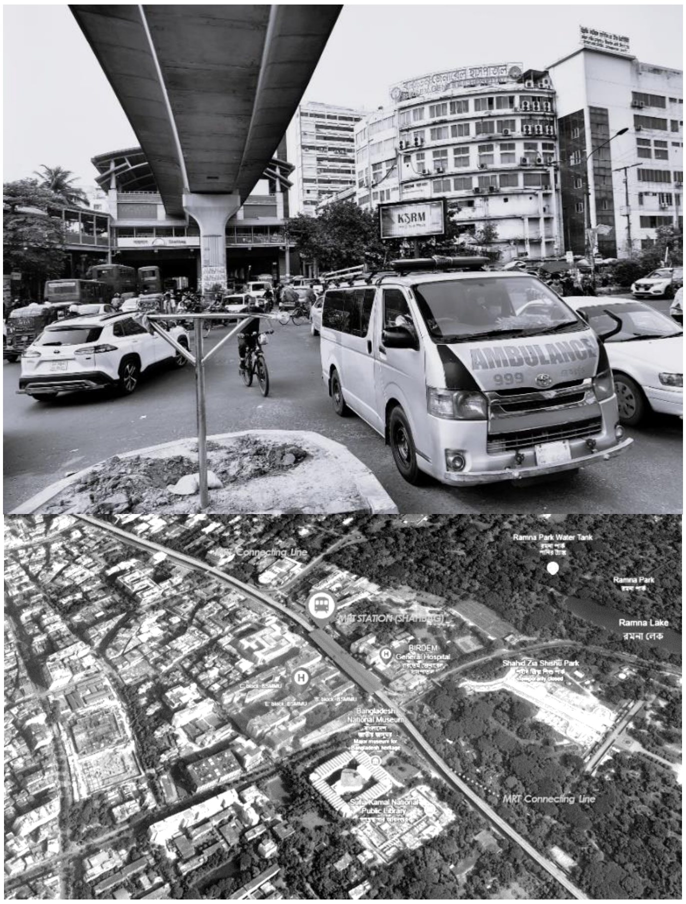


Figure 14. The major part of Dhaka, an important node with MRT and major hospitals, faces critical delays in emergency care due to severe traffic congestion and poor healthcare accessibility.

Our findings strongly indicate that modular MRT-integrated health systems are universally applicable and particularly impactful in cities experiencing rapid urbanization, infrastructure constraints, and significant vulnerability to natural and health disasters. Adapting such innovative, flexible designs globally could significantly enhance preparedness and responsiveness, transforming urban transit nodes into critical lifelines during times of crisis.

Discussion

Architecture as a Tool for Crisis Preparedness

Throughout this study, architecture emerged clearly as more than just a passive container for services—it became a dynamic and proactive agent in crisis management. Traditionally, healthcare facilities are static and rigid, designed for predictable operations rather than rapidly changing scenarios. However, recent global crises, especially the COVID-19 pandemic, have revealed the urgent need for adaptable, flexible, and responsive designs. By integrating modular healthcare units within public transportation hubs, this research demonstrates how architectural solutions can swiftly transition between everyday community needs and emergency healthcare provision. The Miami Civic Center MRT-linked units illustrate a promising pathway: spaces that seamlessly switch from vibrant public realms to essential medical care units during times of urgency. In essence, this approach redefines architecture's role—from passive infrastructure to active resilience-building tool.

Our research highlights the profound potential of integrating healthcare with existing public infrastructure to enhance equitable access. In cities like Miami, many elderly residents and underserved communities often face significant hurdles in accessing timely medical care, particularly during emergencies. By embedding healthcare facilities directly into public transit systems, we not only bring medical services closer to vulnerable populations but also ensure continuity of care during environmental or health crises. This approach transforms public transit nodes from mere commuter spaces into critical lifelines, substantially reducing disparities in healthcare accessibility. Moreover, because these public spaces are already integral to daily life, community acceptance and interaction with healthcare services become more natural and seamless, fostering a stronger overall sense of social equity

From Miami to Dhaka: Lessons, Limitations, and Transferability

The primary testing ground for this research was Miami. The fundamental challenges addressed—aging demographics, climate vulnerability, transportation gaps, and healthcare accessibility—resonate deeply with other urban centers worldwide, particularly in the Global South. Dhaka, Bangladesh, emerged as a valuable parallel context for exploring global scalability. The dense urban fabric, regular flooding events, and chronic traffic congestion in Dhaka mirror many of Miami's challenges, albeit intensified by resource constraints and infrastructure gaps typical in rapidly urbanizing cities.

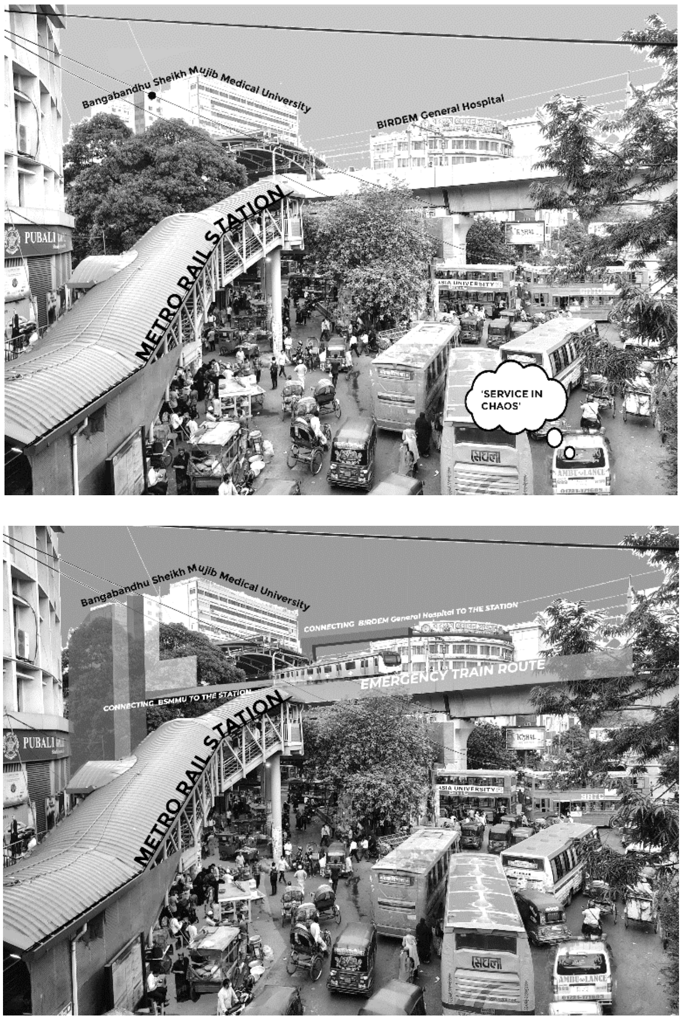


Figure 15. Possible Scenario Analysis in Dhaka: Integrating Metro rail in Shahbagh to adjacent healthcare facilities to increase the efficiency of patient mobilization (Developed by Author).

Despite differences in cultural context, governance structures, and available resources, the core principles of modularity, adaptability, and transit integration hold significant promise in Dhaka. However, several critical limitations and challenges must be recognized. Implementation in Dhaka and similar cities would require tailored local adjustments, including careful consideration of infrastructural capacities, community engagement strategies, financial sustainability, and local disaster management frameworks. Thus, while Miami serves as an effective model, successful global transferability demands flexibility, context-sensitive design adjustments, and collaborative partnerships across multiple stakeholders.

Global Implications: Toward a Scalable, Civic-Embedded Health System

The insights from Miami's case study and the parallel scenario testing in Dhaka underline the global potential of civic-embedded healthcare infrastructure. This research illustrates a universal truth: traditional healthcare delivery, isolated from everyday urban life, falls short during emergencies. Instead, we must move toward flexible, modular, and community-integrated healthcare designs that leverage existing civic resources, particularly public transportation, to deliver equitable and resilient health services worldwide.

Historical precedents, such as the Bhopal Gas Tragedy, where trains became critical lifelines, reinforce the validity of this strategy. By embracing modular healthcare units integrated into transit stations, cities globally can quickly respond to diverse crises, enhancing preparedness and significantly improving health outcomes, especially in underserved or disaster-prone areas. The modular MRT-linked health units proposed here are scalable, replicable, and adaptable, offering a versatile blueprint for cities facing varying degrees of urbanization, resource constraints, and environmental threats.

Ultimately, this research advocates a new paradigm: one where architecture does not merely shelter health services but actively integrates them within the civic fabric. By embedding resilience directly into urban infrastructure, we can better safeguard communities and foster long-term, sustainable health outcomes globally.

Conclusion

This research has shown that metro stations can be more than just transit points—they can become vital support systems during times of crisis. By rethinking healthcare not as something locked inside a distant facility, but as something that moves with the city, we explored how to embed care directly into public infrastructure. Miami, with its climate risks, aging population, and uneven access to health services, offered the right mix of urgency and opportunity to bring this vision to life. By closely examining Miami's specific risks and resources, we illustrated how cities can proactively integrate healthcare with everyday civic life.

What this study showed is simple but powerful: cities can—and should—do more with the spaces we already use every day. By turning transit stations into healthcare-ready spaces that serve both public life and emergency healthcare, we're not just improving access—we're making cities more human and more prepared. It's a way to make healthcare more accessible, especially for those who need it most. This isn't just a design solution—we're proposing a city that's more responsive, more inclusive, and ultimately more prepared for whatever comes next. It's a shift in how we think about equity, resilience, and the role of public space.

Although promising, our proposals remain theoretical. For this concept to become reality, Real-world testing, prototyping, and careful evaluation are essential to truly understand how this system would function—logistically, financially, and operationally. Its success also depends on how well it adapts to different urban conditions, which vary widely depending on local governance structures, infrastructure limitations, and how communities interact with public healthcare.

While Miami provided the initial context, our approach holds global potential. A preliminary parallel analysis for Dhaka, Bangladesh—a city facing similar yet distinct urban challenges—suggests significant applicability. Although Dhaka differs in its density, resource availability, and infrastructural constraints, the core design principles of modularity, flexibility, and transit integration remain relevant. Applying similar scenario analysis methods to Dhaka can demonstrate how modular healthcare strategies could effectively mitigate disaster risks and enhance healthcare accessibility in diverse global contexts.

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Conflict of Interests
The author(s) declare(s) no conflict of interest.

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Chapter 2

Adaptive Pattern Language in Ottoman Sacred Architecture

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Introduction

Sacred architecture has long served as a materialization of cosmological and socio-religious order, spiritual aspirations, and social cohesion (Silva Leite et al., 2024). In Islamic traditions, the mosque is not merely a ritual site but a spatial articulation of metaphysical principles such as tawḥīd (unity), qibla (directionality), and ṭahāra (purity). From its earliest forms, Islamic architecture has developed a symbolic vocabulary where elements such as domes, mihrabs, courtyards, and thresholds mediate between the earthly and the divine, guiding worshippers through structured sacred experiences (Frishman & Khan, 2002; Necipoglu, 2010; Okasha, 1994; Serageldin, 1996).

Within this broader tradition, Ottoman mosque architecture represents a high point of theological, cultural, and spatial synthesis (Alioğlu & Köroğlu, 2011; Kuban, 1997, 2007; Kuran, 1968; Mustafa & Hassan, 2013; Necipoglu, 2010). The works of Mimar Sinan, chief architect of the Ottoman Empire, are widely recognized for their formal clarity, geometric rigor, and integration of symbolic meaning with functional spatial choreography (Kuban, 1987, 1997, 2007; Kuran, 1968; Necipoglu, 2010). His projects are characterized by centralized plans, axial hierarchies, domical sequences, and an urban-scale vision that situates the mosque not only as a ritual core but as a civic and cosmological center.

Despite extensive scholarship on Ottoman mosque architecture—particularly the oeuvre of Mimar Sinan—existing analyses have predominantly focused on structural innovations, stylistic development, and historical typologies. Much of the scholarship either emphasizes engineering ingenuity or stylistic evolution, under-addressing the interpretive, symbolic, and ritualistic logic embedded in spatial form (Kuran, 1968, 1988; Mustafa & Hassan, 2013). These studies, while foundational, often operate within a formalist or materialist paradigm, thereby under-theorizing the symbolic and ritual dimensions that define sacred spatial experience in Islamic traditions. As such, there remains a critical need for analytical tools that bridge architectural form with religious epistemologies and lived theological practices.

One reason for this gap lies in the limitations of existing spatial frameworks. Christopher Alexander's A Pattern Language (1977), though influential in secular design discourse, lacks the theological and symbolic sensitivity required to decode sacred Islamic architecture. While Alexander's system offers transferable spatial archetypes, its universalist orientation overlooks the ritual specificity and metaphysical intentionality that define mosque design.

This conceptual limitation becomes especially apparent in the analysis of Ottoman mosques, where sacredness is not merely symbolized but spatially enacted through orientation, procession, materiality, and symbolic thresholds. Yet few analytical frameworks exist that decode this spatial theology in a systematic, culturally embedded way.

This study thus addresses a twofold research gap:

1. a theoretical gap in understanding how sacred meaning is spatialized within mosque architecture, and
2. a methodological gap in adapting architectural pattern theory to the theological and ritual logic of Islamic architecture.

This study aims to develop a culturally embedded analytical framework for decoding sacred spatial logic in Islamic architecture, with a specific focus on Ottoman mosque architecture. The objectives are threefold:

1. To reinterpret selected patterns from Christopher Alexander's A Pattern Language through the lens of Islamic theological symbolism and ritual structure.
2. To construct a pattern-based framework—the Pattern Language for Ottoman Mosque Architecture—that identifies and systematizes spatial, symbolic, and experiential principles in sacred mosque architecture.

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3. To apply this framework to the Şehzade Mosque by Mimar Sinan, analyzing how sacred meaning is encoded through spatial form, material articulation, and symbolic sequencing.

This study proceeds from the following analytical hypotheses:

H1: The original formulations of Alexander's patterns are insufficient for interpreting Islamic sacred space due to their secular and functionalist epistemology.

H2: Ottoman mosque architecture operates as a spatial theology, where ritual, cosmological, and symbolic meanings are encoded through specific spatial strategies and formal compositions.

H3: A reconfigured pattern framework, grounded in Islamic epistemology, can more effectively decode the layered sacred logic of mosque architecture and serve as a generative tool for contemporary religious design.

This study contributes to architectural theory by proposing a culturally specific, symbolically attuned reinterpretation of pattern language theory. It challenges the secular and universalist assumptions embedded in widely used frameworks such as Alexander's Pattern Language, and demonstrates the necessity of epistemological pluralism in analyzing religious architecture. By developing a pattern-based methodology rooted in Islamic theological and spatial principles, the research offers an interpretive tool for reading sacred architecture as a system of ritual intelligence and metaphysical intentionality. In doing so, it not only deepens the scholarly understanding of Ottoman mosque design, but also provides a generative vocabulary for architects engaged in the design of contemporary religious spaces.

The structure of the paper is as follows:

- Section 2 outlines the methodological orientation of the study, including the case study design, analytical scope, data sources, and the development of the adapted pattern framework.
- Section 3 presents the findings through the application of the framework to the Şehzade Mosque, analyzing how sacred meaning is spatialized across four symbolic domains.
- Section 4 discusses the theoretical implications of the results, situates the findings within existing scholarship, and reflects on methodological strengths and limitations.
- Section 5 concludes the paper by summarizing the key contributions, acknowledging limitations, and offering directions for future research and design practice.

Materials and Methods

Study Design and Case Setting: This research adopts a qualitative, interpretive methodology situated at the intersection of sacred space theory, architectural typology, and symbolic-spatial analysis. It is grounded in the premise that sacred architecture functions as an epistemological medium through which theology, ritual, and metaphysical meaning are spatially enacted. Rather than relying on empirical measurement or behavioral observation, the study applies a hermeneutic approach—treating architectural form as a structured language of symbolic expression and theological intentionality.

The methodological framework is anchored in a critical reinterpretation of Christopher Alexander's A Pattern Language (1977), adapted to reflect Islamic spatial epistemologies. The research does not apply Alexander's patterns directly but transforms them into a culturally embedded analytical tool, capable of decoding sacred spatial logic in mosque architecture. Patterns are thus treated not as functional typologies, but as symbolic and ritual configurations that generate sacred experience.

The study is structured as a single-case, theory-building inquiry centered on the Şehzade Mosque, designed by Mimar Sinan and completed in 1548. As Sinan's first major imperial commission, the mosque holds particular importance in the development of the Ottoman architectural discourse. It demonstrates typological clarity, axial symmetry, centralized planning, and symbolic layering—all of which make it methodologically well-suited for testing the adapted pattern framework. The mosque's integration of commemorative, theological, and multiple functions also exemplifies the multidimensional role of sacred architecture in Ottoman urban and spiritual life (Ediz & Ostwald, 2012; Freely, 2011; Kuban, 2007; Kuran, 1968; Necipoglu, 2010).

The Şehzade Mosque, located in Istanbul's historic Fatih district, was selected for its methodological clarity and typological significance. As an early yet mature example of Sinan's centralized mosque design, it exemplifies the integration of formal order, symbolic geometry, and spatial hierarchy. Its legible planning system and rich architectural articulation allow for a systematic tracing of ritual sequences, spatial transitions, and symbolic elements. These characteristics make the mosque an effective and coherent subject for applying the adapted pattern framework and for investigating how sacred meaning is spatialized within Ottoman mosque architecture (Ediz & Ostwald, 2012; Freely, 2011; Geisler, 2019; Günay, 2020; Mårtelius, 2015; Necipoglu, 2010).

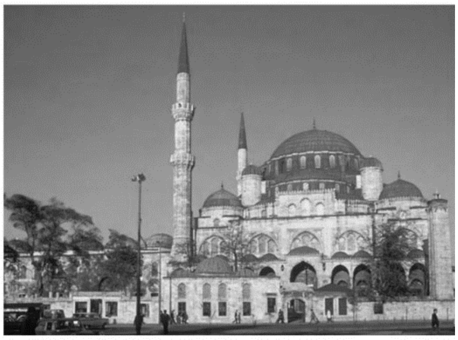


Figure 1. Şehzade Mosque (From: Archnet).

The analytical subject of this study is the architectural and symbolic-spatial system of the Şehzade Mosque, treated not as a static formal object but as a structured expression of theological, ritual, and cosmological meaning. The analysis focuses on how spatial form, sequencing, geometry, orientation, ornamentation, and environmental modulation contribute to the encoding of sacred presence within the mosque's architectural language.

The scope of analysis includes:

- Architectural elements: floor plans, sectional hierarchies, dome structures, circulation paths, thresholds, arcades, courtyards, and mihrab.
- Symbolic and ornamental content: such as calligraphy, geometric patterns, light-filtering systems, and material articulation.
- Ritual-spatial sequences: transitions from profane to sacred zones, stages of purification and prayer preparation, and spatial framing of movement.
- The study does not engage in ethnographic observation or behavioral studies of worshippers, nor does it analyze post-Ottoman modifications or comparative typologies across geographic regions. The aim is not to generalize across mosque forms, but to produce a theory-driven, symbolically embedded reading of sacred space as it is architecturally encoded in a canonical Ottoman context.

The mosque is thus analyzed as a semiotic and ritual field—where formal strategies are treated as operative patterns that convey theological and cosmological intentionality. These patterns serve as the unit of analysis through which Alexander's framework is reinterpreted and reapplied.

This study is based on a triangulated set of materials combining architectural documentation, visual records, and textual-theoretical sources. These materials were selected to support a culturally embedded, symbolically attuned reading of the Şehzade Mosque, and to facilitate the reinterpretation of architectural patterns within an Islamic theological and ritual framework.

Primary architectural documentation—comprising plans, sections, and elevations of the Şehzade Mosque—was obtained from the Archnet digital repository, a reputable platform for scholarly architectural resources. These orthographic drawings formed the basis for identifying spatial hierarchies, circulation paths, axial symmetries, and formal compositions, enabling the precise mapping of spatial sequences and ritual transitions.

Visual materials, including high-resolution photography, satellite imagery, and on-site documentation, were used to verify spatial configurations and material articulation. These images supported the analysis of symbolic elements such as inscriptions, muqarnas, dome ornamentation, and patterns of natural light. Particular attention was given to the role of ornamentation in constructing a non-figurative symbolic field aligned with Islamic theological aesthetics.

Textual sources played a critical role in shaping the analytical framework. Historical and interpretive literature on Ottoman mosque architecture, sacred space, and Islamic symbolism—including the writings of Necipoğlu (2010), Kuran (1968, 1988), Waziri (2008), Frishman and Khan (2002), Kuban (1987, 2007) and Freely (2011)—provided the necessary cultural and theological context for spatial interpretation. In parallel, theoretical texts on architectural typology and pattern theory, particularly Christopher Alexander's A Pattern Language (1977), informed the methodological logic of pattern extraction and reinterpretation. Where relevant, classical Islamic theological and exegetical sources were consulted to align symbolic readings with Qur'anic and Hadithic principles, particularly in relation to ritual space, purity, and divine orientation.

Together, these materials formed an integrated analytical base for reconstructing a pattern language specific to mosque architecture—grounded in spatial observation, historical context, symbolic interpretation, and theological coherence.

The methodological core of this study lies in the critical adaptation of Christopher Alexander's A Pattern Language (1977) to the symbolic and theological context of Islamic sacred architecture. Alexander's original framework, while generative in secular and functionalist design contexts, does not account for the metaphysical intentionality and ritual specificity that characterize mosque architecture. Consequently, the study develops an alternative pattern logic—a Pattern Language for Ottoman Mosque Architecture—by reinterpreting and expanding upon Alexander's typologies through an Islamic epistemological lens.

The development of this framework followed a four-phase interpretive protocol. First, a set of 29 spatial patterns was selectively extracted from Alexander's corpus based on their potential resonance with sacred architectural conditions. These included patterns such as Entrance Transition, Courtyards Which Live, Hierarchy of Open Space, Filtered Light, and Ornament. While these patterns offered spatial clarity, they lacked theological depth, omitting ritual gradation, qibla logic, or metaphysical orientation. Each pattern was thus subjected to a process of conceptual critique and symbolic reassessment in light of Islamic architectural theory, ritual practice, and theological sources.

Second, each selected pattern was mapped onto the architectural structure and spatial system of the Şehzade Mosque. This mapping allowed for the identification of ritual pathways, symbolic thresholds, dome hierarchies, light configurations, and ornamentation as sacred operations rather than merely aesthetic or functional features. Where conceptual gaps emerged—such as the absence of ritual purity (ṭahāra) or directional sanctity (qibla)—new patterns were formulated to supplement or replace Alexander's original formulations.

Third, the resulting pattern set was organized into a structured framework composed of four interrelated macro-domains:

1. Ritual and Sacred Logics, including ablution spaces, directional thresholds, and hierarchies of sanctity;
2. Spatial and Formal Organization, such as centralized dome geometry, axial orientation, and spatial sequencing;
3. Symbolic and Cultural Layers, involving ornanment, calligraphy, muqarnas, and various symbolic elements; and
4. Environmental and Experiential Conditions, such as light modulation, sound absorption, and material tactility designed to induce spiritual inwardness.

Finally, the framework was refined through an iterative analytical process in which each reinterpreted pattern was systematically applied to the spatial and symbolic structure of the Şehzade Mosque. Patterns were evaluated for their theological coherence, spatial correspondence, and symbolic consistency within the mosque's architectural system. This process involved ongoing adjustments to ensure that each pattern reflected not only formal and functional attributes, but also conformed to Islamic ritual logic and metaphysical principles. Interpretations were cross-referenced with Qur'anic exegesis, Hadith traditions, and classical texts in Islamic architectural theory to maintain cultural and epistemological integrity. In doing so, the framework was not used to impose meaning upon architectural form, but to uncover and articulate sacred intentionalities already encoded within the Ottoman mosque typology.

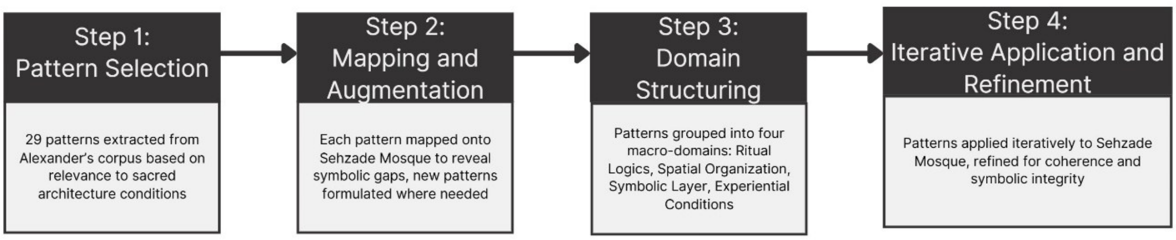


Figure 2. Pattern Development Protocol.

The analytical phase of this study involved a structured interpretive process combining spatial analysis, symbolic mapping, and theological correlation. These techniques were used to apply the reinterpreted pattern framework to the Şehzade Mosque and to identify how sacred meaning is encoded within its spatial configuration.

Spatial diagramming was used to analyze architectural hierarchies, threshold sequences, circulation flows, and geometric compositions. Drawings sourced from Archnet and scholarly archives were reinterpreted through scaled overlays and annotated mappings to reveal how the mosque orchestrates ritual movement, sacred orientation, and spatial gradients of sanctity. Special focus was given to axial symmetry, centralization, dome hierarchies, and the spatial rhythm connecting courtyard, portico, and prayer hall.

Symbolic mapping involved the visual and conceptual identification of non-figurative ornamentation, calligraphic inscriptions, muqarnas, and light-filtering devices, and their alignment with Islamic theological aesthetics. These elements were not treated as decorative surfaces but as semiotic fields—channels for transmitting metaphysical meaning and mnemonic functions related to divine remembrance (dhikr), purity, and cosmological order.

Textual interpretation was conducted in parallel to spatial analysis. Patterns were interpreted not only through visual-spatial analysis but also through engagement with theological and historical texts. Qur'anic and Hadithic references were consulted to contextualize the symbolic dimensions of key spatial elements (e.g., the significance of light, the sanctity of orientation, the ritual function of ablution), while architectural theory provided a secondary frame for symbolic legibility.

Finally, cross-referencing and triangulation ensured that each pattern interpretation was consistent across architectural, symbolic, and theological registers. Visual findings were systematically compared with the theoretical logic of the framework to maintain internal coherence, and with historical accounts of Sinan's work to preserve contextual authenticity. This multilayered analytical process enabled a reading of the Şehzade Mosque not only as a historical structure, but as a spatial embodiment of Islamic sacred ontology.

Presentation of Key Findings

The analytical application of the reinterpreted pattern framework to the Şehzade Mosque yielded a comprehensive reading of the mosque as a spatial-theological system. Through symbolic-spatial analysis, the study reveals that sacred meaning in Ottoman mosque architecture is not merely represented through ornament or ritual function but actively encoded and enacted through architectural structure, spatial hierarchy, and environmental modulation. Each component—from the sequencing of thresholds to the alignment of prayer rows—operates within a larger system of theological intentionality.

The results of the analysis are organized across four macro-domains that structure the adapted pattern language:

1. Ritual and Sacred Logics,
2. Spatial and Formal Organization,
3. Symbolic and Cultural Layers, and
4. Environmental and Experiential Conditions.

Each domain contains a set of patterns derived either from reinterpretations of Alexander's original typologies or from newly constructed formulations specific to Islamic sacred architecture.

In total, the framework comprises forty-two spatial patterns: twenty-nine adapted from Christopher Alexander's A Pattern Language, and fourteen newly constructed patterns designed to address ritual, symbolic, and theological dimensions not captured in the original secular framework. The adapted patterns were critically redefined through symbolic mapping and theological correlation. For example, patterns such as Entrance Transition, Paths and Goals, Hierarchy of Open Space, Filtered Light, Courtyards Which Live, and Ornament were revised to reflect sacred sequencing, spiritual orientation, and embodied ritual movement in the mosque setting.

The newly constructed patterns emerged from spatial-theological analysis and include critical concepts absent from Alexander's system. These patterns capture core Islamic spatial practices and sacred meanings: Qibla Axis, Ablution Entry Sequence, Prayer Rows, Mihrab Focus, Dome Sequence, Quiet Interiors, Calligraphic Walls, and Memorialized Core, among others. They address functions and symbolisms such as ritual purification, divine orientation, acoustic reverence, and cosmological hierarchy—each fundamental to the logic of mosque design.

Collectively, these patterns articulate a layered sacred syntax: from exterior to interior, from horizontal processions to vertical symbolism, from communal gathering to divine alignment. The findings demonstrate that the Şehzade Mosque is not simply an architectural object but a structured field of metaphysical expression—where meaning is not superimposed but architecturally embedded. The following sections present these patterns in detail, organized by domain, and supported by spatial diagrams and analytical tables.

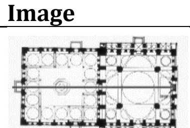
To support the analytical findings, this study integrates a set of visual tools that clarify the structure and application of the pattern framework. A comparative pattern table presents all forty-two patterns, distinguishing between those adapted from Alexander's A Pattern Language and those newly constructed through symbolic and theological analysis. Each pattern is listed with its domain classification, dominant function, and corresponding spatial manifestation in the Şehzade Mosque.

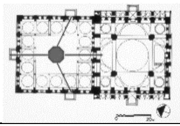
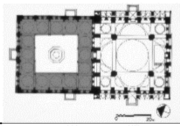
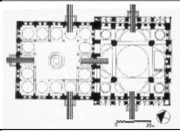
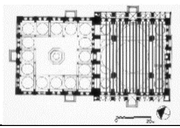
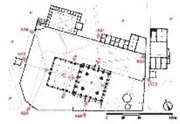
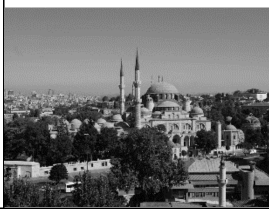
In addition, a series of annotated diagrams overlays selected patterns onto architectural plans and sections of the mosque. These visual mappings highlight how sacred meaning is embedded in elements such as entrance sequences, dome hierarchies, prayer alignments, and calligraphic zones. A framework diagram also visualizes the four macro-domains, illustrating how each contributes to the layered structure of sacred experience—ritual, spatial, symbolic, and experiential.

These figures function as essential components of the research, translating abstract pattern logic into concrete spatial analysis and offering a replicable visual model for interpreting sacred architecture.

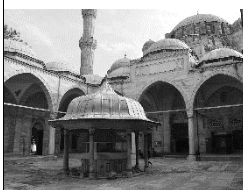
Table 1. Pattern Matrix Organized by Domain → Pattern Type → Name → Source → Function → Spatial Manifestation

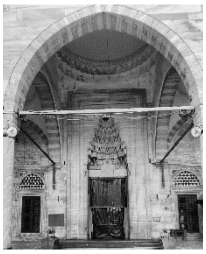
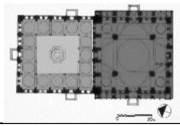
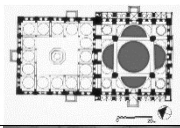
1. Ritual and Sacred Logics

Pattern Name	Type	Function	Spatial Manifestation	Image
Qibla Axis (O1)	Original	Ritual/Spatial	Orientation of prayer hall, mihrab alignment	

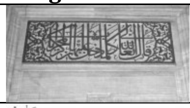
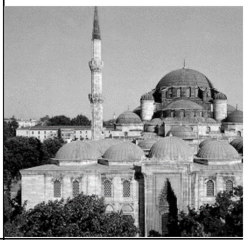
Ablution Entry Sequence (O2)	Original	Ritual	Sequential transition from courtyard to prayer space via ablution facilities	
Entrance to Sacred Zone (O3)	Original	Ritual	Arcade thresholds, transition from public to sacred domain	
Prayer Movement Paths (O4)	Original	Ritual	Directional flow of movement during prayers	
Prayer Rows (O5)	Original	Ritual/Social	Aligned rows within main prayer hall, emphasizing unity	
Paths and Goals (120)	Adapted	Ritual/Spatial	Spatial progression from entrance to focal point	
Holy Ground (66)	Adapted	Ritual/Symbolic	Sanctification of prayer space through placement and hierarchy	
Pools and Streams (64)	Adapted	Ritual/Experiential	Ablution fountains in courtyard	

2. Spatial and Formal Organization

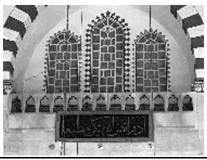
Pattern Name	**Type**	**Function**	**Spatial Manifestation**	**Image**
Entrance Transition (112)	Adapted	Spatial	Layered portals, elevation change at entry	
Main Entrance (110)	Adapted	Spatial	Frontal orientation and articulation of entry	

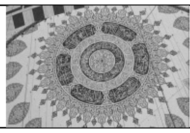
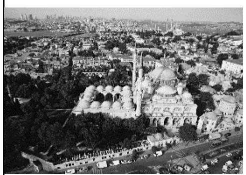
Family of Entrances (102)	Adapted	Spatial	Differentiated side and main entries	
Circulation Realms (98)	Adapted	Spatial	Progressive entry realms (courtyard, arcade, hall)	
Hierarchy of Open Space (114)	Adapted	Spatial	Transition from open (courtyard) to enclosed (prayer hall)	
Courtyards Which Live (115), Common land (67)	Adapted	Spatial/Social	Central courtyard as functional and symbolic gathering space	
Building Complex (95)	Adapted	Spatial	Modular arrangement of mosque and auxiliary structures	
Roof Caps (232)	Adapted	Spatial	Cascading domes and visual termination	
Cascade of Roofs (116), Sheltering Roof (117)	Adapted	Spatial	Hierarchical dome arrangement around central core	
Dome Sequence (O6)	Original	Spatial	Progression of domes as cosmological structure	
Mihrab Focus (O7)	Original	Spatial/Theological	Spatial concentration around the mihrab zone	

3. Symbolic and Cultural Layers

Pattern Name	Type	Function	Spatial Manifestation	Image
Calligraphic Walls (O8)	Original	Symbolic	Qur'anic inscriptions across interior zones	
Memorialized Core (O9)	Original	Symbolic/Spatial	Placement of Şehzade tomb integrated within complex	
Sacred Sites (24)	Adapted	Symbolic	Spatial memory and historical sacredness	
High Places (62)	Adapted	Symbolic	Verticality and domical visibility	
Ornament (249)	Adapted	Symbolic	Non-figurative ornanment and calligraphy	
Building Fronts (122)	Adapted	Symbolic	Façade articulation communicating purpose	
Sacred Skyline (O10)	Original	Symbolic	Mosque silhouette as urban-symbolic anchor	

4. Environmental and Experiential Conditions

Pattern Name	Type	Function	Spatial Manifestation	Image
Filtered Light (238) and small Panes (239)	Adapted	Experiential	Use of stained glass, clerestories	
Indoor Sunlight (128)	Adapted	Experiential	Orientation of domes and windows	

Light on Two Sides (159)	Adapted	Experiential	Double-sided light in galleries	
Layered Light (O11)	Original	Experiential	Temporal modulation of light in relation to time of day and ritual	
Floor Surface (233)	Adapted	Experiential	Texture and tactility of carpeted floors	
Soft Inside Walls (235)	Adapted	Experiential	Acoustic dampening and visual softness	
Warm Colors (250)	Adapted	Experiential	Chromatic tones within interior decoration	
Quiet Interiors (O12)	Original	Experiential	Acoustic stillness to support inward focus	
Connection to Earth (168)	Adapted	Experiential	Groundedness through low platforms, steps	
Thickening Outer Walls (211)	Adapted	Experiential	Buffering external noise and thermal insulation	
Arcades (119), Floor-Ceiling Vaults (219)	Adapted	Spatial/Experiential	Covered circulation and spatial rhythm	
Repetitive Spatial Rhythm (O13)	Original	Spatial/Experiential	Repetition of arches, domes, bays as symbolic rhythm	

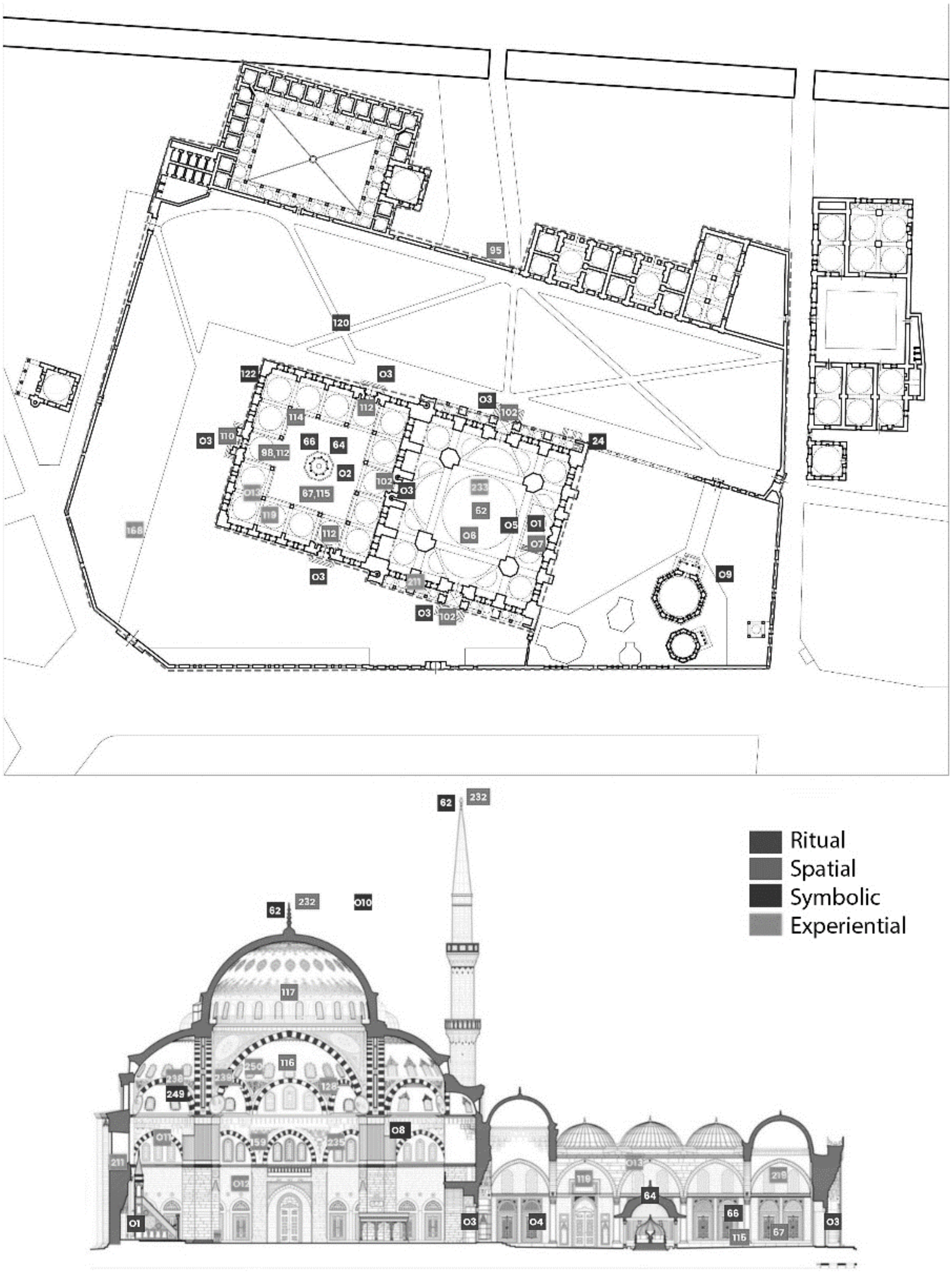


Figure 3. Pattern Overlay Map of the Şehzade Mosque Floor Plan. Selected patterns are annotated according to their spatial manifestation and symbolic role, color-coded by macro-domain.

Pattern Distribution and Thematic Cross-Relations

The developed pattern framework demonstrates a structured distribution of symbolic-spatial functions across four macro-domains. While each pattern was initially classified according to its dominant logic—ritual, spatial, symbolic, or experiential—the analysis reveals significant thematic overlaps and cross-domain interactions, indicating a layered architectural and theological system.

Of the forty-two patterns, the largest concentration appears in the Spatial and Formal Organization domain, which reflects the architectural clarity and compositional hierarchy of Sinan's design. This includes patterns such as Hierarchy of Open Space, Prayer Rows, Main Entrance, and Dome Sequence, all of which define spatial progression, centralization, and enclosure. The Ritual and Sacred Logics domain follows, comprising patterns that structure bodily purification, directional alignment, and sacred access—such as Ablution Entry Sequence, Qibla Axis, and Entrance to Sacred Zone.

The Symbolic and Cultural Layers domain contains patterns like Calligraphic Walls, Sacred Skyline, and Memorialized Core, which articulate theological memory and cosmological reference. Finally, the Environmental and Experiential Conditions domain emphasizes atmospheric depth and sensory engagement through patterns like Filtered Light, Quiet Interiors, and Repetitive Spatial Rhythm. These relationships are summarized in Table 2, which shows how patterns are distributed across the four domains, and identifies overlaps in their symbolic operation.

A key insight from this distribution is the inter-domain operation of several patterns. For example, Courtyards Which Live participates in both Spatial and Experiential domains, functioning as a transitional node and sensory field. Dome Sequence links Formal Hierarchy with Symbolic Verticality, while Prayer Rows spans Spatial, Ritual, and Social meanings.

These thematic overlaps reveal that the pattern framework operates not as a static classification, but as a semiotic lattice—a network of spatial-symbolic relations in which architectural elements carry multiple layers of theological significance. This structural interdependence echoes the Islamic principle of tawḥīd (divine unity), where sacred space integrates form, function, and meaning as a coherent epistemological system.

Table 2. Pattern Distribution by Macro-Domain

Macro Domain	Total Patterns	Adapted	Original	Cross-Domain Overlaps
Ritual and Sacred Logics	8	3	5	5
Spatial and Formal Organization	13	11	2	2
Symbolic and Cultural Layers	7	4	3	1
Environmental and Experiential	14	11	3	2
Total	42	29	13	

Note: Some patterns appear in multiple domains, reinforcing their layered symbolic function

Table 3. Thematic Correlation Table: Theological and Spatial Relations

Pattern Name	Macro Domain	Theological Reference	Symbolic Function	Spatial Zone
Qibla Axis	Ritual & Sacred Logics	Quran 2:144	Divine orientation	Mihrab and prayer hall
Ablution Entry Sequence	Ritual & Sacred Logics	Sahih al-Bukhari 164	Ritual purification	Courtyard and entrance
Entrance to Sacred Zone	Ritual & Sacred Logics	Quran 24:36	Threshold demarcation	Arcade thresholds, Entrances
Prayer Movement Paths	Ritual & Sacred Logics	Sahih al-Bukhari 510	Directed ritual flow	Main Prayer hall
Prayer Rows	Ritual & Sacred Logics	Sahih al-Bukhari 723	Communal alignment	Main Prayer hall
Paths and Goals	Ritual & Sacred Logics	Quran 6:153	Spiritual journey	Processional axis
Holy Ground	Ritual & Sacred Logics	Quran 20:12	Sanctity encoding	Prayer space
Pools and Streams	Ritual & Sacred Logics	Sahih Muslim 241	Purificatory symbolism	Courtyard fountains
Entrance Transition	Spatial & Formal Organization	Quran 7:31	Ritual and ethical preparation	Entry gates
Main Entrance	Spatial & Formal Organization	Quran 24:36	Liminal transformation	Frontal gate
Family of Entrances	Spatial & Formal Organization	Sunan Abu Dawood 462	inclusive participation; architectural hospitality guided by ethical order	Side and main entrances
Circulation Realms	Spatial & Formal Organization	Quran 6:153, Sahih Muslim 867	Segregated flows, Avoidance of disruption during prayer, Pathway integrity aligned with qibla and sanctity	Courtyard to prayer hall

Hierarchy of Open Space	Spatial & Formal Organization	Sahih al-Bukhari 470	Sacred gradation encoded in space—architectural progression from public approach to divine nearness	Aracades, Courtyard, prayer hall
Courtyards Which Live	Spatial & Formal Organization	Quran 9:18	Courtyard as a spiritual agora—hosting collective life, ritual overflow, and ambient sanctity	Courtyard
Common land	Spatial & Formal Organization	Quran 49:13	pace of mutual access, spiritual encounter, and civic mercy	Courtyard, prayer hall
Building Complex	Spatial & Formal Organization	Masjid al-Nabawi	Spatial unity of sacred, civic, and memorial	Mosque, tombs, fountain
Roof Caps	Spatial & Formal Organization	Quran 57:4	the axis of divine sovereignty	Roofline articulation
Cascade of Roofs	Spatial & Formal Organization	Quran 67:3	Sequential domes mirror celestial strata—spatial metaphor for ascent toward divine oneness	Layered domes
Sheltering Roof	Spatial & Formal Organization	Quran 38:27	The dome is like the revolving heavens	Prayer Hall roof, arcades
Dome Sequence	Spatial & Formal Organization	Quran 112:1-4	Central dome symbolizes divine oneness; dome hierarchy mirrors cosmological order	Central and half domes
Mihrab Focus	Spatial & Formal Organization	Quran 2:44	Spatial and spiritual directionality	Mihrab
Calligraphic Walls	Symbolic & Cultural Layers	Quran 24:35	Text as light and guidance	Interior inscriptions
Memorialized Core	Symbolic & Cultural Layers	Islam's strict position on grave worship and elevation of tombs (per Hadith in Sahih Muslim and Sahih Bukhari) led to debates: Scholars like Ibn Taymiyyah and al-Shawkānī condemned elaborate tomb structures within mosques. However, Sunni Ottoman jurists (especially Ḥanafīs) permitted them under specific conditions of intention and structure—seeing them as memorials, not objects of veneration.	Architectural assertion of dynastic piety—tombs placed near prayer halls to embody charitable continuity and proximity to sanctity	Sehzade tomb zone
Sacred Sites	Symbolic & Cultural Layers	Quran 2:125	divine encounter, prophetic memory, and architectural continuity—preserved through form, not figuration.	Historic plot
High Places	Symbolic & Cultural Layers	Quran 23:17	cosmic verticality	Dome and minaret prominence
Ornament	Symbolic & Cultural Layers	Quran 16:6	Non-figurative theology and visual dhikr	Interior decorations

Building Fronts	Symbolic & Cultural Layers	Quran 22:26	The façade of a mosque announces purity of function and clarity of spiritual orientation	Entrance facade
Sacred Skyline	Symbolic & Cultural Layers	Quran 24:36	Vertical testimony—mosque skyline as urban dhikr, asserting sacred presence in public realm	Minarets and domes
Filtered Light, Small Panes, Indoor Sunlight, Light on Two Sides, Layered Light	Environmental & Experiential	Quran 24:35	Spiritual illumination	Clerestories, stained glass, Window orientation, side walls, light gradients
Floor Surface	Environmental & Experiential	Quran 20:12	Consecrated ground	Carpeted prayer hall
Soft Inside Walls	Environmental & Experiential	Quran 16:6	divine beauty	Interior walls
Warm Colors	Environmental & Experiential	Quran 16:13	invoking remembrance (dhikr) and stimulating reflection	Interior pallette
Quiet Interiors	Environmental & Experiential	Quran 22:32	Contemplative silence	Prayer hall
Connection to Earth	Environmental & Experiential	Quran 20:55, Sahih Muslim 522a	Material rootedness and ground symbolısm	Steps, platform, garden
Thickening Outer Walls	Environmental & Experiential	Quran 16:80	Sanctified enclosure—walls separate profane exterior from sacred interior	Walls
Arcades	Environmental & Experiential	Quran 55:17	Ritual passage	Arcades
Floor-Ceiling Vaults	Environmental & Experiential	Quran 88:18	Architectural heavens	Ceiling vaults
Repetitive Spatial Rythms	Environmental & Experiential	Quran 39:23	Symbolic sequence	Arches, domes

Architectural Concentration and Spatial Layers

The spatial analysis of the Şehzade Mosque reveals that sacred meaning is not evenly distributed across the architectural ensemble, but rather intensely concentrated in specific zones, where multiple patterns converge and reinforce each other. These pattern clusters are not arbitrary; they align with core theological functions, ritual sequences, and symbolic hierarchies embedded in the Islamic conception of sacred space.

The entrance and threshold zone serves as the critical interface between the profane urban exterior and the sanctified interior. This zone concentrates several patterns—Entrance Transition, Ablution Entry Sequence, Paths and Goals, and Entrance to Sacred Zone—which collectively construct a graduated ritual threshold. The spatial configuration of porticoes, fountains, and layered gateways guides the visitor through stages of purification and psychological orientation, choreographing a bodily transition toward divine presence. This architectural sequence transforms movement into ritualized enactment, echoing Islamic epistemologies of preparation and intentionality.

Beyond the threshold, the central courtyard operates as a spatial hinge and liminal field. Patterns such as Courtyards Which Live, Filtered Light, Connection to the Earth, and Memorialized Core converge here, making the courtyard a site of both liturgical anticipation and symbolic memory. The integration of the Şehzade Mehmed tomb into the courtyard fabric intensifies its function, linking ritual purification with dynastic remembrance and cosmological reflection. In this zone, sacredness emerges not only through function but through spatial commemoration and symbolic atmosphere.

At the heart of the mosque, the prayer hall functions as the most saturated symbolic field. It is shaped by a dense convergence of patterns including Qibla Axis, Prayer Rows, Mihrab Focus, Calligraphic Walls, Hierarchy of

Open Space, and Quiet Interiors. These patterns collectively align the physical body, architectural form, and theological intention. The hall spatializes the core Islamic principle of tawḥīd—the unity of divine orientation, community structure, and contemplative silence—through the integration of directional geometry, scriptural ornamentation, and acoustic calm.

Above, the dome structure reinforces this symbolic verticality. Patterns such as Dome Sequence, Roof Caps, Light on Two Sides, and Sacred Skyline articulate a cosmological hierarchy that transitions from the grounded alignment of prayer to the metaphysical register of divine transcendence. The central dome, surrounded by cascading smaller domes, becomes not merely a structural element but a symbolic vessel of ascent—reinforcing the theological verticality of the sacred experience.

Even in peripheral spaces—side galleries, corridors, and auxiliary structures—symbolic density persists. Patterns like Family of Entrances, Soft Inside Walls, and Warm Colors articulate inclusivity, environmental modulation, and sensory comfort. These areas support a broader conception of the mosque as both a spiritual and civic institution, where contemplation, teaching, and community co-exist with formal liturgical practice.

In totality, the spatial concentration of patterns reveals the mosque as a layered field of sacred operations. Rather than a single monumental gesture, sacredness is produced through architectural coordination, where ritual, symbolism, form, and sensory experience are spatially integrated. The Şehzade Mosque thus exemplifies a sacred architecture of relational intensities, where theological meaning is not represented through image, but enacted through form.

Discussion and Conclusion

The analysis of the Şehzade Mosque through a reconfigured pattern language reveals that sacredness in Ottoman mosque architecture is not a fixed symbolic attribute but a relational condition, constructed through layered spatial operations. Patterns such as Ablution Entry Sequence, Qibla Axis, Dome Sequence, and Calligraphic Walls demonstrate that theological meaning emerges through the coordination of movement, orientation, vertical hierarchy, and non-figurative inscription. The mosque does not illustrate sacredness; it performs it—through spatial progression, bodily alignment, environmental modulation, and scriptural embodiment.

One of the central findings is that sacred meaning in Islamic architecture operates across domains, requiring analytical models that are both spatially rigorous and theologically grounded. The high incidence of cross-domain patterns—such as Prayer Rows or Courtyards Which Live—confirms that sacred experience is never isolated within a single architectural logic (e.g., form, ritual, or aesthetics), but produced through their integration. The analytical utility of macro-domains lies not in compartmentalization, but in revealing how these layers intersect and intensify at key spatial nodes.

The reinterpretation of Alexander's patterns reveals both the potential and the limits of transposing secular design theory into sacred contexts. While many of his patterns—Entrance Transition, Filtered Light, Paths and Goals—retain architectural value, they required epistemological reorientation to capture the theological and ritual dimensions embedded in mosque architecture. The new patterns constructed—such as Mihrab Focus, Calligraphic Walls, and Memorialized Core—fill critical symbolic gaps and illustrate the necessity of cultural and religious specificity in pattern languages for sacred space.

These findings confirm that sacred architecture, particularly in the Ottoman-Islamic tradition, cannot be adequately theorized through typology or stylistic analysis alone. It demands a symbolic-spatial grammar, where architectural elements operate not only as formal devices but as theological instruments—structuring the believer's journey from purification to alignment, remembrance, and transcendence. The proposed pattern framework makes this grammar visible, interpretable, and adaptable to both scholarly analysis and contemporary design practice.

The interpretive findings of this study both affirm and extend the work of key scholars in Islamic architectural history, sacred space theory, and design methodology. Foundational studies by scholars such as Kuban (2007) and Necipoğlu (2010) have thoroughly documented the formal typologies, stylistic evolution, and cultural significance of Ottoman mosque architecture, particularly in relation to Mimar Sinan's oeuvre. However, these studies often emphasize architectural mastery and urban symbolism without providing an analytical framework capable of decoding how sacred meaning is spatially enacted through specific architectural configurations.

This research also intersects with broader theoretical treatments of sacred space, such as those by Grabar, Waziri, and Serageldin, who have emphasized the theological and symbolic depth of Islamic architecture. While these contributions recognize that mosque architecture is more than functional typology, they tend to remain either descriptive or philosophically abstract, lacking a systematic analytical tool for interpreting sacred space as a structured symbolic field. By contrast, the pattern framework developed in this study offers a replicable system for tracing sacred meaning through spatial, ritual, symbolic, and experiential layers.

The most direct methodological comparison arises with Christopher Alexander's A Pattern Language (1977). Alexander's contribution lies in articulating spatial patterns that support human-centered environments through typological clarity and intuitive design logic. Yet his framework, developed in a secular and largely Euro-American context, is limited in its capacity to address ritual specificity, metaphysical symbolism, and theological intentionality—elements essential to sacred architecture. Previous attempts to apply Alexander's framework in religious contexts have typically done so without critique or adaptation, thereby flattening cultural difference.

This study departs from that trend by offering a culturally embedded reinterpretation of selected Alexander patterns, while also constructing new patterns to capture symbolic and ritual logics specific to Islamic theology and Ottoman architectural expression. In doing so, it positions itself as both a methodological supplement to Alexander's work and a conceptual bridge between design theory and sacred spatial analysis.

In summary, while earlier studies have richly documented Ottoman mosque architecture and theorized the sacred in Islamic design, this study contributes a formalized, multi-domain analytical framework that clarifies how sacred meaning is systematically embedded in space. It does not replace historical or stylistic approaches, but rather complements them by offering a symbolic-architectural grammar grounded in Islamic epistemology and validated through spatial application.

A key strength of this study lies in its development of a culturally specific, symbolically attuned analytical framework for interpreting sacred architecture. By reconfiguring selected patterns from Alexander's A Pattern Language and supplementing them with new patterns grounded in Islamic ritual, theological, and spatial epistemologies, the study offers a replicable model for analyzing how sacred meaning is architecturally enacted. The four-domain structure—ritual, spatial, symbolic, experiential—provides a comprehensive interpretive lens that avoids the reductivism of purely formalist or functionalist approaches.

Another methodological strength is the use of cross-domain pattern mapping and architectural concentration analysis, which reveals not only the presence of symbolic patterns but their spatial clustering and theological intensity in specific zones of the mosque. This allows for a deeper understanding of how sacred space operates as a layered system, not simply a composition of isolated elements. The visual tools—pattern matrices, annotated overlays, and spatial diagrams—translate abstract symbolic logic into analytical clarity, enhancing both academic and design applicability.

However, the study also faces certain limitations. First, it is based on a single case study, and while the Şehzade Mosque is typologically and symbolically rich, the findings may not be generalizable across all Islamic or Ottoman mosque types. Future research should test the framework on other typologies (e.g., hypostyle, regional vernacular) to assess its adaptability.

Second, the study is conducted through interpretive symbolic analysis, which, while rigorous, remains non-empirical. It does not include user perception studies, ethnographic engagement, or historical textual analysis beyond selective theological references. These omitted dimensions may limit the framework's depth in capturing lived experience or historical nuance.

Finally, while the adapted pattern language offers theoretical and analytical value, its application in contemporary mosque design remains propositional rather than tested. Its value as a generative design tool would require application in a live design process or pedagogical setting.

Despite these limitations, the framework demonstrates significant potential as a scholarly and pedagogical tool for interpreting sacred space. Its originality lies in its capacity to synthesize symbolic, ritual, spatial, and environmental logics into a unified analytical grammar rooted in Islamic sacred architecture.

The pattern framework developed in this study has significant implications for both architectural theory and design methodology, particularly within the domain of sacred architecture. Theologically grounded yet spatially rigorous, the framework offers an alternative to conventional formalist or typological analyses by treating sacred architecture as a semiotic and ritual system. In doing so, it extends pattern theory beyond its original secular-humanist scope, demonstrating that spatial languages can be culturally specific, symbolically charged, and epistemologically plural.

For scholars of Islamic architecture, the framework provides a replicable model for interpreting mosque design as a layered theological field, rather than as a stylistic or functional artifact. It complements historical studies by offering a tool for decoding how architectural forms communicate sacred meaning through coordinated spatial, symbolic, and sensory operations.

In terms of design practice, the framework opens new possibilities for contemporary mosque design, particularly in post-traditional or pluralistic contexts where the symbolic logic of sacred space must be rearticulated without relying on historical replication. The pattern set may serve as a generative toolkit for designers seeking to integrate theological intentionality, ritual structure, and cultural continuity into new architectural expressions.

Future research should explore the application of this framework across diverse mosque typologies—including regional variants, vernacular forms, and modern reinterpretations—to assess its adaptability and limitations. Further work may also extend the methodology into other sacred traditions, enabling comparative analysis across religious architectures. Additionally, integrating user-based studies, such as perception mapping or ethnographic engagement, would deepen the framework's sensitivity to lived sacred experience and social usage.

Finally, the pattern framework may be developed into a pedagogical instrument for design education, particularly in courses focused on sacred space, cultural theory, or architecture and theology. By making visible the invisible logic of sacred form, it invites both students and practitioners to design not only with form, but with meaning.

This study developed a multi-domain pattern framework for interpreting sacred spatial logic in Islamic architecture, using the Şehzade Mosque as a case study. Drawing on and extending Christopher Alexander's A Pattern Language, the research reinterpreted twenty-nine of his original patterns through an Islamic epistemological lens and introduced thirteen new patterns specific to theological, ritual, and symbolic dimensions absent in the original system. The patterns were organized across four macro-domains—ritual, spatial, symbolic, and experiential—revealing that sacred meaning in the mosque is enacted through architectural form, movement, orientation, and atmosphere.

The framework provides a structured method for decoding sacred space that bridges design theory, Islamic theology, and architectural analysis. It shows that Ottoman mosque architecture, particularly under Sinan, operates not only through typological elegance but through an embedded symbolic grammar. The framework has potential application in contemporary mosque design, architectural pedagogy, and comparative sacred architecture studies.

This study is based on a single case and employs an interpretive symbolic method without ethnographic or empirical user data. It also does not address the design implementation of the framework in contemporary practice, which remains a subject for future application.

Future work should test the framework across other mosque typologies, regional traditions, and even non-Islamic sacred architectures to evaluate its adaptability and limits. Empirical studies involving users and designers may also deepen its interpretive scope. Further development as a pedagogical model could support design education in culturally and theologically sensitive contexts.

In a design culture increasingly marked by abstraction, eclecticism, or superficial symbolism, the need for epistemologically grounded architectural frameworks is more urgent than ever—particularly in the domain of sacred space. This study proposes that the mosque is not simply a site of worship or cultural expression, but a spatialized theology—a structured embodiment of metaphysical principles enacted through architectural form. By constructing a pattern language attuned to Islamic sacred logic, this research affirms that meaning in architecture is not accidental, aesthetic, or representational alone—it is designed, encoded, and lived. What is required, then, is not only better buildings, but better grammars of sacred form, capable of honoring both historical continuity and contemporary transformation.

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Conflict of Interests
The author(s) declare(s) no conflict of interest.

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Chapter 3

The Role of History in Architecture Design: An Analytical Research Study

* Shalini Sheoran, Manoj Panwar

Introduction

"Cities actually grow gradually along with history. So, when we do things in the city in the contemporary era, we are actually doing things within the historical process. Therefore, when my works intervene in the city, I hope they can connect the past with the future." (Liu Jiakun, Pritzker Prize Architecture 2025 Laureate)

We live in history. We are constantly reinterpreting the histories of our past and our historic surroundings. All design decisions are historically situated, influenced by cultural, political, and social forces. Bruno Zevi, a prominent Italian architectural theorist, emphasized that historic structures were deeply contemporary to the times in which they were created. He argued that architecture should be understood not merely as a static object but as a dynamic, evolving practice that reflects the social, cultural, and technological contexts of its era. Zevi's approach sought to bridge the gap between the past and present, advocating for a historiography that recognizes the relevance of historical architecture in contemporary discourse. Zevi's work encourages a re-evaluation of architectural history, urging scholars and practitioners to approach it not as a mere chronological record but as a living dialogue that informs and enriches current architectural endeavours. By acknowledging the contemporary relevance of historic structures, Zevi advocated for a more nuanced and interconnected understanding of architecture across time (Zevi, 1978).

History serves as a critical bridge between the past and the future, enabling individuals and societies to learn from previous experiences to shape informed decisions and sustainable innovations for the future (Carr, 1961). As Carr noted, "History is an unending dialogue between the present and the past", highlighting its role in guiding future action through reflective understanding. In architectural education, history is not merely a record of past styles and structures—it acts as a critical tool for shaping future design ideologies. By studying historical contexts, architects gain insight into cultural, social, and environmental values that continue to influence contemporary and future design approaches. As Mallgrave (2005) argues, "architectural history provides the cultural and intellectual continuity that allows innovation to be rooted in meaning rather than disconnected form."

Background and Context

"Learning is not simply a process of absorbing information, but one of actively constructing knowledge through interaction with the environment and with the others" (Bransford, Brown & Cocking, 2000)

Redefining history in architecture education through various educational theories and concepts can be termed an innovative and interdisciplinary approach that enriches how historical knowledge is taught and integrated within the architectural discourse. This method aligns with current pedagogical movements advocating for constructivist, experiential, and reflective learning in design education (Salama, 2015). The learning theories of Behaviorism, Cognitivism, Constructivism, Humanism, Experiential, Transformative, and Connectivism were critically analyzed for this study.

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Problem Statement and Research Gap
Connecting learning theories to the integration of history in design education is essential because it ensures that the teaching approach is intentional, effective, and learner-centered. This method:
a. Informs how students learn best
b. Deepens critical thinking and reflection
c. Encourages application over rote learning
d. Promotes interdisciplinary & connected thinking
e. Supports diverse learner needs

Connecting learning theories to historical integration in architectural design helps to:
a. Make history relevant and applied, not abstract or isolated.
b. Foster deeper understanding and critical engagement.
c. Equip students to design informed, meaningful, and context-sensitive solutions.
This approach doesn't just teach history, it uses history as a lens to shape thoughtful, responsible designers.

Objectives
The objective of the study is to:
a. Understand the learning theories of Behaviorism, Cognitivism, Constructivism, Humanism, Experiential, Transformative, and Connectivism.
b. Analyze the learning theories in the context of the five definitive questions informed by Schunk (1991).
c. Analyze the learning theories in context to History integration in Architecture Design.

Structure of the Chapter
"Learning theories provide instructional designers with verified instructional strategies and techniques for facilitating learning as well as a foundation for intelligent strategy selection" (Ertmer & Newby, 2013). The research is based in the five definitive questions informed by Schunk (1991) that serve to distinguish each learning theory from the other:
1. How does learning occur?
2. Which factors influence learning?
3. What is the role of memory?
4. How does transfer occur?
5. What types of learning are best explained by the theory?

And the 2 questions adapted with modifications from the study of Ertmer & Newby (1993):
1. What basic assumptions/ principles of this theory are relevant to the instructional design of *'Architectural Design'*?
2. How should instruction be structured to facilitate *'History'* learning?

The learning theories of Behaviorism, Cognitivism, Constructivism, Humanism, Experiential, Transformative, and Connectivism were analyzed for the current research study. The theories were understood in their existing context and further understood in the context of their possible applications towards redefining the role of history in architecture education.

Materials and Methods

The study adopted a qualitative, literature-based analytical methodology to understand the context of existing learning theories. The method allowed for critical engagement with existing theoretical texts, peer-reviewed articles to develop a synthesized understanding of the subject. an analytical study focuses on interpreting and evaluating existing information to draw conclusions or understand patterns. It undertakes a narrower approach and focuses on interpretation & critical analysis.

Research Design
The research design is qualitative and analytical, involving a comparative evaluation of existing literature and theories relevant to architectural education and historical integration. A thematic analysis approach was used to identify recurring pedagogical principles and historical narratives within architectural discourse.

Sources & Data Collection
A keyword search on 'Google Scholar' with keywords 'learning theories in design' provided 93 research articles. 28 articles were rejected due to non-availability of full texts, 3 were rejected due to different language, and 4 were

rejected for duplicity. Title sorting led to rejection of 5, and Abstract sorting led to rejection of 12. A total of 41 research articles were reviewed for the current study. Sources were selected based on relevance to architectural pedagogy, historical analysis, and learning theories. Peer-reviewed journal articles, theoretical texts by key authors, and architectural education frameworks were prioritized. Cross-referencing was further used to reach relevant texts.

Analytical Framework

A thematic analysis approach was employed to extract and categorize recurring themes related to historical interpretation, teaching practices, and learning strategies. The analysis was guided by conceptual frameworks taken from Schunk & Ertmer & Newby's studies. These frameworks were used to map the alignment between existing learning theories, practices, and potential pedagogical innovations in the architecture education and history of architecture.

Justification of Method

This methodology is appropriate because it allows for the synthesis of interdisciplinary perspectives and provides a conceptual basis for rethinking the role of history in architectural education, grounded in established educational theories. It allows for identifying theoretical gaps and proposing more inclusive, reflective, and learner-centered strategies for teaching history in architectural contexts.

Results

Learning theories play a critical role in shaping architectural pedagogy, guiding how students conceptualize space, form, structure, and the socio-cultural impact of design. Since architecture is both a creative and technical discipline, theories such as constructivism, experiential learning, cognitivism, and others provide essential frameworks for integrating knowledge, skill, and critical thinking in design education. According to Salama (2015), architecture education must move beyond rote technical training to foster "critical inquiry, reflection, and experiential engagement," all of which are rooted in learning theory. Kolb's experiential learning model is particularly relevant, as it aligns with studio-based learning, where students learn through design iterations, critique, and reflection (Kolb, 1984). Constructivist theory, as described by Piaget and later by Vygotsky, emphasizes the importance of students constructing their own understanding through problem-solving and collaboration—a process central to architectural design studios (Vygotsky, 1978; Piaget, 1952).

Behaviorism began with a basic stimulus–response and evolved through the contributions and works of Pavlov, Watson, Thorndike, and Skinner. Previously, learners acted with specific goals in mind, responding predictably to given stimuli. While behaviorism offered significant advancements over earlier theories in its time, evolving learner needs and societal changes have highlighted the necessity for more contemporary approaches to learning. Learning evolved from rote memorization toward a more analytical form of literacy focused on extracting meaning. A knowledgeable individual came to be defined as a problem solver—someone who engages with their environment to explore hypotheses and draw broader conclusions. (Gredler, 2005). In the second half of the 20th century, a new branch of cognitivism emerged, highlighting the role of social, cultural, and personal factors in learning. The theories developed by Lev Vygotsky and Albert Bandura specifically addressed these dimensions. And later constructivism built upon these ideas, proposing that learners actively construct knowledge through interaction with their environment, experiences, and social context (Edgar, 2012).

Learning theories help educators adapt their teaching to meet varied learning styles (Schunk, 1991) and help develop structured yet flexible curricula that build toward creative synthesis and innovation (Salama, 2015). Effective instructional design requires understanding how knowledge is constructed and retained (Ormrod, 2020). The following theories were undertaken for the study:

1. Behaviorism
2. Cognitivism
3. Constructivism
4. Humanism
5. Experiential
6. Transformative
7. Connectivism

1. Behaviorism

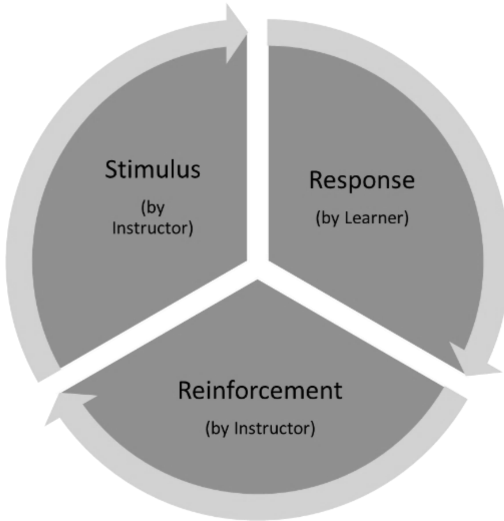

Figure 1. The Learning Theory of Behaviorism (source: Authors).

Behaviorism posits that learning occurs through associations formed between stimuli and responses, and is effectively strengthened by rewards and punishments (Watson, 1913; Skinner, 1953). John B. Watson introduced behaviorism in the early 20th century as a psychological approach focused on observable behavior rather than internal mental states. B.F. Skinner has been a major contributor to the Behaviourist Theory and expanded on Watson's ideas and introduced Operant Conditioning, emphasizing reinforcement and punishment as key mechanisms of learning.

2. Cognitivism

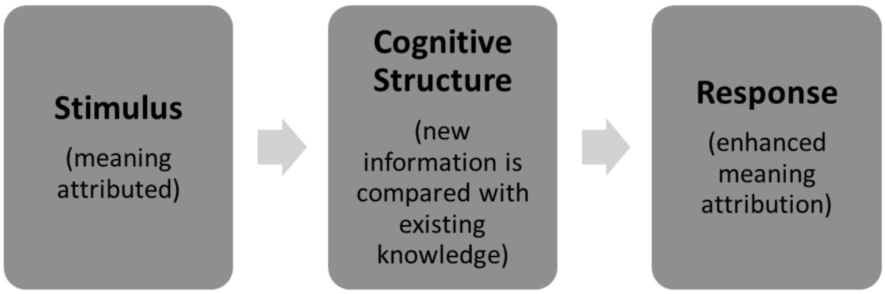

Figure 2. The Learning Theory of Cognitivism (Source: Authors).

Cognitivism views learning as an active mental process of acquiring, storing, and retrieving information, emphasizing understanding over rote memorization (Piaget, 1952; Bruner, 1960; Gagné, 1965; Bandura, 1977; Neisser, 1967; Miller, 1956 & Chomsky, 1956). Jean Piaget's Cognitive Development Theory focused on how children construct knowledge through stages of development, emphasizing schemas, assimilation, and accommodation. Jerome Bruner's Discovery Learning & Spiral Curriculum emphasized that learning is an active process in which learners build new ideas upon their existing knowledge. Robert Gagné's Conditions of Learning identified hierarchies of learning and how different types of learning require different instructional conditions. Albert Bandura's Social Cognitive Theory introduced the concept of observational learning, showing that people can learn through modeling and imitation.

"Learning is essentially a change in a learner's schemata, which are shaped by meaningful learning, organization, and elaboration" (Chomsky, 1956). In education, cognitivist principles can be applied through various strategies like, that of scaffolding (providing momentary assistance to help learners accomplish a task or understand a concept), metacognition (prompting learners to reflect upon how they think and learn) and interactive learning (engaging in discussions and group activities to enhance comprehension).

3. Constructivism

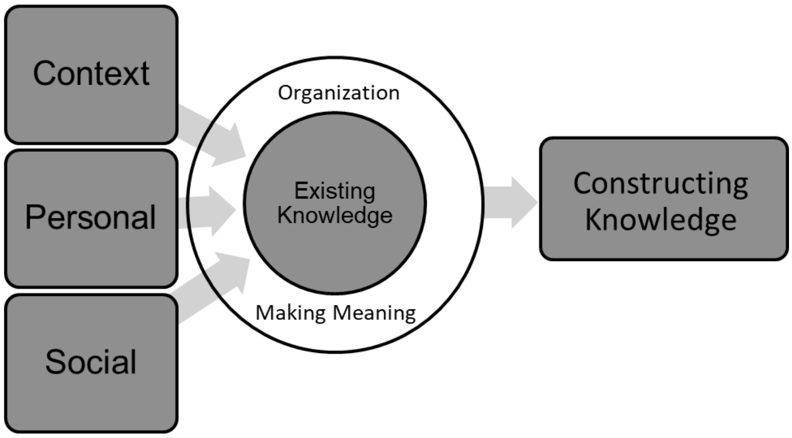

Figure 3. The Learning Theory of Constructivism (Source: Authors).

Constructivism holds that learners actively build their own understanding and knowledge through experiences and reflection, either individually (Piaget) or socially (Vygotsky) (Piaget, 1952; Vygotsky, 1978). Jean Piaget's Cognitive Constructivism emphasized that "learners actively construct knowledge through interaction with their environment". He identified stages of cognitive development, "sensorimotor, preoperational, concrete operational, formal operational". He emphasized that 'Knowledge is built individually through assimilation and accommodation'. Lev Vygotsky's theory of Social Constructivism emphasized the importance of social and cultural contexts in the learning process by introducing the concept of the Zone of Proximal Development (ZPD), which stressed that learning occurs through social interaction and scaffolding. He emphasized that 'Knowledge is co-constructed through dialogue and collaboration'.

4. Humanism

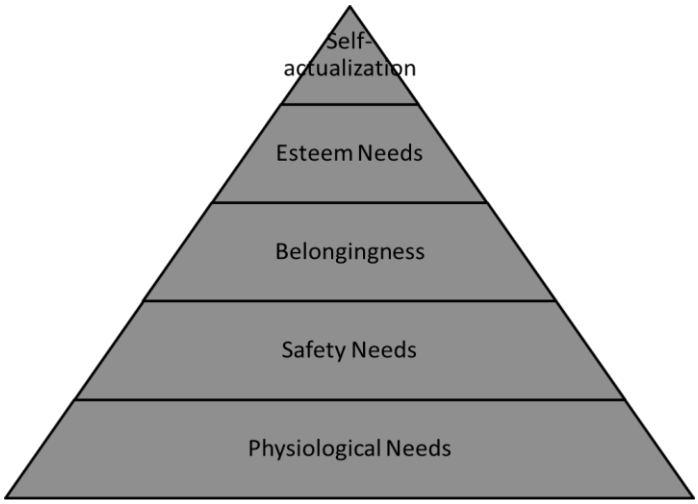

Figure 4. The Learning Theory of Humanism, adapted from Maslow (Source: Authors).

Humanism in education focuses on the development of the learner's full potential by addressing emotional well-being, personal goals, and self-motivation. It promotes holistic, student-centered learning where empathy, freedom, and respect are core (Maslow, 1943; Rogers, 1969). Abraham Maslow's Hierarchy of Needs proposed that learning occurs best when basic needs (e.g., safety, belonging, esteem) are met. He emphasized self-actualization as the highest goal of human development. Carl Rogers's Person-Centered Learning advocated for learner autonomy, self-directed learning, and a supportive educational environment. He believed that education should help individuals become fully functioning persons.

5. Experiential

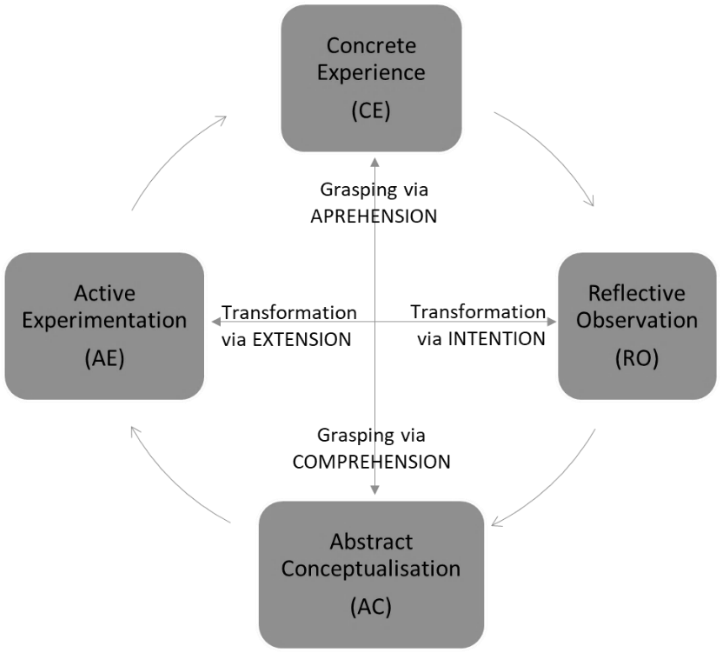

Figure 5. The Experiential Learning Theory, adapted from Kolb (Source: Authors).

In 1984, David Kolb developed the Experiential Learning Theory, defining "learning as a process in which knowledge is created through the transformation of experience, integrating perception, cognition, and behavior". It synthesized ideas from earlier theorists (like Dewey, Lewin, and Piaget) into a formal Experiential Learning Theory. He proposed that "learning is a cyclical process involving four stages: Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation". This model emphasizes that learning occurs through reflection on doing.

John Dewey – Advocated for "learning by doing" and linked experience to education.

Kurt Lewin – Contributed to field theory and action research, influencing Kolb's thinking.

Jean Piaget – His ideas on cognitive development and experiential interaction informed Kolb's framework.

6. Transformative

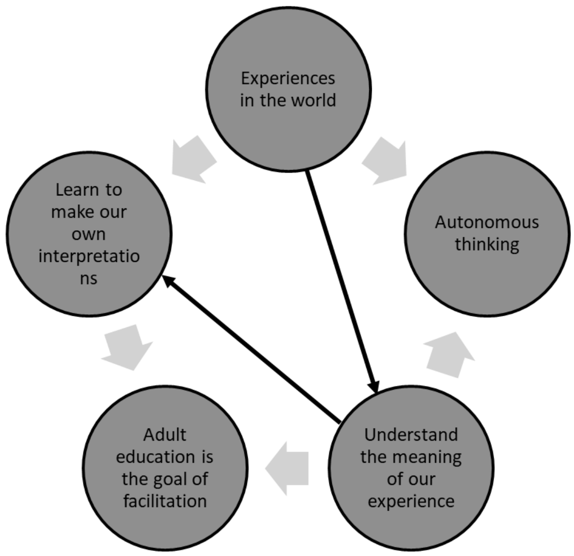

Figure 6. The Transformative Learning Theory, adapted from Mezirow (source: Authors).

Mezirow (1978, 1991) developed the Transformative Learning Theory, explaining how adults change their worldviews through critical self-reflection, often caused by challenging experiences, leading to personal and social transformation. Jack Mezirow introduced Transformative Learning Theory in the late 1970s, based on his research on how adult learners change their frames of reference through critical reflection. He defined transformative learning as the process by which individuals critically reflect on their beliefs, assumptions, and experiences, resulting in a shift in perspective and development of more inclusive and discriminating worldviews. Later Contributors: Patricia Cranton – Expanded Mezirow's ideas to include identity and authenticity in teaching & Edward Taylor – Conducted meta-analyses and broadened the application of the theory.

7. Connectivism

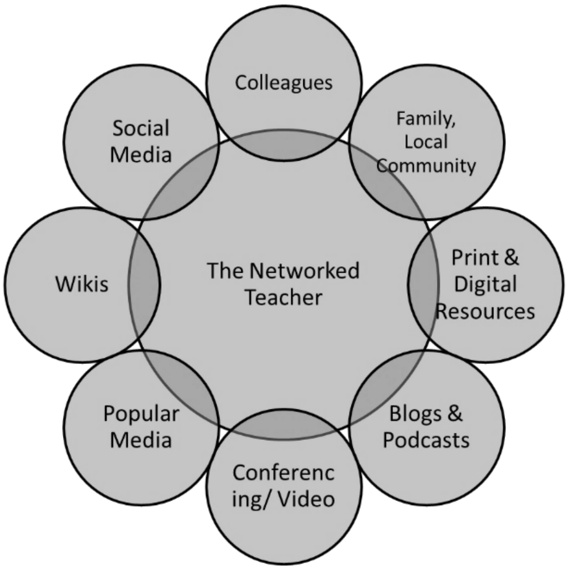

Figure 7. The Learning Theory of Connectivism, adapted from Siemens (source: Authors).

Connectivism, proposed by George Siemens (2005) and further developed with Stephen Downes, explains how learning happens in a digital world through connections with people, digital networks, and information systems.
Siemens introduced Connectivism as a learning theory for the digital age, arguing that traditional theories (Behaviorism, Cognitivism, Constructivism) do not fully address how people learn in networked, technology-driven environments. He emphasized that learning is no longer an individual process but one that occurs across networks of information, people, and digital tools. Downes expanded on Siemens' ideas, especially in the context of personal learning environments and open online learning. He contributed significantly to the practical application of connectivist principles in online education.

Presentation of Key Findings

The learning theories were analysed on the five definitive questions informed by Schunk (1991) that serve to distinguish each learning theory from the other (Table 1):

1. How does learning occur?
2. Which factors influence learning?
3. What is the role of memory?
4. How does transfer occur?
5. What types of learning are best explained by the theory?

Table 1. Learning Theories in context to Schunk's 5 Definitive Questions (source: Authors).

S.No	Learning Theory	How does learning occur?	Factors influencing learning	Role of memory	How does transfer occur?	Types of learning best explained	References
1.	Behaviorism	Learning is a change in behaviour due to environmental stimuli and reinforcement	Reinforcement schedules, environmental stimuli and repetition.	Memory is a passive store for learned behaviours.	Transfer occurs when behaviours are applied in similar contexts.	Best explains rote memorization and skill acquisition.	Skinner (1953); Watson (1913); Biggs & Tang (2011)
2.	Cognitivism	Learning is an active process of internalizing and processing information	Cognitive structures, prior knowledge and mental models.	Memory is an active processor and organizer of information.	Transfer occurs when learners apply cognitive structures to new problems.	Best explains problem-solving and conceptual understanding.	Anderson (1980); Piaget (1952); Biggs & Tang (2011)

3.	Constructivism	Learning is a process of constructing new knowledge based on prior experiences	Social interaction, cultural context and active problem-solving.	Memory is a dynamic system that integrates new information with existing knowledge.	Transfer occurs through authentic tasks and real-world problem-solving.	Best explains design thinking and critical analysis.	Vygotsky (1978); Bruner (1960); Duffy & Cunningham (1996)
4.	Humanism	Learning is a self-directed process focused on personal growth and self-actualization.	Motivation, self-concept and emotional factors.	Memory serves as a repository for personal experiences and self-reflection.	Transfer occurs when learning aligns with personal goals and values.	Best explains self-directed learning and value-based decision-making.	Rogers (1969); Maslow (1943); Knowles (1984)
5.	Experiential Learning	Learning occurs through direct experience followed by reflection.	Concrete experiences, reflective observation, abstract conceptualization and active experimentation	Memory is engaged through reflection on experiences.	Transfer occurs when learners apply insights from experiences to new situations.	Best explains internships, studio projects and fieldwork.	Kolb (1984); Schon (1983)
6.	Transformative Learning	Learning is a process of critically examining and changing one's worldview.	Disorienting dilemmas, critical reflection and discourse.	Memory is involved in reconstructing meaning and perspectives.	Transfer occurs when new perspectives are applied to personal and professional contexts.	Best explains paradigm shifts and deep learning.	Mezirow (1991); Cranton (2006)
7.	Connectivism	Learning is a process of connecting specialized nodes or information sources	Network of connections, digital tools and collaborative environments.	Memory is distributed across networks and technologies.	Transfer occurs through the ability to navigate and utlilize networks effectively.	Best explains learning in digital and networked environments.	Siemens (2005); Downes (2007)

Table 1 lists the 5 definitive questions as per the study of Schunk (1991) which are supportive to present the comparisons of the different learning theories. Learning is a continuous process and different scholars have tried to understand the process by navigating different paths, which has led to the formation of these several learning theories.

In behaviorist theory, learning is conceptualized as a measurable change in behavior that results from an individual's response to external stimuli. Cognitivist learning theory views learning as an active mental process involving the internalization, organization and interpretation of information. It involves active mental processing and organization of information. Constructivist learning theory suggests that learners build knowledge through experience and social context. Humanism learning theory says, learning to be a self-driven process rooted in personal growth and eventually leading to self-actualization. Experiential learning occurs through the cyclic process of experience, reflection, conceptualization and application. Transformative learning takes learning as a perspective- changing process and goes through reframing of past experiences in the light of new insights. Connectivism views learning as navigating and forming networks and connections through digital systems.

Learning in context to Behaviorism includes reinforcement schedules, environmental triggers and repetitive practice. Learning as per cognitivism encodes, stores and retrieves structured knowledge. Learning as per Constructivism integrates new information with prior knowledge. Learning as per Humanism acts as a repository of personal meanings shaped through reflection. Learning in context to Experiential supports reflection and meaning-making from experience. Learning as per Transformative reframes the past experiences in light of new insights. And learning in context to Connectivism is externalised and distributed across the digital systems.

Knowledge transfer as per Behaviorism occurs when conditioned behaviours are applied in similar contexts in which they were originally acquired, whereas, in Cognitivism, knowledge transfer occurs through applying the cognitive schemas to new contexts. In Constructivism, the knowledge transfer occurs through actual tasks that require real-world application, while in Humanism, knowledge transfer occurs when learning aligns with personal values and goals. In Experiential learning, applying insights from experience to new situations leads to knowledge transfer while in Transformative learning, when learners apply new perspectives to transform behaviour, the learning occurs. And in Connectivism, learning happens when learners build and access connections across platforms.

Learning is best applied in rote memorization and skill development through consistent repetition in Behaviorism. Cognitivism is better applied in problem-solving, conceptual understanding and instructional design. Constructivism is best applied towards inquiry-based learning, project-based and interdisciplinary work. Humanism is best applied in counseling, adult education and value-centered pedagogy. Experiential learning is best applied in studio-based education, internships and fieldwork. Transformative learning is best applied in social justice education, leadership and personal transformation. Connectivism is best applied in online learning, digital literacy and knowledge work in networked environments.

Learning theories offer distinct yet complementary perspectives on how individuals acquire, process and apply knowledge. Behaviorism focuses on observable behaviours, which can be reinforced with repetition (Skinner, 1953). Cognitivism emphasizes internal mental processes and structured knowledge organization (Anderson, 2010), while constructivism highlights the active construction of understanding through experience and social interaction (Vygotsky, 1978; Piaget, 1952). Humanism learning theory centers on personal growth and intrinsic motivation, viewing learning as a pathway to self-actualization (Maslow, 1970; Rogers, 1969). Experiential learning focusses on the cyclical process of learning through direct experience and reflection (Kolb, 1984), whereas transformative learning involves deep shifts in perspective through critical self-examination (Mezirow, 1991). And connectivism addresses learning in the digital age, where knowledge is distributed across networks and accessed through technological and social connections (Siemens, 2005). Together, the learning theories provide a strong foundation for designing diverse and effective learning environments.

Discussion

The process of learning has long been a central focus for philosophers and educators and remains relevant today (Edgar, 2012). Socio-cultural learning theories emphasize that learning is inherently social and shaped by cultural contexts (Bowen et al., 2020). Understanding adult learning theories is key to developing effective educational strategies, informing instructional design, curriculum development and educational planning (Yanchar et al, 2010; Quratulain, 2021). Research supports that aligning curricula with appropriate learning theories improves program effectiveness and help achieve desired learning outcomes (Khalil et al., 2016; Budiningsih et al., 2019; Shrivastava & Shrivastava, 2017).

“The interest in learning theories for creative problem-solving in design education is increasing yet the existing literature remains fragmented, encompassing a wide range of theoretical perspectives, research methods and educational settings” (Berberoğlu & Unal, 2024). Reflection plays a vital role in design education, fostering intentional, rigorous and inclusive creativity and needs further studies to develop detailed academic processes to use learning theories as better tools to integrate history and other aspects into design.

However, a paradox exists between contemporary architectural education, which often emphasizes fragmentation and architectural practice, which demands integration. This raises practical questions about whether the design studio truly provides accessible, comprehensive knowledge central to architectural practice (Berberoğlu & Unal, 2024).

Integrating the development of a personal design philosophy into undergraduate design education encourages continuous reflection and self-awareness. This process can be both visual & textual. A constructivist learning approach, combining studio-based learning with technology, can enhance this process by enabling students to actively construct knowledge. Understanding the historical evolution of educational theories further enriches this learning, offering insight into both past practices and future directions (Dalton, 2017; Keane 2014; Budd, 2011; Edgar, 2012).

After a comprehensive study of the various learning theories prevalent in today’s times, it is quite evident that all the theories address particular aspects of a very complex process called ‘learning’. And these theories also seem to be having an impact on specialised subjects and their learning, or various parts of the subjects. In light of the information, it can be easily said that no theory in isolation can address the complexity of modern learning needs. Each theory could be interpreted as a specialized tool with its help learning can be better understood, designed and facilitated.

Interpretation of Key Findings

“Learners must be engaged in the process of learning through understanding the relevance of information” (Edgar, 2012). Learning theories can serve as a foundation for integrating the key areas of expertise that teachers need to develop to support the success of the students (Darling-Hammond & Bransford, 2005). “Understanding the learning process is a complex undertaking. We must understand that not one theory or belief is the cure in education today. All learners are different, and that individualized instruction and education facilitate learning” (Edgar, 2012).

The learning theories provide us with complementary perspectives that can help support to formulation of strong pedagogical foundations. Architecture education combines multiple disciplines and relies on hands-on learning. To be effective, it must go beyond the technical training to nurture conceptual thinking, ethical responsibility and creative problem solving. Such a holistic approach works to prepare students towards handling building design alongside thinking critically, innovating responsibly and engaging meaningfully with the real world challenges. Keeping in view such a variety of aspects of learning involved a comprehensive mix of various learning theories bound primarily by constructivism, could produce better results.

Table 2. Comparative Analysis of Learning Theories in Architecture Education (source: Authors).

S.No.	Theory	Basic Assumptions/ Principles	Application to Architectural Design Instruction
1.	Behaviorism	-Learning is a change in observable behaviour -Reinforcement strengthens learning	-Use design drills, repetition, and practice -Implement feedback loops (peer critiques, quizzes) to reinforce positive behaviour
2.	Cognitivism	-Learning involves mental processes -Prior knowledge impacts new learning	-Scaffold design concepts using prior knowledge -Assign design problems to cognitive engagement
3.	Constructivism	-Learners build knowledge from experiences Learning is contextual and active	-Project-based and studio learning -Encourage collaborative design and critique sessions
4.	Humanism	-Learning is student-centered -Focus on self-actualization and personal growth	-Allow for self-directed design projects -Promote personal reflection and expression in design
5.	Experiential	-Learning occurs through experience and reflection -Doing+Reflecting= Knowledge	-Organize site visits, real-world design problems -Encourage reflective journals, design reviews
6.	Transformative	-Learning changes one's worldview -Critical reflection leads to information	-Use critical debates on design ethics and social impacts -Facilitate re-evaluation of traditional design paradigms
7.	Connectivism	-Learning is network-based -Knowing where to find information is the key	-Encourage digital collaboration tools -Foster global design communities and industry connections

Behaviorism sees learning as a change in observable behaviour and supports learning through repetition, practice and reinforcing positive behaviour (Skinner, 1953). For eg, reinforcing the climate responsiveness of built forms through positive feedback. Cognitivism shifts the focus to internal mental processes, aiding in the development of conceptual understanding and problem-solving strategies essential for analytical design thinking (Anderson, 2010). Constructivism, through the works of Piaget and Vygotsky, underscores active knowledge construction through experience and social interaction, aligning well with the iterative and collaborative nature of design studio pedagogy (Piaget, 1952; Vygotsky, 1978). Humanistic learning theory adds a personal and ethical dimension, encouraging self-directed learning, empathy, and value-driven design approaches (Rogers, 1969; Maslow, 1970). Kolb's experiential learning model reinforces the centrality of real-world engagement through site visits, internships, and project-based studios, as a cyclical process involving experience, reflection, conceptualization, and experimentation (Kolb, 1984). Transformative learning theory works through critical reflection and change in one's worldview by facilitating re-evaluation of traditional design paradigms and use of critical reflection towards design ethics and social impact (Mezirow, 1991). Connectivism works on the principle of learning being network-based and encouraging digital collaboration tools and fostering global design communities (Siemens, 2005).

Table 3. Application of Learning Theories towards History integration in Design (source: Authors).

S.No.	Learning Theory	Application for History Integration	Instructional examples
1.	Behaviorism	Repetition and reinforcement helps students to memorize historical elements, terminology and chronological information.	Using quizzes, flashcards, drawings, models, and exercises to reinforce different elements and scales & proportion.
2.	Cognitivism	Helps students organize historical knowledge in mental schemas of typology, periods, etc.	Concept mapping of historical typologies in context to contemporary design tasks, analysis of precedent studies.
3.	Constructivism	Students construct understanding of history by engaging with it in the context of their own design processes.	Reinterpreting historical building typologies and spatial planning, reinterpreting the old into contemporary spaces.

4.	Humanism	Encourages students to connect emotionally and ethically with historical narratives.	Design projects responding to local heritage and/ or marginalized historical narratives.
5.	Experiential Learning	Allows learning through direct interaction with historical environments and culture.	Site visits to heritage sites, preparing measured drawings of historic places, reconstructing spatial configurations through models.
6.	Transformative	Critical reflection on architectural history fosters shift in worldview (colonialism, gendered histories)	Addressing projects with postcolonial narratives, reinterpreting suppressed historical voices.
7.	Connectivism	Digital tools link students to global archives, digital reconstructions and historic databases.	Use of online platforms (Google arts & culture, Artstor, museum websites, history recreators, GIS for historic cities, etc) for understanding & reinterpreting history.

Behaviorism supports foundational knowledge acquisition through repetition and reinforcement, making it effective for memorizing key historical facts, styles, and architectural movements (Skinner, 1953). Cognitivism enables learners to structure and internalize complex historical narratives, encouraging the analysis of spatial, cultural, and chronological patterns in architectural development (Anderson, 2010). Through constructivism, students engage in the active construction of meaning by relating historical knowledge to current design contexts, thereby fostering interpretive and contextual thinking in studio projects (Vygotsky, 1978; Piaget, 1952). Humanistic approaches promote an empathetic and values-based engagement with history, helping learners connect emotionally and ethically with past societies and ideologies, which is particularly important when designing in heritage-sensitive environments (Maslow, 1970; Rogers, 1969). Experiential learning is supported through the site visits to heritage sites, observing, measuring and preparing measured drawings of the historic places. Alongside reconstructing spatial configurations through making models provides hands-on learning experiences, which can be further integrated in design through reflection and learning of structure, space, materials, among others (Kolb, 1984). Transformative learning theory supports critical reflection on architectural history and helps foster a shift in worldview, for eg, post-colonial constructs, gendered histories, etc., by addressing the projects through the reinterpreting of the suppressed historical voices (Mezirow, 1991). Connectivism promulgates the use of digital tools to connect students to global archives, historic databases and digital reconstruction platforms through the use of online platforms for understanding & reinterpreting history (Siemens, 2005).

The relevance of Constructivism

Constructivist learning theory is highly relevant to architecture education as it emphasizes active, experiential learning, which aligns with the hands-on nature of architectural practice. By engaging the students in real-world design challenges, constructivism fosters deeper understanding and critical thinking (Vygotsky, 1978). Powers (2019) discusses how constructivist pedagogy in the design studio encourages active student participation, fostering a deeper engagement with architectural concepts. Andjomshoaa et al. (2011) highlight that the constructivist methods, such as 3D modelling and collaborative learning, facilitate the acquisition of tacit knowledge and improve pedagogical efficacy in architectural design education. The existing studies underscore the effectiveness of constructivist approaches in cultivating the skills necessary for future architects.

Research supports the application of constructivism in architecture education, demonstrating that constructivist approaches enhance creativity, collaboration and problem-solving skills among students. The focus on context-rich and active learning experiences, in the theory of Constructivism, makes it a valuable framework for architecture education, preparing students to navigate the complexities of the built environment.

How does Constructivism aid the Integration of History in Architecture Education?

Constructivism has significantly transformed architectural education by shifting from traditional, teacher-centered methods to more interactive and student-centered approaches. This shift also emphasizes active learning, where students engage in constructing their own understanding through experiences and reflection. In architecture design studios, this approach helps foster creativity and critical thinking by encouraging students to actively participate in every stage of the learning process (Ceylan et al., 2010). Research indicates that constructivist pedagogies lead to improved design performance by promoting tacit knowledge acquisition, which is crucial for architectural practice. Students exposed to constructivist methods showed significant improvements in their design processes compared to those taught through the traditional approaches (Andjomshoaa et al., 2011). The constructivist approach emphasizes critical thinking and contextual learning, encouraging students to move beyond fixed solutions towards actively engaging with the spatial, cultural and functional complexities of architecture (Salama, 2015).

The integration of constructivist theory into architecture education would foster a more dynamic and effective learning environment, enhancing students' creative thinking skills and better preparing them for the complexities of the real-world architectural practice. Constructivism is a learning theory that bridges theory and practice, emphasizing that knowledge is not fixed but rather evolving, socially and culturally influenced, and inherently subjective. It views the learner as an active thinker, creator, and builder of understanding (Brooks and Brooks, 1993). Research supports the effectiveness of constructivist methods in the architectural design and history integration. Gatt (2003) underscores that constructivist approaches such as, scaffolding and inquiry-based learning, enhance student's historical thinking skills and promote a more comprehensive understanding of architectural heritage.

Conclusion

Constructivist classroom environments prioritize active, inquiry-based learning where students investigate issues directly rather than relying solely on textbooks. The design studio setting encourages collaboration, discussion and critical thinking, valuing students for their reasoning and problem-solving abilities. A key component is understanding learners' preconceptions and how they incorporate new experiences into their existing knowledge frameworks (Resnick, 1995; Adams, 1996).

"Responsibility in the learning process should be shared and negotiated amongst teachers and learners" (Powers, 2019). A rich studio environment, with diverse informational sources and representations, supports reflection on prior knowledge. The studio is a natural setting for constructivist learning, given the unpredictable and exploratory nature of design. Incorporating constructivist principles in the studio-based education is bound to enhance the credibility of current teaching methods and to deepen the learning & knowledge construction.

Even though all the learning theories play some or the other positive role towards learning in architecture design, Constructivism is highly relevant to integrating architectural history in architecture design education, as it emphasizes active learning, students get to immerse in thinking and discussing historical examples and their relevance. Constructivism also supports experience sharing and collaborative learning that aligns with the nature of architectural practice. By engaging students in hands-on activities, group projects and critical reflection, constructivist approaches deepen the understanding of design principles in historical contexts. Integrating constructivist methods in design studios helps students to build both theoretical understanding and practical skills, making it a highly effective educational approach in architecture education. The research supports the importance of constructivism in creating dynamic, engaging, and innovative learning environments in architecture education in the context of the integration of history with architectural design.

Limitations of the Study

While the study provides a comprehensive review, it is limited by its reliance on primarily secondary sources and English-language sources, highlighting the impact of valuable global or Western perspectives in the context of architectural history and pedagogy. Also, the subjective character of theoretical analyses has certain limitations.

Recommendations for Future Research

- Further studies in the context of the human learning process can further enhance the application of learning theories in the integration of various subjects with their historical relevance, especially focusing on academia in architecture education.
- An in-depth discussion about the extent to which learning theories could and should be manifested in the design paradigm is required, which may lead to better instruction strategies, making learning more effective & enriched.
- The role of learning theories in guiding curriculum design and educational planning could be further delved into.
- Incorporating the 'Theories of Change' as suggested by John Mayne could help delve deeper into the approach of 'learning theories in architecture education', especially in the context of history integration in the design studio.
- Practical experience is invaluable, but lacks an overarching framework to help organize knowledge, or systematically understand and improve the teaching and learning process. Theory and practice help reform each other to enhance learning. Delving deeper into the nuances of academics & practice in the context of learning theories & learning from history would be insightful.
- Another avenue for further research lies in instructor training. Although existing studies emphasize the crucial role educators play in fostering reflective learning environments, there is limited exploration of how teachers acquire the skills, knowledge and attitude required to effectively guide the learning processes.

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Conflict of Interests
The author(s) declare(s) no conflict of interest.

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Chapter 4

Traces of Local Identity in High Rise Building façades in Manama, Kingdom of Bahrain

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Introduction

Manama's skyline has undergone rapid evolution in the past two decades, marked by the formation of high-rise buildings. This notable change results from a confluence of factors, including globalisation, rapid urban growth, and the liberalisation of real estate markets (Wiedmann, 2013), leading to a new era of architectural ambition and economic development. Almoayyed Tower, the first skyscraper built in 2004, was later surpassed by the Bahrain World Trade Centre (BWTC), which integrates large-scale wind turbines, symbolising the nation's commitment to sustainable development and technological innovation. The emergence of the fully glazed façades has elevated the city's image to new design directions, dramatically reshaping Manama's skyline and significantly departing from the predominantly low-rise, traditional structures (Ahmed, 2021). Although it is comparatively less aggressive than other Gulf cities, such as the Emirate of Dubai, the impact of modernisation on vernacular and traditional architecture has been significant and irreversible (Dayaratne, n.d.).

While these glass-clad skyscrapers have become potent symbols of modernity and economic prosperity, they also present challenges in creating culturally resonant spaces (Elkadi, 2006).

This architectural disconnect stems from a complex interplay of factors. First, globalization has played a significant role, encouraging the adoption of international design trends, often imported from Europe and the United States, which has led to a diverse array of building façades that, while visually striking, may lack a strong connection to the local cultural and environmental context (Abdel-Aziz & Shuqair, 2014; Assali, 2017; Salman, 2019). Second, technological advancement has led to the identical production of high-rise buildings (Faragallah, 2024). In other words, the uniformity in building designs led to a loss of local identity and a disconnect from the surrounding environment. Faragallah (2024) illustrates how high-rise buildings in the Arab region, which are recognised as significant energy consumers, often lack environmental considerations. Although attention has been given to addressing pressing ecological concerns, particularly in light of climate change, it has sometimes overshadowed considerations of cultural continuity in architectural design (Moscatelli, 2023). Therefore, new high-rise buildings are questioned about their implementation to withstand Bahrain's climate and to adapt to its cultural context.

Façades play a pivotal role in creating the identity of a place (Baper, 2024) by acting as cultural storytellers, environmental mediators, and visual anchors. Indeed, high-rise façades would be more potent in doing so due to their broader visual impact on communities. Coupled with Gaber et al.'s (2022) allegation that human minds communicate primarily with the visual character of buildings, recalling their images, not names. The buildings must represent an "emotional state" or a firm belief, or the building itself must be a great event and symbol that the people of the city or country relate to and be a reference for them to be proud of, to visualise memories strongly. Accordingly, Moscatelli (2023) asserts that the formal and plastic character of façades should evoke emotional cues referencing cultural values to secure their continuity. A "continuity of memory," as referred to by AbuOrf & Wafi (2020), that extends beyond merely copying traditional design vocabulary neither ""falsifying history" in search for identity that translates traditional values into "meanings, inspiration, and emotional rooting," targeting the present and aspiring to the future.

Undeniably, recently, the current high-rise façades are far from representing these values. Instead, the international design approach adopted led to the loss of cultural distinctiveness, resulting in identical solutions regardless of their locations. Although critical regionalism has gained traction since Frampton (n.d.) called for the

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architecture of resistance that respects local culture, geography, and climate as a response to globalization's homogenizing effects, the fears of erasing regional architectural distinctiveness are transcending in parallel to the continuous adoption of global styles, leaving a widened gap between past and present. In Bahrain, particularly in Manama, a few notable buildings reflect the local identity, whereas many do not. The challenge here, and indeed for many rapidly developing cities, lies in striking a balance between embracing architectural innovation and maintaining a sense of place that reflects local heritage and values, a key concern of critical regionalism.

Based on this context, this study aims to examine the current design trends in high-rise building façades in Manama, focusing on the integration of innovative technologies and sustainable practices that contribute to the development of a local identity. Thus, the primary study question is: to what extent do those façades mediate the balance between local identity, innovation, and sustainability? To answer this question, it is first necessary to establish a theoretical framework that can assess local identity parameters in architectural designs. Then, the permanency of identity will be evaluated, as apparent in selected case studies from Manama's iconic structures. This analytical study is supported by a questionnaire directed to design experts to address their insights. Lastly, the goal is to synthesise actionable insights for culturally grounded sustainable design. A comparative evaluation of how other Gulf cities balance modernity with cultural heritage situates the study within broader architectural dialogues, strengthening its contributions to sustainable urban development.

In the study's conclusion, Manama's architectural transformation reflects the broader challenges that many cities face in the era of globalisation. While the emergence of high-rise clusters and iconic buildings has reshaped the city's skyline, it has also sparked meaningful discussions about cultural identity, sustainability, and the role of architecture in shaping urban experiences. As Manama continues to develop, the principles of critical regionalism, tempered by an understanding of the fluid nature of cultural identity, may offer a path towards creating a built environment that is both globally competitive and locally meaningful. The following section discusses the main definitions, theoretical frameworks, critiques, and existing empirical models for measuring identity. This is followed by an explanation of the adopted methodology and an analysis of the methods used. The final sections present the main findings of this study, which suggest a framework for reflecting local identity in sustainable architectural façades.

Identity

The term identity, as defined in the Oxford Learner's Dictionary, encompasses an individual's or entity's intrinsic characteristics and distinguishing feelings, beliefs, or attributes that differentiate them (Oxford University Press, 2025). Nevertheless, Salman (2019) extends this definition to include collective identities ranging from a group of people to a society, a country, or even a nation. Moreover, Garg & Mahima (2020) attribute identity distinction to social behaviour, cultural practices, local traditions, political aspects, the history of a place, religious identity, or essential landmarks. In architectural discourse, Kumaraku & Pula (2023) delineated two dimensions of identity. First, objective identity refers to the internal characteristics of the building, which are rooted in its material character. Secondly, a subjective identity is linked to external conditions and is determined by the building's interpretation. The latter dimension aligns with Leach's (2003) assertion that identity is a fluid and multifaceted concept, a view supported by many scholars. For example, Mahgoub's (2007) study on architecture and the expression of cultural identity in Kuwait interviewed eighteen Kuwaiti architects, who unanimously linked identity to climate, region, and culture, with some also including religion. Conversely, they held discordant views about architectural identity expressions, which range from the identical replication of traditional elements to symbolic and metaphorical reinterpretations that suit contemporary needs. Whereas Dayaratne (2016) believes that the non-static, multifaceted nature of identity suggests it is developed by more than just the revitalisation of the vernacular, but rather that the vernacular offers a veneer of that identity, which is rooted in the past and can be projected into the future. Similarly, Salman (2019) views vernacular architecture as a medium that symbolises identity, mirroring a nation's place, time, and culture.

Moreover, Adebayo et al. (2013) argue that identity is established fundamentally by considering the cultural aspects and historical context of a person, group, or region. In this view, local identity is not an inherent or static attribute; instead, it is constructed through the dynamic interplay of cultural practices, values, and collective memory. Salman (2019) and Shao (2014) similarly emphasise that culture is central to forming and expressing local identity. Masri et al. (2024) call for integrating heritage into urban development to ensure that cultural identity is at the essence of shaping evolving cities. This perspective aligns with Garg & Mahima (2020), who contend that architecture is not merely a passive reflection of culture but an active agent in its evolution and redefinition. Thus, culture comes to the fore whenever the concept of identity is discussed.

Architecture serves as a powerful medium for cultural expression and transmission, which is necessary for constructing identity (Adebayo et al., 2013; Al-Hoshary & Hamza, 2023; Masri et al., 2024). It translates intangible cultural values, traditions, and historical narratives into tangible forms—buildings and urban spaces— that reflect and shape urban identities. As Rapaport (1977) and Assali (2017) noted, architecture bridges the gap between the abstract dimension of cultural identity and the concrete realities of the built environment, addressing both aesthetic preferences and functional requirements.

The expression of cultural identity in architecture is inherently varied (Figure 1). As posited by Neil Leach, the fluid nature of cultural identity in an increasingly globalised world challenges the notion of a fixed local identity that can be easily preserved or expressed through architecture. Some architects draw inspiration from historical styles and vernacular techniques, viewing cultural identity as rooted in the past and embodied in traditional forms and materials. In contrast, others prioritise contemporary values and future aspirations, creating modern designs that reflect the evolving cultural values and ambitions of their time (Mahgoub, 2007). This duality is evident in the blending of traditional and contemporary elements, which acknowledges both historical roots and future directions (Garg & Mahima, 2020). Such synthesis is crucial for creating architecture that resonates with local cultures while remaining relevant in a rapidly changing world.

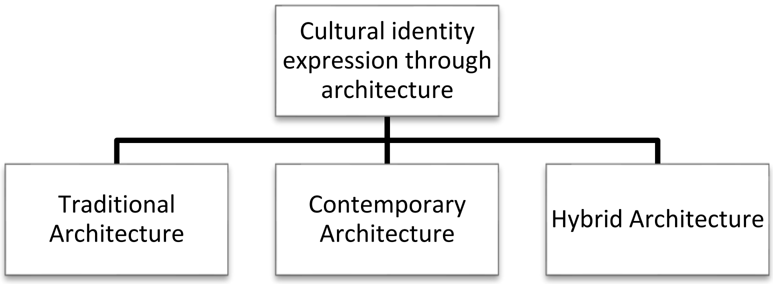

Figure 1. Cultural Identity Representation Approaches (Developed by the Authors).

Critical regionalism offers a theoretical framework that advocates for a balance between global modernist principles and the preservation of local cultural and geographical contexts (Abuorf & Wafi, 2020; Norouzi & Khademi, 2021). It seeks to resist the homogenising effects of globalisation by grounding architectural practice in the specificities of place—climate, topography, local materials, and cultural traditions—while embracing technological advancements. Abuorf & Wafi (2020) and Norouzi & Khademi (2021) highlight that critical regionalism advocates for an architecture that is both modern and contextually grounded, fostering a sense of place and belonging.

Nevertheless, critical regionalism is not without its challenges. Eggener (2002) critiques the approach for its potential to marginalise the diversity it seeks to champion, particularly in rapidly developing cities like Manama. Critical regionalism remains a valuable lens for addressing contemporary architectural challenges despite these critiques. Considering geographical factors such as climate, light, topography, and local tectonic forms can provide a means to maintain regional identity while embracing modern architectural innovations (Norouzi & Khademi, 2021). The Bahrain World Trade Centre exemplifies this approach, integrating wind turbines that respond to local environmental conditions within a contemporary architectural framework. Such projects demonstrate how architecture can mediate between tradition and modernity, ensuring that urban environments remain meaningful, sustainable, and culturally vibrant.

The manifestation of cultural identity in architecture has gained traction as a critical response to the modernisation processes that prioritise Western architectural paradigms, often at the expense of local cultural identity (Moscatelli, 2022). Therefore, various theoretical frameworks have been proposed to understand and measure local identity, each offering unique perspectives and methodologies.

Recently, Baper's (2024) model addresses the lack of comprehensive metrics measuring architectural identity by focusing on façade characteristics as cultural signifiers and proposing a new model that includes three key pillars: mental image (collective perceptions of place), originality (distinctiveness from globalized norms), and building regulations (institutional influences on forms) as the main identity-influencing parameters. In contrast, Shao (2014) adopts a holistic approach, framing local identity through four interactive aspects: physical (materiality and geometry), social (communal practices), sensory (emotional engagement), and memory (historical continuity). This model emphasises the interaction between humans and their environment, bridging between concepts of cultural identity, place identity, personal identity, and community identity.

On a larger scale, Oktay (2006) links urban identity with sustainability, focusing on the integration of natural, social, and built elements. Urban spaces reveal their character through their architecture. Thus, architecture emerges as the most influential visual element, evoking sensory experiences that reinforce identity. Meanwhile, Kumaraku & Pula (2023) decipher architectural identity based on three defining plans: formal (spatial organisation), stylistic or linguistic (aesthetic language), and technological (construction methods). The construction methods as identity markers were absent in Moscatelli's (2023) and Shao's (2014) models. Instead, Moscatelli (2023) acknowledges the ability of formal and plastic characters to transmit cultural values. Thus, she identifies four criteria for cultural transmission through forms: compositional aspects (spatial hierarchy), plastic figuration (sculptural quality), expressive value (symbolism), and context connection (site responsiveness). While both Kumaraku and Pula (2023) and Shao (2014) emphasise materiality and geometry as identity carriers, they reject superficial stylistic limitations, advocating for a deeper cultural resonance.

Finally, the fluidity of identity possesses measurement challenges that arise from its contextual and temporal qualities (Adebayo et al., 2013). To address this, a new model grounded in critical regionalism is conceptualised to provide a roadmap for architects to design high-rise buildings that are visually distinctive, temporally resilient, and culturally vibrant.

Table 1. Classification of Identity measure models according to their focus, design parameter, and limitation (Developed by the Authors).

Model/ framework	Focus	Parameters/ dimensions	Limitation
Shao (2014)	Local identity Emergent from lived experiences (ideological) Shaping the urban identity	Physical Social Sensory Memory	• Although environmental aspects are touched on through the physical dimension (architecture, natural elements, and landscape), there is less emphasis on how environmental sustainability or ecological practices help define local identity. • Local identity could also be influenced by political factors or governance structures, such as how city policies, planning decisions, or community initiatives contribute to a sense of belonging.
Baper (2024)	Evaluative Approach Façade Identity Fostering innovations, compliance	Originality, Building regulation, mental images	• Lack of an analytical breakdown of architectural components • By concentrating on originality and visual impact, the model might insufficiently address the rich contextual influences conveyed by cultural or regional factors.
Moscatelli (2023)	Architectural identity	Compositive aspects, Plastic figurations Expressive value, Context connection	•
(Kumaraku & Pula, 2023)	Descriptive approach, Representative identity Internal qualities vs Externally imposed phenomenological	Formal Stylistic Technological dissection	• By viewing identity through multiple rather than prioritised lenses, comparisons between buildings may become more subjective when one aspect is more critical than another.
(Oktay, 2005)	Cultural sustainability	Physical, social, cultural, ecological, and temporal	• The economic and functional aspects of city life also contribute significantly to identity. • The evolution of local economies, the balance between tourism and local trade, and the functionality of urban spaces (that host a mix of uses) all influence how a city is experienced and remembered.

Local Identity Parameters for High-rise Buildings' Façades

Context is a perspective that shapes architectural design, encompassing the historical, social, cultural, and physical aspects of an architectural identity (Baper, 2024). Therefore, to identify local identity parameters for high-rise buildings from a critical regionalism lens, it is imperative to incorporate both contemporary innovations and a region's unique, context-specific attributes. The following is a theoretical framework and explication that synthesises key parameters from identity studies and critical regionalism theory.

Contextual integration

Context in architecture refers to the interconnected physical, cultural, social, and environmental conditions that shape how a building is designed and perceived within its surroundings. It encompasses both tangible and intangible elements.

a. Physical Context: Natural Elements and Built Environment: Site response, orientation, passive environmental considerations, and views and vistas.
b. Cultural Context: Heritage expressions
   - Metaphoric Forms: Metaphorically employing shapes or features that relate to local culture or landscape. It enhances the building's more profound meaning to be successful. It allows the viewer to draw their symbols and interpretations on it, where people repeatedly try to stand in front of these architectural masterpieces to uncover their moral and symbolic connotations. (Gaber et al., 2022)

- Symbolism: Distinctive Skyline Presence: Creating a unique, recognisable silhouette that contributes to city identity
- Meaning and Narrative: Having a story about the building is one of the reasons for its iconicity, as it creates a sense of mystery and sparks people's passion to talk about, visit, and take memorial photos next to it. The more stories and legends that are told about the building's history, the more people become attached to it, and the building becomes classified as an icon from their perspective.

c. Social Context
- Pedestrian Experience: Prioritising human-scale interactions at the street level
- Base-Middle-Top Articulation: Differentiating building zones to address both street-level and skyline presence

Innovation

Using modern construction techniques, Technological innovations in high-rise buildings can manifest in various areas, including geometric form, construction, materials, vibration-damping systems, and energy efficiency. The development of computer technology has facilitated the design of high-rise buildings with complex structural and functional solutions. Increased computing power has enabled the development of more advanced engineering programs, which better simulate the actual behaviour of a structure when building models (Szolomicki & Golasz-Szolomicka, 2019). Remarkably, technological advancements have paved the way for adopting international styles in Arab regions. However, modern technologies should consolidate the continuity of architectural identity on building façades. (Assali, 2017).

Materials and Methods

This study employs a qualitative approach to analyse the manifestation of local identity in the façades of high-rise buildings in Manama, Bahrain. Theoretical grounding has laid the foundation for the analytical study of selective high-rise buildings in Manama by constructing an identity parameter model to evaluate the reflection of identity in these case studies. In parallel, a web-based questionnaire was conducted to gain deeper insights from the viewpoints of architects and stakeholders regarding their perspectives on trends in high-rise buildings in Bahrain. The survey consisted of a self-administered questionnaire featuring a mix of multiple-choice questions, Likert scale questions, and open-ended questions formatted in Google Forms and disseminated to a group of experts in the field of architecture. Finally, a comparative analysis with similar Gulf-region cities was done to enhance the study's validity. (Figure 2)

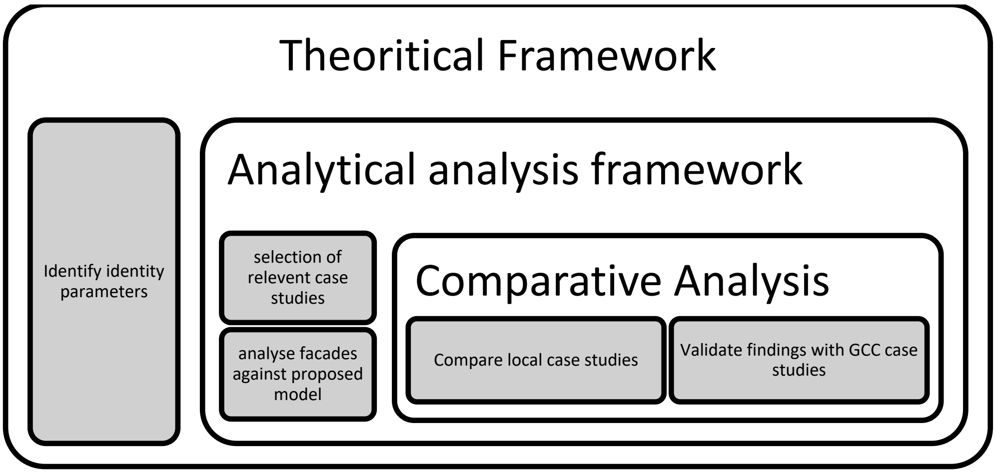

Figure 2. The methodology adopted in the study (Developed by the Authors).

Figure 3. The Case studies are localised in the city (Developed by the Authors).

Case Study

The case study selection criteria were based on location, technological advancement, temporal and typological range, and design strategies.

- Location: The Bahrain Financial Harbour to souq axis has been symbolically perceived as the axis of evolution of Bahrain as a nation, as it rhythmically connects the many nuanced approaches that extend from historicism to globalisation (Masri et al., 2024). Due to this critical reference, the selected projects were located within 3.5 km of it and had distinct temporal and typological ranges, addressing various design influences over that period. (Figure 3)
- Temporal Range: The selection of buildings encompasses a variety of completion dates, ranging from the 1980s to 2025.
- Typological Range: Commercial and Mixed-Use Buildings
- Design Strategies: Pragmatic, iconic, analogical, canonic, symbolic, and metaphoric.

Visual survey

The aim is to document notable high-rise buildings with more than 15 floors, within the selected predefined location (Figure 3) and classify them in a matrix to finalise the selection of case studies: Table 3, Table 4.

The Council on Tall Buildings and Urban Habitat (CTBUH) established international standards for measuring and defining tall buildings, which can be summarised as the relationship between height and context, proportion, and the integration of relevant technologies in tall buildings (*Tall Building Criteria*, 2025).

The United Gulf Bank has 12 floors, yet it was selected due to its historical significance.

Table 3. Visual Documentation of the Evolution of High-rise Buildings in Manama, Bahrain

	Residential	Commercial	Mixed Use
1980		 United Gulf Bank	

1988		 National Bank of Bahrain	
2004		 Almoayed Tower	
2005		 Alzamil Tower	
2008		 Bahrain Financial Harbor	 BWTC
2015		 Four Seasons Hotel	
2016			 Amfa Tower 2
2019	 Amfa Tower	 Sayacorp Tower	
2021		 GrandSwiss BelHotel waterfront	 Harbour Heights

2024	 Onyx Towers		

Table 4: List of Selected Case Studies (Developed by Authors)

	Building Name	Architect	Year	Typology	Design Strategy	Floors No
1	United Gulf Bank	Skidmore, Owings & Merrill LLP (SOM)	1980	Commercial	Canonic	12
2	Alzamil Tower	Gulf House Engineering	2005	Commercial	Symbolic	
3	Bahrain World Trade Centre (BWTC)	Atkins	2008	Commercial with mixed use	Iconic	50
4	Four Seasons	Skidmore, Owings & Merrill LLP (SOM)	2015	Hotel	Iconic	68

Questionnaire Design

A well-designed questionnaire ensures a reliable and accurate data collection. This questionnaire is designed to validate the discussion and avoid any bias. First, it gathers demographic information such as Nationality, Residency Status, Profession and Years of experience. Second, seven open-ended questions are presented in proper flow to address the interviewees' perspectives regarding the status of existing buildings, opportunities and challenges, and the role of technology in manifesting local identity.

A total of 33 participants responded to the web-based questionnaire, most of whom were Bahraini residents with diverse design backgrounds. Notably, more than 48% of respondents had over 15 years of professional experience in the field, lending significant expertise to the survey results. (Figure 4)

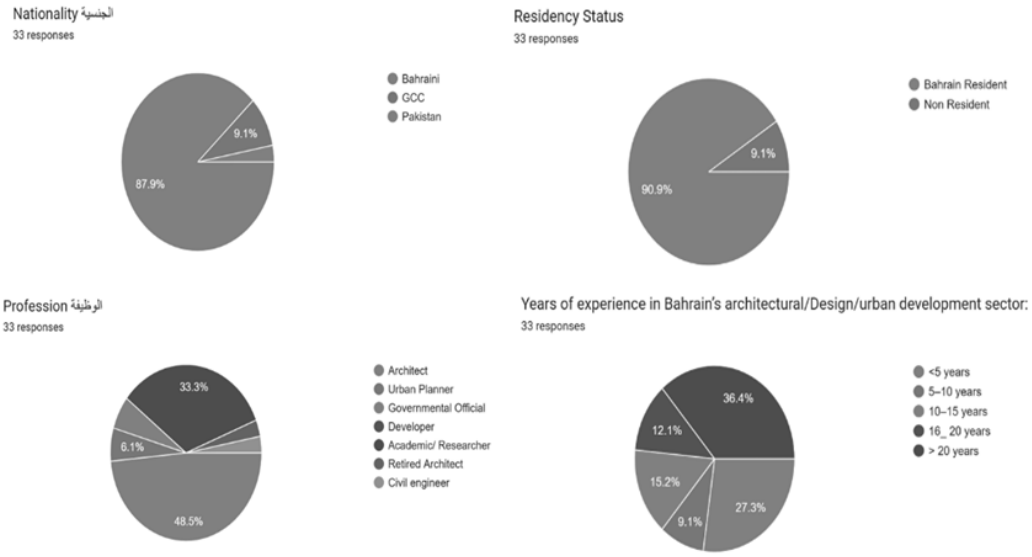

Figure 4. Participant Demographic Information.

Results and discussions

Traces of Local identity in the Selected case Studies

a. Gulf United Bank

i. Contextual Integration:

Cultural Symbolism: Curved façade inspired by Bahrain's traditional fishing boats (dhows), with green glass fins mimicking the Persian Gulf's emerald waters. Arabesque glass-block terraces and atrium reinterpret Islamic geometric patterns in modernist forms. Climate Response: Deep-set windows and pre-cast concrete lattices reference vernacular heat-resistant walls, while transoms filter harsh sunlight. Urban Harmony: 12-story scale respects Manama's low-rise 1980s skyline, with a shaded arcade blending into the pedestrian streetscape.

ii. **Innovation:**

As for its time, Pre-cast concrete exterior incorporates deep-set windows and green glass fins to mitigate solar heat, referencing both local architectural sunscreens and the Gulf's emerald waters.

b. **Alzamil Tower:** A striking example of contemporary architecture that blends traditional Bahraini motifs with modern design. Won the **Aga Khan Award for Architecture (2007)** for its successful synthesis of heritage and innovation (Gulf House Engineering, 2021)

i. **Contextual Integration:**

The architectural concept dwells on the theme of the new emerging from the old," says Yasser Yacoub, manager of the engineering department at Gulf House Engineering. "To convey this theme, the towers feature granite skirting at the base which blends into natural stone cladding at the lower levels, incorporating elements of Islamic architecture, and then into modern precast and aluminium and curtain-walling featuring high-performance tinted glass. The taller tower flares outwards towards the top of the concave-shaped building. The other tower tapers in a stepped fashion from the 9th floor." ("Zamil Tower to Be the 'gateway' to Manama," 2002)

Morphological Bridging: The lower floors feature transformed Islamic motifs that respond to the historic fabric of Manama Souq, while the upper tiers adopt a sleek, modern aesthetic.

Urban Gateway: Twin towers linked by an overpass create a symbolic entrance to the souq, blending traffic flow with cultural monumentality.

ii. **Innovation:**

Early example of "hybrid heritage" design in Gulf high-rises, using parametric modelling to abstract traditional patterns.

The structure utilises pre-cast concrete elements and lightweight steel systems for efficiency, while the incorporation of structural glazing enhances both aesthetics and performance.

c. **BWTC**

i. **Contextual Integration:**

Tapered, elliptical profiles act as aerodynamic foils, channelling wind between the towers while evoking the region's sailing culture.

Sail-shaped towers (240m tall) draw inspiration from traditional Arabian wind towers and trading ships, creating a visual link to Bahrain's maritime heritage

Three skybridges with integrated wind turbines form a striking silhouette, symbolising Bahrain's modern economic ambitions

Iconic lighting displays (e.g., National Day celebrations) transform the towers into a shared cultural symbol, raising awareness for social causes

ii. **Innovation:**

World's first integrated wind turbines (29m diameter) generate 11–15% of the building's energy, supported by computational fluid dynamics and wind-tunnel testing.

Double-glazed, gas-filled windows and energy-recovery systems minimise thermal load, aligning with Bahrain's post-oil sustainability goals.

Panoramic elevators and innovative infrastructure (e.g., Otis' high-speed lifts) enhance user experience while showcasing cutting-edge engineering.

d. **Four Seasons Hotel**

i. **Contextual Integration:**

Cultural Metaphor: Sail-shaped towers evoke Bahrain's maritime heritage, with their north-facing orientation funnelling Gulf winds.

ii. **Innovation:**

Two textured concrete piers that support a stack of 17 hotel floors at lower elevations and two restaurant and conferencing floors at the building's summit.

Energy-efficient systems and thermal management in the glass curtain walls mitigate the Gulf's extreme climate.

The case study analysis summarised in Table 2 revealed various traces of cultural representations in high-rise buildings, each reflecting the cultural context of its era and location. However, as you track these developments chronologically, it is evident that the new developments are accelerating towards being completely glass-finished. Despite criticisms about their environmental impact, glass skyscrapers remain popular due to their economic benefits and the sleek, transparent aesthetic they offer. Architects like Ken Shuttleworth have called for a shift away from all-glass buildings, citing concerns about energy efficiency (Astbury, 2025). Studies indicate that glass buildings require excessive air conditioning in the summer and lose heat in the winter. However, the trend of building glass skyscrapers is accelerating because glass curtain walling is an efficient and economical solution, and there is a continued obsession with a sleek, transparent aesthetic. New technologies are emerging to enhance the thermal efficiency of glass, but critics argue that reducing the amount of glass used would be a more effective approach. Therefore, we should take steps to use more contextually appropriate alternatives, reducing the amount of glass and incorporating other materials to better preserve cultural heritage.

Table 2. Case Study Analysis (developed by the Authors)

		Physical	**Cultural**	**Social**	**Technology**
1	**UGB**	Pre-cast Concrete Exterior Wall: References the thick, heat-resistant walls and latticed sunscreens found in local architecture. Solar Orientation and Deeply Recessed Windows Green Glass Fins	Design draws on the rounded form of Bahrain's traditional fishing boats The building's colour scheme alludes to the natural palette of the region: the emerald-green waters of the Persian Gulf and the pale beige sand of the desert Dhow-inspired curves	The three-story arcade at ground level provides shaded pedestrian access, aligning with regional urban traditions of shaded walkways.	Pre-cast concrete exterior incorporates deep-set windows and green glass fins to mitigate solar heat, referencing both local architectural sunscreens and the Gulf's emerald waters.
2	**Alzamil Tower**	Gateway Concept: The tower spans Khalifa Avenue, serving as a symbolic gateway to Manama's historic souq. This design reinforces its role as a transitional landmark between the historic city centre and the modern business districts.	The tower's lower levels incorporate intricate traditional Islamic and Bahraini motifs, responding to the historic context of nearby old buildings, while the upper floors transition into a sleek, modernistic form.	The bridge connecting the two towers over Al Khalifa Road acts as a symbolic gateway to the Manama souq, reinforcing its role as a physical and cultural landmark.	The structure utilises pre-cast concrete elements and lightweight steel systems for efficiency, while the incorporation of structural glazing enhances both aesthetics and performance.
3	**BWTC**	Tapered, elliptical profiles act as aerodynamic foils, channelling wind between the towers while evoking the region's sailing culture.	Sail-shaped towers (240m tall) draw inspiration from traditional Arabian wind towers and trading ships, creating a visual link to Bahrain's maritime heritage. Three skybridges with integrated wind turbines form a striking silhouette, symbolising Bahrain's modern economic ambitions.	Iconic lighting displays (e.g., National Day celebrations) transform the towers into a shared cultural symbol, raising awareness for social causes.	World's first integrated wind turbines (29m diameter) generate 11–15% of the building's energy, supported by computational fluid dynamics and wind-tunnel testing. Double-glazed, gas-filled windows and energy-recovery systems minimise thermal load, aligning with Bahrain's post-oil sustainability goals. Panoramic elevators and innovative infrastructure (e.g., Otis' high-speed lifts) enhance user experience while showcasing cutting-edge engineering.

4	**Four Seasons**	Floor-to-ceiling glazing on the north and south façades provides unparalleled views of the Arabian Gulf and the surrounding Manama skyline.	Dual-tower "H" silhouette: The 201.5-meter twin monoliths, connected by suspended floors, evoke a gateway metaphor, symbolising Bahrain's role as a regional connector. This form avoids literal cultural references but aligns with the nation's trade-centric history through its monumental presence.	The arrival via boats pulling in from the harbour enhances the user experience.	Two textured concrete piers that support a stack of 17 hotel floors at lower elevations and two restaurant and conferencing floors at the building's summit. Energy-efficient systems and thermal management in the glass curtain walls mitigate the Gulf's extreme climate.

Balancing Technology and Local Identity in High-rise Architecture: Scale Matters

The interplay between technology and local identity in high-rise buildings is a nuanced challenge that must be addressed on both the building and urban scale. (Figure 5) indicates a clear consensus among participants regarding avoiding direct replication of traditional architectural features in new high-rise projects. As articulated by respondent 6:

"It is important to emphasise that expressing local architectural identity in high-rise buildings should not rely solely on treating façades with superficial architectural and decorative elements or imitating façade elements from old heritage buildings. Rather, this identity must emanate from the building's correct architectural and functional design as an integrated unit."

Nevertheless, more respondents favoured a hybrid approach, blending traditional elements with modern materials and techniques. Approximately 30 % expressed a preference for a contemporary reinterpretation of cultural symbolism. As respondent 21 noted:

"Preserving local identity is extremely important. However, architecture needs to respond to contemporary times and modern technology, moving forward from a traditional to a more modern reinterpretation. Beit Quran in Bahrain is a good example, as well as several contemporary mosques."

Conversely, a minority argued against the necessity of maintaining local identity in new skyscrapers, emphasising the importance of distinguishing contemporary architecture from the past and highlighting sustainability as a key driver for innovation.

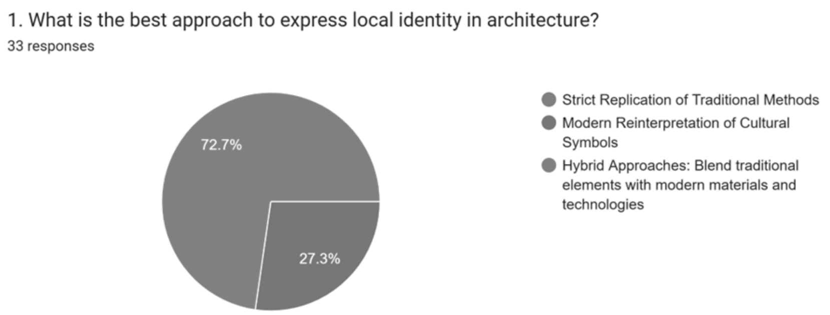

Figure 5. Participants' point of view on expressing local identity.

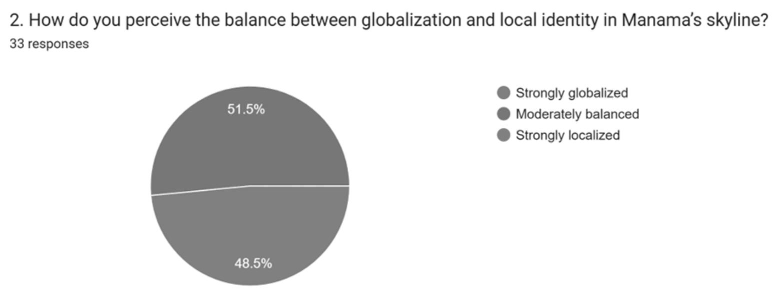

Figure 6. Respondents' perspective on the degree of balance between globalisation and local identity.

Moreover, regarding the current state of Manama's urban fabric, survey responses (figure 6) were nearly equally divided between those who perceived a strongly globalised skyline and those who recognised a more balanced or hybrid architectural character. One respondent observed:

"The skyline of Manama has fully converted to high-rise glazed buildings. The older buildings, which used to dominate the skyline of Manama, such as Bab Albahrain and the 70s construction building, are no more visible."

Another participant offered a more nuanced perspective:

"It is more of a mix between both, depending on the different areas of Manama, some areas are globalised in their architecture, while others are underdeveloped or a hybrid of old and new buildings."

These responses indicate an awareness of the gradual dominance of new developments over Manama's traditional skyline. However, some participants believe a degree of balance remains, contingent upon the specific area under consideration. Given the study's focus on high-rise buildings, it is noteworthy that over 60% of respondents felt the current façades are unlikely to reflect local identity, while 30% were neutral. Only 3% believed there is some degree of identity reflection. The subsequent case study analysis aims to address this issue in greater detail (Figure 7).

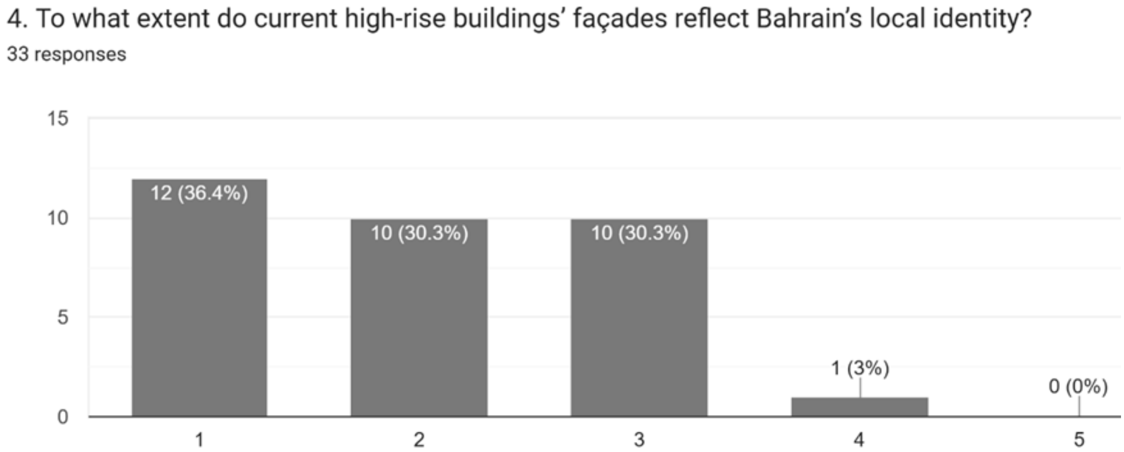

Figure 7. Survey Results.

Building Scale vs. Urban Scale

On the building scale, architects integrate advanced materials, structural systems, and innovative technologies to improve efficiency and safety while referencing traditional forms, materials, or motifs to maintain cultural resonance. At the urban scale, architects must consider broader factors, such as the impact of high-rise buildings on city skylines, urban density, and the relationship with historical urban fabrics. Compatibility between a high-rise building and its environment requires a holistic approach, considering land use, landscape integration, and urban nodes. This approach bridges architectural innovation with the continuity of local identity and urban character, fostering a harmonious blend of tradition and modernity. Thus, the balance should not be confined to a single scale; rather, it should be a multi-scalar dialogue, ensuring that technological advancements enhance both the individual building and its contribution to the broader urban context.

Technology as a Bridge: Achieving Balance

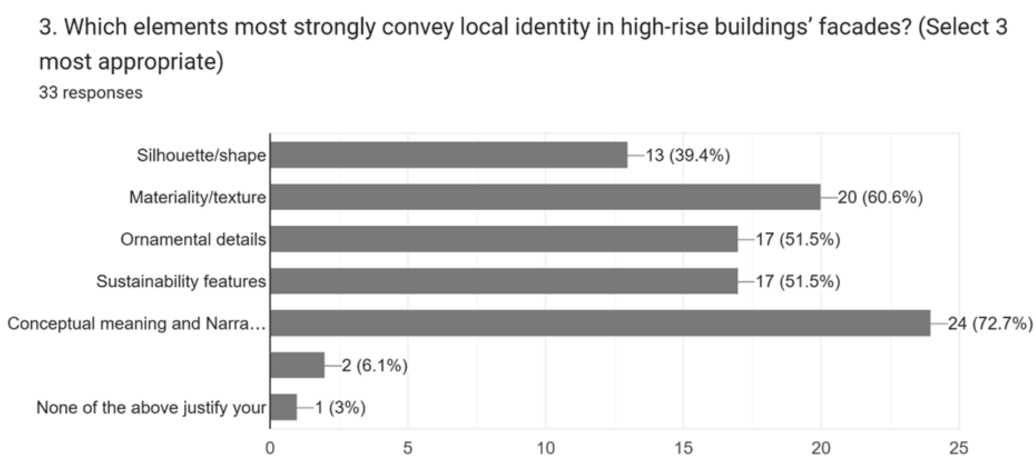

Figure 8. Respondents' perspectives on the best elements conveying local identity.

Participants were also asked to identify the parameters most strongly conveying local identity and the role of technology in shaping it. The majority agreed (Figure 8) that conceptual meaning and narratives effectively reflect identity in high-rise buildings, followed by materiality and texture, with ornamental details and sustainability features considered less influential compared to the previous parameters mentioned. One respondent commented:

"Conceptual meaning might be more adaptable to high-rise buildings. Other factors, such as shape and materiality, might be achievable to a certain extent in high-rise buildings, especially since the current approach is linked to fully glazed buildings. In cases where design approaches are not related to high rise, for example, having restrictions on height factors such as materiality and shape might convey the identity more powerfully."

This raises a critical question regarding the necessity of glass façades in high-rise design. Additionally, several participants emphasised that identity should be experienced through the buildings' functionality rather than superficial ornamentation.

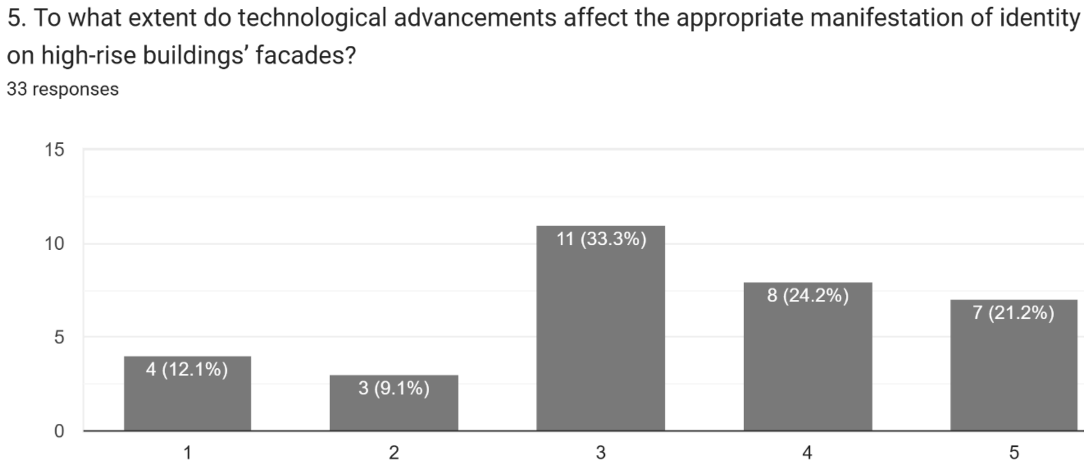

Figure 9. Respondents' views on the effects of technology on local identity Manifestations

While the majority acknowledge the effect of technology on the manifestation of identity (Figure 9), their justifications varied, with some viewing technology as supportive of identity and others as potentially detrimental to it. Architects highlighted the creative use of advanced tools and methodologies to express identity. For example, the use of parametric and dynamic façade designs in the UAE has improved energy efficiency and incorporated regional architectural heritage (Bande et al., 2022). Similarly, generative AI in façade design has created contextually relevant designs that reflect local identity (Jo et al., 2023). Machine learning helps decision-makers and designers select the optimal building facade architecture from multiple options, efficiently implementing suitable technical solutions. Additionally, it aids in assessing the sustainability of each alternative. In essence, machine learning is a valuable tool for enabling designers to develop sustainable solutions aligned with strategic authority goals (Elghonaimy & Sultan, 2024).

Technology plays a pivotal role in achieving a balance between tradition and innovation in high-rise architecture.

- Material Innovation: Advanced materials such as cross-laminated timber or high-performance composites allow for traditional aesthetics with modern performance, enabling architects to reinterpret local forms without sacrificing structural integrity or sustainability.
- Digital Design Tools: Building Information Modelling (BIM), parametric design, and virtual reality enable architects to visualise, simulate, and refine the integration of traditional elements with cutting-edge systems, ensuring harmony at both the building and urban scales.
- Sustainable Systems: Smart building technologies—such as energy-efficient HVAC, renewable energy integration, and water recycling—can seamlessly incorporate designs that reference traditional passive strategies, marrying heritage with high performance.
- Customisation and Prefabrication: Modern fabrication techniques enable the creation of bespoke façade elements that reflect local motifs, making it feasible to produce culturally resonant architecture at scale without incurring excessive cost or complexity.

In sum, technology should not be viewed as antithetical to tradition. Instead, it serves as a powerful enabler, allowing architects to reinterpret and revitalise local identities in high-rise buildings while meeting the demands of modern urban life.

Imposing local identity-building codes: Necessity and nuance

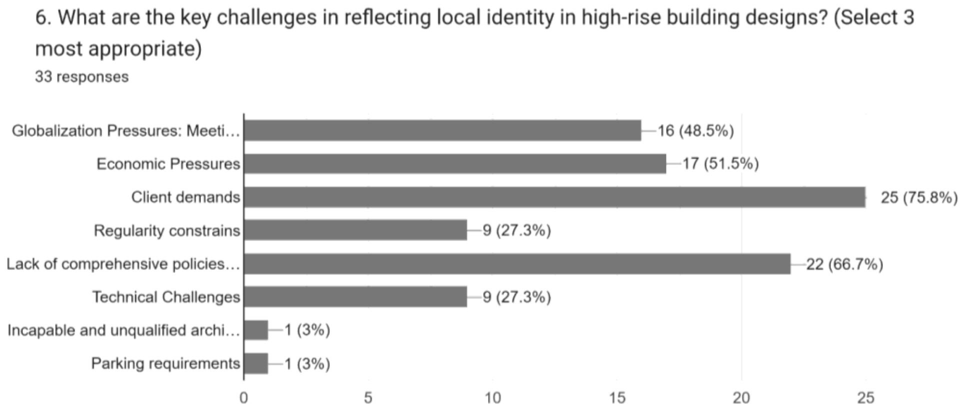

Figure 10. Participants' Responses regarding the challenges of representing local identity in building facades

The most challenging criteria for achieving local identity in high-rise buildings were client demands, lack of comprehensive policies, and economic pressures (Figure 10). The findings suggest that client-driven requirements could be better managed by implementing practical policies that guide the appropriate reflection of identity in new development.

The issue of implementing local identity through building regulations for high-rise structures is intricate. On one side, local identity codes can protect cultural heritage, prevent cultural homogenization, and cultivate a sense of belonging in rapidly globalising urban centres. Conversely, strict enforcement may hinder architectural innovation, restrict technological integration, and lead to superficial imitation rather than genuine expression. Architectural scholars contend that a deviation from tradition is never absolute; instead, reimagining tradition involves reworking and integrating it in a meaningful manner. Consequently, while some regulatory guidance is advantageous for preserving cultural continuity, building codes should possess sufficient flexibility to facilitate creative reinterpretation and technological progress, rather than mandating static replicas of historical forms. For instance, traditional built environments typically feature limited architectural forms that could inspire high-rise building design. Such environments are primarily characterised by low-rise architecture, thereby limiting their applicability to vertical construction. (Al-Kodmany & Ali, 2012)

For instance, the wind tower exemplifies a distinctive traditional architectural form that can be adapted into contemporary tall building designs. Nevertheless, several pertinent questions may emerge. What other forms of vertical vernacular architecture, apart from the wind tower, are present in Bahrain? To what extent can additional skyscrapers integrate the wind tower motif into their architecture? If every Bahraini skyscraper were to adopt this form, the city's aesthetic could suffer from a uniform and monotonous appearance. Consequently, incorporating traditional architectural forms into modern skyscrapers presents a formidable challenge. The complexity of the design remains ambiguous and may not appeal to lay observers, who lack interest in the underlying philosophical concepts or subtle metaphors that architects and critics can perceive.

Conclusions and Recommendations

To conclude, culture, identity, and architecture share a reciprocal and dynamic relationship. Architecture serves as a cultural identity reflector, an influencer, a repository of collective memory, and a driver for social cohesion. Integrating cultural identity into architectural practice is crucial for fostering a sense of place, continuity, and belonging in an increasingly globalised world. However, the ongoing proliferation of glass high-rise buildings, such as those in Manama, comes at the expense of local identity and environmental responsiveness. In parallel, glass façades reflect a global fascination with modernity, technological advancement, and economic progress; their widespread adoption, however, risks creating visually homogeneous skylines and buildings that are poorly adapted to local climates and cultural contexts.

This study emphasises the importance of incorporating local identity into high-rise design, not merely as a gesture to tradition, but as a vital approach for achieving sustainability, cultural continuity, and urban distinctiveness. Examining case studies and contemporary practices reveals that it is possible to harmonise innovative technologies and sustainable materials with culturally resonant design elements. Such an approach ensures that high-rise buildings contribute positively to the urban fabric, fostering a sense of place and belonging for current and future generations.

- **Create Incentives for Outstanding Local Designs**

To encourage architects and developers to prioritise local culture, sustainability, and eco-friendly practices, urban policymakers should establish clear incentives. These could include tax breaks, expedited permitting, or bonus floor area ratios for projects that demonstrate a straightforward integration of regional identity and sustainable technologies. By rewarding excellence in design, cities can inspire a new generation of buildings that both honour heritage and address environmental challenges.

- **Assess and Celebrate Cultural Importance at the Ground Level**

Ground-level design is where buildings interact most with daily life and community identity. Planners should assess the cultural significance of façades and public spaces, ensuring that a meaningful portion of each project reflects local traditions, materials, and artistry. This approach strengthens sociocultural integrity and fosters a sense of belonging among residents.

- **Focus on Contextual Design: Rethink Glass Façades**

While glass façades have become synonymous with modern skyscrapers, their universal application often overlooks local climate, energy efficiency, and cultural context. Cities should carefully evaluate whether such designs are appropriate, especially in hot climates where glass can increase energy demands. Instead, encourage the use of adaptive façades, local materials, and passive design strategies that respond to both place and people.

- **Engage Communities Through Early Perception Surveys**

Meaningful urban development begins with listening. Developers and architects should conduct perception surveys at the outset of each project, engaging local communities, cultural authorities, and environmental experts. This participatory approach ensures that new buildings reflect regional values, history, and needs, resulting in urban projects that are more widely accepted and cherished.

- **Balance Modernity with Tradition**

Technological innovation and cultural sensitivity are not mutually exclusive; instead, they can coexist and complement each other. Encourage the integration of advanced systems—such as high-performance glazing, renewable energy, and innovative building technologies—while adapting them to local climates and customs. Avoid one-size-fits-all solutions in favour of tailored approaches that respect tradition and drive progress.

- **Promote Local Identity Through Policy and Regulation**

Urban policymakers play a crucial role in shaping city skylines. By enacting regulations and offering incentives that prioritise local identity and sustainability, cities can foster a diverse, resilient, and vibrant urban fabric. Zoning codes, design guidelines, and heritage overlays should all reflect a commitment to cultural continuity and environmental stewardship.

- **Support Multidisciplinary Research and Education**

The future of high-rise design lies in collaboration. Encourage research that bridges architecture, urban planning, sociology, and environmental science to discover effective ways of blending modernity with regional identity. Academic and professional programs should emphasise culturally sensitive, sustainable design principles, preparing the next generation of practitioners to lead with empathy and innovation.

- **Establish Professional Awards for Contextual Innovation**

Recognition inspires excellence. Launch national or regional awards—modelled after the Aga Khan Award for Architecture—that celebrate innovative high-rise projects rooted in the local context. These awards should highlight not only aesthetic achievement but also contributions to community, sustainability, and cultural continuity.

By following these recommendations, cities can ensure that future high-rise buildings transcend their roles as mere symbols of economic growth. Instead, they become lasting landmarks—celebrating local heritage, addressing environmental challenges, and enriching the daily lives of urban residents. In this way, the skyline becomes a tapestry of stories, values, and aspirations unique to each place.

Acknowledgement

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Conflict of Interests

The author(s) declare(s) no conflict of interest.

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Chapter 5

Smart Energy Retrofits in Retail: Driving SDG 7 for Sustainable Cities

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Introduction

The United Nations promotes accessible and clean energy through Sustainable Development Goal 7 (SDG 7), titled "Affordable and Clean Energy," which seeks to provide reliable, sustainable, modern, and affordable energy for all (United Nations, 2015). Energy drives improvements in quality of life and mitigates environmental impacts. SDG 7 strives to reduce global energy access inequalities and promote widespread adoption of clean energy through solutions based on renewable energy sources (United Nations, 2015). Increasing environmental challenges and growing sustainability awareness compel all countries to adopt greener practices (IPCC, 2018).

Turkey aligns with the European Union Green Deal of 2019 and implements various regulations and directives to advance its energy transition process (European Commission, 2019). Public and private sectors actively pursue energy efficiency projects and renewable energy investments. These initiatives span multiple areas, including border carbon regulations, green and circular economy practices, clean and secure energy supply, sustainable agriculture, smart transportation solutions, and efforts to combat climate change (Özbuğday and Erkut, 2020). Companies support these projects through green financing models, strengthen international collaborations through diplomatic initiatives, and raise public awareness through educational activities (Yılmaz and Arı, 2021). These efforts demand technological transformation and robust financial infrastructure to help companies achieve their sustainability goals.

The retail sector, known for its high energy consumption, prioritizes energy efficiency and renewable energy integration to achieve environmental, economic, and social sustainability. Retail businesses, with their large-scale operations and extensive supply chains, consume significant energy, which increases operational costs and carbon emissions (Akyüz and Üstün, 2019). Store lighting, heating-cooling systems, refrigerators, and electronic devices generate a substantial carbon footprint in retail operations. Transitioning to sustainable energy not only addresses environmental needs but also delivers economic benefits in the retail sector. Improving energy efficiency lowers operating costs, while adopting renewable energy sources reduces long-term energy dependency and shields against energy price volatility (Demir and Çankaya, 2022). Furthermore, sustainable energy practices enhance social sustainability by building community trust and strengthening brand reputation as environmentally responsible entities (KPMG, 2023).

This study examines the role of smart energy retrofitting solutions in the energy-intensive retail sector. It aims to emphasize how such upgrades help preserve the ecological, social, and economic value of existing buildings—ultimately extending their lifespan and reducing the need for demolition. Rooted in principles of flexibility, resilience, and phased implementation, Adaptive Urbanism empowers cities to effectively respond to evolving environmental, economic, and social challenges (Meerow et al., 2016). Within this paradigm, retrofitting retail spaces with renewable energy systems—such as solar power—not only bolsters urban resilience but also advances social sustainability by cultivating public engagement with low-carbon transitions (Kaya & Özkan, 2023).

In periods of limited energy resources and challenging economic conditions, retrofit projects emerge as strategic solutions by improving existing systems. These projects, which offer cost-effective alternatives to new facility investments, significantly advance energy efficiency goals by enhancing the performance of existing buildings and energy infrastructure (Tosun and Yılmaz, 2019). Retrofit applications modernize lighting systems, replace heating, cooling, and ventilation systems with high-efficiency devices, and integrate building automation

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systems. These measures reduce energy consumption and carbon emissions, contributing to environmental sustainability. Moreover, retrofit projects deliver long-term economic benefits by lowering operating costs and align institutions with climate policies (Gökçe and Kaya, 2023). In countries like Turkey, with substantial existing building stock, retrofit applications serve as indispensable tools for the feasibility and scalability of energy transformation.

In Turkey's retail sector, companies increasingly prioritize energy efficiency and renewable energy investments in their corporate strategies. Retailers transition to LED lighting systems in stores and shopping malls and employ building energy management systems to control heating, cooling, ventilation, and lighting processes intelligently, achieving significant energy savings (Kara and Şahin, 2020). Retailers also modernize cooling systems, implement heat recovery systems, and undertake building insulation projects to reduce energy consumption substantially. In the renewable energy domain, many retail companies install rooftop solar energy systems to meet their electricity needs. They also invest in large-scale solar power plants (SPPs) and secure long-term energy purchase agreements with wind power plants (Erden and Akın, 2021). Retailers document these efforts with green energy certificates like I-REC (International Renewable Energy Certificate) and YEK-G (Turkish Renewable Energy Resource Guarantee System), reinforcing their environmental commitments, while initiatives like establishing electric vehicle charging infrastructure advance sustainability in transportation. These initiatives are strategically significant in mitigating environmental effects while ensuring the industry's enduring competitiveness.

Problem Statement, Hypotheses, and Structure

The retail sector, particularly hypermarkets and shopping malls, consumes high amounts of energy due to systems like lighting, cooling, heating, and ventilation. Reliance on fossil fuels increases operational costs and exacerbates environmental issues, such as global warming and resource depletion. Global retail leaders invest in solar and wind energy to achieve carbon neutrality, yet Turkey's implementations remain limited in scope. Consequently, comprehensive research on the sectoral impacts, scalability, and long-term outcomes of such initiatives remains scarce.

This study highlights CarrefourSA's İstinye Solar Power Plant (SPP) project as a flagship energy retrofit initiative in Turkey's organized food retail sector, evaluating its effectiveness through comparison with global counterparts IKEA and Walmart. Grounded in Sustainable Development Goal 7 (Affordable and Clean Energy), the research investigates how renewable energy retrofits contribute to environmental sustainability (H1: reduced energy consumption/carbon emissions), economic benefits (H2: lower operational costs/long-term savings), and social value (H3: enhanced brand perception). By employing a methodology that combines comparative analysis, in-depth case study examination, and SWOT analysis, the study not only assesses Turkey's retail sector sustainability efforts but also positions them within the global sustainability landscape. The findings synthesize the triple-bottom-line impacts of such initiatives, addressing critical literature gaps while providing insights into Turkey's potential for scaling sustainable retail practices and its contribution to international sustainability objectives.

Materials and Methods

This study examines renewable energy adoption strategies in global retail by analyzing three distinct case studies: IKEA and Walmart as international sustainability leaders and CarrefourSA as Turkey's domestic benchmark (Figure 1). To ensure robust cross-company comparisons, the research employs a tiered data collection approach. For IKEA and Walmart, quantitative metrics have been systematically extracted from their official 2023 sustainability reports, providing standardized global benchmarks. Meanwhile CarrefourSA's data, have been sourced from multiple channels: internal company reports, collaboration documents with İklimSA (a sustainability-focused Turkish organization within the same investor group that specializes in climate change mitigation, energy efficiency, and sustainable projects), and the Solar Energy Atlas published by Turkey's Ministry of Energy and Natural Resources (2023). This multi-source methodology has enabled a balanced comparison while accounting for regional variations in data availability and reporting frameworks.

These cases represent varying market contexts, allowing for a comparative assessment of photovoltaic (PV) system implementations and their operational impacts in retail environments. By investigating these examples, the research aims to identify key patterns, innovations, and challenges in sustainable energy adoption, with a particular focus on how solar energy integration aligns with broader corporate sustainability goals across different economic and regulatory landscapes.

Figure 1. Solar Energy System Projects by Global Retail Companies:
IKEA Memphis, Walmart California and CarrefourSA İstinye SPP Projects
(Ikea SPP: http://www.seattleglobalist.com/wp-content/uploads/2017/01/Ikea-Solar-1-of-1.jpg
Walmart SPP: https://www.solarpowerworldonline.com/wp-content/uploads/2019/05/Walmart-featured-image.png
CarrefourSA SPP: https://kurumsal.carrefoursa.com/tr/hakkimizda/bizden-haberler/carrefoursa-magazalari-kendi-enerjisini-uretiyor)

IKEA Memphis Project (2016): As part of its global sustainability strategy, IKEA deployed a 1.2 MW rooftop solar plant at its Memphis store in 2016, covering 37,000 m^2 with 3,800 high-efficiency panels. The system generates 1.5 million kWh annually, fulfilling 90% of the store's energy needs while reducing CO_2 emissions by 1,500 tons (equivalent to 300 cars' annual emissions) and cutting energy costs by 20%. Integrated battery storage and smart grid technologies ensure nighttime operations and real-time efficiency.

By 2023, this project contributed to IKEA's 1.7 GW global renewable capacity, which includes 920,000 solar panels and 534 wind turbines producing 4.5 million MWh yearly — surpassing the company's total energy consumption. The Memphis initiative exemplifies IKEA's leadership in scalable PV solutions, aligning with its 2030 carbon-neutrality goal through energy independence, cost savings, and advanced grid management (IKEA, 2023).

Walmart California Portfolio (2019): In 2019, Walmart implemented a groundbreaking 10 MW distributed solar portfolio across 50 California stores, utilizing 185,000 m^2 of rooftop space with 28,000 polycrystalline panels. This ambitious system generates 14 million kWh annually, fulfilling 30% of the energy needs for 364 Walmart facilities statewide while reducing annual CO_2 emissions by 650,000 tons—equivalent to the carbon footprint of 90,000 U.S. households (Walmart, 2023). Beyond environmental benefits, the project delivers 15% energy cost savings through optimized power generation and consumption. The installation incorporates microgrid technology and battery storage, ensuring uninterrupted operations during grid outages and allowing excess energy to be stored for peak demand periods.

As a cornerstone of Walmart's 100% renewable energy by 2035 strategy, this scalable model demonstrates how large retail chains can effectively transition to sustainable energy. The initiative's impact extends beyond infrastructure through community partnerships and environmental awareness campaigns, reinforcing Walmart's commitment to both ecological and social responsibility while setting a replicable standard for renewable energy adoption in the retail sector.

CarrefourSA İstinye SPP Project (2024): In 2024, CarrefourSA achieved a significant milestone in Turkey's retail sector with the inauguration of a 620 kWp solar power plant atop its İstinye Hypermarket in Istanbul. Covering 10,000 m^2 of rooftop space with 1,113 high-efficiency monocrystalline panels, the system generates 1 million kWh annually—meeting 45% of the store's electricity demand while reducing 374.8 tons of CO_2 emissions, equivalent to the annual energy consumption of 187 Turkish households (CarrefourSA, 2024).

The solar power project was systematically executed using a proven five-phase methodology (Sev, 2009). The process commenced with a comprehensive Current Situation Assessment, involving structural integrity evaluations and detailed energy audits to establish baseline conditions. This informed the Goal Setting & Strategy Development phase, where measurable objectives and actionable roadmaps were formulated. During the Design & Planning stage, engineers leveraged solar irradiation data to optimize panel configuration for maximum energy yield. The Implementation phase then transformed these plans into reality through precision installation of all system components. Finally, the Review & Performance Evaluation phase ensured ongoing optimization through real-time performance monitoring and thermal validation protocols, creating a closed-loop system for continuous improvement. This methodical approach guaranteed both technical excellence and operational efficiency throughout the project lifecycle (Figure 2).

This systematic approach ensured maximum efficiency in Istanbul's favorable climate (2,741 annual sunlight hours declared at the Solar Energy Atlas (Turkey's Ministry of Energy and Natural Resources, 2023). Though currently lacking battery storage—creating seasonal limitations—the project delivers 25% energy cost savings and establishes an important precedent for renewable energy adoption in Turkish retail. The installation features optimized panel layouts, advanced inverters, and real-time monitoring through İklimSA (a sustainability-focused Turkish organization within the same investor group that specializes in climate change mitigation, energy efficiency, and sustainable projects), demonstrating how urban retail spaces can effectively integrate renewable solutions despite space constraints. As Turkey's first major retail solar initiative, it represents both an operational achievement and a powerful symbol of sustainable commerce.

Figure 2. CarrefourSA İstinye SPP Project Execution Stages (From the Authors' Archive)

Focusing on these commercial solar energy initiatives. this study utilizes a two-phase analytical approach. The first phase involves a systematic comparison of three major solar projects (IKEA, Walmart, and CarrefourSA), assessing both quantitative factors—such as installation specifications (area coverage, panel quantity) and operational metrics (energy capacity, output, emission reductions, cost efficiency)—and qualitative aspects, including sustainability benefits, technological implementations, and project timelines (Figure 1).

The second phase focuses on a dedicated SWOT analysis of CarrefourSA's solar installation, examining its internal operational strengths and weaknesses as well as external market opportunities and threats. By combining measurable performance data with strategic assessments, this dual-method framework offers comprehensive insights, facilitating cross-project benchmarking while also enabling a detailed evaluation of CarrefourSA's competitive positioning and market potential within the solar energy sector.

Comparative Analysis of Retail Solar Energy Projects: Case Studies and Key Findings

Table 1 presents a detailed comparison of solar energy initiatives implemented by three major retailers - IKEA, Walmart, and CarrefourSA - across different global markets. The analysis examines their physical infrastructure, energy production capabilities, environmental benefits, and strategic approaches to renewable energy adoption.

Table 1. Comparative Analysis of Retail Solar Power Plant Projects (by the authors)

Parameter	IKEA (Memphis, 2016)	Walmart (California, 2019)	CarrefourSA (İstinye, 2024)
Physical Characteristics			
Installation Area	37,000 m^2 (6 acres)	185,000 m^2 (50 stores)	10,000 m^2 (1 store)
Panel Count	3,800	28,000	1,113
Performance Metrics			
Installed Capacity	1.2 MW	10 MW	620 kWp
Annual Energy Production	1.5 million kWh	14 million kWh	1 million kWh
CO_2 Reduction	1,500 tons/year	650,000 tons/year	374.8 tons/year
Energy Cost Savings	20%	15%	25% (estimated)
Strategic Value			
Sustainability Impacts	Renewable Energy, Energy Independence	Scalability	Local Leadership, Environmental Awareness
Technological Features	Smart Energy Management, Battery Systems	Microgrid, Energy Optimization	High-Efficiency Panels, Internal Monitoring
Implementation Timeline	8 months	12 months	6 months

The analysis reveals three distinct models of solar adoption in retail: IKEA's technology-intensive, energy independent approach, Walmart's large-scale, multi-location deployment and CarrefourSA's localized, policy-optimized solution.

IKEA's Memphis project (2016) demonstrates a comprehensive approach to sustainable energy with its 1.2 MW solar installation. The system spans 37,000 m^2 with 3,800 panels, generating 1.5 million kWh annually - sufficient to meet 90% of the store's electricity needs. The project's most innovative feature is its integrated battery storage system, which enables energy independence by storing excess production for nighttime use. This technological advantage comes with a significant $1.5 million investment, reflecting IKEA's commitment to being a sustainability leader in the retail sector. The installation reduces carbon emissions by 1,500 tons each year while incorporating smart energy management for optimal performance.

Walmart's California initiative (2019) represents one of the largest retail solar deployments, with a massive 10 MW capacity spread across 185,000 m^2 at 50 store locations. This expansive system produces 14 million kWh annually, covering 30% of the energy needs for 364 facilities. The project's microgrid technology ensures reliable power supply while maintaining connection to the main grid. Although using slightly less efficient polycrystalline panels, the scale of implementation results in extraordinary environmental benefits - reducing CO_2 emissions by 650,000 tons annually, equivalent to removing about 140,000 cars from the road each year.

CarrefourSA's İstinye project (2024) illustrates how regional retailers can effectively implement solar solutions. Despite its smaller 620 kWp capacity (1,113 panels across 10,000 m^2), the system meets 45% of the store's energy demand through 1 million kWh of annual production. The project capitalizes on Turkey's abundant sunshine (2,741 hours/year) and national renewable energy incentives to achieve 25% cost savings. While lacking battery storage, its advanced monitoring system and rapid 6-month implementation demonstrate how retailers can achieve meaningful sustainability results even with limited resources.

These cases demonstrate that successful solar implementation requires alignment between corporate sustainability goals, local conditions, and available technologies. While global chains can invest in cutting-edge systems and wide-scale deployments, regional players like CarrefourSA show that significant progress can be made through well-designed, context-specific solutions. The projects collectively highlight the growing importance of solar energy in retail operations worldwide, with each model offering valuable lessons for businesses pursuing renewable energy strategies.

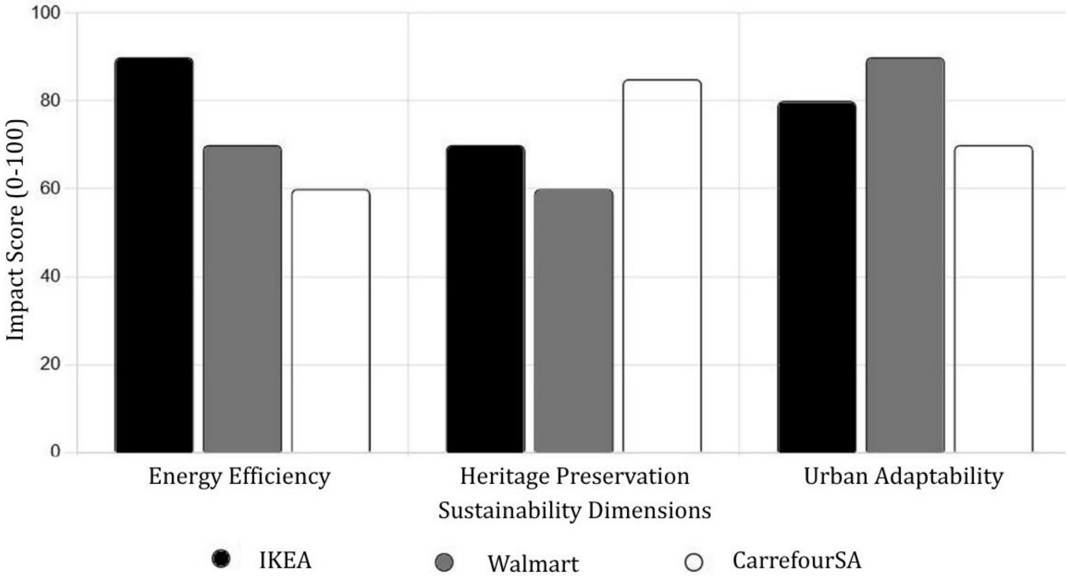

Figure 3. Comparative Impact of Adaptive Retrofitting on Sustainability (Developed by Author)

SWOT Analysis of CarrefourSA's İstinye SPP project and Key Findings

CarrefourSA's İstinye Solar Power Plant (SPP) represents a significant step toward Sabancı Holding's commitment to reduce carbon emissions by 41% by 2030. This initiative showcases the potential for renewable energy adoption in Turkey's retail sector while highlighting both its strengths and areas for improvement.

Strengths: The İstinye SPP demonstrates strong environmental and economic benefits. With a 620 kWp capacity, the system generates 1 million kWh annually, covering 45% of the store's energy needs and reducing CO_2 emissions by 374.8 tons per year—equivalent to the annual consumption of 187 households. Despite rising energy costs in Turkey, the project delivers 25% savings, enhancing operational efficiency. Its strategic location in Istanbul boosts brand visibility, aligning with growing consumer demand for sustainable businesses. Additionally, the use of high-efficiency monocrystalline panels and real-time monitoring ensures reliable performance, while the rapid six-month implementation sets a benchmark for future projects.

Weaknesses: However, the project faces limitations in scalability and technological advancement. Compared to global competitors like IKEA and Walmart, which operate solar capacities of 1.7 GW and 500 MW respectively, CarrefourSA's initiative remains modest in scale. The lack of battery storage leads to a 30-40% drop in energy production during winter months, reducing efficiency. Furthermore, the $500,000 initial investment may deter smaller retailers from adopting similar solutions, and the absence of a clear expansion plan across CarrefourSA's 1,000+ stores limits broader impact.

Opportunities: Turkey's abundant sunlight (2,741 hours annually) provides an excellent foundation for scaling solar energy projects. Government incentives, including the EU Green Deal and YEKDEM (National Renewable Energy Support Mechanism)- incentives subsidies, offer financial support for further renewable energy investments. The growing consumer preference for eco-friendly brands (65% by 2025) presents an opportunity to strengthen customer loyalty. Future enhancements, such as AI-driven energy management and electric vehicle charging stations, could further elevate CarrefourSA's sustainability leadership.

Threats: The project must navigate several challenges, including competition from global retailers with advanced technologies like IKEA's battery storage and Walmart's microgrid systems. Seasonal energy fluctuations and regulatory changes, such as potential reductions in government incentives, pose additional risks. Economic instability and rising material costs may also hinder future investments in renewable energy.

The SWOT analysis underscores that the İstinye Solar Power Plant (SPP) represents a groundbreaking initiative in Turkey's retail sector, proving the feasibility of solar energy integration while highlighting opportunities for further innovation. To fully capitalize on this potential, CarrefourSA should focus on scaling the project across its store network, investing in advanced energy storage systems, and pursuing continuous technological advancements. By proactively addressing these strategic priorities, the company can not only enhance its operational sustainability but also reinforce its leadership in the transition toward eco-conscious retail practices.

Conclusion and Discussion

This study demonstrates that retrofitting plays a pivotal role in advancing environmental sustainability within the retail sector, as exemplified by the CarrefourSA İstinye SPP Project's substantial reductions in carbon emissions and energy costs. A comparative analysis with industry leaders such as IKEA and Walmart further reveals that retrofitting not only decreases operational expenditures but also enhances brand reputation, contributing to broader economic and social sustainability objectives.

Beyond its immediate benefits, retrofitting supports urban resilience—a key principle of adaptive urbanism (Meerow et al., 2016). By integrating renewable energy solutions into retail spaces, cities can better adapt to climate change challenges. The CarrefourSA case illustrates this through improved community awareness and sustainable transportation initiatives, including electric vehicle charging stations. However, the economic impact of retrofitting varies across contexts: CarrefourSA achieved a 25% reduction in costs, outperforming IKEA and Walmart (both at 15%). This disparity underscores the influence of local factors on retrofitting outcomes, suggesting that tailored strategies are essential for maximizing sustainability gains.

These findings illuminate promising directions for future investigation into adaptive retrofitting solutions. The study underscores the critical need to develop tailored approaches that translate sustainability theory into practical applications, particularly in urban contexts grappling with dual energy and economic challenges. The demonstrated success of case-specific interventions suggests that hybrid methodologies combining technological innovation with localized adaptation strategies may offer the most viable path forward. Researchers should particularly focus on developing decision-support frameworks that help stakeholders navigate the complex trade-offs between environmental benefits, implementation costs, and operational feasibility in crisis-affected urban markets.

Limitations of the Study

This study has several limitations that influence the interpretation and applicability of its findings. First, its reliance on the CarrefourSA İstinye SPP Project as a primary case study restricts the generalizability of results to other retail environments, particularly smaller-scale operations or regions with differing regulatory and climatic conditions. While the qualitative comparative analysis with IKEA and Walmart provides valuable insights, the dependence on secondary data—without complementary primary data from stakeholder interviews or consumer surveys—may obscure nuanced social perceptions and behavioral impacts. Second, the economic analysis does not fully account for the upfront capital expenditures required for retrofitting, a critical factor for smaller retailers with limited liquidity. This omission may overstate the short-term feasibility of such projects despite their demonstrated long-term benefits.

Third, the study's cross-sectional design (with data current to June 2025) lacks longitudinal assessment, preventing analysis of how sustainability outcomes evolve over time, such as fluctuations in energy savings or maintenance costs. Additionally, the exclusion of energy storage systems (e.g., battery technology like IKEA's) limits understanding of how retrofitting can mitigate renewable energy intermittency—a key challenge for scalability.

Future Research Directions for Sustainable Retrofitting in Retail

The current research identifies several crucial gaps that require further investigation. Future studies must expand their focus to include small and medium-sized enterprises (SMEs) in the retail sector, as these businesses face unique implementation challenges despite representing a substantial market segment. Examining SMEs will yield valuable insights about scaling retrofitting solutions across different business models and operational scales.

Methodological improvements should become a key focus for upcoming research. Scholars need to combine quantitative energy data with qualitative social impact measurements through mixed-methods approaches. Implementing longitudinal study designs would be particularly beneficial for tracking both short-term results and long-term sustainability outcomes of retrofitting projects.

Energy storage integration presents another vital research opportunity. Following successful examples like IKEA's Memphis project, researchers should investigate how emerging battery technologies and smart grid solutions can solve renewable energy intermittency issues in retail environments. These studies should evaluate technical requirements, cost efficiency, and geographic-specific implementation barriers across various climate zones.

Several specific research areas demand focused attention: developing customized energy storage systems for different retail formats, analyzing financing options for smaller retailers, and examining retrofitting's long-term urban effects. Implementing rigorous methodologies will be essential, including comparative case studies, stakeholder analysis frameworks, economic modeling, and policy evaluations. Future research could cover context-specific retrofitting models that account for local infrastructure constraints and resource availability, cost-optimized implementation strategies for financially constrained environments, and scalable solutions that maintain efficacy across varying urban densities and building typologies.

These research initiatives will establish the necessary evidence base for creating adaptable implementation strategies. By filling these knowledge gaps, researchers can provide practical guidance to both business leaders and government officials, promoting wider adoption of sustainable retrofitting practices worldwide. The findings will help achieve balanced solutions that address environmental sustainability while maintaining economic feasibility and social responsibility in the retail industry.

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PART I I

Urban Morphologies, Systems, and Equitable Transitions

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Chapter 6

Contentious Issues and the Reality of Urban Sprawl

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Introduction

Urbanization represents a persistent, global, and inevitable course of urban development, to the effect that urban scholarship has continuously expressed concern over the rapid pace of urbanization worldwide, which affects both developed and developing nations (Sudhira et al., 2004; Jat et al., 2008). As Sharma, Kumar and Kumar (2024) observed, human civilization has continually reshaped the earth over time, reflecting the deep ongoing influence of urban processes. In line with this, Idowu and Olaniyan (2009) emphasize the implications of a growing global population, noting that the nature of urban settlements has evolved, with many semi-urban areas and medium-sized towns transitioning into fully urbanized regions. This global urban development is manifesting in increasingly complex urban dynamics, characterized by the rapid proliferation of informal housing and the concentration of impoverished families in peri-urban zones. As noted by various scholars, the continuous expansion of cities in terms of size and population leads to the widespread challenge of urban sprawl (Ewing, 1997; Olujimi, 2009; Mangweta, Mokoeleet and Monama, 2022; Sharma, et al., 2024).

There is a growing global concern and awareness regarding urban sprawl and its ramifications (Downs, 1999; Feng, 2009; Olanrewaju and Adegun, 2021). As Ajiboye, Eren, and Ugese (2022) noted, understanding the dynamics of urban growth and changes in land use has a significant impact on the future, especially in urban planning. Numerous studies have characterized urban sprawl as a widely recognized yet contentious issue, often debateable (Torrens, 2008; Aljoufie et al., 2013; Aguda and Adegboyega, 2013). The term "urban sprawl" encompasses a range of undesirable characteristics associated with urban growth, including environmental degradation, uncontrolled development, and unplanned suburbanization (Cillier, 2010; Noor and Rosni, 2013; Liu, et al., 2018; Sharma, et al., 2024). There is no wishing away the environmental problems that comes with urban sprawl, even more so the environmental footprints caused by automobile dependency, consumption patterns, eradication of farmlands and green areas that characterise the urbanization process of developing countries (Ajobiewe, 2020). It is precisely because of these reasons that the debates around urban sprawl have flourished in recent decades, and despite the myriads of propositions – as it is a frequently discussed phenomenon – it remains poorly understood due to its varied interpretations among different stakeholders.

This study adopts a three-stage methodological approach. First, it synthesizes scholarly debates and theoretical frameworks on urban sprawl, examining key definitions, causes, and global experiences. Second, it uses Minna, Nigeria, as a representative case to explore urban growth trends and governance challenges common to developing cities. Finally, it maps and quantifies urban expansion over time, with particular attention to land cover changes and identifiable sprawl patterns. These contentious issues encompass definitions, characteristics, causes, measurements, impacts, and consequences, which are both far-reaching and undeniable. In the following sections, the article presents an understanding (theoretical and analytical) of urban sprawl then goes a step further to explore the realities of urban living in various regions worldwide, then concludes whilst focusing on a study conducted in Minna, a city in Nigeria, covering 1972 - 2015.

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Interpreting Urban Sprawl within Theoretical Contexts

In urban studies, theories play a crucial role in elucidating the complexities of the urban phenomena such that analyzing urban growth and residential location in relation to the concept of urban sprawl becomes feasible. This recourse to theory is at the very least important in that "there is no practice without theory", a sentiment one would find appealing should Neil Brenner's critique of naïve objectivism is invoked on the basis of rationalizing the importance of theory (see Brenner, Madden and Wachsmuth 2011; Brenner and Schmid, 2015). There are in fact a number of classical descriptive theories (Burgess, 1925; Hoyt, 1939; and Harris and Ullman, 1945) that have been proposed and, in some cases, modified (Vance, 1964, Mann, 1965, Kearseley, 1983, and White, 1987) and reconceptualized to explain the urban phenomena. These classical descriptive theories which as Ajobiewe (2020) reiterated, were works of the Chicago School of Urban Sociology, and for the most part attempted an ecological (functionalist) explanation of urban development.

Although they continue to gain a widespread nostalgic appeal even today not only in the context of land use patterns and urban structure (Cillier, 2010), it is important to add that these ideas of the Chicago school have been notably criticised since the 1960s (see Lefebvre, 1970; Harvey, 1973; and Massey, 1991 cited in Scott and Storper, 2014). Despite these waves of criticisms, they are relevant to the ongoing discourse on urban sprawl because the do offer a fundamental approach to a city-centric paradigm, that has characterised the urban discourse in recent decades. A succinct recapitulation of these theories—the 'classics of urban theory'—highlights key assumptions, including: (1) urban areas expand outward in a radial, concentric pattern from a central point (Burgess Theory; see Figure 1); (2) high-quality residential zones typically develop along the most efficient transportation routes, near existing commercial hubs, or adjacent to open land (Sector Theory; see Figure 2); and (3) urban development often occurs around multiple central business districts (CBDs) or distinct nuclei, rather than from a single origin point (Multiple Nuclei Theory; see Figure 3)."

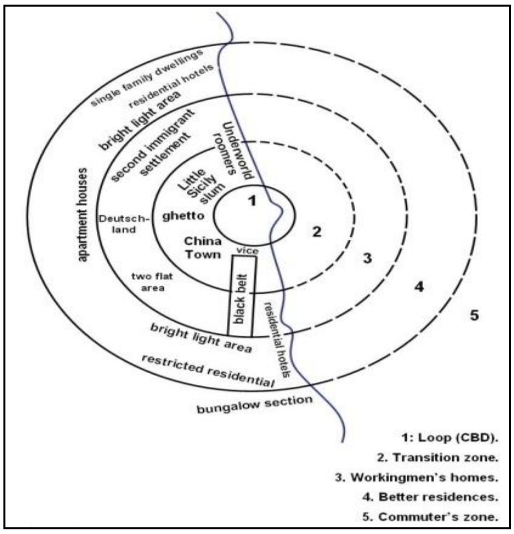


Figure 1. Burgess Theory (1925).

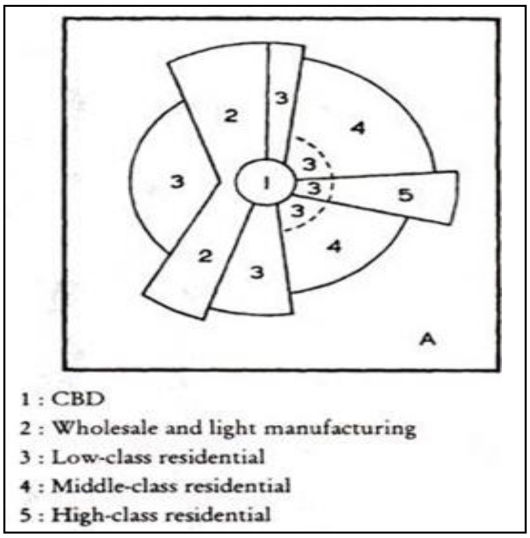


Figure 2. Hoyt's Theory (1939).

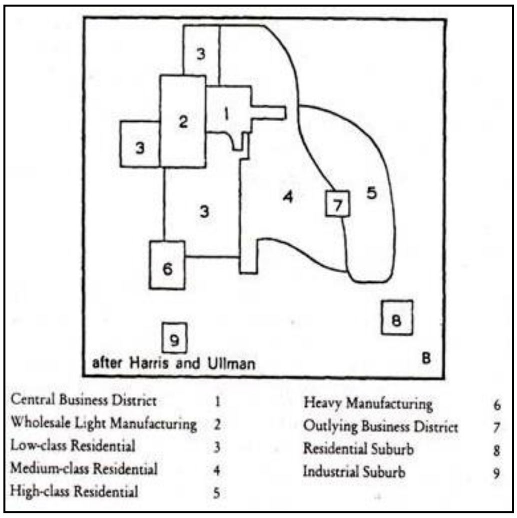


Figure 3: Harris and Ullman (1945)

Beyond the classics of urban theory, there are as well some modified descriptive theories which build upon the classical theories of Burgess, Hoyt, and Harris and Ullman to show the significance of Central Business Districts (CBDs) and nodal canters in the urban structure of cities during the 20th and 21st centuries. Pacione (2005) and Cellier (2010) employed this theoretical framework to analyse the contemporary composition of urban structures in the 21st century. The theories encompassed within this framework include Vance's Urban-Realm Theory, Mann's Theory of Urban Structure, Kearsley's Modified Burgess Theory, and White's Theory of the 21st Century City. In Vance's Urban Real Theory (1964), there is an emphasis on the development of self-sufficient urban areas, characterized by the emergence of a new downtown that operates independently from the traditional downtown. Mann's Theory of Urban Structure (1965) argues that industrial land use acts as a magnet for residential development among the working class, thereby providing employment opportunities for skilled individuals who can afford longer commutes.

For Kearsley (1983) which ultimately expands upon Mann's framework, the creation of new towns and the establishment of public or private residential estates in suburban areas are direct results of urban renewal initiatives and economic decentralization. Pacione (2005) acknowledges the foundational role of concentric theory in the development of White's Theory of the 21st Century City which argues that the presence of industrial anchors and public sector oversight significantly influences zoning regulations and the overall urban structure. Additionally, the land value theory, articulated by Alonso in 1964, elucidates the relationship between land value and land use. In this sense, land located in urban centres are highly sought after yet limited in availability, resulting in intense competition among various users. This intense competition highlights the strong preference for homeownership in peripheral areas, attributing this trend to the lower cost of land in these regions, which consequently attracts a significant population (Hirsch, 1973; Onokerhoraye and Omuta, 1986). Although transportation costs to these areas may be elevated, the appeal of acquiring a substantial parcel of land or the prospect of reduced rental prices continues to motivate such relocations. Proponents of land value theory have corroborated this assertion, indicating that urban development typically gravitates toward more affordable and accessible land (Cellier, 2010; Cobbinah and Amoako, 2014).

From the foregoing, we illustrate the interrelationship of the theories as factors influencing urban sprawl using the urban sprawl wheel (Figure 4) in line with other scholars (Song and Zenou, 2006; Franz et al., 2006; O'Sullivan, 2009; Cellier, 2010; Cobbinah and Amoako, 2014; Idowu, 2017) to explain the processes of urban transformation. The factors that contribute to urban sprawl, as inferred from these theories, include urban growth, population increase, economic activity, location preferences, availability of space, transportation influences, land use patterns, physical planning strategies, transportation costs, government intervention, low rental and land values, social factors, and horizontal movement patterns.

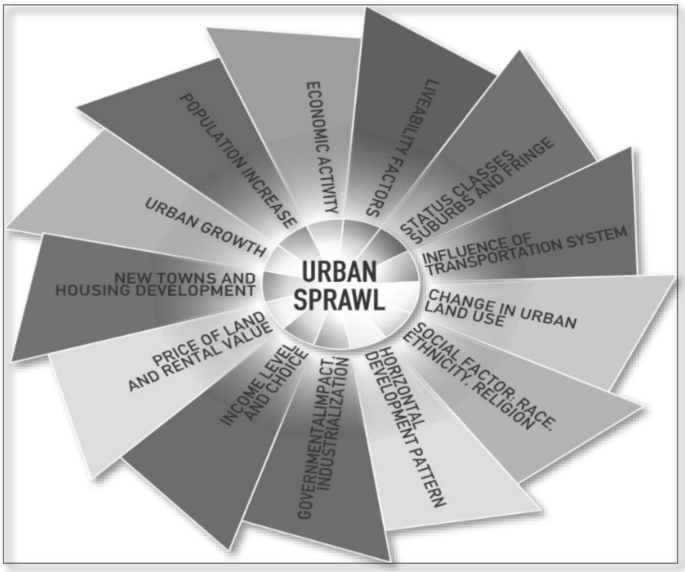


Figure 4: Urban Sprawl Wheel.
Source: Idowu (2017).

Urban Sprawl in Context: Causes, Costs, Control, and Comparative Perspectives

Urban sprawl is a spatial phenomenon that is widely recognized, complex, and often surrounded by controversy (Torrens, 2008; Liu and Jiang, 2011). Cervero (2000) emphasized the complex processes and challenges involved in defining urban sprawl, as well as the various patterns it reflects. Frank et al. (2000), Frenkel and Ashkenazi (2008), and Sharma, et al. (2024) all address the challenges of defining urban sprawl, noting that these difficulties stem from differing and often conflicting perspectives. The body of literature addressing urban sprawl is extensive and varies across different global regions (Torrens, 2008; Hamidi and Ewing, 2014). Researchers have identified several common distinguishing features, including growth patterns, social and aesthetic attributes, decentralization, accessibility, density characteristics, fragmentation, loss of open space, and dynamic processes (Ewing, 1997; Song and Zenou, 2006; Torrens, 2008; Hamidi and Ewing, 2014). Burchell et al. (1998) categorized sprawl into two primary forms: low-density residential scattered development and non-residential scattered commercial and industrial development, highlighting ten specific features that characterize urban sprawl. Conversely, Franz et al. (2006) argue that some features used to define urban sprawl are ambiguous, as they simultaneously reflect both the causes and consequences of sprawl, similar to its characteristics. This is supported by Glaster et al. (2001), who assert that much of the confusion surrounding the characterization of urban sprawl stems from the conflation of ideology, experience, and effects. The various characterizations of urban sprawl in the literature encompass growth, social characteristics, aesthetic preferences, decentralization, accessibility, density, open space, dynamics, and dispersion.

Urban sprawl is attributed to a multitude of causes (Frank et al., 2000). Numerous scholars have examined the factors contributing to urban sprawl, asserting that it cannot be attributed to a singular cause due to the complex and interrelated nature of these factors (Frank et al., 2000; Siedentop, 2005; Frenz et al., 2006; Song and Zenou, 2006; Frenkel and Ashenazi, 2008; Downs, 1999; Besussi et al., 2010). Besussi et al. (2010) note that the causes of urban sprawl are predominantly linked to rapid urbanization and urban agglomeration, resulting in a multifaceted process that leads to inefficient resource utilization in the fringe areas of cities. Frank et al. (2000) identified several factors that promote urban sprawl, including rent gradients, demographic shifts, increasing affluence, land assembly economics, transportation costs, mortgage interest deductions, and land use regulations. Siedentop (2005) delineated two competing causal frameworks for urban sprawl: the first is driven by the demand for urban land, while the second is influenced by specific regulatory frameworks that dictate land ownership, utilization, and distribution in peri-urban regions. Moreover, urban planning itself has been identified as a contributing factor to urban sprawl (Franz et al., 2006).

A multitude of methodologies have been proposed in measurement of urban sprawl (Ewing et al., 1997; 2002; Franz et al., 2006; Torrens, 2008; Terzi and Kaya, 2011). The Smart Growth Movement (SGM) pioneered one of the earliest approaches, which involved visual representations of urban sprawl from a planning perspective, along with the development of various analytical factors to assess and measure the proliferation of sprawl (The Sierra Club, 1998; Ewing et al., 2002). Subsequently, various scholars have devised distinct techniques, categorizing their methodologies. Notable categories for measuring urban sprawl include: (1) density-related measurement techniques, which estimate the population residing in metropolitan areas and the fluctuations in the percentage of the metropolitan population within urban locales (The Sierra Club, 1998); (2) income-based techniques, which investigate the costs and benefits associated with urban sprawl, such as improved housing affordability and increased equity in housing opportunities across racial demographics (Burchell et al., 1998; 2000; Downs, 1999); (3) methods that assess the degree of employment decentralization (Knap et al., 2005); and (4) comparative analyses of sprawl incidents relative to the age of metropolitan areas and the extent of political fragmentation within those areas. The emergence of remote sensing data and the integration of Geographic Information Systems (GIS) into urban sprawl research have mitigated some of the challenges faced by earlier researchers (Sudhira et al., 2003; 2004; Hamidi and Ewing, 2014). The use of remote sensing and GIS provides an alternative framework for mapping, measuring, and monitoring urban sprawl (Weng, 2010; Basawaraja et al., 2011; Kumar and Tripathi, 2014).

As has been established in literature, urban growth and encroachment are inevitable outcomes of urbanization. The challenge lies not in preventing them, but in managing these changes sustainably and innovatively (Sharma, et al. (2024). This requires identifying, monitoring, and mapping the patterns and directions of sprawl and land use changes, an area that demands further research. The impacts of urban sprawl are complex and multifaceted, affecting various disciplines that engage with the concept (Wassmer, 2005). The impact of urban sprawl can include economic efficiency (Downs, 1999; Ewing et al., 1997), rising cost of infrastructure (Gordon and Richardson, 1997; Ewing et al., 2002; Galster, 2001), and loss of ecologically sensitive lands (Kahn, 2000; Johnson, 2001). The distinctions between the elements of urban sprawl become more pronounced when differentiating its impacts from its consequences. This indicates that the impacts and consequences of urban sprawl are interconnected and are often used interchangeably in various studies (Wassmer, 2005; Frenz et al., 2006; Bhatta, 2009). Broadly, the consequences of urban sprawl can be categorized according to their costs, effects on infrastructure, and environmental implications (Downs, 1999; Frank et al., 2000; Johnson, 2001).

The consequences of urban sprawl are linked to a variety of economic, social, and environmental challenges. Although urban sprawl can produce both positive and negative outcomes, the often uncontrolled or uncoordinated nature of this growth typically leads to negative effects that outweigh the benefits (Bhatta, 2010). These consequences encompass increased costs for infrastructure and public services, inefficiencies in energy supply, widening wealth disparities, detrimental impacts on wildlife and ecosystems, loss of agricultural land, and burdens on rural economic activities and land use. In response to the growing concerns about urban sprawl, countries around the world have implemented various policy instruments aimed at managing urban growth and curtailing the spread of sprawling environments (Bengston and Young, 2006). The effectiveness of these policies is frequently scrutinized in the literature. Johnson (2001) and Bengston and Young (2006) identified key land use strategies and policies adopted in numerous cities across the United States, Europe, and Asia. These strategies, collectively referred to as urban containment policies, include green belts, urban growth boundaries, and urban service boundaries.

Urban sprawl poses a significant spatial challenge for numerous cities worldwide (Almeida, 2005; Oueslati et al., 2015). This phenomenon has been frequently documented in cities such as Washington-Baltimore, Virginia, New York, and New Jersey in the United States. Masek et al. (2000) observed a development pattern in Northern Virginia characterized by a strip configuration along highways, leading to a dispersed urban layout. In New York and New Jersey, a substantial expansion of land area has occurred despite a decline in population growth. Gillham (2002) emphasized the development pattern in the metropolitan regions of Los Angeles, which lacks a singular dominant city centre. Thomas (2002) reported on the unprecedented rate of conversion of green open spaces in Michigan, where potentially contaminated land is being redeveloped near large metropolitan areas. These urban growth patterns highlight the prevalence of urban sprawl in the United States. The layout of the road network has significantly influenced development patterns, connecting various land uses to a secondary network of arterial roadways lined with commercial establishments. Consequently, this has led to the creation of intricate neighbourhoods and roadways that resemble a web, linking individual residences in the urban periphery and extending beyond the visible horizon (Gillham, 2002). Europe is characterized by some of the highest urban agglomeration densities in the world, with over 75% of its population living in urban areas. According to Oueslati et al. (2015), the expansion of urban areas in Europe is occurring at a significantly faster rate than the growth of their populations. For instance, a program aimed at reducing spatial densities was initiated in the early 1970s, primarily targeting medium-sized cities across Europe. However, subsequent studies have shown that there has been no noticeable decrease in spatial agglomerations within Europe, as the demand for land in urban areas, suburbs, and peripheries continues to rise (European Environment Agency, 2006).

An empirical investigation conducted by Queslati et al. (2015) examined the dynamics of urban sprawl across 282 European cities during the years 1990, 2000, and 2006. The researchers employed two indices of urban sprawl to evaluate changes in artificial land area and the degree of fragmentation within each city. The initial findings revealed significant variations in the prevalence of urban sprawl throughout Europe. The report on the state of European cities highlighted that the evolving economic and social contexts associated with urban transitions have profoundly impacted urban development. Notably, a substantial number of residents have recently migrated from urban centres to suburban areas, where land and housing are more affordable, and thereby exacerbating urban sprawl.

The phenomenon of urban sprawl has prompted extensive research, discussions, and policy initiatives in developing countries (see Sudhira et al., 2003; 2004; Oladele and Oladimeji, 2011; Aguda and Adegboyega, 2013; Xu et al., 2013; Laraba and Shola, 2013). Latin America is recognized as one of the most urbanized regions in the world, with approximately 84% of its population living in urban areas, which leads to complex urban dynamics (Torres, 2011). Many peri-urban areas surrounding medium and large cities in Latin America are experiencing three primary forms of growth: rapid expansion, informal housing, and the concentration of impoverished families. The factors contributing to the prevalence of irregular settlement patterns in Latin America include national population growth, rural-to-urban migration, economic development, property rights, land tenure legislation, and fluctuations in land market prices (Torres, 2011). Cities experiencing such rapid growth include Santiago in Chile, Cancun in Mexico, Camisea in Peru, La Paz in Bolivia, and Macaé in the state of Mato Grosso, Brazil.

In Asia, urban sprawl has intensified over recent decades, leading to dispersed development and sprawling growth patterns (Xu et al., 2013). The primary drivers of changes in land use patterns are the rates of urbanization and population growth (Sudhira et al., 2003; 2004). Urban sprawl is particularly evident in radial patterns around city centers and linear patterns along major highways. Numerous studies conducted in cities such as Udaipur, Mangalore, Bangalore, Raichur, Delhi, Mumbai, Tokyo, Kolkata, and Karachi support this observation, highlighting the excessive consumption of land (Feng, 2009). The pattern of urban growth in China has been linked to the reforms implemented in the 1980s, which resulted in inadequate regulation of development and uncoordinated construction activities in peri-urban areas (Feng, 2009; Feng and Li, 2012; Xu et al., 2013). In Africa, several studies, including those by Okewole (2002), Olujimi (2009), Sebego and Gwebu (2013), and Cobbinar and Amoako (2014), have examined the dynamics of urban sprawl. Olurin (2003) noted that the effects of population dynamics in African cities have led to significant hardships that are often difficult to articulate, as many major cities on the continent struggle with the challenges of rapidly deteriorating physical and living environments. Poor urban planning has been identified as a critical factor undermining both sustainable development and the creation of healthy living conditions in Africa (UN-Habitat, 2010). In Northern Africa, urban growth is characterized by the overcrowding of low-income neighbourhoods in cities such as Cairo, Tripoli, Rabat, and Tunis. In West Africa, urban sprawl is prevalent in major cities and medium-sized towns, including Lagos, Kumasi, Karu, Ibadan, Oshogbo, and Lomé, among others. East Africa remains the least urbanized sub region; however, cities like Nairobi and Dar es Salaam have experienced significant annual growth, indicative of spatial expansion and a high rate of urban sprawl.

Central Africa is witnessing a rapid increase in urban populations, leading to the expansion of cities into peri-urban areas across the region (UN-Habitat, 2011). The drive for affordable housing and land values has drawn many individuals to satellite cities, as well as suburban neighbourhoods across Africa. According to UN-Habitat (2011), several factors beyond residents' preferences for suburban lifestyles have contributed to the spatial expansion of cities in Africa. These factors include ineffective land regulation systems, weak planning controls, and inadequate management of peri-urban areas, land speculation, improvements in commuting infrastructure and services, and increased population mobility. The sprawling characteristics of numerous cities and towns in Nigeria have garnered attention from various scholars (Okewole, 2002; Olujimi, 2009; Alabi, 2009; Aguda and Adegboyega, 2013). These studies largely attribute the unregulated and chaotic urban expansion observed in many Nigerian cities and medium-sized towns to the rapid pace of urbanization. Research focusing on cities such as Lagos, Ibadan, Oshogbo, Akure, Ilorin, Ogbomosho, Enugu, Kano, Kaduna, Abuja, and Lokoja has highlighted these trends. The urbanization process in Nigeria has been primarily driven by socio-political changes, economic advancements, and demographic transformations, which have collectively contributed to urban sprawl. The growth of peri-urban areas is primarily driven by the increasing population in cities, which has intensified pressure on surrounding peri-urban regions. Olujimi (2009) indicated that economic factors and innovations in housing development significantly impact the construction of self-owned homes and commercial shops in suburban areas. Furthermore, land developed without proper layout plans or building approvals, leading to disorganized suburban growth that can eventually evolve into slum areas.

Material and Method

Minna (see Figure 6) is the capital of Niger State, one of Nigeria's 36 states, located in West Africa. Situated about 150 km northwest of Abuja, it spans the Chanchaga and Bosso local government areas and covers approximately 6,789 square kilometers, with a population density of 34.48 persons per square kilometer (NISEPA, 2020). Its population grew from 345,000 in 2016 to 439,612 by 2019. The city has 26 administrative wards, up from six in 1957, comprising both core and peri-urban areas. Rapid urban growth has outpaced the provisions of the 1979 Master Plan, resulting in unplanned expansion. Minna's historical growth was shaped by key infrastructural developments. The arrival of the railway in 1905 connected the city to major trade routes in Northern Nigeria and established it as a key collection point for agricultural produce. The transfer of colonial officials from Bida in 1924 elevated its status to Regional Administrative Headquarters (Morenikeji et al., 2015). The construction of the Zungeru–Paiko road in 1928 further supported urban expansion. Pre-independence infrastructure, including the Bosso Dam (1949) and electricity supply (1956), attracted more settlers and spurred population growth. Following Nigeria's independence in 1960 and Minna's designation as the capital of Niger State in 1976, the city gained political and economic significance, accelerating its spatial and social development.

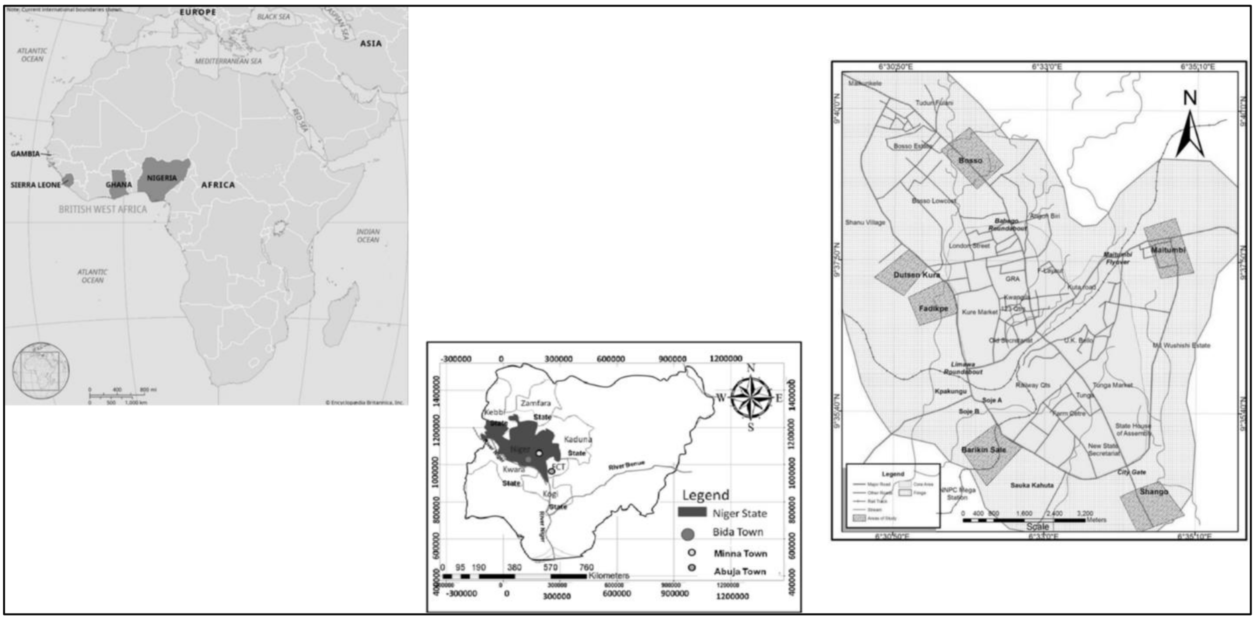


Figure 5: Minna in the Context of Africa, Nigeria and Niger State
Source: Adapted and modified from Chado, Johar and Muhammad (2016), Abdullahi and Olatunde (2017).

The data acquisition phase involved collecting a comprehensive set of satellite images covering the period from 1972 to 2015 to enable a long-term analysis of land use changes. Alongside these images, topographic maps and administrative boundary data were obtained to provide geographic context and ensure accurate spatial referencing. To enrich the analysis and better understand the factors influencing land use change, additional ancillary data such as road networks, land use records, and infrastructure development plans were also gathered. These datasets collectively supported a multidimensional understanding of urban growth and landscape transformation over time.

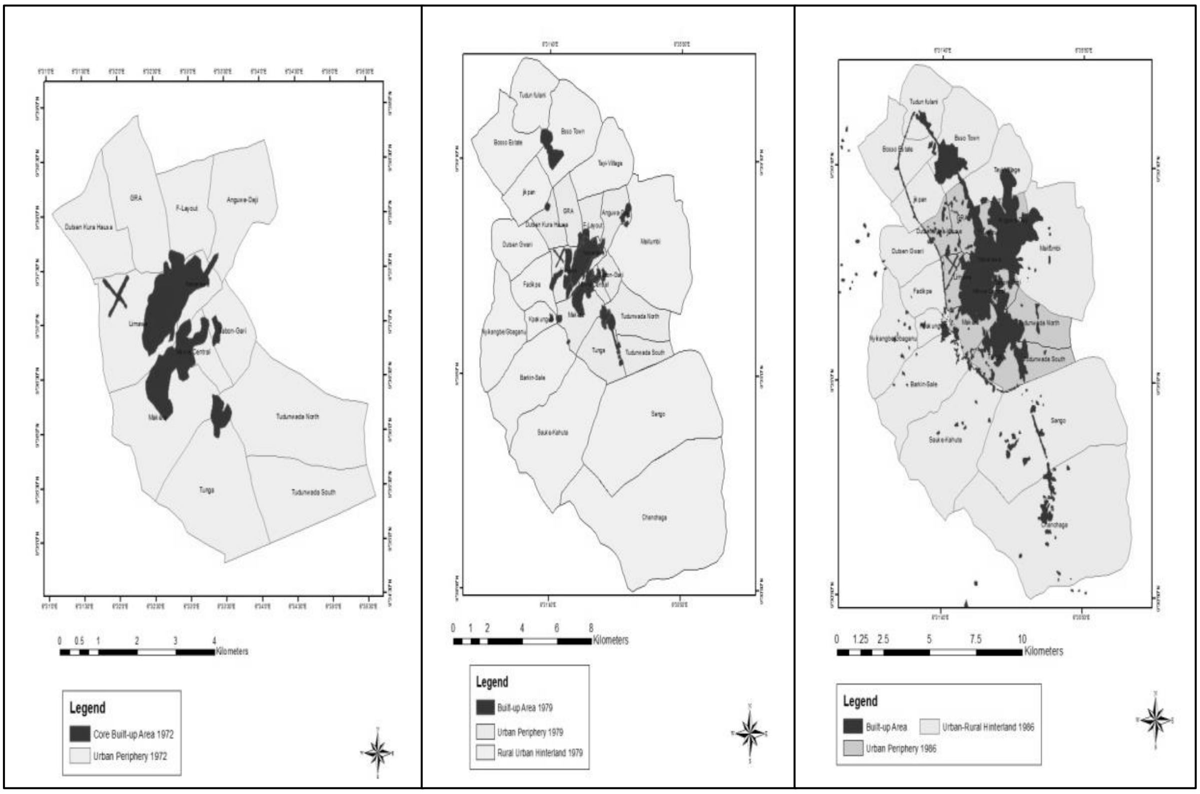
During the image pre-processing stage, the raw satellite images were standardized through a series of steps including image compositing, which merges multiple images to create a seamless representation, and boundary clipping, which confines the data to the specific study area to eliminate irrelevant regions. The processed images were then subjected to a supervised classification technique to identify and categorize land cover types. This classification segmented the landscape into three primary categories: built-up areas, vegetation, and water bodies, reflecting the major land use types relevant to urban expansion analysis. To assess the reliability and accuracy of this classification, an accuracy assessment was conducted. Following the methodology of Roissiter (2004) and Ajiboye et al. (2022), the classified images were rigorously compared with ground verification data. For this purpose, 150 reference points, carefully selected across various land use types, were identified using Google Earth Pro 2021 to serve as validation benchmarks. The resulting accuracy evaluation employed a confusion matrix approach, which yielded classification accuracy rates of ranging from 87% to 89.5%. This range reflects a consistently high level of precision in the land use classification throughout the study period.

Subsequently, change detection analysis was performed through post-classification comparison, which involved comparing classified images from different years to identify and quantify changes in land cover over time. This step produced change maps that visually illustrated the spatial and temporal patterns of built-up area expansion throughout the study period. The analysis also enabled the identification of predominant directions in which urban areas expanded, offering insights into the nature of urban growth. To further understand these patterns, spatial pattern analysis was conducted by overlaying urban sprawl layers from multiple years. This comparative layering technique allowed for a detailed examination of how urban growth evolved spatially, revealing trends, hotspots, and the overall dynamics of land use transformation. Together, these methods provided a robust and comprehensive framework for understanding the processes and implications of urban development within the study area.

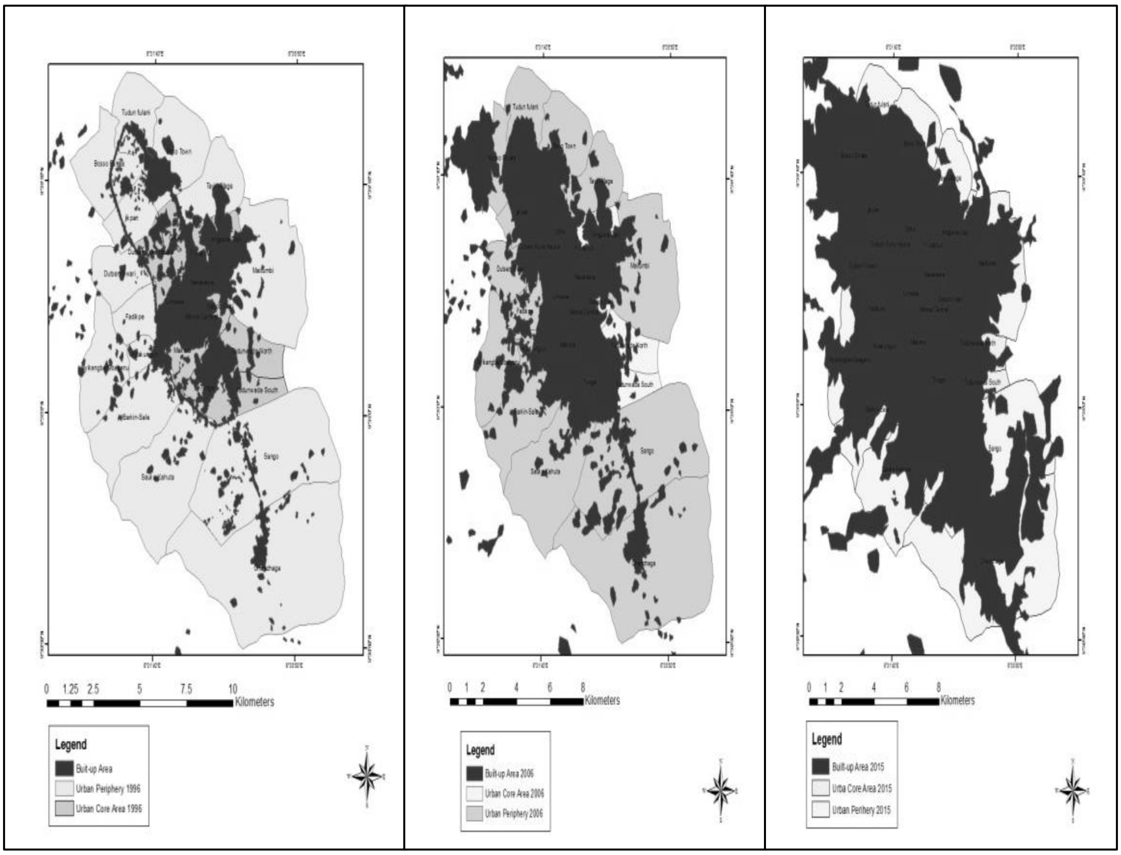
Urban Sprawl in Minna, Nigeria (1972-2015)

Idowu et al. (2020) documented the gradual expansion of urban sprawl in Minna from 1972 to 2015 (Figures 6, 7, 8 and 9). In 1972, Minna was primarily centred on the railway station, with the built-up area limited to the densely populated settlement near the station. The surrounding residential neighbourhoods included Limawa, Makera, Nasarawa, Tudunwada, and Old GRA. The identified peri-urban areas were Limawa, Makera, Angwa-Daji, Dutsen-Kura Hausa, New GRA, Tunga, F-Layout, and the airport road (Figure 5). Figure 6 illustrates four key settlements within Minna's peri-urban area in 1979: Bosso to the north, Tudunwada to the south, Maitumbi to the east, and Kpakungun to the west. These neighbourhoods served as anchors for the further expansion of Minna's peri-urban area, which was significantly influenced by Minna's designation as the administrative capital of Niger State in 1976, resulting in rapid growth.

Figure 6 illustrates Minna's development in 1986. Between 1979 and 1986, satellite settlements situated farther from the core area began to expand toward it, benefiting from newly constructed roads that linked the core area to affordable housing estates. The placement and distribution of government projects in Minna during this period were vital to its development. The growth of Minna's peri-urban area continued, albeit at a slower pace (see Figure 6). Between 1986 and 1996, a trend of dispersed development emerged outside the core area, characterized by a linear strip pattern along major highways and access roads. Neighbourhoods such as Tudunwada, Tunga, F-Layout, and GRA expanded toward the core, while areas like Bosso Town, Tayi Village, Kpakungun, and Chanchaga developed in various directions. Figure 7 illustrates the sprawl development of Minna in 2006. At that time, Minna appeared as a spatially clustered city, with significant integration between the peri-urban and core areas. The neighbourhoods affected included Tudun-Fulani, Bosso Town, Tayi Village, Kpakungun, Dutsen Kura-Gwari, Jikpan, and Bosso Estate. By 2015, the peri-urban area of Minna had undergone significant growth (Figure 7), prompting Orintunsin (2014) to characterize it as a highly cosmopolitan community. This expansion of Minna's peri-urban neighbourhoods diverged from the typical growth patterns observed in northern Nigerian cities, with access to land for various uses identified as a crucial factor in this development.



Figures 6. Land Use and Urban Growth in Minna (1972, 1979, and 1986).



Figures 7. Land Use and Urban Growth in Minna (1996, 2006, and 2015)

The map overlay illustrating the spatial development of Minna (Figure 8) reveals a striking and progressive pattern of urban expansion over several decades. In 1972, the town's developed area had already experienced a notable increase, reportedly expanding to thirty-two times its original size. By 1979, this growth had slowed but remained significant, with the urban footprint reaching thirteen times its previous extent. A more moderate pace of expansion was recorded in 1986 and 1996, with each period showing a threefold increase. By 2006, the town's developed area had doubled yet again. These figures underscore not only a rapid and sustained pace of urbanization but also changing phases of development, likely influenced by socio-economic factors, migration, and policy shifts. The continued expansion reflects a combination of population growth, infrastructural investment, changing land use needs, and increasing demand for residential, institutional, and commercial spaces. The spatial overlay provides a visual narrative of this transformation, showing how once outlying areas have been absorbed into the city's fabric and how Minna has evolved from a compact settlement into a sprawling urban center.

Figure 9 further highlights the directional trend of this urban expansion, revealing that Minna has been growing predominantly towards the west. This westward expansion is not random but strongly influenced by the strategic siting of key institutional and infrastructural assets in that direction. Most notably, the location of the permanent site of the Federal University of Technology, Minna, and the headquarters of the National Examinations Council (NECO) in the western part of the city has acted as a magnet for residential development, commercial activity, and service provision. These institutions have created employment opportunities, increased human traffic, and spurred demand for land and infrastructure in their vicinity. The westward movement is further enabled by the construction of a major western bypass, a critical piece of infrastructure intended to enhance vehicular circulation and regional access. This bypass incorporates two major flyovers, strategically built over the railway lines and the River Suka, both of which previously served as physical barriers to movement and development. By linking the western neighborhoods to the Minna–Bida road, this corridor has not only facilitated expansion but has also helped integrate emerging urban areas into the city's broader transport and economic network. As a result, Minna's growth has become increasingly structured and directional, shaped by both planned interventions and organic responses to institutional presence and infrastructural availability.

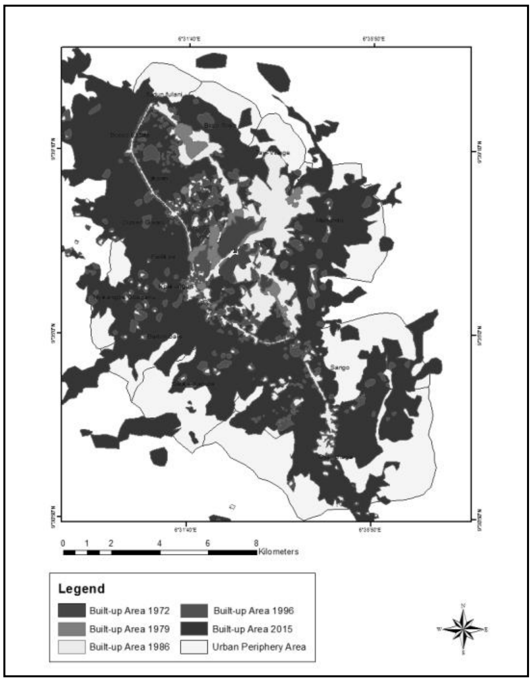


Figure 8: Changes in the Built-up Area of Minna 1972 – 2015.

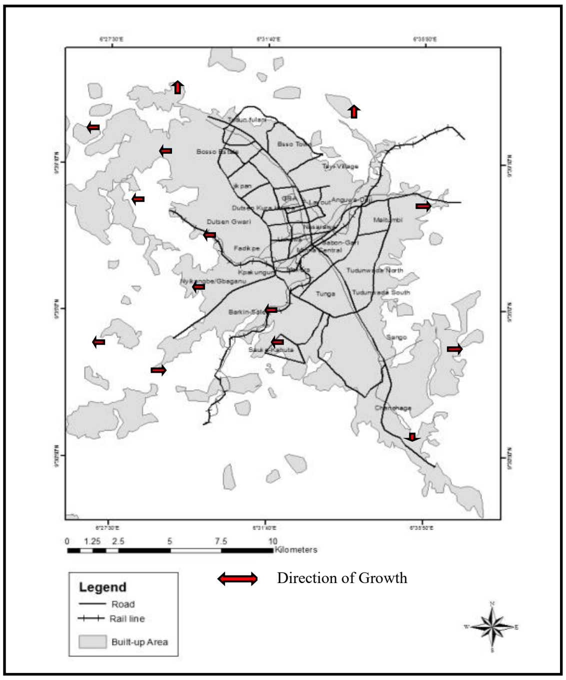


Figure 9. The Direction of Peri-urban Growth in Minna.

Conclusion and Recommendations

This article examined the concept of urban sprawl, emphasizing the debates surrounding its definition and manifestations in both scholarly literature and real-world contexts. The discussion highlights that while the term "urban sprawl" is widely used in planning discourse, there remains no universally accepted definition. Instead, it is often characterized by a range of ambiguous features that reflect both the causes and consequences of unplanned urban expansion. The article also explored the relevance of classical descriptive and revised descriptive theories in interpreting the spatial formation and dynamics of urban sprawl, offering insight into how various urban forms emerge and evolve over time under different socio-economic and political conditions. In the context of Nigeria, and particularly in Minna, urban sprawl is predominantly linked to weak regulatory frameworks and the absence of coordinated planning, leading to unregulated and disorganized development patterns. The growth of peri-urban areas in Minna reflects a reactive rather than proactive planning approach, where economic forces, population pressure, and informal land transactions shape urban expansion with little oversight. To address these challenges, it is essential that the planning and development of urban areas and their fringes are not left to chance or dictated solely by market dynamics. Instead, deliberate and strategic urban management policies should be implemented to guide orderly growth and prevent the negative consequences of sprawl, such as congestion, environmental degradation, and inefficient infrastructure delivery. A sustainable planning approach is especially crucial for managing the expansion of peri-urban neighborhoods, ensuring they are integrated into the urban system with adequate services and infrastructure. Furthermore, formalizing customary land titles and streamlining land registration processes in Minna should be prioritized, as this would enhance land tenure security, encourage planned development, and reduce land-related conflicts. Such efforts will contribute to a more equitable and sustainable urban future for Minna and similar cities across Nigeria.

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Conflict of Interests

The authors declare no conflict of interest.

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Chapter 7

Lost Spaces, Lost Learning: Towards Urban Interventions to Address Educational Disparities in Low-Income Communities in Phnom Penh, Cambodia

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Introduction

Education is widely acknowledged as a critical driver of development and prosperity in the ASEAN region. However, disparities in access and quality persist across countries, income groups, and genders. While progress has been made in educational standards, there is a pressing need to shift from traditional rote-learning methods to approaches that promote autonomous learning, creativity, and problem-solving. Rote learning, which emphasizes memorization over understanding, is increasingly seen as outdated and insufficient in preparing students for real-world challenges. In contrast, experiential, inquiry-based, and active learning approaches rooted in the science of teaching and learning foster critical thinking and deeper engagement. These methods require supportive environments and collaborative spaces that allow children to explore, question, and construct knowledge with others, rather than passively receive information. Learning poverty rates, which reflect the percentage of children unable to read or write by the age of ten, vary significantly, with Cambodia at 51%, a disparity exacerbated by the COVID-19 pandemic (ASEAN, 2022).

UNICEF defines lifelong learning as a continuous process that begins in early childhood and extends throughout life, encompassing formal, non-formal, and informal learning opportunities. It emphasizes the development of a broad set of skills, including cognitive, social, emotional, and practical skills, that empower individuals to adapt and thrive in an ever-changing world (UNICEF, 2019). In parallel, UNESCO's Learning City initiative promotes cities by integrating educational policies with broader urban development strategies, cities can foster a culture of continuous learning, ultimately improving the long-term prospects of their populations (ASEAN, 2022), and mobilizing resources across all sectors to foster inclusive learning for people of all ages. A Learning City ensures equitable access to quality education, revitalizes learning in families and communities, and creates environments that support learning in workplaces and through digital platforms (UNESCO, 2015). Both initiatives highlight the importance of inclusive, flexible, and community-centered education strategies, particularly in urban areas, where spatial planning, public infrastructure, and community engagement can play a crucial role in enabling access to lifelong learning for marginalized groups, including children in low-income communities.

Global Issues

The majority of the global population lives in urban centres. Of the 4 billion people living in urban areas today, nearly a third of them are children. It is estimated that by 2050, almost 70 % of the world's children will live in urban areas, many of them in slums (UNICEF, 2023). Millions more make the move each month, many end up in slums or informal settlements. An estimated 350 – 500 million children live in slums, with limited access to essential services like health care, education, and sanitation (UNICEF, 2022).

Around the world, 258.4 million, or 17 per cent of the world's children, adolescents and youth, are out of school. The proportion is much larger in developing countries: 31 per cent in sub-Saharan Africa and 21 per cent in Central

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Asia, vs. 3 per cent in Europe and North America. (UNESCO, 2019). Additionally, 39.7% of the urban population lives in slums. Share of households living below the updated national poverty rate is at 17.8% and 22.8% in urban and rural areas, respectively (UN-Habitat, 2023). Among children, 44.2% are classified as multidimensionally poor, facing an average of 3.6 out of five deprivations, underscoring the deep challenges of poverty and inequality in urban environments (UNICEF, 2014). Children aged 5-14 years, 44 per cent of children are classified as multidimensionally poor, meaning they are deprived not just in income, but across multiple basic needs. According to UNICEF (2014), this classification is based on five key dimensions: education, health, nutrition, housing, and access to clean water and sanitation. On average, these children experience 3.6 deprivations out of 5, highlighting the complex and overlapping barriers they face in achieving a decent quality of life. This multidimensional approach goes beyond income to reflect the real, lived experiences of poverty, especially in urban low-income communities.

Challenges-Cambodia

Phnom Penh's low-income communities face significant challenges, including overcrowding, poor infrastructure, and a lack of public spaces, exacerbating the struggles of children living there (Plack et al., 2024). Children in these areas often lack proper learning spaces, limiting their development, while child labor and unsafe conditions further restrict their educational opportunities (UNICEF, 2018). Government policies frequently fail to address the educational needs of poor children, and long physical distances to schools act as additional barriers to access (UNICEF, 2011). According to UNESCO (2021), Cambodia ranks highest in terms of out-of-school children for primary school (6-11 years old) and upper secondary school-age (14-18 years old) children.

Urban poverty, spatial inequality, and limited infrastructure are recurring themes in the literature on educational disparities in Southeast Asian cities. A review of existing studies reveals that children in low-income urban communities face multiple overlapping barriers to education, including financial problems, child labor, school dropout, unsafe environments, and inaccessible infrastructure. These challenges are deeply rooted in both socio-economic and spatial factors, and they directly affect children's physical mobility, learning outcomes, and emotional well-being. This literature review aims to explore how these factors interact within the urban context of Phnom Penh City. The following sections will examine key issues found in the literature: the impact of household income on education, including child labor and school dropout; space limitations and lack of accessibility; infrastructure and safety issues; gaps in child-focused urban planning; the scale and experience of urban childhoods; and specific child safety challenges in Cambodia. Together, these themes form the foundation for understanding how urban conditions shape educational inequality and point to the need for child-responsive urban interventions.

The Issue of Household Income-Cambodia

Child Labor

About 54.6% of parents of out-of-school adolescents wish for their children to pursue education but are hindered by financial constraints, with 21.7% unable to afford private schooling, often seen as a better option in underfunded public systems (UNICEF, 2018). Many families prioritize immediate income needs, pushing children into the workforce over education, highlighting the link between poverty, education access, and difficult family decisions (UNICEF, 2018).

Poverty is the primary driver behind child labor. Low levels of income in the capital’s urban poor communities often force children to acquire jobs to contribute to household income (UNICEF, 2018). Integration of these children into regular schooling becomes challenging as they get used to being financially independent. Children are mostly employed in the informal sector, which largely remains outside the purview of government regulation. (UNICEF, 2018).

Figure 1. Children Collecting Recyclables on an Urban Road in Phnom Penh (Pictured by author).

School Dropouts

Of the adolescents currently out of school, 87.5 percent stated that they had previously attended school. The lack of attention from teachers, as well as the need to pay informal fees to teachers, emerged as important barriers to enrolment and continuous participation in schools (UNICEF, 2018).

Already living below the poverty line, parents cannot afford to pay an informal fee. Discussions with community members revealed that teachers often only tend to pay attention to students during extra classes for which they charge a fee. Unable to obtain this money (often up to the value of 10,000 Cambodian riels or US$2.50 a month), adolescents from poor families tend to start to fall behind on education and subsequently drop out of school (UNICEF, 2018).

Child Marriage

About 42.9 percent of families that reported child marriages claim that they got the adolescent married because of societal pressure and to align with the family's traditions/beliefs (UNICEF, 2018), and 35.7 percent claimed that the marriage took place because of the couple's desire to get married and 21.4 percent got their children married before the age of 18 because the girl had gotten pregnant (UNICEF, 2018).

Space Limitations and the Lack of Accessibility

Safety

17.8 percent of the children's families reported that they were aware of a case where an adolescent from the community was missing from home. Missing children are often at risk of trafficking, as seen by the fact that within Phnom Penh's urban poor communities, about 42.2 percent of families reported that they believe that missing children are susceptible to trafficking, and 30.5 percent believe that missing adolescents are at risk (UNICEF, 2018).

Travel Distance

A long distance between home and school can compound the effects of poverty, with poor households often unable to cover the cost of transportation (Chitondo, 2022). According to parents, the reasons for dropping out during primary education include the high cost of schooling, the poor quality of services, and long travel distances to school (World Bank, 2018).

Moreover, traffic-related safety concerns can impact decisions to walk or bicycle. When more children are driven, more parents become convinced that traffic conditions are unsafe for walking or bicycling. Fifty-five percent of parents who reported not allowing their children to walk or bicycle to school identified the number of cars along the route to school as a significant issue in their decision-making process (WBTS, 2021).

Infrastructure and Safety Issues

The sidewalks are often occupied by illegally parked vehicles, outdoor café seating, merchandise displays, and planters. This makes it difficult and sometimes dangerous for pedestrians to walk on the sidewalks. As a result, people have little alternative but to take a walk on the roadways, making such circumstances extremely unsafe for pedestrians and more vulnerable for children (Saphan, 2007, 238ff.).

Pedestrians, including schoolchildren, are particularly vulnerable to traffic accidents. In 2011, pedestrians accounted for 13% of traffic fatalities in Phnom Penh, with a rise in pedestrian fatalities over the years. The lack of dedicated pedestrian lanes and safe crossings exacerbates these risks (Handicap International, 2011).

Urban Planning Principles

Urban planning often overlooks the specific needs of children because of outmoded thinking that children are not capable of contributing to urban development (UN-Habitat, 2020).

Urban planning shapes how children live, learn, and grow. UNICEF (2018) emphasizes that integrating children's rights into city planning creates inclusive, sustainable spaces for all. This approach aligns with the New Urban Agenda (NUA), which calls for strengthening the capacity of governments at all levels to work with vulnerable groups, including children and youth, in shaping urban development. NUA Article 148 specifically promotes inclusive governance by ensuring that children, along with women, older persons, persons with disabilities, and local communities, are meaningfully included in decision-making processes related to urban and territorial planning. This principle reinforces the importance of this research, which explores how the exclusion of children's needs in urban planning contributes to educational disparities and limits opportunities for learning and growth (UN-Habitat, 2017).

Sustainable infrastructure, water, sanitation, food security, waste management, and clean energy support health and environmental stability (UNICEF, 2018). Digital connectivity is also vital for education and social inclusion (UNICEF, 2018). This is reinforced by the New Urban Agenda (NUA), which promotes the development of inclusive digital governance tools and ICT policies to ensure access for all, including children and youth (UN-Habitat, 2017). By encouraging the use of digital platforms such as geospatial information systems, the NUA highlights how technology can support more inclusive urban planning and improve access to services, critical for marginalized communities where digital access can help bridge educational and social gaps.

Prioritizing these elements in urban planning ensures cities where children and communities can truly thrive (UNICEF, 2018). This vision is supported by the New Urban Agenda, which emphasizes capacity-development initiatives to empower and strengthen the skills of women and girls, children and youth, enabling them to actively shape the urban environments they live in (UN-Habitat, 2017).

Together, UNICEF's advocacy for child-inclusive urban development and the New Urban Agenda's commitment to participatory and equitable planning reflect a shared vision. Both frameworks emphasize the importance of integrating children's rights, digital access, and community participation into the planning process. Their alignment underscores a growing global initiative to create cities that are not only inclusive and sustainable but also responsive to the specific needs of children and vulnerable groups.

Space and Scale of Urban Childhoods

Child-responsive urban planning is crucial for ensuring inclusive and sustainable cities. Urban spaces must cater to children's developmental needs, integrating accessibility, mobility, and social inclusion (UNICEF, 2018).

According to UNICEF(2018), the key principles in Shaping Urbanization For Children include:

Human-scaled Urban Design: Cities should provide age-appropriate services across home, street, neighborhood, and city levels, yet many lack a human-centered design.

Proximity & Walkability: Public amenities should be within walking distance, but car-oriented planning has reduced safe mobility options.

Public Space: Outdoor areas should foster play, social interaction, and economic engagement to support children's well-being.

Mixed-Use Development: Essential services, education, healthcare, and economic activities must be integrated into neighborhoods.

Independent Mobility: Safe walking, cycling, and public transport options enable autonomy, benefiting the wider community.

Neglecting child-friendly urbanization leads to poorly serviced, segregated areas, impacting long-term social and economic outcomes. A child-focused or responsive approach to designing cities enhances sustainability and equity in urban environments (UNICEF, 2018) and "will meet the needs not only of families but also other vulnerable populations like women and older persons" (UN-Habitat, 2020).

Gaps

The disparities discussed manifest as significant gaps in the academic achievement of children living in slums or low-income areas. The lack of learning spaces contributes to lower enrollment rates, high dropout rates, poor academic performance, and limited access to quality education. Children in low-income communities are often forced to work or support their families, further limiting their opportunities for education. Poor infrastructure, including unsafe areas and inadequate school access routes, compromises children's safety and discourages school attendance. Studies across different contexts support this pattern. For example, in South Asia and Sub-Saharan Africa, children in poverty face significant challenges transitioning to secondary school, often dropping out early due to cost, distance, and discrimination (Lewin & Little, 2011). Research in Colombia shows that credit and loan programs can improve higher education access and reduce dropout rates for low-income students (Melguizo et al., 2015). In the U.S., low-income Black and Hispanic children have benefited from nature-based environmental education, which not only improves academic outcomes but also supports physical and mental well-being (Sprague et al., 2020). In early childhood education, social justice approaches are found to support greater inclusion of financially disadvantaged families (Fenech & Skattebol, 2019). These studies highlight that while conditions differ globally, the barriers to education for poor children are strikingly similar, underscoring the importance of safe infrastructure, inclusive policies, and community support to ensure educational access.

Research Framework

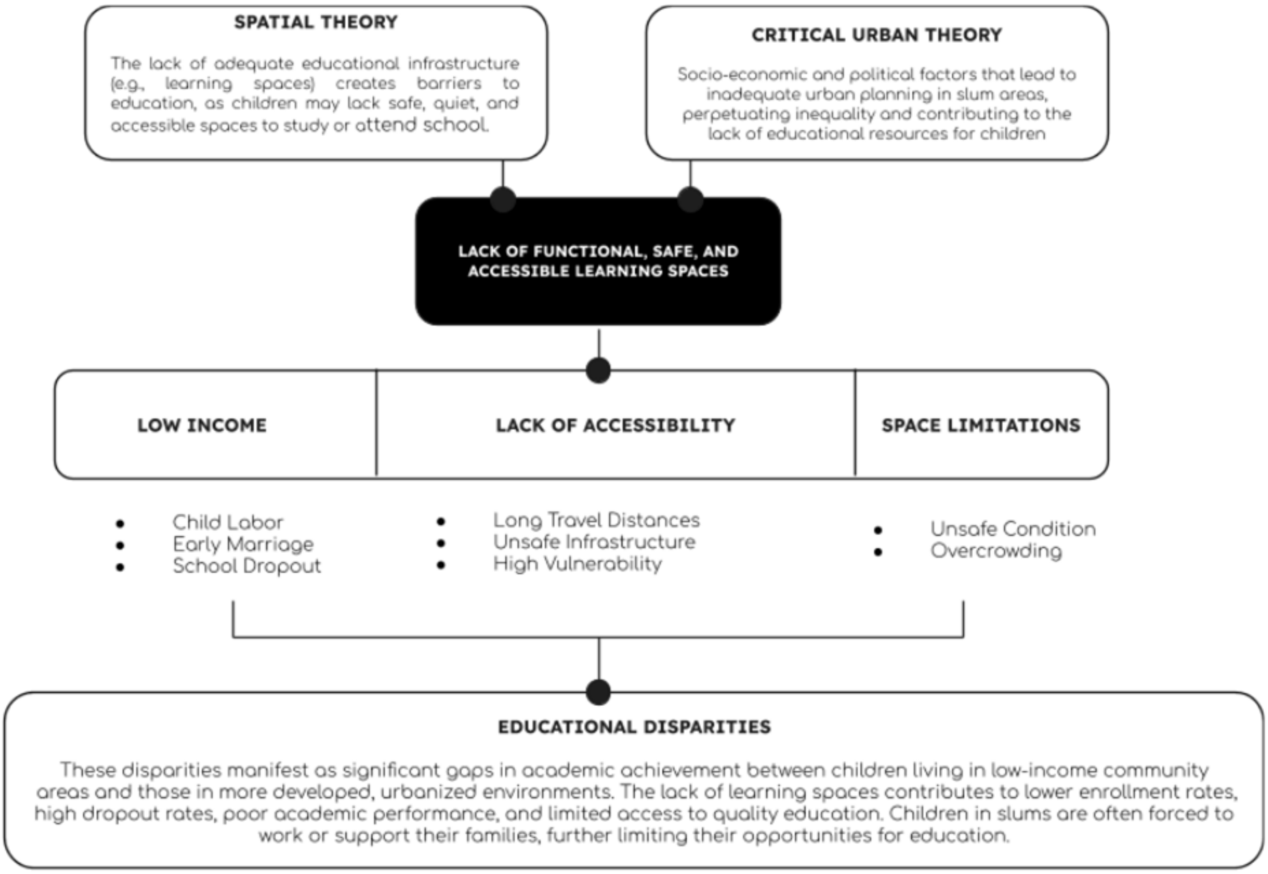

Figure 2. Conceptual Framework of Spatial and Critical Urban Factors Leading to Educational Disparities in Low-Income Communities (Framework by author).

This conceptual framework highlights how educational disparities among children in poor communities stem from three interconnected factors: low income, space limitations, and lack of accessibility. Low income forces children into child labor, early marriage, and school dropout, while inadequate space creates unsafe and overcrowded living conditions that hinder learning. Additionally, poor accessibility, characterized by long travel distances, unsafe infrastructure, and high vulnerability to accidents, further limits access to education. These challenges converge to create a lack of functional learning spaces, defined as safe and accessible environments essential for education. Grounded in spatial theory and critical urban theory, the framework underscores how inadequate urban planning and socio-economic inequities perpetuate these disparities. It calls for integrated solutions, including urban design interventions and policy reforms, to create equitable educational opportunities for children in low-income communities. and to enhance children's Right to the City. Every child has every right, as recognized in the UN Convention on the Rights of the Child (UNICEF, 2021).

Research Question

How does spatial and urban factors impact access to learning in Cambodian low-income communities & how can urban design address the inequalities?

Research Objectives

- To identify the spatial and urban factors contributing to challenges in access to learning in Cambodian low-income communities.
- To propose urban intervention approaches to address the issues causing educational disparities.

Research Flow

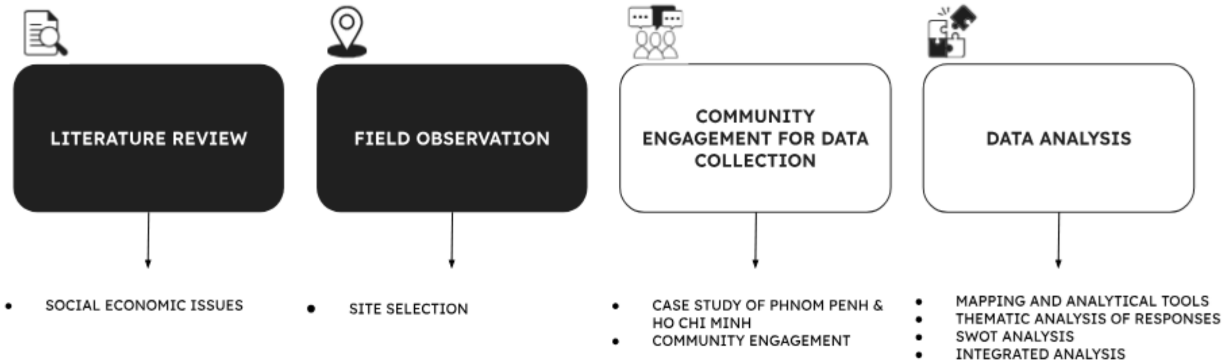

Figure 3. Research Flow from Literature Review to Data Analysis (Diagram by author).

Methodology

Asking children how they go to school, the obstacles they face, their fear of going to school alone, and the factors that influence their travel experience can help us understand and improve their journey.

Children draw on their experiences to school, highlighting the challenges they encounter. These drawings serve as a powerful tool for understanding the emotional and practical difficulties children face on their way to school, offering valuable insights for improving their safety and well-being.

Thematic analysis of interview responses to identify common problems and explore the opportunities for solutions.

Findings

Phnom Penh Case Studies

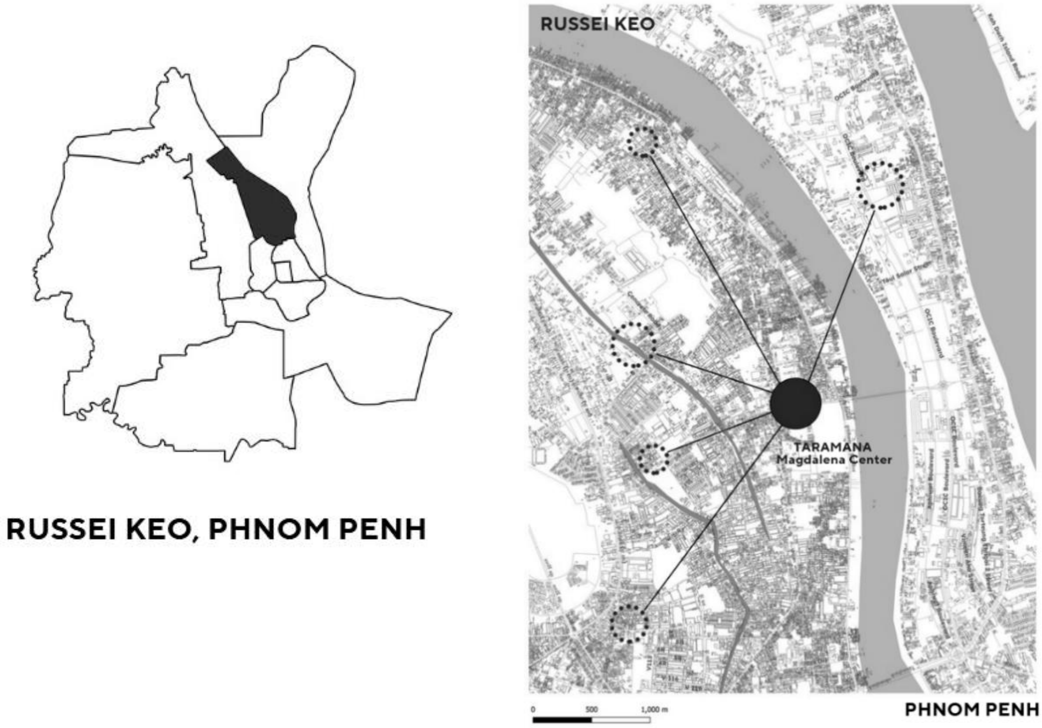

Figure 4. Location of Case Study Areas in Phnom Penh (Developed by author).

Taramana in Cambodia was selected as case studies due to their contrasting urban contexts and approaches to child-responsive urban planning. Taramana highlights the challenges faced by marginalized children in underserved urban areas, demonstrating the role of localized interventions in improving educational access and social inclusion. By analyzing these cases, this study aims to compare how different urban settings impact child-friendly development and identify effective strategies for fostering inclusive urban environments.

Data Collection

Figure 5. Field-Based Data Collection Activities at Taramana Center in Phnom Penh (Conducted by author).

Taramana was selected as the case study site in Phnom Penh because it works directly with children from underserved urban communities in Phnom Penh, a neighborhood facing serious issues related to poverty, poor infrastructure, and limited access to education. Unlike formal schools, Taramana acts as a supplementary learning center for children who are often at risk of dropping out due to economic pressures, long travel distances, or unsafe environments.

Children actively participate in various research activities, including drawing, answering interview questions, and engaging in classroom-based discussions. The activities aimed to understand children's daily experiences and mobility patterns through participatory and child-friendly methods. These activities highlight both group sessions and individual interactions, emphasizing an inclusive, hands-on research approach centered on children's voices.

Participants Profile

Table 1. Participant Profile of Children from the Taramana Community Center, Phnom Penh (Developed by the author)

No.	Name	Age	Grade	Boy/Girl
1	Vin Monychansursdey	12	6	Girl
2	Nan Sreyleak	12	5	Girl
3	Sang Sokheng	11	5	Boy
4	Khiev Chan meta	11	5	Girl
5	Hong Bunheng	11	5	Boy
6	Ly Rosana	12	6	Girl
7	LyReaksmey Moninich	12	6	Girl
8	Choung Vibol	11	5	Boy
9	Sovan Kanha	12	5	Girl
10	Ang Sok Reasksa	11	5	Girl
11	Phanara Sophalen	12	5	Girl
12	Hang Sreychu	11	5	Girl
13	Treng Sereyvuth	10	5	Boy
14	Sovan Sreyka	10	5	Girl
15	Kosal Dalis	10	5	Girl

Gender	Age Group
Boys	4
Girls	11
Total	15

The table presents demographic data on 15 students surveyed. The students range in age from 10 to 12 years old and are enrolled in grades 5 and 6. There is a higher proportion of girls (11) than boys (4) in this group, as seen in the table, which categorizes the students by age and gender, showing that the majority are girls.

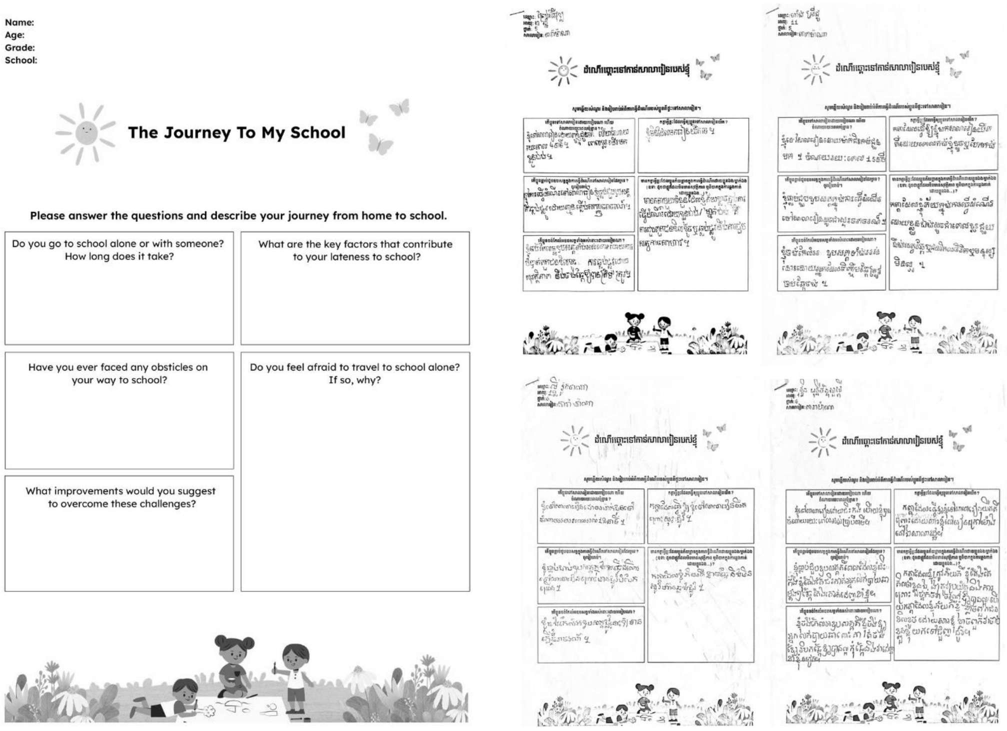

Figure 6. Child-Completed Survey on Home to School Journey (Organized by the author).

The form asked simple and open-ended questions about who they travel with, what delays them, what kind of obstacles they face, and what they wish could be better. The answers, written in Khmer, were where students described their daily commute from home to school. They described who they travel with, what makes them late, the obstacles they face, and some common issues raised were poor roads, lack of sidewalks, or being forced to walk in unsafe areas. What stood out most was how many of them had ideas to fix it, like safer sidewalks, more lights, school buses, or even security near their routes. These surveys didn't just collect data, they gave space for children to speak honestly about what their school journey feels like. It showed that physical safety and emotional comfort are equally important when thinking about access to education. These responses were later transformed into drawings during the experiential mapping activity, helping visualize their emotions, fears, and everyday realities.

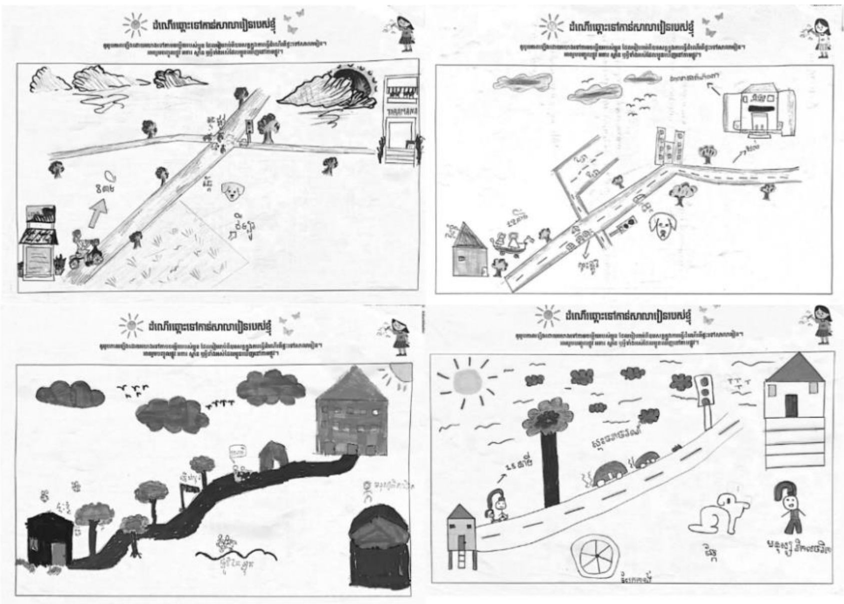

Figure 7. Experiential Mapping by Children Illustrating Daily Commutes to School (Organized by the author).

In Phnom Penh, the most significant safety concern is aggressive dogs, followed by heavy and chaotic traffic, where cars, tuk-tuks, and motorcycles fail to maintain safe distances. Additionally, the threatening behavior of certain passers-by, particularly individuals with mental health issues or those under the influence of alcohol or drugs, further contributes to unsafe public space conditions. These factors collectively create a hazardous environment, especially for vulnerable populations such as children.

The children's drawings also reveal deep feelings of fear and discomfort, with many maps emphasizing isolated roads, dark alleyways, and areas where they feel unsafe walking alone. Most routes lack proper sidewalks, traffic signals, or any visible safety infrastructure, leaving children to navigate busy and poorly managed roads. Moreover, their illustrations highlight the physical and emotional burden of long travel distances, often marked with estimated walking times, reflecting their awareness of how time-consuming and tiring these commutes are. Despite these risks, the children's ability to clearly represent their environment through experiential mapping underscores their strong spatial awareness and the need for urban interventions that prioritize their safety and accessibility.

Thematic Analysis of Common Issues

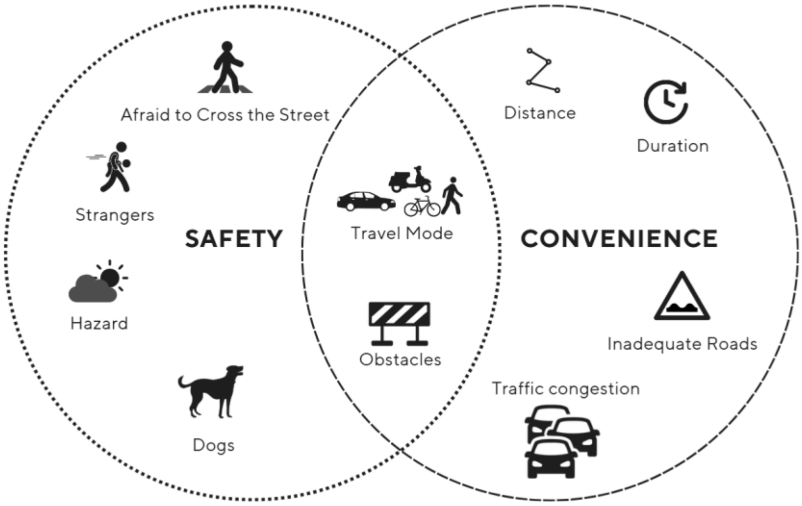

Figure 8. Thematic Analysis of Safety and Convenience Issues in Cambodian Children's School Commutes (Developed by the author).

Key issues children face on their school journeys in Phnom Penh, categorized into two overlapping themes: safety and convenience. On the safety side, children expressed fear of crossing the street, encounters with strangers, physical hazards, and aggressive dogs, factors that make them feel constantly vulnerable. These are not just physical dangers but are deeply tied to emotional stress. On the convenience side, long distances, extended travel durations, inadequate road conditions, and traffic congestion make daily commutes tiring and unpredictable. In between these two themes, shared concerns like the mode of transport and physical obstacles reflect how safety and convenience often intersect. For example, walking or biking on narrow, broken roads without sidewalks poses both danger and discomfort. This thematic breakdown reinforces how urban neglect affects not just infrastructure but children's sense of well-being.

Table 2. Summary of Issues in Cambodian Children's School Commutes (Developed by the author).

Issues	
Long Commutes	Long distances to schools, especially for low-income communities
Traffic Congestion	Dense urban traffic creates barriers to safe and timely travel
Unsafe Infrastructure	Poor road quality, encroached sidewalks, lack of pedestrian space
Lack of Child-Safe Design	Limited urban planning for children's needs
Poverty & Education	Child labor, dropout due to informal fees, and inaccessible quality schooling
Psychosocial Fear	Fear of strangers, mental health-related threats, and stray dogs
Urban Planning Engagement	Children's urban needs are often neglected in planning
Child Labor & Dropout	Widespread, poverty-driven, informal school fees, children entering informal jobs

This study highlights several shared urban challenges, including the lack of child-responsive design in urban environments and unsafe urban mobility that negatively affects school access and attendance. Educational disparities are further driven by factors such as poverty, inadequate infrastructure, and weak urban planning. These issues underline the urgent need for integrated solutions across urban design, policy, and infrastructure to ensure equitable access to education for all children.

Affirming and Extending the Literature

The literature, including reports from UNICEF (2018, 2023) and the World Bank (2020), consistently highlights poverty, infrastructure gaps, and poor accessibility as key barriers to education for low-income urban children. These are primarily framed as external and physical limitations, such as long travel distances, lack of sidewalks, or school fees, which undeniably remain important. However, these factors tend to overlook how children emotionally experience their environments. The literature emphasizes access, but not how fear, anxiety, or trauma may prevent children from using that access even when it's technically available.

This research challenges that limited framing. If the literature sees low-income status as the main contributor to exclusion, the findings here suggest something deeper: emotional safety is not just secondary, it is central. The children's voices reveal that psychological perceived fear, the fear of being kidnapped, attacked, or simply walking alone, can be a more significant barrier than physical distance or road condition. This insight is transformative. If emotional insecurity is what shapes children's mobility and willingness to attend school, then urban planning must treat emotional safety as a core design and policy priority, not an afterthought.

Therefore, physical and emotional safety should not be separated; they are intertwined in children's everyday decision-making. By being on the ground and listening to children directly, this study reveals how essential it is to recognize the perception of danger, not just physical hazards. These feelings often go unmeasured and unplanned for in official documents or city policies. Yet, they profoundly affect whether a child feels empowered to walk to school or is too afraid to leave home. Future research and urban interventions must explore this gap more deeply, converting emotional insights into tangible planning outcomes that prioritize children's well-being in both body and mind.

New Insights Beyond Existing Literature

One of the most important findings that came up during the fieldwork was how much fear shaped the way children move through their cities.

In Cambodia, kids talked a lot about stray dogs, being followed by strangers, and even running into people under the influence of drugs or alcohol. These are not always seen as 'urban planning' issues, but they have a huge impact on how safe children feel about going to school, something that is not well captured in existing frameworks like the Child Protection and Education Needs for the Children and Adolescents of Phnom Penh's Urban Poor Communities (UNICEF, 2018).

These findings suggest a crucial gap in the current child-rights-based urban research, which often overlooks the intersections of safety, trauma, and social neglect in shaping educational access.

Recommendations for Future Research and Action

Listen to children more: Their stories and drawings tell us what the data does or could not. How we address their fears should be part of how we design cities.

Include emotional safety in planning: Fear of kidnapping or drug use in public is just as real as traffic danger. These need to be discussed in urban policies.

Create safer school routes: That includes better lighting, protected sidewalks, and speed limits, but also community safety.

Discussion and Conclusion

This research explored how spatial, urban, and even psychological factors shape access to education in low-income communities in Cambodia, and how thoughtful urban design can help reduce these inequalities. The findings show that the physical environment, ranging from long and unsafe commutes to poor road infrastructure, as well as emotional aspects such as fear of hazards or kidnapping, can have a strong influence on whether children can attend school and feel safe doing so.

The country share challenges related to poor planning, limited safety measures, and a lack of inclusive urban design. These conditions not only restrict children's access to education but also perpetuate cycles of poverty and social inequality. Addressing these disparities requires integrated urban interventions focused on child-friendly infrastructure, improved safety, and inclusive public policies. This aligns with UNICEF's Child Friendly Cities Initiative (CFCI), which supports local governments in realizing the rights of every child, especially the most excluded, by creating safe, inclusive, and sustainable urban environments. According to the CFCI framework, child-friendly cities are built through child-responsive spatial planning, inclusive social services, and policies informed by disaggregated local data. The initiative also emphasizes that children must have a say in decisions affecting their lives and that governance must ensure their survival, development, and participation.

By embedding these principles into urban planning, service delivery, and community design, local governments can move toward inclusive cities where even the most marginalized children are seen, heard, and protected. For Phnom Penh and other growing Southeast Asian urban areas, the path forward must involve not only building physical infrastructure but also cultivating environments where every child can move freely, learn safely, and grow with confidence. This research highlights the urgent need to bridge the gap between infrastructure and emotional security and to ensure that children's lived experiences shape the future of urban design and educational equity.

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Conflict of Interests
The author(s) declare(s) no conflict of interest.

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Chapter 8

From Concept to Practice: Crafting Responsive Spaces for Sustainable Urban Living

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Introduction

The beginning of the modern era marked a significant shift in the unsustainable trajectory of urban development. Cities were faced with multiple and contradictory problems; issues of economic development and environmental protection - changes in land use of public open spaces and degradation of natural habitats for extensive construction, vehicle density versus pedestrian, unequal economic opportunities in income distribution, spatial insecurity versus social justice - that were considered to favor population growth and responsiveness to its needs, were some of the acute urban issues that had a negative impact on the quality of life of citizens. These changes led to the emergence of the sustainable urban development movement at the 1972 UN Conference in Stockholm, which aimed to strengthen the human environmental legacy and establish a discourse against upcoming crises (Sustainable Development Commission, 2011). The movement's first pillar was the conservation of natural resources, reduction of non-renewable energy consumption, reduction of pollution, and strengthening of the relationship between humans and nature.

In the late 1990s, dimensions of sustainability beyond the environment began to emerge. Maslow believed that human needs are collective and social in nature, and that urban space is the mediator through which social interactions take place (Maslow, 1943). Its essential prerequisite is the development of a comprehensive and integrated approach to meet social expectations (Kühn & Bobeth, 2022), which can guarantee the quality of human life by adapting urban infrastructure, providing sufficient green spaces, creating walking facilities and public gatherings (Bonnes et al., 2018). Studies (Gehl & Svarre, 2013; Carmona, 2019; Karimi & Suzanchi, 2021; Naya et al., 2023) have shown that public spaces that can provide sufficient quality to their users play an important role in achieving sustainability goals. As a result, urban and environmental planners and designers have sought solutions to adapt sustainable urban spaces to the users' needs, and new insights have emerged to better connect people with their living environment, such as the Responsive Environments Theory. This study attempts to describe the role of Responsive Environments Theory in creating sustainable urban environments through a descriptive review research method and considers the perspectives of different research on these principles for creating livable urban spaces. Conducting this study will help to dispose concerning the myriad challenges that urbanisation constitutes.

Responsive Environments Concept

The acquisition of the term 'responsive urban environments' dates back to the era of consumption reduction strategies and the transition from the industrialization of cities (Bayulken & Huisingh, 2015). This term was Inherently created with the aim of optimizing and balancing multifunctional urban systems. According to Krueger (1977), a "Responsive Environment" defines a conceptual communication that understands human behavior and unites people in a shared visual, auditory and overall sensory experience. Van Poll (1997) described responsive environments as those that depend on the specific physical conditions of the environment to increase the level of social interactions and encounters. In fact, the physical characteristics of the environment increase the individual's sense of well-being and satisfaction. Montgomery (1998) linked responsive urban environments to a wide range of factors such as the functional diversity of the environment, physical characteristics, urban public facilities and the right of individuals to choose activities (Gehl, 2000). According to Falahat (2007), the characteristics of imageability,

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legibility, enclosure, human scale, transparency, complexity, coherence and order make the environment responsive (Lynch, 1960; Jacobs, 1993). Alves Lino argued that a responsive environment is one in which the principles of aesthetics, visual user interaction, physical accessibility, semantic embodiment and intimacy of presence in space are considered in the design and construction phases (Alves Lino et al., 2010). Scott-Harden (2012) explored responsive environments in terms of effective communication in the structural features of the environment. He considered stimuli such as the physical shape, size, colour and composition of physical elements to drive human active interaction with the environment. Lennon et al. (2019) considered responsive environments to be those that ensure public wellbeing and health, and have environmental values such as easy access to green spaces and urban open spaces with walking and cycling facilities. Waal et al. (2021) found that network-oriented urbanism is effective in creating responsive environments.

Studies show that three key dimensions are involved as a constructive tool for improving human-environment interaction and creating an environment that responds to users' needs: physical factors, functional factors and environmental factors (Fig. 1).

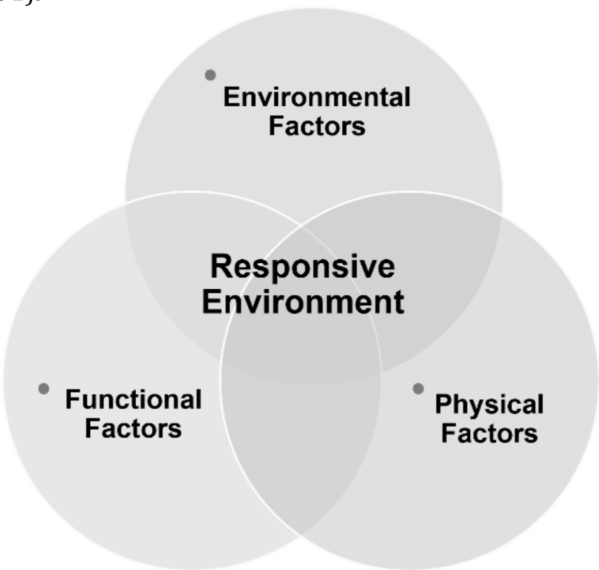

Figure 1. Factors affecting responsive environments.

Fundamentals of Responsive Environments Theory

Bentley *et al*. (1985) focused specifically on the principles of Responsive Environments Theory in a book of the same name, based on seven qualities: permeability, variety, legibility, robustness, visual appropriateness, richness and personalization. As the aim of this research is to identify the domain influences of these principles for sustainable urban spaces, it is necessary to discuss their characteristics and consequences that will shape urban nature.

Permeability

From Bentley's perspective, permeability is a physical and visual quality (Bentley et al., 1985), and has been found in various studies under titles such as form, short and direct connections (Gehl, 1987), hierarchical configuration of streets with urban texture (Purwantiasning, 2022), and access to public transport and parking services (Zhou & Gao, 2020).

Variety

Bentley (1985) argues that functional and spatial variety makes urban space attractive and creates a sense of place. Other researchers consider variety to has positive effects on socio-economic dimensions such as increased productivity (Craven et al., 2020), increased innovation and creativity (Hundschell et al., 2022), increased competitive advantage (Turi et al., 2022), increased socio-economic wellbeing (Livingston et al., 2022) and the consolidation of social capital (Ramos et al., 2024). The study by Zhang et al. (2024) also highlights the importance of urban plant variety in improving socio-economic well-being.

Legibility

Legibility has been defined as a property of visuality and physical clarity (Bentley *et al*., 1985; Lynch, 1960), like architectural details such as shape, color, and composition (Koseoglu & Onder, 2011). Caduff & Timpf (2008) suggest that legibility can be discussed from three perspectives: perceptual, cognitive and contextual. Lynch (1960) considers focal open spaces, efficient vegetation and transport links to be the causes of spatial legibility.

Robustness

There are different views and definitions of environmental robustness. Bentley (1985) refers to the physical characteristics of the ground surface and the body of the space. On the other hand, Hall (2015) refers to the coherence of pedestrian access networks; Baker *et al*. (2021) to vegetation that absorbs air, sound and visual pollutants; Li *et al*. (2024) to factors such as thermal and environmental comfort, including the use of light, shading, temperature and favourable winds; and finally, Fathi *et al*. (2020) to high walkability, quality and diversity of public transport services.

Visual appropriateness

Visual appropriateness is a component of responsive environments, identified by Gehl (2013) as one of the fundamental principles of urban landscape quality, along with factors such as human scale, distance and depth of space. According to Januchta-Szostak (2010), visual phenomena related to the location of elements, including position, orientation, and apparent form, such as dispersion or continuity, number of facets, transparency or rigidity, and verticality or horizontality, play a special role in the quality of the visual appropriateness of an urban environment.

Richness

Regarding the richness component, research highlights the role of the environment, such as cleanliness (Hikmah & Arifin, 2024), the use of multifunctional and environmentally friendly urban furniture (Shilin, 2022). Gehl (2013) states that vegetation is a factor that increases visual attractiveness and influences environmental richness. Bentley (1985), on the other hand, believes that physical features such as shape, colour, dimensions and materials play a role in enhancing richness (Rapoport, 2005; Lang, 1987). According to Cullen (2004), transport links and space-softening vegetation are also effective in enhancing richness quality.

Personalization

Bentley also looked for the quality of belonging colour in the physical characteristics of the environment through which the user's comfort and control over the environment is realised (Bentley, 1985; Lang, 1987). Hikmah & Arifin (2024) considered urban cleanliness and waste management to be effective in increasing personalization. Other studies (Jacobs, 1993; Falahat, 2007) have pointed to the complexity, structural coherence and cleanliness of the environment in improving this quality.

Table 1 summarizes studies on seven environmental qualities.

Table 1. Summary of Responsive Environments Principles.

<table>
<tr><th>Principles</th><th colspan="2">Definitions</th><th>Referencess</th></tr>
<tr><td rowspan="3">Permeability</td><td colspan="2">Physical and visual access</td><td>(Bentley et al., 1985)</td></tr>
<tr><td colspan="2">Shape and short connection, Hierarchical configuration of streets with urban texture</td><td>(Gehl, 1987)
(Purwantiasning, 2022)</td></tr>
<tr><td colspan="2">Access to public transport and parking</td><td>(Silavi et al., 2017)
(Zhou & Gao, 2020)</td></tr>
<tr><td rowspan="7">Variety</td><td rowspan="2">Functional/spatial variety</td><td>Strengthening the sense of place</td><td>(Bentley et al., 1985)
(Moussa, 2023)</td></tr>
<tr><td>Enhance innovation and creativity</td><td>(Hundschell et al., 2022)</td></tr>
<tr><td rowspan="3">variety of service and commercial activities</td><td>Increase competitive advantage</td><td>(Turi et al., 2022)</td></tr>
<tr><td>Increasing economic productivity</td><td>(Craven et al. , 2020)</td></tr>
<tr><td>Socio-economic wellbeing</td><td>(Livingston et al., 2022)</td></tr>
<tr><td>Ethnic and social variety</td><td>Strengthening social capital</td><td>(Ramos et al., 2024)</td></tr>
<tr><td>Variety of plant species</td><td>Socio-economic well-being</td><td>(Zhang et al., 2024)</td></tr>
<tr><td></td><td colspan="2">Imageability, Structural transparency</td><td>(Bentley et al., 1985)
(Falahat, 2007)
(Jacobs, 1993)
(Lynch, 1960)</td></tr>
</table>

Legibility	Colour, Shape, Dimensions, Stimulating the five senses, Different functions over time	(Caduff & Timpf, 2008)
	Focal open spaces, Combination of vegetation with physical elements, Coherent traffic links	(Lynch, 1960)
Robustness	Uniform surfaces on the floors of urban spaces	(Bentley *et al.*, 1985)
	Thermal and environmental comfort (Lighting, Temperature, Favourable wind, Shading)	(Li *et al.*, 2024)
	Effectiveness of flooring materials in absorbing surface run-off, Multipurpose and modular urban furniture	(Shilin, 2022)
	Pedestrian network coherence, Quality and variety of public transport services	(Hall, 2015) (Fathi *et al.* 2020)
Visual appropriateness	Building skyline, Facade composition details	(Bentley *et al.*, 1985)
	Dispersion or continuity, Number of facets, Transparency or Rigidity, Verticality or horizontality	(Januchta-Szostak, 2010)
	Enclosure, Human scale, Distance and Depth	(Gehl, 2013)
Richness	Shape, Color, Dimensions, Material, Facade composition	(Bentley *et al.*, 1985) (Rapoport, 2005) (Gyurkovich & Pieczara, 2021)
	Green spaces and efficient vegetation (Absorbs air, Noise and Visual pollution)	(Baker *et al.*, 2021)
	Trees, Building forms, Traffic functions	(Cullen, 2004)
	Complexity, Coherence and Elegance	(Falahat, 2007) (Jacobs, 1993)
Personalization	Environment Physical structure	(Bentley *et al.*, 1985); (Lang, 1987)
	Cleaning and waste management	(Hikmah & Arifin, 2024)
	Complexity, Coherence and Elegance	(Falahat, 2007) (Jacobs, 1993)

Materials and Methods

In terms of purpose, this research is based on applied and this is a review and descriptive study methodologically, which will use in-depth documentary studies according to the research question, what is the role of the Responsive Environments Theory in creating a sustainable urban environment. The aim of this study is to identify the impact of the Responsive Environments Theory in shaping and strengthening sustainable urban spaces, which, given its positive recognition, plays a significant role in creating inclusive cities, improving economic dynamism and enhancing environmental quality. In general, this method involves interpreting the literature related to the foundations of the Responsive Environments Theory and extracting its criteria with the process of achieving sustainable development goals.

Relationship between Responsive Environments Theory and Sustainability Dimensions

Sustainable urban spaces are achieved through the harmonious interaction of the three social, economic, and environmental dimensions, as follows:

- **Social Sustainability:** Maintaining a balance between the interactions of cultural and social systems with natural ecosystems (Muhar et al., 2018), integrating a hierarchy of human demands and needs with natural resources, and promoting respect for nature. It seeks to reduce alienation and increase civility and attachment to place (Eizenberg & Jabareen, 2017).
- **Economic Sustainability:** Optimising dynamic processes, avoiding irreversible patterns, and wasting materials and energy, etc. (Velenturf & Purnell, 2021, Notteboom *et al.*, 2022).
- **Environmental Sustainability:** Strengthening the biodiversity of ecosystems (Matta *et al.*, 2011), using flexible, cyclical and self-regulating natural systems for human purposes (Naveh, 2010).

Meanwhile, several studies have examined the impact of the principles of responsive environments on dimensions of sustainability in urban spaces. Gehl's (1987) research focused on three benefits of the quality of permeability in urban spaces. First, the proper connection of streets to the urban fabric improves social interactions among citizens; second, shortening the length of the street leads to easier access and reduced traffic congestion; and finally, better access to commercial areas increases property values and the prosperity of commercial businesses. Appropriate use of this quality therefore helps to reduce road traffic and increase the presence of pedestrians. As a result, creating permeability in cities creates sustainable conditions in various social, economic and environmental dimensions. Oloyede Alabia & O Abubakar (2023) pointed out the positive correlation between increasing street permeability and the social goals of sustainable development, in particular the reduction of crime. A study by Moulay *et al*. (2017) on the legibility of urban parks in Malaysia showed a direct relationship between clear structure and increased accessibility and social interaction for users. In Cairo, Ahmed Abdel Ghaffar & Abd El Aziz (2021) investigated the relationship between economic sustainability and urban form. The results showed that the three components of permeability, legibility and robustness of urban areas in terms of access to public transport services ensure optimal urban functionality, which has a direct role in the economic growth of commercial areas, improving the quality of housing projects, minimizing travel costs and maximizing economic benefits and mutual benefits. Barton & Gutiérrez-Antinopai (2020) highlighted to the role of physical diversity and structural complexity of the environment in increasing visual richness and its positive impact on social and environmental sustainability. Boongaling Agaton *et al*., (2020) found that the use of electric public transport is effective in increasing urban robustness and therefore environmental sustainability. Research by Mouratidis *et al*. (2024) on factors influencing social sustainability in Scotland showed that personalisation, as it is known, increases public participation and a sense of control over places, neighbourhoods and the development of urban areas. In this study, the physical standardization of public spaces and the public transport system increases social interaction, identity, belonging and safety for citizens. Amanpour & Delfannasab (2024) showed that physical factors resulting from the physical integrity of urban facades, including dimensions, proportions and overall urban design based on aesthetic principles, contribute significantly to the sustainability of urban spaces. Bharmoria & Sharma (2024) emphasize the impact of the visual quality of urban landscapes through physical change on social, economic and environmental aspects. This study identified measures based on improving urban robustness, including improving urban transport infrastructure and pedestrian networks, reducing vehicle speeds and increasing pedestrian safety, as solutions to increase the environmental sustainability of urban design. The results of the study by Yaralioglu & Kara (2025) found that the physical structure is the most important measure of the sustainability of urban space. Increasing urban robustness through green infrastructure and environmental efficiency emerged as the highest priority parameters. Social measures influenced by urban robustness include safety and control, comfort, interaction, continuity, recognizability and meaning. Measures of economic vitality include contribution to the local and urban economy and increased local employment.

Discussion and Conclusion

The present study identified three factors that influence the sustainability of urban spaces, which can also be achieved by adopting the theory of Responsive Environments in macro policies on the characteristics of physical design, appropriate urban function and measures to preserve and improve the environment (Fig. 2).

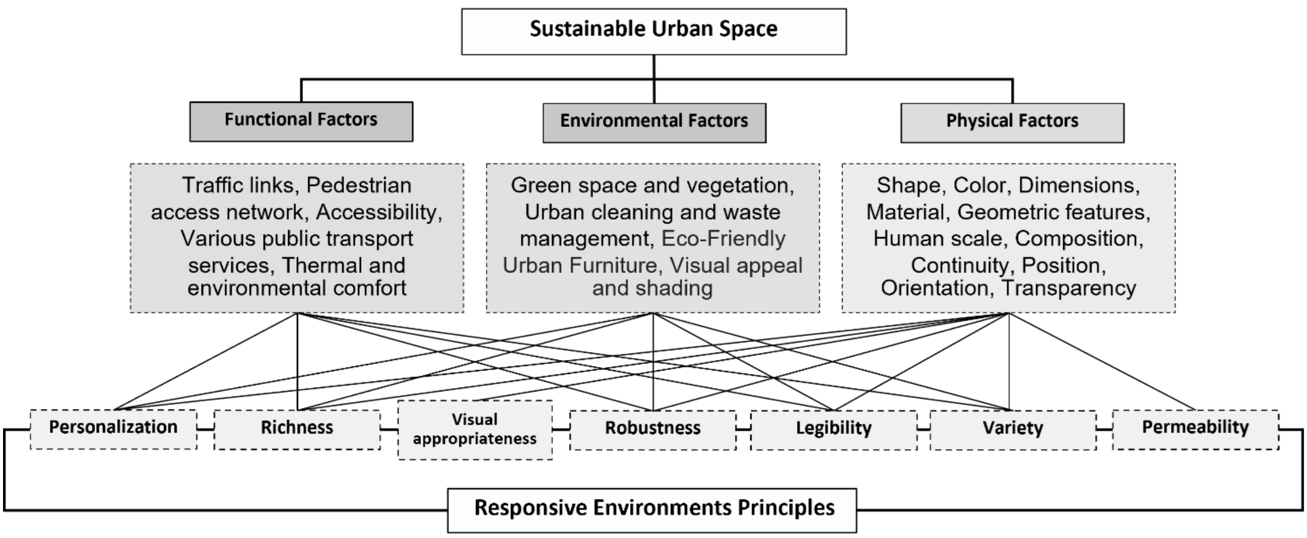

Figure 2. The effectiveness of 'responsive environment' principles in achieving urban sustainability.

The quality of permeability plays a significant role in improving the social, economic and environmental levels of urban areas that can be achieved through physical change. Better pedestrian access to urban areas creates a suitable context for the formation of social relationships, areas of greater economic stability and reduced vehicle density, which can have a significant impact on improving the quality of the environment.

However, the quality of variety contributes to the social, economic and environmental dimensions of sustainability in different ways. Ethnic and demographic variety enhances social relations and strengthens social capital. On the other hand, functional variety enhances economic growth in urban areas. The variety of plant species also contributes to biodiversity and the balance of urban ecosystem cycles.

The quality of legibility is also directly related to each of the three social, economic and environmental dimensions. Legible spaces give users a stronger sense of place and increase the opportunities for social interaction. From an economic perspective, legible spaces ensure the future of development and better economic exchange. This quality can be transformed into sustainable urban spaces through physical, functional and environmental changes. Improving the quality of green spaces and urban nature also enhances people's images and sense of attachment to urban landscapes.

Visual appropriateness can have a direct impact on presence in space, the formation of social relationships and appropriate economic opportunities. Physical changes to improve visual quality play an effective role in social and economic sustainability.

The two qualities of robustness and richness have a tangible relationship with environmental characteristics. Considering environmental criteria in thermal and environmental comfort and using eco-friendly urban furniture play an important role in environmental and economic sustainability. Increasing the robustness of urban spaces through better pedestrian access, better public transport links or appropriate physical structure increases social interactions and improves economic relationships.

The quality of richness, like the quality of legibility, enhances the sense of place in the space and is achieved by combining physical, functional and environmental factors that play a particular role in the process of social, economic and environmental sustainability.

Making physical changes according to personal preferences increases the sense of satisfaction with the environment, while strengthening physical, functional and environmental features increases the sense of belonging to the urban spaces and provides a stronger social and economic base.

Overall, the results emphasize the convergence of three key factors: physical, functional and environmental in the modern urban context to create sustainable urban spaces, which is achieved as a result of a balanced and proportionate distribution of 'responsive environments' principles. It is also necessary to accept this reality that the improvement of only one factor affecting the achievement of urban sustainability can have a profound conclusion in the whole process of creating Responsive Environments. Although the research findings mostly point to the impact of physical changes on the responsiveness of the environment to citizens' needs, they also point to the need to preserve and enhance the urban natural environment because of its tangible impact on sustainable urban development, in a way that enhances the durability of urban relationships and facilitates the continuation of growing generations in cities.

Generally, the results indicate a high correlation between the principles of Responsive Environments and the empowerment of different social, economic and environmental levels. This suggests that adopting urban spatial plans within the framework of physical, functional and environmental measures is a reliable way to achieve sustainable, livable urban development with a human-centered focus. In short, the results of this study will help satisfy the daily needs of a wide range of users and, in particular, create order, balance and control in the planning and urban redesign of areas lacking environmental values.

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Conflict of Interests

The Authors declare that there is no conflict of interest.

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Chapter 9

Parametric Approaches for Energy-Efficient Urban morphologies

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Introduction

Background and Context

The rising demand for sustainable urban development in response to the twin challenges of climate change and rapid urbanization has intensified the imperative for energy-efficient urban environments (Umoh et al., 2024). As rural populations increasingly migrate to cities, the resulting urban growth places additional pressure on housing, infrastructure, and employment opportunities. This urban expansion is accompanied by a surge in energy demand, largely influenced by heightened population activity (Aidaoui et al., 2024; Menai et al., 2024). In this context, Urban morphology, defined by elements such as building layout, density, orientation, and spatial configuration, plays a pivotal role in shaping environmental performance. It affects solar exposure, airflow, shading, and heat retention, with empirical studies showing that urban heat islands can elevate energy demand by 10% to 35%, depending on urban density and form (Salvati et al., 2015). To address these challenges, cities are increasingly embracing strategies that minimize energy consumption. In Algeria, this vision is reflected in the Taka Nadhifa program, a clean energy initiative launched within the framework of the strategic energy partnership with the European Union. This program aims to rationalize energy use, particularly in the energy-intensive construction sector (Maiza, 2010; Salah-Salah & Harbi, 2023).

Conventional urban planning approaches, typically grounded in static, typology-based models, often lack the adaptability required to dynamically respond to environmental performance metrics (Bruno et al., 2011). Consequently, many urban morphologies are developed without fully leveraging their potential to reduce energy consumption or enhance thermal comfort (Ebaid & Helim, 2024). In response, urban designers and planners are more and more adopting parametric design methodologies to model, simulate, and optimize urban form (Umoh et al., 2024). Urban energy modelling plays a crucial role in this process, offering a data-driven framework to assess solar potential and inform design decisions that foster more energy-efficient urban configurations (Harbi et al., 2024)

Parametric design utilizes algorithmic tools that enable the dynamic manipulation of spatial and morphological variables. These tools allow for the rapid generation and evaluation of multiple design iterations based on performance criteria such as energy use intensity, solar access, and microclimatic behavior (Pektas, 2023). When integrated with advanced simulation platforms, such as EnergyPlus, Ladybug, or computational fluid dynamics (CFD), parametric approaches can reveal the environmental consequences of design choices across scales (Ibrahim et al., 2021; Salvati et al., 2015). This performance-driven, data-informed design process is particularly impactful during early-stage planning, where strategic decisions regarding form and layout have long-term implications (Doelling & Nasrollahi, 2013; Farouk et al., 2019).

In climate-sensitive regions, especially hot-arid and Mediterranean zones, where energy demand for cooling is high and passive design strategies are essential, parametric tools provide critical insights. They enable the reconfiguration of urban form to improve solar control, thermal comfort, and energy efficiency (Aboulfaraj et al., 2024; Eshraghi et al., 2024; Ibrahim et al., 2022). As a result, parametric approaches are gaining traction not only in academic research but also in professional design practice and urban policymaking.

Yet, despite the growing interest and evident potential, the integration of parametric methods into mainstream urban planning remains fragmented. There is a lack of comprehensive frameworks to systematically evaluate the

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effectiveness, scalability, and contextual applicability of different parametric techniques. Most existing studies are highly context-specific, limiting their generalizability across diverse climatic conditions and urban scales (Robinson, 2011; Zhang et al., 2024). This underscores the need for a consolidated understanding of how parametric approaches can be more holistically adopted to inform energy-efficient urban morphologies worldwide.

Based on these studies, "How can parametric design methodologies be systematically integrated into early-stage urban planning to optimize energy-efficient urban morphologies across diverse climatic and spatial contexts?"

Objectives and Hypotheses

This paper aims to conduct a systematic review of the state-of-the-art parametric approaches applied in urban morphology design to enhance energy efficiency. It seeks to categorize and evaluate the performance of various computational methods and tools based on their effectiveness, scalability, and applicability in different design contexts. Furthermore, the study identifies the key morphological parameters that most significantly influence energy performance, with a particular focus on hot-arid and Mediterranean climates. By synthesizing current research trends and identifying existing gaps, the paper contributes to advancing the development of integrated parametric workflows for optimizing energy-efficient urban forms.

Hypotheses:

- H1: Among morphological parameters, building orientation, height-to-width ratios, and street layout exert the strongest influence on energy performance in specific climates.

- H2: Integrated frameworks using multi-objective optimization techniques are more effective than single-objective or manual parametric approaches in identifying energy-efficient urban configurations.

Materials and Methods

This study employs a mixed-method approach combining bibliometric analysis and systematic literature review (SLR) to critically examine the development, applications, and performance of parametric design approaches for enhancing energy efficiency in urban morphologies. The dual-method strategy ensures both quantitative insight into the research landscape and qualitative depth in content analysis, enabling a robust and comprehensive evaluation of the topic.

Research Design

The methodology was designed to answer the following research questions:

- What are the dominant parametric approaches and tools used to optimize energy performance in urban morphology?
- Which morphological parameters are most frequently studied and found to be impactful in different climatic contexts?
- What are the emerging research trends, gaps, and future directions in the application of parametric design for energy-efficient urban planning?

To address these questions, the study followed a three-phase workflow:

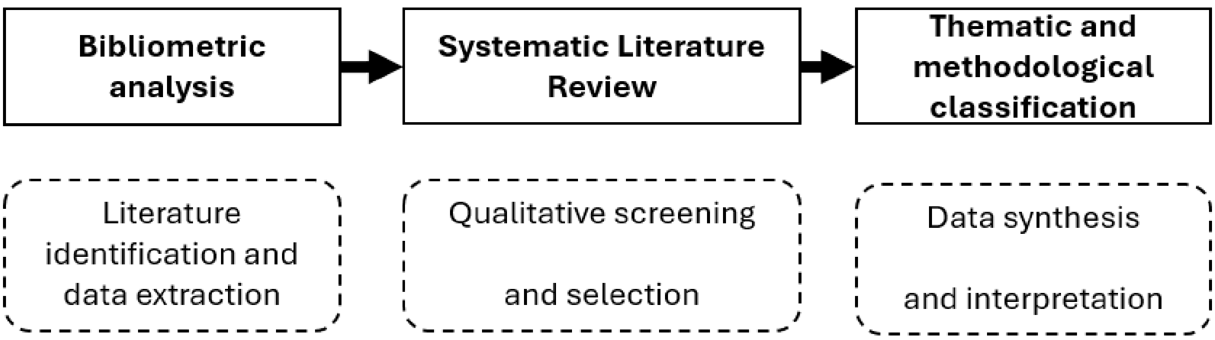

Figure 1. three-phase workflow of the research methodology.

bibliometric analysis

A bibliometric analysis was conducted to map the intellectual structure, thematic evolution, and research trends within the domain of parametric approaches for energy-efficient urban morphology. The Dimensions AI database was selected for its broad multidisciplinary coverage and integration of citation analytics across scholarly outputs in architecture, urban planning, and environmental sciences. The search strategy employed Boolean logic using the following keyword combination: ("parametric design") AND ("urban morphology" OR "urban form") AND ("energy efficiency" OR "energy performance"). The query was restricted to English-language publications, including papers published between 2016 and 2024. After de-duplication and abstract-based relevance screening, a refined dataset of 561 documents was selected for in-depth bibliometric mapping. VOSviewer software was used to construct and visualize bibliometric networks, including co-authorship relationships, offering insights into the structure and collaboration dynamics of the field.

Systematic literature review

A systematic Literature Review (SLR) was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The review focused specifically on peer-reviewed studies that applied parametric tools for urban-scale energy efficiency analysis. Inclusion criteria encompassed studies utilizing frameworks; those applied at the urban or neighbourhood scale rather than limited to single-building analyses; studies incorporating energy performance metrics such as energy use intensity (EUI), solar access, and thermal comfort; and case studies situated in hot-arid or Mediterranean climates. Exclusion criteria eliminated studies focused exclusively on material, structural, or facade optimization without addressing urban morphological configurations and studies conducted at the building scale without extrapolation to broader urban or neighbourhood contexts. From the 561 documents identified through bibliometric filtering, 68 met the criteria for full-text analysis. Each article was systematically reviewed and classified according to its methodological approach, including generative algorithms, rule-based modelling, machine learning, or multi-objective optimization; the tools and software utilization, the morphological parameters assessed, and the key performance indicators measured.

Results

The Bibliometric Analysis

This chart highlights the growing academic interest in energy-efficient morphology and parametric urban design over the past decade, showing a clear and steady rise in publications from 2016, peaking in 2024. This trend reflects the increasing recognition of parametric approaches as essential tools in sustainable urban planning.

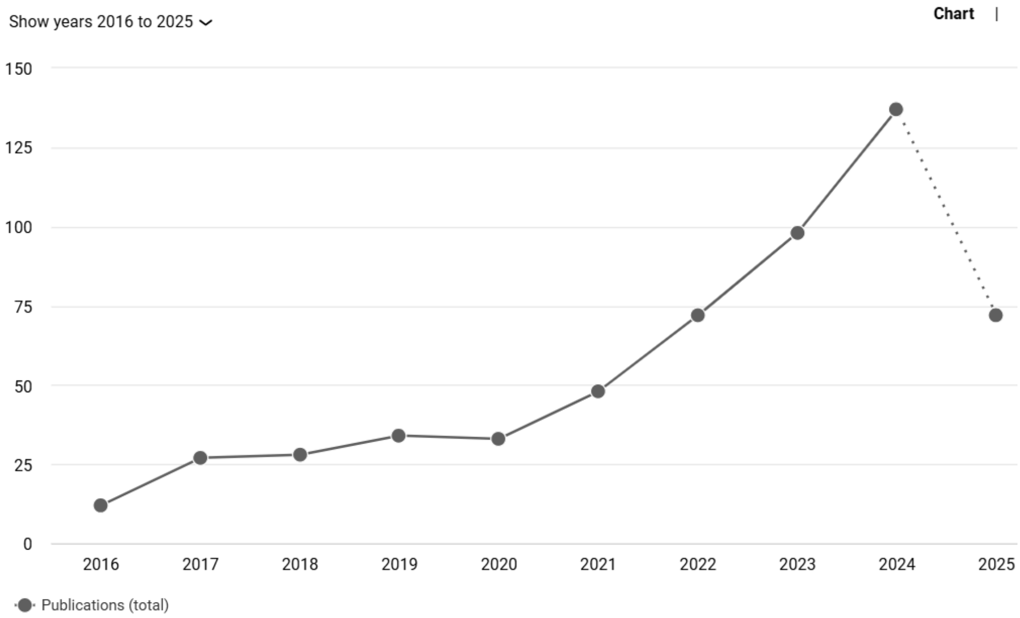

Figure 2. Annual Growth of Publications on Parametric Approaches for Energy-Efficient Urban Morphologies (2016–2025). Source: Dimensions Database: (https://www.dimensions.ai).

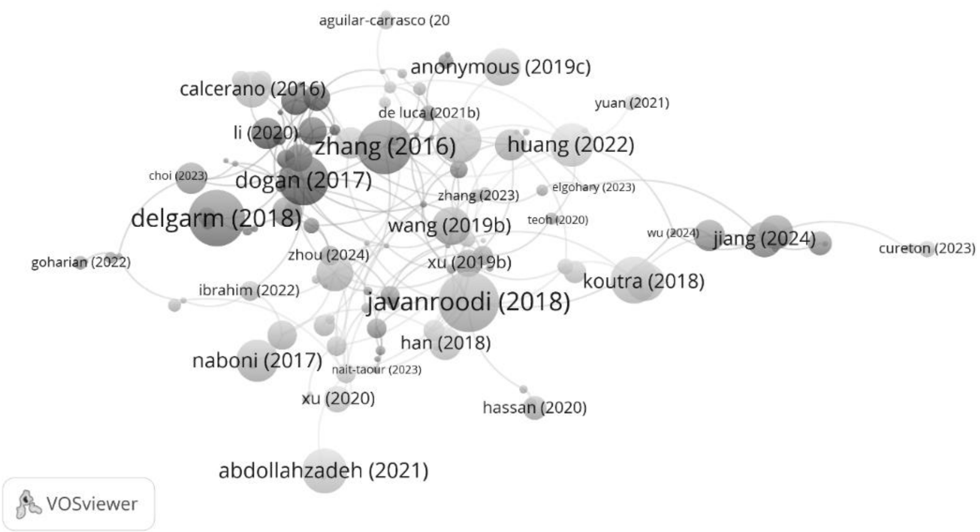

Figure 3. Co-authorship Network Visualization of Key Researchers.

This VOSviewer author co-citation map reveals key contributors and collaborative clusters in the field of parametric urban design for energy efficiency. Central figures like Zhang (2016), Delgarm (2018), Dogan (2017), and Javahroodi (2018) form dense nodes, indicating strong citation influence and thematic connectivity. The presence of multiple clusters, each represented by distinct colors, reflects diverse methodological approaches and research focuses. Emerging researchers such as Jiang (2024) and Goharian (2022) suggest a growing and evolving field, while the interlinked network underscores increasing interdisciplinary collaboration.

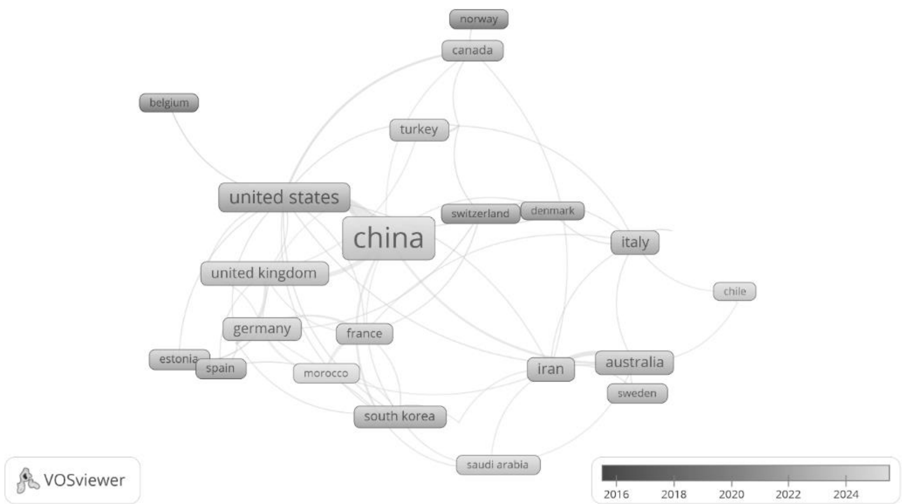

Figure 4. A network visualization mode bibliometric map based on co-authorship nations.

The co-authorship network map generated using VOSviewer provides a comprehensive overview of the international research collaboration landscape in the field of parametric design and urban energy efficiency from 2016 to 2024. China appears as the most central and influential contributor, demonstrating both high publication output and strong international collaboration ties, particularly with the United States, the United Kingdom, Iran, and Australia. This centrality highlights China's pivotal role in advancing research on energy-efficient urban morphologies through parametric approaches. The United States, United Kingdom, Germany, and Iran also emerge as key players with dense interconnections, indicating active and sustained participation in the field.

The color gradient, which reflects the average publication year, reveals temporal trends in research engagement. Countries such as Belgium and Norway, indicate earlier involvement around 2016–2018, while countries like Morocco, Chile, and Saudi Arabia, suggest more recent entry into the field. This temporal dynamic underscore a growing global interest, particularly from regions that face climatic challenges well-suited for parametric energy optimization strategies, such as hot-arid and Mediterranean climates.

Emerging contributors, including Morocco and Chile represent a rising research interest, likely driven by the practical need for climate-responsive urban planning. The network illustrates a shift from a traditionally

Eurocentric and North American research dominance toward a more geographically diversified engagement. Overall, the map reflects the increasing globalization of research efforts in parametric urban design, emphasizing the value of interdisciplinary and cross-regional collaboration to address energy efficiency challenges in urban environments.

The Systematic Review

Design Parameters and Their Influence on Urban Energy Efficiency

Building Design Parameters

Energy usage is greatly influenced by **building morphology**, which includes elements like building height, form, and orientation. Energy usage intensity (EUI) can be significantly decreased by improving these characteristics, according to studies. For example, a study conducted in Hangzhou, China, showed that Energy Use Intensity can be decreased by up to 7.73% by improving morphological characteristics such aspect ratio, floor area ratio, and orientation (Feng et al., 2024). Similarly, it has been discovered that larger floor area ratios and compact building forms lower heating energy consumption in temperate-humid climates (Kocagil, 2021; Mangan et al., 2021). Furthermore, building geometry and orientation markedly influence environmental performance metrics, including solar gain, daylight availability, and wind behavior. A study in Tehran highlighted that optimized building orientation can lead to a 41.3% to 61.1% reduction in solar radiation variation compared to traditional configurations (Mavahebi Tabatabai et al., 2025).

Other important factors in building design are **the type of plan and the height of the building**. For instance, it has been demonstrated that square plans and pavilion-style structures outperform rectangular and slab-type buildings in terms of energy efficiency in temperate-humid climates (Mangan et al., 2021). Furthermore, it has been discovered that taller structures with lower height-to-width (H/W) ratios have superior sun access and energy consumption (Ibrahim et al., 2021; Kocagil, 2021)

The building envelope, including factors such as opacity, transparency, and solar control systems, also plays a significant role in energy consumption. Studies have shown that optimizing these parameters can lead to further reductions in energy use. For example, in Istanbul, the integration of building envelope optimization and solar control systems was found to improve energy performance by up to 19% (Kocagil, 2021).

Urban Form Parameters

Urban density and layout are key parameters in urban form optimization. Higher urban densities have been shown to reduce energy consumption by promoting more efficient use of land and infrastructure. For example, in hot arid climates, compact and medium-density urban forms have been found to perform better in terms of thermal comfort and energy efficiency (Ibrahim et al., 2021). Similarly, in severe cold regions, higher building densities have been found to reduce energy consumption by improving insulation and reducing heat loss (Wang et al., 2024). A study in Switzerland demonstrated that parametric modelling can help balance built density with solar potential and daylighting performance (Peronato, 2014). **Street width and orientation** are also important parameters in urban form optimization. Narrower streets in hot climates can reduce urban overheating by providing shade and promoting natural ventilation (Ibrahim, Kershaw, Shepherd, & Coley, 2021; Wai et al., 2024). A study in Kayseri, Turkey, found that canyon geometry parameters, such as aspect ratio and length-to-height ratio, significantly influence microclimatic conditions and energy consumption (Toren & Sharmin, 2024).

Green spaces and public areas play also a crucial role in urban microclimates and energy consumption. Studies have shown that strategically located green spaces can reduce urban overheating and improve outdoor thermal comfort (Ibrahim et al., 2021; Wai et al., 2024). Additionally, public spaces with optimized layouts and orientations can enhance solar access and reduce the need for artificial lighting (Kocagil, 2021; Mangan et al., 2021).

Key Methods for Enhancing Energy Efficiency in Urban Morphologies

These are the most recognized and widely adopted parametric approaches in energy-efficient urban design. These methods are at the core of how designers simulate and optimize urban morphology to reduce energy consumption:

Parametric Energy Simulation Method

The parametric energy simulation method integrates algorithmic modelling tools—such as Grasshopper (a plugin for Rhinoceros 3D)—with advanced environmental simulation engines like Ladybug and Honeybee. These tools import local weather data and generate interactive visual outputs, allowing designers to assess environmental performance metrics from the earliest design stages (Sadeghipour Roudsari & Pak, 2013). This integration enables comprehensive analysis of energy efficiency and climate responsiveness across various urban and architectural configurations (Delmas et al., 2018).

Typical applications of the parametric energy simulation method include the analysis of solar gains based on building geometry, orientation, and spatial layout; the simulation of annual or seasonal energy consumption while accounting for both morphological and climatic variables; and the evaluation of thermal comfort at multiple spatial scales—ranging from individual buildings to entire neighbourhoods, by incorporating factors such as solar exposure, natural ventilation, and interior temperature dynamics (Wai et al., 2024; Wang et al., 2024). A major strength of this method lies in its capacity for real-time performance feedback on flexible parametric geometries. This facilitates iterative design refinement and supports informed, energy-conscious decision-making from the conceptual phase onward. Ultimately, it fosters a more responsive and sustainable approach to urban design (Aboulfaraj et al., 2024).

Multi-Objective Optimization Method

This method involves the use of evolutionary algorithms such as Galapagos (single-objective) A genetic algorithm that optimizes single-objective problems, demonstrating effectiveness in architectural design by finding feasible solutions and outperforming other tools in specific scenarios (Cubukcuoglu et al., 2019). and Octopus (multi-objective) a multi-objective optimization tool that extends the capabilities of Grasshopper, enabling the simultaneous consideration of various design criteria, thus providing a more comprehensive solution set (Meraihi et al., 2021). These plug-ins are integrated within Grasshopper, to simultaneously optimize several design criteria. It is particularly effective for exploring trade-offs between conflicting objectives in complex urban environments (Bruno et al., 2011). The applications of this method include finding a balance between built density, solar access, building orientation, and form factor (Ibrahim et al., 2022). Rather than identifying a single "best" solution, this method generates a range of optimal solutions based on Pareto efficiency (Li et al., 2024), offering designers a set of well-balanced alternatives. While the advantages of this approach lie in its ability to deliver intelligent design options that account for conflicting constraints while preserving creative control over urban form (Showkatbakhsh & Makki, 2022) . In urban contexts—where goals such as maximizing sunlight exposure, increasing density, minimizing energy use, and complying with land-use regulations often conflict—multi-objective optimization provides a robust framework (Sicuaio et al., 2024). It supports the development of scenarios that reconcile morphological, environmental, and regulatory priorities, making it especially valuable in urban planning and development studies.

Genetic Modelling Method

The genetic modelling method is based on the use of genetic algorithms to automatically generate a wide range of urban or architectural form variants. Genetic algorithms (GAs) mimic evolutionary processes, utilizing selection, mutation, and recombination to evolve solutions to optimization problems (Hsu, 2009). Each variant is evaluated from the outset using predefined energy performance criteria, such as energy use intensity (EUI) or solar gain. This approach enables the rapid and systematic exploration of complex morphological configurations by manipulating parameters such as building height, orientation, and spacing. By simulating and comparing these alternatives, the method identifies the most energy-efficient solutions. One of its main advantages is the direct integration of sustainability objectives into the generative process, making it a powerful tool for optimizing urban form in the early design stages (Boyukliyski et al., 2022; Sohail, 2023).

Comparative Analysis of Different Methods:

Table 1. comparative analysis of different methods.

Method	**Key Parameters**	**Energy Reduction Achieved**
Simulation Tools	Building height, street width, green spaces, public areas	Significant reductions in heating and cooling energy consumption (Wai et al., 2024) (Ibrahim et al., 2021) (wang et al., 2024)
Multi-Objective Optimization	Building orientation, layout, spacing, typology	Up to 27.8% reduction in heat emissions (Qiu et al., 2023) (Li et al., 2024)
Genetic Algorithm	Aspect ratio, floor area ratio, orientation, number of floors	Up to 7.73% reduction in EUI (Feng et al., 2024) (Boyukliyski et al., 2022)

Integration with Artificial Intelligence and Machine Learning

While generative design methods are already well established (Elshanshoury et al., 2023), the integration of more advanced machine learning (ML) techniques presents a promising trajectory. Deep learning models trained on large datasets of urban configurations and environmental performance metrics could enable predictive modeling, pattern recognition, and adaptive form generation beyond traditional simulation limits (Eshraghi et al., 2024),. These models have the potential to automate and accelerate design-space exploration, offering real-time feedback without extensive computational overhead.

Recent studies have begun to demonstrate the transformative potential of ML and artificial intelligence (AI) in parametric design workflows. For instance, Lu et al. (2022) employed a Generative Adversarial Network (GAN) to predict the environmental performance of urban blocks based on simulation results, significantly improving the speed and efficiency of the optimization process. Similarly, Huang et al. (2024) applied ML techniques to assess and refine the impact of urban morphology on photovoltaic system performance, enhancing solar energy efficacy in urban environments.

Discussion

The results from both the bibliometric analysis and the systematic literature review offer compelling evidence that parametric approaches are becoming pivotal in optimizing urban morphology for improved energy efficiency. The upward trend in scholarly publications from 2016 to 2024, particularly the peak observed in 2024, underscores the growing recognition of these computational methods within sustainable urban planning. The bibliometric insights also reveal a geographically expanding research network, with China, the United States, and the United Kingdom emerging as central contributors, while countries from hot-arid and Mediterranean regions like Saudi Arabia are increasingly engaging with parametric tools to address their specific climatic challenges.

The systematic review further demonstrates how parametric methodologies, particularly parametric energy simulation, multi-objective optimization, and genetic modelling, enable the exploration of complex design spaces. These methods allow for performance-driven decision-making in the early stages of urban form generation. For instance, the integration of tools such as Grasshopper, Ladybug, and EnergyPlus facilitates high-resolution simulations that assess solar gain, energy consumption, and thermal comfort across varying spatial and climatic contexts.

Each method reviewed offers distinct advantages in optimizing urban form for energy efficiency. Parametric energy simulation enables real-time feedback and interactive visualization, supporting iterative refinement based on environmental performance. Multi-objective optimization tools like Galapagos and Octopus facilitate the balancing of competing goals through Pareto-optimal solutions. Genetic algorithms automate the exploration of diverse morphological variants, proving especially effective in early design stages. Building on these established generative approaches, the integration of advanced machine learning (ML) techniques presents a compelling future direction, with the potential to further enhance predictive capabilities and design efficiency.

Crucially, the findings highlight key morphological parameters—such as building height, plan typology, orientation, street width, and urban density—as influential drivers of energy performance. These elements are not only frequently studied but have also shown measurable impacts across diverse climate zones.

In sum, parametric design methods are reshaping the discourse on urban energy performance by enabling a data-rich, iterative, and performance-based approach to planning. As cities worldwide confront the dual challenges of climate change and urbanization, these methods offer a promising pathway toward more adaptive, efficient, and context-responsive urban environments.

Conclusion

This study has examined the transformative potential of parametric design approaches in advancing energy-efficient urban morphologies, particularly in the face of accelerating urbanization and climate-related challenges. Through a systematic review of existing methodologies, tools, and applications, it becomes evident that the convergence of parametric modelling, environmental simulation, and optimization techniques offers a powerful framework for performance-driven urban design. These approaches enable the dynamic manipulation of urban form based on real-time environmental feedback, allowing designers to explore a wide range of solutions that balance solar access, thermal comfort, and energy use.

While tools such as genetic algorithms, multi-objective optimization, and simulation-integrated parametric platforms are increasingly being adopted, their application remains largely fragmented and context-specific. The integration of advanced machine learning techniques further extends the potential of generative design by automating complex design-space explorations and enhancing predictive capabilities. However, despite significant progress, the widespread adoption of these methods in mainstream urban planning is still limited by the lack of standardized frameworks and generalized models.

To fully realize the benefits of parametric design for sustainable urban development, future research must focus on developing adaptable, scalable methodologies that are sensitive to climatic diversity and urban complexity. This calls for interdisciplinary collaboration between urban designers, environmental engineers, and data scientists, as well as greater integration of these tools into planning policies and education. Ultimately, a performance-driven, data-informed design paradigm holds the key to creating more resilient, livable, and energy-efficient cities.

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Conflict of Interests

The author(s) declare(s) no conflict of interest.

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Chapter 10

Built Form and Market Value in Residential Layouts

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Introduction

Housing form in cities is often a direct reflection of urban policies and regulatory frameworks. Over the past few decades in Tehran, rapid urbanization combined with top-down building codes has transformed the traditional housing morphology. Courtyard-centered houses have largely given way to row apartment buildings under the pressures of modernization and regulatory compliance (Mohajer Milani & Einifar, 2020; Mohajer Milani & Einifar, 2017). Studies have posited that formal regulations—such as land use plans, building coverage limits, and sprojection requirements—are among the principal drivers of these transformations (Mohajer Milani & Einifar, 2020; Madanipour, 1998). For instance, the introduction of the "60% + 2m" building code in Tehran mandated that new constructions occupy only the northern 60% of a plot with a 2-meter frontal projection, giving rise to a standardized row-house apartment typology throughout the city (Mohajer Milani & Einifar, 2017; Shayesteh & Steadman, 2016). This policy not only standardized the mass-space configuration of buildings, but also created distinct spatial patterns (e.g., the so-called "northern" vs. "southern" apartment layouts) as developers maximized buildable area within the code's geometric constraints (Mohajer Milani & Einifar, 2017; Madanipour, 1998).

Urban form standardization has had clear benefits, such as efficient use of land and faster housing production, helping Tehran accommodate a growing population. However, it has also introduced challenges. Modern Tehran apartments often feature repetitive internal layouts that may not fully align with inhabitants' cultural preferences or evolving lifestyles. One notable concern is the preservation of privacy and hierarchy in domestic space – a cornerstone of traditional Iranian housing design (Dousti, 2018; Nayyeri Fallah & Khalili, 2015; Khamenehzadeh, 2017; Khozaei Ravari, Hassan, Abdul Nasir, & Mohammad Taheri, 2022; Seifian & Mahmoudi, 2007). In classic courtyard homes, spatial organization naturally segregated public guest areas from private family areas, reinforcing social norms of privacy (Nayyeri Fallah & Khalili, 2015). In today's standardized apartments, by contrast, open-plan living areas and exposed kitchens have become common as a result of space-saving and market trends, potentially at odds with longstanding cultural expectations of separation (Nayyeri Fallah & Khalili, 2015). Researchers have highlighted that privacy as a cultural value still plays a critical role in shaping how spaces are used, even if contemporary layouts do not inherently support it (Nayyeri Fallah & Khalili, 2015). For example, Nayyeri Fallah *et al.* (2015) found that lessons from traditional Iranian housing could inform better spatial organization in modern high-density units to address privacy needs.

Another outcome of policy-driven design uniformity is its interplay with housing market trends. The past several decades witnessed significant shifts in Iranian urban demographics and housing demand. Average household size in Tehran has steadily declined – by 2016 it was around 3.0 persons, with one- and two-person households comprising over a third of all households (Makino & Natsume, 2025). This demographic change creates demand for smaller, more efficient units. Yet the market's response, largely constrained by one-size-fits-all building rules, has been to supply many similar mid-sized apartments rather than a diverse mix of unit types. A longitudinal study by Darvish *et al.* (2019) analyzed Tehran apartments over five decades and noted a progressive reallocation of space within units (e.g. shrinking kitchen and living areas, smaller private rooms) to accommodate changing lifestyles. These findings suggest a housing stock in flux: while policies ensured a baseline uniformity (making units easier to mass-produce), the needs and preferences of residents have been evolving, sometimes leading to a mismatch. On one hand, standardization has made housing a commodity in Tehran's volatile real estate market – with apartments often bought and sold as investment assets. On the other hand, the lack of variety and flexibility in layouts could limit how well new housing meets the nuanced preferences of smaller families,

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multigenerational households, or those seeking features like home offices or enclosed kitchens, which the current dominant designs seldom provide.

Given this context, this study aims to read the contemporary urban form of Tehran's housing by examining its prevalent internal layouts and linking them to the policies that generated them. We focus on identifying the common apartment layout typologies that have emerged under regulatory influence, and we discuss how these typologies relate to market indicators such as housing supply trends and user satisfaction. The overarching goal is to elucidate the impact of urban policies on both the physical configuration of housing and the broader housing market, thereby informing future policy directions.

Theoretical Frameworks for Reading Urban Form

Urban form is often the unintended archive of past regulations. As Hillier and Hanson (1984) theorized in *The Social Logic of Space*, spatial layouts of buildings embody "rules" that can be analyzed as networks of connected spaces, revealing the social logic imposed by designers or policymakers. Space syntax research has since demonstrated how formal constraints and cultural norms shape these spatial networks in predictable way (Shayesteh & Steadman, 2013). In parallel, the typo-morphological approach (or urban morphology) emerged to classify and analyze the city's physical fabric. Typo-morphology, rooted in mid-20th-century Italian and French scholarship (Muratori, Caniggia, Panerai), combines typological and morphological analysis to describe urban form across scales (Cataldi, 2002; Moudon, 1997). It views the city as a dynamic structure shaped through time by the interplay between built forms and their users (Saylan & Gürer, 2024). This framework highlights recurring building types, street patterns, and open-space configurations, providing a contextual understanding of how housing layouts evolve. Crucially, both space syntax and typological morphology inform urban design and policy by revealing the linkages between spatial structure and social outcomes.

Another perspective considers urban policy as a form of design in itself. Planning regulations – such as zoning laws, building codes, and housing standards – act as invisible architects of the city by prescribing what can be built where. Scholars have noted that these rules not only constrain construction but actively shape the emergence of new building typologies and urban patterns (Shayesteh & Steadman, 2013). For instance, blanket regulations on building heights, plot coverage, or street access have introduced generic housing types and uniform layouts across different cities (Shayesteh & Steadman, 2013)(Mohajer Milani, 2021). This regulatory design perspective emphasizes that urban policies embed particular spatial visions (e.g., notions of density, order, or aesthetics) that manifest physically in housing layouts and city form. In summary, space syntax and typo-morphology provide analytical lenses to "read" spatial configurations, while an urban policy design lens recognizes that policy decisions themselves are a driving force sculpting the residential fabric.

Global Perspectives on Spatial Configuration, Daylight, and Housing

Major urban thinkers worldwide have enriched these frameworks with insights on how urban form affects social life, environmental quality, and housing markets. Madanipour foregrounds the socio-spatial interplay in city design, arguing that urban space is both product and shaper of society. His studies of Tehran's modernization, for example, show how imported Western planning models (New Town ideals, modernist layouts) strongly influenced the city's 20th-century form (Madanipour, 1998). Madanipour (1998) notes that foreign-trained planners brought paradigms from places like Paris, London (e.g., Milton Keynes concepts), and America, leaving a tangible imprint on Tehran's housing layouts and neighborhood design. This underscores a global pattern: planning ideas and policies circulate internationally, often reconfiguring local urban forms.

In contrast, Jan Gehl champions a human-centered approach, reminding planners that quality of space at eye level – sunlight, walkability, social interaction – is crucial for livability. Gehl's classic *Life Between Buildings* (1971) critiqued the modernist obsession with towers and open plazas that prioritized *sun, light, and air* at the expense of street-level public life. Modernist planners (e.g., Le Corbusier's "towers in a park") indeed ensured ample daylight and ventilation, but as Gehl argues, this often eliminated the traditional streets and social spaces that make cities vibrant (Gehl, 1971). Gehl's work, alongside William Whyte and others, demonstrated that intimate, well-designed urban spaces encourage casual interactions – an insight prompting policies to reclaim streets for pedestrians and ensure human-scale design (e.g., limiting blank facades, providing sunlight in public squares). Similarly, Jane Jacobs famously contended that diverse, fine-grained urban form underpins economic and social vitality. In *The Death and Life of Great American Cities* (1961), Jacobs identified *four ingredients for vibrant urbanism*: mixed uses, short blocks, varied building ages, and sufficient density (Jacobs, 1961). She showed that overly rigid, top-down schemes (such as uniform high-rise housing projects or superblocks) often disrupt this diversity, undermining local economies and community "eyes on the street." Jacobs' legacy has led urban policy toward "zoning for diversity", encouraging a mix of housing types and retention of older buildings – policies aimed at sustaining the unplanned richness that markets and communities create.

Access to daylight in housing is another universal concern linking design and policy. Pioneering work by Ralph Knowles introduced the *solar envelope* concept – a hypothetical volume within which buildings can be constructed so as not to overshade their surroundings (Knowles, 1981). This idea, and similar climate-based design principles, have influenced city guidelines worldwide by ensuring new buildings do not rob neighbors of sunshine. For example, the "right to light" is implicitly protected in many codes: in the UK, the Building Research Establishment (BRE) (2011) guidelines and local bylaws use tools like the 45° rule to prevent excessive shadowing, while in Japan (Sorensen, 2002) and China (Wang & Li, 2009) explicit solar access standards shape development. Research in building science also links daylight to energy efficiency and health, reinforcing why urban regulations often mandate minimum sunlight exposure for dwellings. In sum, global scholarship converges on a key point: the configuration of space – from street networks down to building massing – profoundly affects social interaction, environmental quality (light, air), and even economic dynamics. Planners and designers like Madanipour, Gehl, Jacobs and others advocate for policies that respect these relationships: policies that create human-scaled, well-lit, mixed environments tend to yield more sustainable and vibrant housing outcomes.

From an economic perspective, urban policy's impact on housing markets has been a focus of both planners and economists. A growing body of evidence shows that restrictive land-use regulations can constrain housing supply and drive-up costs (Gyourko & Molloy, 2014). Glaeser, Gyourko, and colleagues (Gyourko & Molloy, 2015; Glaeser & Gyourko, 2003), for instance, demonstrate that stringent zoning in high-demand cities results in prices far above construction costs, effectively a regulatory tax on housing. In a broad review, Gyourko et al. (2014) conclude that regulation "appears to raise house prices, reduce construction ... and alter urban form". In other words, planning decisions about density and layout can have unintended consequences on affordability and spatial equity. Conversely, scholars like Alain Bertaud argue that flexible, market-responsive planning can improve housing outcomes: when policies allow a variety of housing types and sufficient density in accessible locations, the market can better meet demand, moderating price spikes (Bertaud, 2018). Thus, integrating economic insight, we see that urban form and housing market trends are intertwined – policies that change building heights, parcel sizes or permitted layouts not only reshape city skylines but also influence land values, development rates, and who can afford to live where (Gyourko & Molloy, 2015). This literature underpins the need for balance: urban regulations should guide development to achieve public goods (like daylight, open space, historic character) *without* unduly impeding the supply and diversity of housing.

Urban Form Regulations: International Case Studies

To concretize these themes, this section reviews how urban policies in various global contexts have affected housing layout – from East Asian megacities to European and Middle Eastern traditions.

Tokyo, Japan: Japanese building codes explicitly incorporate sunlight considerations in shaping urban form. The national Building Standards Act employs *"shadow line restrictions"* that limit a building's height and shape so it won't encroach into the defined "shadow zones" of neighboring properties (Japan Ministry of Land, n.d.). There are multiple such restrictions – for instance, the *neighboring land* and *roadside* shadow angles, and a stricter *north-side* setback in low-rise zones – all designed to ensure that even in dense Tokyo neighborhoods, houses receive a minimum amount of direct sunlight (Ministry of Land, 2018). In practice, this means many buildings taper or step back as they rise, preserving light for streets and yards. Additional *shadow duration* regulations use the winter solstice as a benchmark to prevent new constructions from casting long shadows on adjacent lots for more than a set number of hours (E-Housing Japan, n.d.). Together, these rules have encouraged the characteristic slender, low- to mid-rise building profiles in Tokyo's residential areas, as developers opt to build up within a constrained envelope rather than cover entire plots. The emphasis on sunlight in Japanese codes reflects a cultural priority on natural light and ventilation in homes, and it has spawned a variety of innovative design responses (from multi-level setbacks to angled roofs) to maximize floor area while respecting the light rights of neighbors.

Shanghai, China: China's big cities likewise enforce sunlight access standards, profoundly shaping housing layouts in high-density districts. In Shanghai, for example, residential zoning regulations require that each south-facing dwelling unit receive at least one continuous hour of direct sunlight at winter solstice (during the critical 9am–3pm period) (Quan, 2017). This rule – common across Chinese cities – means that tower blocks must be spaced sufficiently apart, or staggered in height, so that lower floors aren't in permanent shadow. Planners use a formula (often based on a multiple of building height, e.g. a 1.4H shadow radius) to determine the needed spacing between buildings (Quan, 2017). The outcome is visible in Shanghai's newer housing estates: tall apartment slabs or point towers are often arranged in parallel rows or checkerboard patterns with generous gaps, avoiding the wall-to-wall canyon effect. At a fixed floor-area ratio (FAR), meeting the solar requirement typically forces trade-offs in form: taller, slimmer towers with smaller footprints can achieve the sunlight standard more easily than lower, bulkier blocks (Liu, Tang, & Zheng, 2024). Indeed, a study of Shanghai's codes notes that under a given FAR, increasing building height necessitates proportionally greater spacing, which the city mandates to guarantee each building's access to sun and air (Liu, Tang, & Zheng, 2024). In sum, Shanghai's urban policies illustrate a clear case where environmental performance metrics (daylight access and energy use) directly influence housing form, producing a distinctive skyline of widely spaced high-rises set in green space. While this approach ensures light and ventilation – vital in the hot, humid climate – it also raises questions about land use efficiency and social life at ground level, issues that Chinese planners are actively debating.

London, UK: London's urban form has long been shaped by planning rules aimed at health, safety, and amenity, from 19th-century bylaws to modern development control. A historical example is the Public Health Act of 1875 (Great Britain, 1875), which empowered local authorities to enact housing by-laws establishing minimum standards for light and ventilation. Under these by-laws, the infamous tightly packed "back-to-back" houses were outlawed; instead, every new dwelling had to have its own yard or open space and windows of a certain size for adequate daylight (Hall, 2002). These standards gave rise to the characteristic Victorian terraced house layout with narrow, through-plan houses each having a small rear yard – a direct result of regulations ensuring no house was without fresh air and natural light. The legacy of those byelaw terraced houses (1875–1914) is still apparent in London's urban fabric and was a marked improvement in public health terms over earlier slum housing (Rosenfeld, Allen, & Okoro, 2011). In the contemporary era, London's planning system uses explicit guidelines to prevent new buildings from blocking their neighbors' light. A common rule of thumb is the "45-degree rule", used by many councils when assessing extensions or infill developments ((BRE), 2011). In essence, an imaginary 45° line drawn from the mid-point of a neighbor's nearest window should not be breached by the proposed construction, thus safeguarding a reasonable amount of sky view and daylight for existing homes. While not a hard law, this guideline (outlined in the UK's BRE Guide to Daylight and Sunlight) is widely applied to shape massing of additions. Moreover, London's recent housing design guides stipulate minimum daylight factors for habitable rooms and often require sunlight analysis for large projects. The cumulative impact of these policies is a city where even in high-density redevelopments, attention is paid to spacing, height, and orientation to maintain liveability – a practice rooted in London's long planning tradition of balancing growth with environmental quality.

Mediterranean and Middle Eastern cities: In many historic cities of the Mediterranean basin and the Middle East, traditional urban form was governed not by modern zoning, but by a mix of customary rules and incremental codes that evolved over centuries. Researchers like Besim Hakim have documented how, under Byzantine, Islamic, and Ottoman influences, informal but remarkably consistent codes guided the layout of streets and homes (Hakim, 2008). A quintessential feature was the courtyard house – a typology that naturally provided privacy, daylight, and cooling ventilation in a hot climate. Rather than mandating front and rear yards as in European codes, these traditional codes encouraged inward-oriented courtyards and close clustering of buildings along narrow streets, with mutual agreements to protect views and solar access to the courtyards. For example, medieval Arab cities had rules about not overshadowing a neighbor's courtyard; in some cases a homeowner's right to light was expressed through limits on the height of the opposite wall relative to the width of the street or courtyard between (Hakim B. , 1986). An interesting element in Mediterranean Islamic cities was the concept of *"fina"* – a small strip of public-right-of-way directly along private walls. While the fina (about 1–1.5 meters) was public, the adjacent owner had conditional use of it, effectively setting buildings back a bit to ensure passage and light. Another feature was the *"sabat"* (Mirmoghtadaee, 2009), a room built to span over a street or alley, connecting upper floors of a house – these were allowed only if a certain clearance was kept and if it didn't unduly darken the lane (Hakim B. , 2008). Similar ideas also observed in Yazd, kashan and many other Iranian cities (Kiani, 1999; Memarian & Brown, 2003) Such rules, though not written in a single code, were maintained by local tradition and jurists and resulted in organically evolved urban layouts: shaded, sinuous streets with the occasional covered passage, and residential quarters that maximized interior comfort. Importantly, these indigenous coding practices achieved high-density, climate-responsive environments long before modern planning (Memarian & Brown, 2003). Contemporary scholars draw lessons from them, suggesting that flexible form-based codes inspired by traditional principles could produce more sustainable outcomes than rigid zoning (Hakim B. , 2008). The Mediterranean example thus broadens the perspective on urban policy: it shows that urban form can be guided by culturally embedded "rules of the game" that balance private interests (light, privacy) with collective form (cohesive streetscapes), offering a contrast to the top-down regulatory regimes elsewhere.

Housing Layout Evolution in Tehran under Policy Constraints

Focusing on Iran and Tehran in particular, a rich vein of scholarship examines how urban policies over the past century have reshaped housing morphology. Tehran's residential landscape transitioned dramatically from low-rise, courtyard-centered neighborhoods to dense grids of apartments – a change deeply entwined with planning decisions (Mohajer Milani, 2021; Shayesteh & Steadman, 2013). Shayesteh and Steadman (2013) trace this co-evolution of regulations and built form in Tehran. Early Pahlavi-era interventions (1930s–1960s) imported modern planning concepts into the traditionally organic city fabric. For example, in the 1930s a new building code limited houses to 40% plot coverage (with the building positioned on the northern edge of the lot) – the rest was to remain open yard (Shayesteh & Steadman, 2013). This was a radical departure from the virtually 100% courtyard coverage of traditional houses, and it was intended to improve sanitation and access. Additionally, a law required every dwelling plot to have direct street access, largely to accommodate the burgeoning use of private cars (National Building Code office, 2017). This mandate led to the carving of new streets and alleys so that no plot was landlocked. While these policies had modernizing intentions, their impact on the historic fabric was severe: *"it is easy to see the devastating impact of these imported regulations on the historical fabrics of Iranian cities by comparing 1950s aerials with today"*, notes Shayesteh (2013). Similarly, Habibi (1996)and Madanipour (2006) emphasize how the introduction of street-access laws dismantled cohesive traditional neighborhoods and fragmented the courtyard-based fabric into isolated plots with poor spatial logic. Whole swaths of Tehran's dense traditional quarters were subdivided or disrupted – large courtyard estates were split so each piece touched a new access lane, and the continuous street fronts of old neighborhoods gave way to patchier, disparate constructions.

In 1968, Tehran's first comprehensive Master Plan further altered housing development. Among other changes, it increased allowable plot coverage to 60% and set new height limits and projection rules, accelerating a move toward multi-story buildings (Madanipour A. , 1998). Over the subsequent decades (1970s–2000s), as urban land values surged, these regulations in combination with market pressures led to the demolition of many one- or two-story houses and their replacement by maximally sized apartment blocks. It is observed by many scholers (Shayesteh & Steadman, 2013; Mohajer Milani & Einifar, 2020; Mohajer Milani & Eynifar, 2019; Sultanzade, 2005; Madanipour A., 2006) that planning and building controls not only constrained traditional construction but *"encouraged the introduction of new generic housing typologies"*, fundamentally changing Tehran's urban form. The typical outcome was the *"row apartment"*: a multi-unit residential building built on a narrow plot, directly abutting neighbors on either side, with a small projection in front – effectively a modern vertical version of the row house. Researchers Mohajer Milani and Einifar (2019) document how Tehran's common housing type evolved from courtyard houses to these row-type apartments over the late 20th century. As they describe, first the traditional central-courtyard homes were replaced by linear "row" houses (attached houses with no side yards) as an intermediate step; later, those two-story row houses gave way to 4–6 story walk-up apartments and eventually elevator buildings, all following the row alignment. This progression was fueled by rapid population growth, modernization, and the real estate market's response to new regulations that permitted higher densities (Mohajer Milani & Einifar, 2019).

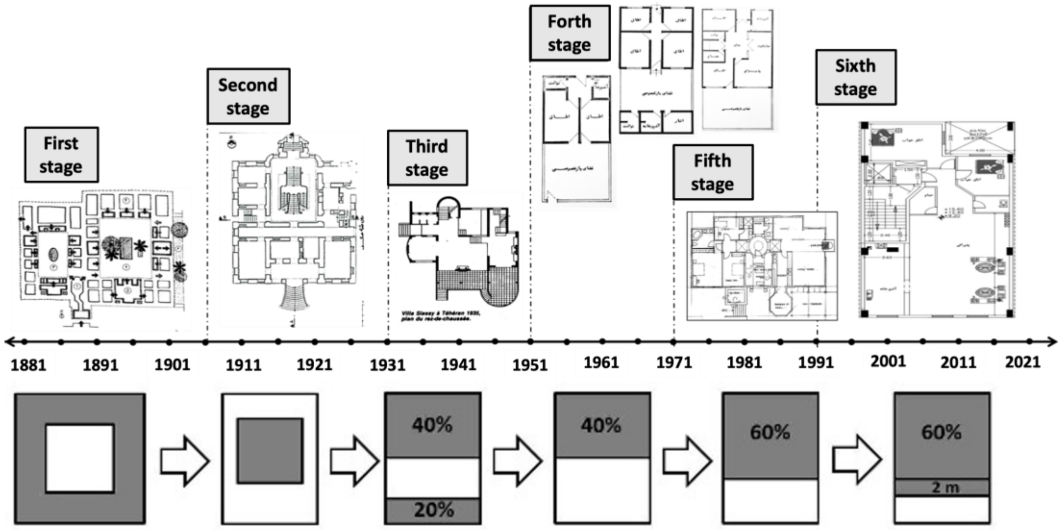

Figure 1. Typological evolution of residential units in Tehran (1881–Present)

A major challenge noted in Iranian scholarship is reconciling new housing layouts with cultural norms. Traditional Iranian houses had clearly defined private and semi-private domains (e.g., *andaruni* vs *biruni* spaces) and were well-suited to extended family living, with courtyards as central social spaces. The shift to compact apartments disrupted these patterns. Milani and Einifar (2019) and Haeri Mazandarani (2008) emphasize that the internal organization of today's typical Tehran apartment unit – often a small, single-level flat – differs greatly from the Iranian archetype, lacking features that used to accommodate privacy gradations, seasonal room use, and domestic flexibility. Residents and designers have had to adapt cultural practices to fit the new layouts. For instance, the concept of a private open space shifted from an inner courtyard to perhaps a balcony or nothing at all; likewise, maintaining visual privacy from neighbors became more difficult in closely spaced apartments. Some studies point to a loss of social cohesion and identity as neighborhoods redevelop piecemeal; the fine-grained mosaic of courtyards and alleyways that fostered close-knit communities has been replaced in places by anonymous apartment blocks (Pourjafar & Hakimian, 2011). As one study notes, densification has been a "place-undermining process," erasing collective memories attached to older forms and leading to weaker place attachment among residents (Shirazi &

Keivani, 2018). Shayesteh and Steadman describe how *"the lack of an overall plan for street facades"* during the boom in private apartment construction left many streets with chaotic skylines and haphazard aesthetics, as each building was designed in isolation (Rabbani & Soltanzadeh, 2014). This reflects a gap in Iran's urban management: while certain quantitative aspects (like density or shadow casting) were regulated, qualitative aspects of urban design (harmony of facades, public realm design) were often neglected until recently.

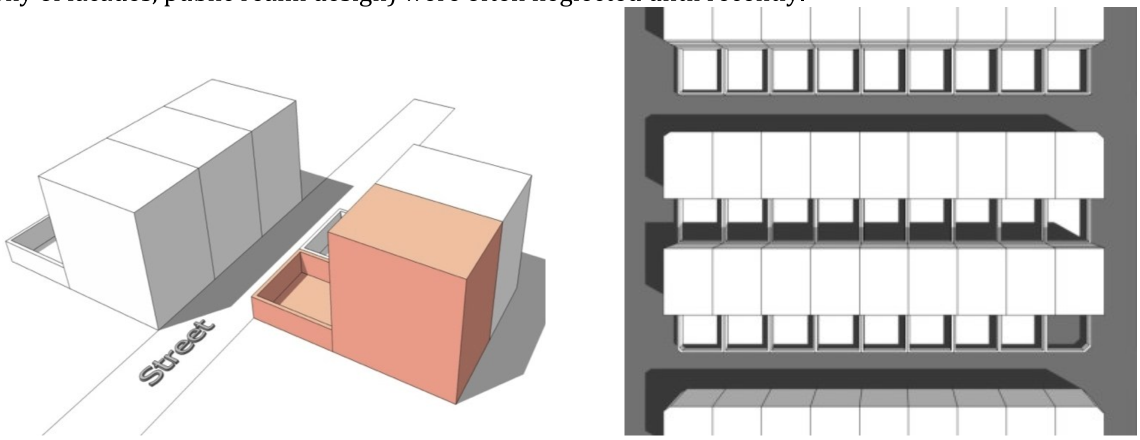

Figure 2. a typical standardized layout that emerged from rigid urban policies—especially the ones tied to the 60% + 2-meter rule

On the other hand, the Tehran case also highlights some positive outcomes of policy. The introduction of modern building codes improved housing in terms of structural safety, access to infrastructure, and provision of light and air to each unit. Tehran today has far less of the substandard, overcrowded housing that plagued it a century ago; much of that can be credited to enforcement of minimum standards and the redevelopment process (notwithstanding issues of displacement and heritage loss) (Piran, 2000). Moreover, as newer plans incorporate concepts like smart growth and sustainability, there is an opportunity to correct earlier problems. For example, current Tehran master plan revisions and design guidelines are beginning to emphasize context-sensitive design, historical preservation, and mixed-use development, in line with global best practices (Tehran Municipality, 2020). Local researchers argue for tailoring regulations to Iran's diverse climatic regions and cultural contexts – suggesting that a more context-sensitive, typology-based code could mitigate the one-size-fits-all approach of the past (Shayesteh & Steadman, 2013; Mohajer Milani & Einifar, 2020; Mohajer Milani & Eynifar, 2019; Sultanzade, 2005; Madanipour A. , 2006; Mirmoghtadaee, 2009). There is also a growing discourse on participatory planning in Tehran, aiming to involve communities in shaping redevelopment so that new housing projects better reflect residents' needs (for open space, communal areas, etc.) and maintain social networks.

In summary, the Iranian experience – and Tehran's in particular – vividly illustrates the double-edged role of urban policy in housing evolution. Top-down regulations were instrumental in moving the city towards modern infrastructure and higher density to accommodate growth, but they also inadvertently disrupted traditional urban form and social patterns. The literature from Tehran's scholars like Shayesteh, madanipour and Mohajer Milani provides a nuanced understanding that can inform other fast-urbanizing cities: it underlines the importance of balancing quantitative development goals with qualitative, cultural, and climatic considerations in policy-making.

Synthesis: Spatial and Economic Consequences of Policy Decisions

Bringing together insights from these theoretical frameworks, global cases, and local studies, we can better comprehend how urban policies reverberate through both the spatial configuration of cities and their economic dynamics. A clear thread in the literature is that urban form is not a passive outcome – it is actively produced by design choices and planning rules, which in turn create certain economic conditions. Policies that dictate lot sizes, building heights, street layouts or open-space ratios will determine the physical structure of neighborhoods (the "reading" of urban form), but they also set the stage for how land markets operate and for who benefits or loses. For example, a decision to lower allowable density in a city center can preserve light and reduce congestion, but it may also constrain housing supply, driving up prices – an economic consequence noted by many scholars (Gyourko & Molloy, 2014). Conversely, upzoning or relaxed codes might spur development and improve affordability, yet if done without urban design guidance it could degrade environmental quality or heritage character. Thus, spatial and economic outcomes are two sides of the same coin in urban policy.

The literature emphasizes that careful policy design can yield win-win outcomes. One example is the integration of environmental design principles (like solar access or energy efficiency) into zoning – as seen in Tokyo and Shanghai – which aims to ensure that higher density does not come at the cost of liveability. Another example is the use of form-based codes and typomorphological analysis in cities like those in the Mediterranean: by understanding traditional patterns, planners can craft regulations that allow incremental growth while respecting historical morphology, thereby maintaining social continuity and property values (Hakim B. , 2008). In economic terms, this can make neighborhoods more attractive and resilient, preventing the blight or value decline that sometimes accompanies insensitive redevelopment. Knowles's solar envelope concept demonstrates how translating a spatial theory into a regulatory tool can protect access to sun and sky in dense cities, potentially boosting long-term property values and energy savings. Likewise, Jacobs' advocacy for mixed-use, human-scale blocks has informed policies that revitalize urban economies (e.g., through adaptive reuse incentives for old buildings and fine-grained zoning that fosters local businesses).

Crucially, multiple authors stress feedback loops between space and economy. Hillier's space syntax research on the "movement economy" posits that well-integrated street networks naturally attract more pedestrian flows and commerce, which increases land value – a virtuous cycle if reinforced by supportive policy. On the flip side, if a policy (say, superblock planning or single-use zoning) disrupts connectivity, it can deaden street life and reduce economic opportunity in an area. Empirical studies in housing economics further confirm that restrictive policies often create scarcity that benefits a few (landowners) at the expense of overall affordability, illustrating how market effects of policy can exacerbate spatial inequality. This underscores a lesson echoed throughout the literature: urban policies must be evaluated not only for their physical design intentions but also for their socioeconomic consequences.

All in all, the bodies of literature reviewed – spanning theoretical frameworks, global exemplars, and Tehran's local narrative – collectively inform a deeper understanding of how urban policies shape housing layout and market trends. They teach us that reading urban form is essentially reading the imprint of rules, norms, and interventions over time. A policy aimed at improving one aspect (like daylight, density, or traffic flow) will have ripple effects on spatial configuration (street patterns, building forms) and on economic factors (housing availability, prices, urban vitality). By synthesizing space syntax analysis, typo-morphological studies, and real-world case evidence, we gain a powerful interpretive lens: we can discern how a given policy decision – be it a zoning change, a new building code, or a master plan directive – is likely to reconfigure the geometry of communities and alter the economic landscape for residents and investors. Such insight is invaluable for contemporary urbanism, where the goal is to craft policies that harmonize spatial quality with market viability, fostering urban forms that are both socially sustainable and economically inclusive. The literature ultimately advocates for integrative approaches: using spatial analytics to guide policy (so that design is evidence-based), and using economic understanding to fine-tune design regulations (so that they achieve desired outcomes without unintended market distortions). This integrated perspective will be crucial in reading and shaping urban form in the face of ongoing challenges, from rapid urban growth to housing affordability crises, in cities worldwide.

Materials and Methods

This study builds upon previous research that analyzed the spatial impact of urban design regulations on Tehran's residential architecture using typo-morphological and space syntax approaches (see Mohajer Milani, 2021; Mohajer Milani & Einifar, 2019; 2020). These earlier works examined 150 apartment floor plans from across Tehran and demonstrated how standard regulatory tools—especially the 60% plot coverage rule and the 2-meter frontal projection requirement—shape internal housing layouts. They revealed that such regulations consistently produce dual-unit-per-floor layouts, with distinct differences between front (south-facing) and rear (north-facing) units. The present paper does not repeat that spatial analysis but builds upon it to evaluate a different dimension: economic consequence. Specifically, it investigates whether the spatial disparities created by regulatory design rules are recognized and priced by the housing market.

A comparative market analysis was conducted to examine pricing differences between front-facing (south-oriented) and rear-facing (north-oriented) apartment units. Drawing from the earlier spatial research, it is established that front units typically benefit from better sunlight exposure and higher spatial integration, while rear units experience reduced daylight and often more fragmented layouts.

To test whether these orientation-based differences correlate with economic value, a simulated dataset of ten matched case pairs was constructed. Each pair consists of two apartments within the same building or immediate neighborhood, matched by key attributes such as floor area, floor level, building age, and construction quality. The primary differentiating factor is unit orientation. This matched-pair design allows for controlled, internal comparisons and has been widely used in housing valuation studies to isolate specific spatial features (Rosen, 1974; Gyourko, Mayer, & Sinai, *Superstar Cities*, 2013).

Property price data were collected from online real estate platforms commonly used in Tehran (Divar.ir, Iranfile.ir), covering listings from 2018 to 2024. Listings were included only if they offered clear details on unit orientation, size, and building specifications. These were cross-referenced for consistency and corrected where necessary based on average regional price benchmarks.

While the sample size does not aim for statistical generalization, it allows a qualitative-comparative evaluation of pricing logic under Tehran's regulatory housing design. Such a qualitative-comparative approach is commonly employed in urban morphology and real estate valuation studies when the goal is not to generalize statistically but to identify consistent patterns or economic signals (Yalciner & Erkip, 2016; Manganelli, 2022). Moreover, due to practical limitations such as data availability, comparable housing stock, and reliability of listing information, this scale was determined to be optimal for ensuring internal validity without overextending the inference.
This method provides insight into how regulations—notably those affecting building orientation, unit positioning, and layout constraints—translate into observable market behavior. It captures the pricing impact of spatial inequality without requiring qualitative interviews or inferred opinion data. Although the sample is not representative in a statistical sense, it reflects plausible mid-market behavior in Tehran and serves to test whether spatial differences embedded in regulated housing design are recognized and priced by the market.

Regulatory Form and Spatial Outcome

Tehran's prevailing housing layouts are a direct spatial outcome of urban regulations—particularly the "60% plot coverage + 2-meter frontal projection" rule and the widespread use of narrow, north-oriented plots. The dominance of north-oriented plots is largely a result of historical subdivision patterns and municipal building codes that position buildings on the northern edge to maximize southern exposure for front units (as explained in Shayesteh & Steadman, 2013; Mohajer Milani & Einifar, 2020; Mohajer Milani & Eynifar, 2019; Sultanzade, 2005; Madanipour A. , 2006). These constraints shape a consistent internal logic: two residential units per floor arranged in a front-and-back pattern, divided by a central stairwell. As a consequence, one unit faces south with broader exposure to daylight and view corridors, while the other is positioned toward the north, relying on narrow light-wells for illumination. Figure 3 show this logic as the front (south-facing) unit benefits from direct sunlight and broader street exposure, while the rear (north-facing) unit relies on a small internal lightwell for illumination. This spatial configuration—mandated by the "60% + 2m" rule and north-oriented plot norms—structurally embeds environmental disparity within a single floor, leading to differentiated market values.

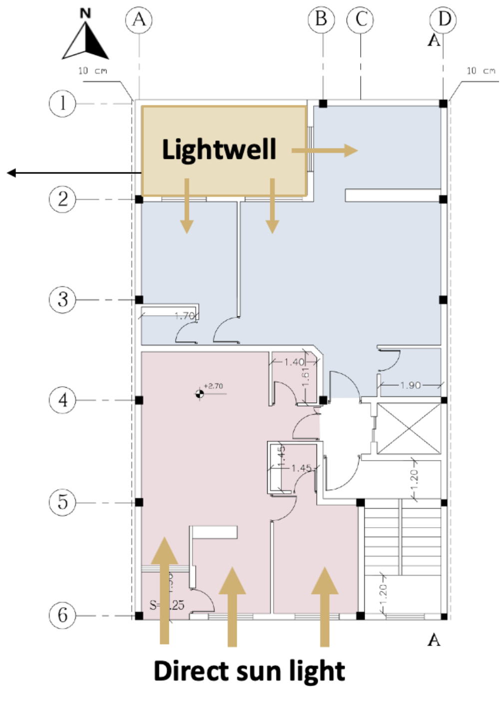

Figure 3. Typical dual-unit floor plan in Tehran shaped by regulatory design logic.

Price Disparities Based on Orientation

While the regulatory code ensures a standard building form, its spatial outcomes introduce a critical variable—orientation—that directly affects housing value. In the front-and-back arrangement produced by the "60% + 2m" rule, one apartment receives optimal daylight and visual access to the street, while the other is relegated to rear-facing conditions with limited light and privacy. These conditions are not incidental; they are structurally embedded in Tehran's housing fabric, and their economic consequences are consistently reinforced in real estate practice. Buyers implicitly recognize orientation as a proxy for livability—favoring south-facing units with greater sunlight, visual openness, and better thermal comfort. Developers, in turn, price these units accordingly, resulting in a recurrent value gap even within the same building.

Based on this argument, we conducted a matched-pair comparative analysis of ten apartment cases—where all variables were held constant except orientation. Across all ten pairs, we found that the price premium for front-facing (south-oriented) units ranges between 10% and 18%. For example, in Pair 1, the south-facing unit was priced at 1,100 million IRR/m^2, while its north-facing counterpart was listed at 930 million IRR/m^2—a 15.45% difference. This pricing gap is not merely anecdotal: it is consistently visible in listings from platforms such as Divar and Iranfile and corroborated by Tehran's pricing benchmarks. To further validate these findings, we engaged in a series of consultations with active real estate brokers in Tehran. Although formal interviews were not part of the study design, these field-based expert conversations served to contextualize the observed trends. This informal triangulation adds practical weight to the claim that buyers actively prefer front units for their better light, ventilation, and ambiance. Figure 4 visualizes the average price per square meter across all case pairs. The difference between orientations confirms that southern exposure remains a major driver of unit valuation.

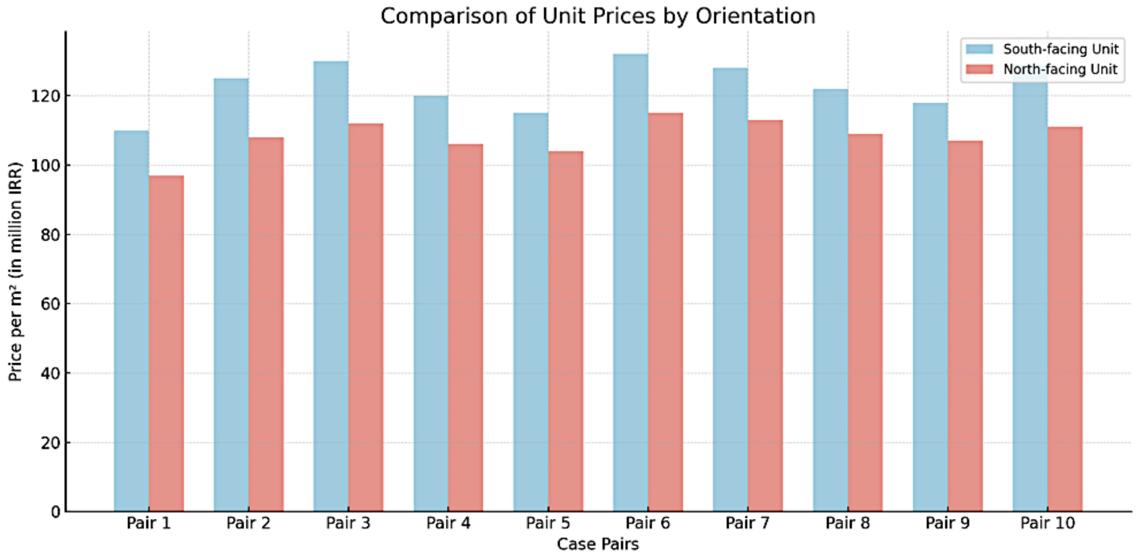

Figure 4: Bar chart showing average market prices for south- vs. north-facing units

The chart shows that front units consistently achieve higher prices, with an observed 10–18% premium for the street-facing orientation. This price disparity is directly attributed to qualitative differences: front units benefit from better natural light and view corridors, whereas rear units are disadvantaged by lower daylight and privacy issues (overlooking narrow courtyards or light-wells). Expert interviews corroborate that buyers consider south-facing units as more valuable investments, driving up their market rate. Table 1 complements this by detailing each case in the matched-pair analysis. Each pair includes a south- and north-facing unit with matched characteristics.

Table 1. Orientation-Based Price Differences (Matched Pairs)

Case Pair	Floor Area (m^2)	Floor Level	South Unit Price (M IRR/m^2)	North Unit Price (M IRR/m^2)	% Difference
Pair 1	105	2nd	1,100	930	−15.45%
Pair 2	92	3rd	1,050	880	−16.19%
Pair 3	87	4th	990	860	−13.13%
Pair 4	110	1st	1,150	970	−15.65%
Pair 5	100	2nd	1,070	910	−14.95%

The primary cause of this disparity lies in environmental quality. South-facing units receive extended hours of direct sunlight, particularly in winter months, improving thermal comfort, interior brightness, and visual connection to the outside. These factors enhance residential desirability, which the market translates into higher property values. Conversely, north-facing rear units suffer from limited daylight, poor natural ventilation, and reduced spatial integration, as previously shown in space syntax analyses. These factors lead to a consistent price devaluation of the rear half of the typical building layout.

Importantly, this pricing pattern is not a result of consumer taste alone but a structural consequence of the regulatory regime. The mandated configuration effectively produces a bifurcated housing product within each floor: one spatially and environmentally privileged, and the other disadvantaged. Attempts to mitigate this disparity—such as adding side windows, using split-level units, or shifting the stair core—are often constrained by code limitations or cost considerations. As a result, the majority of developers default to the standard configuration, further entrenching this built-in hierarchy.

Spatial Inequality and Embedded Value Gaps

The observed price gap between front- and rear-facing units is not a superficial market anomaly but the product of deeply embedded spatial asymmetries generated by Tehran's regulatory design framework. While Section 4.2 quantified the economic effects of unit orientation, this section examines how such effects are rooted in systematic environmental inequities shaped by regulatory geometry.

As illustrated earlier, regulations such as the "60% + 2m" rule enforce a dual-unit-per-floor layout, with one unit facing south and the other relegated to the rear. This layout inherently privileges the front unit with better solar access, thermal gain, ventilation, and visual connectivity to public space. In contrast, the rear (north-facing) unit is environmentally disadvantaged—often enclosed by neighboring buildings, dependent on small lightwells, and deprived of long-duration sunlight. Over time, these spatial disadvantages are capitalized into the real estate market, creating consistent pricing differentials.

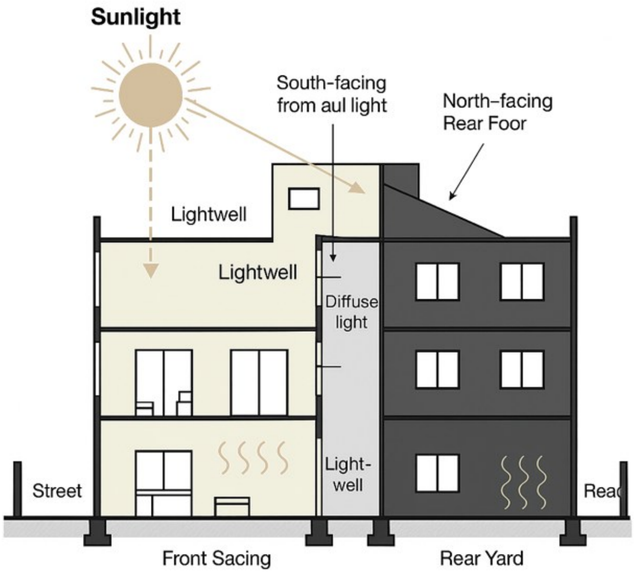

Figure 5. Sectional representation of daylight disparity in Tehran's regulated dual-unit apartment layout.

This architectural section illustrates the environmental hierarchy created by regulatory form. The south-facing front unit benefits from direct solar exposure and visual openness to the street, while the north-facing rear unit receives limited diffuse light via a narrow lightwell. This disparity in daylight access underpins the persistent market value gap between front and rear apartments.

This spatially enforced hierarchy has become a normalized feature of Tehran's housing stock. Although some developers attempt minor design modifications (such as adding side windows or reorienting internal layouts), these adjustments are typically limited by zoning codes, setbacks, and structural considerations. As a result, spatial inequality is not only replicated but reinforced by the regulatory framework itself.

Table 2. Summary of Regulatory Impact Pathway

Regulatory Tool	Spatial Outcome	Environmental Impact	Economic Effect
60% Coverage Rule	Narrow footprint; Deep plans	Low daylight in deep spaces	Lower rear unit valuation
2m Frontal Projection	Increased front articulation	Enhances front daylight or view	Higher front unit value
North-Oriented Plot Norms	Staircase-centered, front or back split units	South = sun; North = shaded	Embedded price hierarchy
Dual-unit per floor logic	Rear units rely on side setbacks or lightwells	Unequal daylight access	10–18% price gap (avg.)

These findings highlight that what appears as architectural uniformity is in fact embedded economic inequality. Sunlight, once treated as a technical concern in building codes, becomes a form of currency in Tehran's housing market—an asset distributed unequally by design. Several key implications emerge:

- **Regulations create unintended hierarchies.** The uniform application of spatial rules (e.g. north-side building logic, frontal projection constraints) indirectly create two types of residential products within the same building footprint: one favored by the market, and one discounted.
- **Buyer preferences confirm spatial logic.** Interviews with brokers and listings confirm that buyers consciously seek south-facing units, and price their preferences accordingly. While not always stated in advertisements, this information is widely communicated in informal real estate networks.
- **Design compliance limits innovation.** Developers rarely deviate from the "safe" typology, even if better daylight solutions exist, due to regulatory and financial limitations. As a result, spatial inequality becomes normalized.

In summary, the results show a direct causal chain from regulatory form to spatial arrangement to economic value. Tehran's design codes—especially the coverage rules and orientation constraints—systematically shape apartment layouts that yield unequal outcomes. The market responds by rewarding daylight access and penalizing its absence.

Discussion and Conclusion

Tehran's residential fabric, as examined in this study, reflects the spatial imprint of decades of regulatory planning. Repeated application of the "60% plot coverage + 2-meter frontal projection" rule, together with the prevalence of north-oriented plots, has produced a dominant housing layout: a dual-unit floor plan split front to back along a central core. While this form appears standardized and neutral on the surface, it encodes a deep structural imbalance. Through spatial analysis and market comparison, this study has shown that orientation—though never explicitly priced in regulation—is materially valued by the housing market, with front-facing (south-oriented) units commanding consistent price premiums.

This spatial-economic pattern is not incidental; it emerges from the very logic of Tehran's urban design code. Regulations originally intended to ensure basic access to light and air have unintentionally crystallized a hierarchy of value within the same building footprint. Units facing the street benefit from environmental advantages—sunlight, ventilation, thermal comfort—that rear units cannot replicate due to lightwells and constrained boundaries. As demonstrated in our matched-pair pricing analysis, this asymmetry translates into an average 10–18% price gap, repeatedly affirmed by market data and corroborated through professional insight.

By closely reading the relationship between built form and regulation, the study underscores how housing inequality can be spatially manufactured. The regulatory script not only defines building envelopes but also structures patterns of desirability and exclusion. Buyers respond accordingly, with orientation becoming a proxy for livability, and thus for value. As such, the paper contributes to a growing understanding of how urban policy does not merely shape the skyline—but also the social and economic geography of housing access.

To mitigate these embedded disparities, there is a clear need to rethink rigid building templates and allow for more adaptive typologies—those that better distribute daylight, frontage, and environmental quality. Design incentives encouraging dual-aspect layouts, adjustable stair cores, or alternative massing strategies could begin to challenge the regulatory assumptions that now divide units into high-value and low-value categories by default.

Ultimately, the findings illustrate that **urban form is not merely the outcome of architectural decisions—it is a built record of policy choices, and their consequences ripple through the city's housing market**. Addressing spatial inequality, therefore, begins with acknowledging how deeply it is rooted in the rules that shape what gets built, where, and for whom.

The evidence presented calls for a revaluation of Tehran's urban design regulations through a more equity-oriented and performance-driven lens. Rather than relying on prescriptive spatial formulas—such as the dual-unit layout enforced by the "60% + 2m" rule—urban policy should shift toward form-based and outcome-sensitive codes that prioritize environmental equity across all units. This could include incentivizing dual-aspect apartments, permitting staggered massing that improves rear light access, or relaxing frontal projection limits in exchange for daylight optimization. Regulatory frameworks should also integrate daylight simulation metrics and livability indicators into the approval process, ensuring that spatial quality is not sacrificed in the name of uniformity. By embedding flexibility and performance standards into building codes, Tehran's urban development can better align with goals of social inclusion, environmental justice, and long-term market sustainability.

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Conflict of Interests

The author(s) declare(s) no conflict of interest.

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Chapter 11

Placemaking Strategies for Public Spaces in Bahrain: By Integrating Inclusivity and Cultural Expression

* Dina Abdullah, Dr. Najla Allani

Introduction

With the rise of urbanism, it has become necessary to include nature in our built environment and coexist with it instead of pushing it away. In recent years, the success measure for cities has largely depended on the livability and quality of life (QoL) in those cities (Ballas, 2013; Amin, 2008). With the rise of mental health issues, the role of cities has expanded beyond merely providing functionality and speed to creating spaces where people can pause, socialize, and engage with their urban environment. Research indicates that walking in nature can significantly reduce stress and increase people's happiness levels. Therefore, integrating nature into our built environment is crucial for enhancing people’s physical and mental health (Olcoń et al., 2023).

Public spaces are integral in forming the social and cultural fabric of cities. They foster human and cultural interaction, and they offer numerous benefits to their users. These benefits cover multiple dimensions, including health, economic, environmental, and social benefits (Yılmaz & Mumcu, 2016). Moreover, the quality of public spaces often determines the quality of life in our cities. Consisting of parks, streets, plazas, and the spaces between buildings, these open spaces help shape our cities and define their image (Gehl Institute, 2017; Lynch, 1960).

One of the major benefits of public open spaces is that they foster communities and shape cultural identities (El-Kholei & Yassein, 2022). This implies the importance of understanding the culture in which these spaces are located and designed, as it helps adapt the design strategies to the needs of a specific culture (Gehl Institute, 2017). Therefore, given their benefits in creating a sense of community and promoting social cohesion, it is essential to design public spaces that ensure inclusiveness and cultural expression (Dalal et al., 2024).

Countries worldwide are now becoming more concerned with creating healthier public spaces by incorporating urban design guidelines that promote livability and enhance the QoL in cities (Cramer-Greenbaum, 2020). Bahrain is one of the countries that have been working diligently to enhance its public open spaces and improve their quality. This effort aligns with Bahrain’s 2030 economic vision, which entails meeting UN SDG No. 11, which proposes the creation of more green public spaces to enhance safety and sustainability in countries (*THE 17 GOALS*, n.d.). Therefore, Bahrain has developed a plan to meet this SDG by creating more public spaces and improving the conditions of existing ones (*Sustainable Development Goals*, n.d.). However, these guidelines provide general regulations regarding only the physical aspects of public spaces, without considering the social or cultural aspects of the community (Zoning Regulations for Construction in Various Areas in the Kingdom of Bahrain, 2022).

For public spaces to be successful, they should offer a diverse range of activities and functions, attracting people from all walks of life (Priess et al., 2021). Placemaking is one of the concepts studied over the past few decades to enhance the quality of public spaces and foster a sense of community and belonging to their location. It employs a multi-layered approach that creates a range of functions to enable the space to accommodate multiple activities, cater to people from diverse backgrounds, and foster a sense of community by keeping the user at the heart of the design process (Figure 1) (Costa et al., 2024).

To transform public spaces into lively communities, Project for Public Spaces (2021) identified eleven main principles for placemaking. These principles are divided into four major groups: first, underlying ideas that entail the community is the expert and needs to be involved in the design of their public spaces, as the primary users of the space. Second is planning

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and outreach, which suggests observing the space and how people use it to understand how they feel about it and then creating a vision of what the place should be—third, triangulating and experimenting with quick and small projects to translate ideas into actions and lastly, implementing changes, keeping in mind that projects are never finished. It is an ongoing process that keeps adapting to changes in people's lives (Costa et al., 2024).

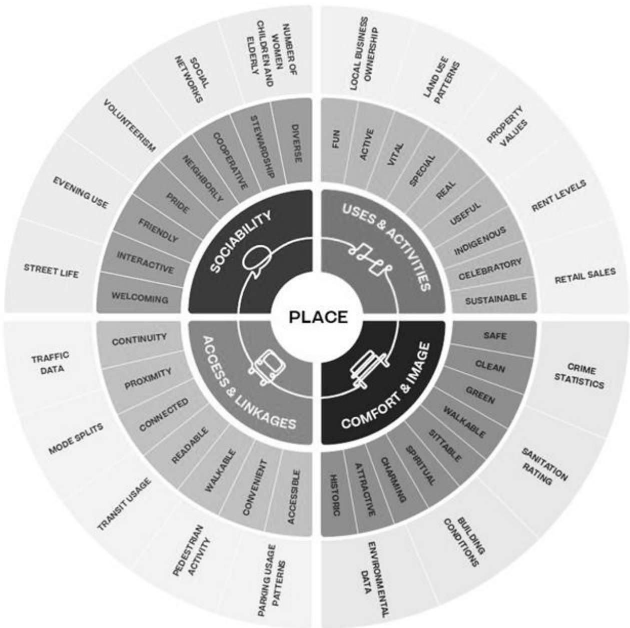

Figure 1. Attributes of a good place (Project for Public Spaces).

Inclusivity and Placemaking

Inclusivity means designing spaces that are welcoming and comfortable to everyone. It is about creating equitable places that empower all segments of society, allowing them to be a part of the community and belong to their city. This includes individuals who are more likely to face issues with comfort and safety in public spaces, such as women, children, elderly people, individuals with special needs, and those from diverse ethnic backgrounds (*Designing Inclusive Spaces*, 2018). This approach allows public spaces to cater to all users by creating a safe environment for everyone. Therefore, to achieve inclusivity in design, it is important to recognize the types of users of the spaces, understand their needs, and establish ways of offering them a safe and welcoming environment. (*Equity and Inclusion: Getting Down to the Heart of Placemaking*, 2016). Figure 2 shows the main users who could face issues with the design of the public spaces and the areas of improvement according to placemaking qualities.

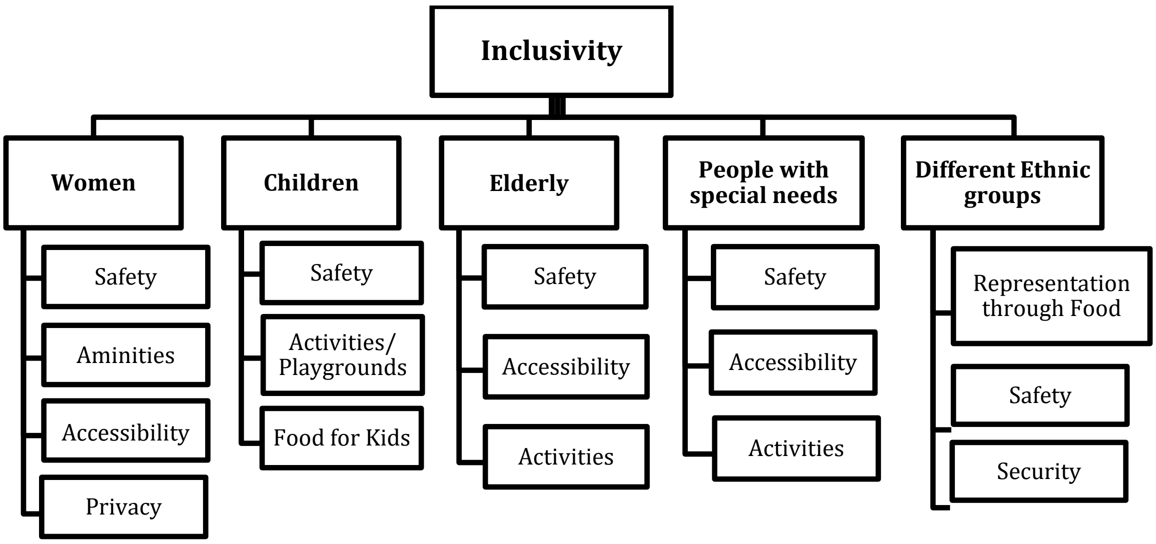

Figure 2. Main user groups' structure and the issues of public spaces (Author, 2024).

Safety and Security in Public Spaces
Inclusive public spaces should be comfortable and welcoming to everyone, with clean, well-maintained public amenities (*Designing Inclusive Spaces*, 2018). For women, facilities like clean restrooms, nursery rooms, and prayer spaces enhance comfort and safety, allowing them to stay longer (Malhotra & Aulakh, 2023). Well-lit areas and wide walkways improve nighttime security (*Safer Cities for Women and Girls Through a Place-based Approach*, 2011).

In addition, children's play areas should prioritize safety in design and function by being located away from streets and parking lots and using protective flooring to prevent injuries (*Designing Inclusive Spaces*, 2018). Furthermore, people with special needs should be able to navigate the spaces safely and independently. This can be achieved through the choice of appropriate materials, clear pathways, ramps, rails, and interactive or braille signage for visually impaired users (*Accessibility in Public Spaces – Definition and Explanation*, n.d.).

Moreover, elderly people require special attention to safety and accessibility, which can be achieved by implementing safe flooring and providing calming and low-effort activities that appeal to the older generations (*Designing Inclusive Spaces,* 2018). Lastly, to make public spaces inclusive for diverse ethnic groups, they should provide opportunities to celebrate their culture on certain occasions and make them feel welcome within their community (*8 Lessons to Promote Diversity in Public Places*, 2007).

Promoting Diversity
A good design influences people's lifestyles and helps improve social connections with others. To ensure public spaces are inclusive, the design should lay the ground for diversity and inclusion by providing spaces and platforms that can accommodate functions, uses, activities, and events to cater to people from all age groups, genders, educational backgrounds, and ethnic groups. Therefore, incorporating multiple uses allows users to find activities that suit them. Public spaces should be accessible to everyone, which means celebrating the diversity of our cities. The cultural fabric of society is made up of people from all backgrounds, ethnic groups, and social levels. Therefore, it is essential to create public spaces that celebrate this diversity. It could be facilitated by integrating different functions and activities representing people from various backgrounds through food, sports, and cultural celebrations. Moreover, it encourages all community members to participate in the design process and local activities to make them feel heard and appreciated (*8 Lessons to Promote Diversity in Public Places*, 2007).

Creative Placemaking

There are four main types of placemaking: Standard placemaking, strategic placemaking, tactical placemaking, and creative placemaking (Wyckoff, n.d.). This research focuses on creative placemaking, which is a term used to describe projects that integrate Art in the development of community projects (Ellery et al., 2020).

As the name suggests, creative placemaking involves transforming creative projects or activities centered on art, culture, and creative thinking. These projects can take place in cultural settings, utilize existing structures, or be implemented in other locations by incorporating artistic and creative activities, such as movie screenings in public parks, painting murals on walls, and outdoor concerts. These elements create a creative and lively atmosphere of art and culture to bring the community together (Wyckoff, n.d.).

Cultural expression and placemaking

With the rise of globalization, cities' local identities are shifting to meet global standards, and their cultural characteristics are fading with time. This causes our public spaces to lose touch with their local and regional qualities, alienating people and affecting their sense of belonging and attachment to their cities (Yan et al., 2024).

In recent years, there has been a growing awareness of the role of integrating culture into people's experiences and activities to emphasize local characteristics and promote sustainable development (Yan et al., 2024). This results from understanding the importance of cultural activities in enhancing people's mental and physical health, as well as their educational and learning opportunities. Additionally, integrating cultural activities positively impacts the country's economic growth and fosters a cohesive community (Local Government Association, 2017).

Placemaking emphasizes the role of art and cultural representation in enhancing social cohesion and preserving cultural heritage, given that every community has its unique culture (Yan et al., 2024; Local Government Association, 2017). Cultural identity is mainly linked to people's sense of belonging, understanding, and appreciation of their place. This idea is capitalized in placemaking by employing the community's potential to create public events and activities that promote health and happiness (Local Government Association, 2017).

Impact of Cultural Expression
According to Yan et al. (2024), research on the design of public spaces and placemaking showed that relying solely on the physical aspects of the design proves insufficient. This results in public spaces void of human connection or lacking a link to cultural values and identity. Therefore, designing spaces that shape social interactions and promote cultural understanding is essential (El-Kholei & Yassein, 2022).

One of the significant impacts of cultural expression is building stronger communities by bringing the public together and engaging them in a project or allowing them to participate in cultural events. This builds up their sense of pride and belonging to their community. The interaction between community members can create social cohesion and make the community feel a sense of responsibility and unity (Local Government Association, 2017).

Another positive impact of cultural expression is developing and supporting local talents. Culture is dynamic in that it is constantly changing and growing with the people. Therefore, the locals can contribute to their culture by playing an integral part in shaping it. Placemaking in open spaces creates the right platform for local talents to be directly involved in creative activities and showcase their talents in different ways (Local Government Association, 2017).

Lastly, effective collaboration between private, public, and community organizations to assist in delivering small community projects improves social cohesion and facilitates future developments (Local Government Association, 2017).

Art as a form of Cultural Expression

Art is an integral part of cultural expression in cities worldwide, serving as a means to communicate artists' feelings and perceptions, and fostering a dialogue between artists and their cities. Public spaces act as a platform to bring art closer to the people, contributing to the community's collective memory and creating meaningful experiences through art festivals and initiatives (García-Esparza et al., 2023).

Artistic practices such as reviving ancient crafts, historical storytelling through LED projections, and bringing back old music are all forms of cultural and artistic expression. This integration of Art into public spaces helps activate those spaces. It adds a layer of depth to the human experience, making it a personal experience tailored to the city's history and culture (Đukanović & Živković, 2015). Placemaking enables the creative incorporation of small interventions and events to enrich the meaning of public spaces and foster stronger community connections (Yan et al., 2024).

Integrating art projects inspired by the city's heritage within public spaces not only helps with cultural expression, but also placing historic objects in different contexts helps bring the experience of heritage and culture closer to the people. Moreover, drawing inspiration from the heritage and reintroducing it through contemporary art forms like photography, sculptures, and art installations makes it more accessible to people from all levels of society, which reintroduces public spaces on a more profound and multi-layered level instead of a linear process of design that ignores symbolic and cultural meaning (García-Esparza et al., 2023).

Bahrain Fort, one of the country's most valuable historic sites, has been bringing culture and history closer to people by hosting diverse cultural events, lectures, and activities either at the site itself or at the Bahrain Fort Museum next to it. One of the creative ways of engaging the public in learning about the history of this magnificent structure is through an event called "Sound and Light Show," which usually takes place at the fort during the 'Spring of Culture' event. The fort's walls become storytellers, projecting an engaging narrative about the history of Bahrain and the fort (Shubbar & Furlan, 2019)—figure 3.

Figure 3. Screening at Bahrain fort (Inserro, J.,2018) .

Despite the growing interest in designing public spaces and incorporating more greenery into urban developments, it is evident that most research has focused on methods and strategies for designing them from sustainable, economic, and social perspectives; little research has been conducted on inclusivity and the cultural aspects of designing public spaces. Inclusivity and cultural expression are key in defining how people interact with their cities according to their cultural preferences and needs.

This chapter addresses two primary research questions: whether the design of open public spaces in Bahrain lacks inclusivity and cultural expression, and how to utilize placemaking attributes to develop strategies that facilitate the incorporation of this concept into public space design.

The primary objective of this research is to develop strategies for placemaking in Bahrain that promote inclusivity and cultural expression in public spaces. By integrating these strategies into future planning policies, public spaces can improve their performance, serve the community, and attract more visitors. The research is based on the hypothesis that some public spaces in Bahrain lack inclusivity and cultural representation, aiming to address this gap by proposing placemaking strategies that can enhance their functionality and cultural significance.

The study examines placemaking and the design of open public spaces in Bahrain and worldwide. It begins with a comprehensive literature review, followed by data collection through field observations and questionnaires. A mixed-methods approach combining quantitative and qualitative analysis is used to identify and read patterns through NVivo. The findings are then compiled and analyzed to establish clear strategies for enhancing inclusivity and cultural expression in public spaces in Bahrain.

Materials and Methods

The research is conducted through different phases: Data collection and case studies of three major open public spaces in Bahrain, questionnaires to be conducted to explore users' perspectives on the three public spaces in study, analyzing and representing the data gathered using NVivo and Excel, to find similar parameters and factors amongst the answers from the questionnaires conducted and lastly, creating strategies to enable the implementation of placemaking principles into the open spaces in Bahrain to create inclusive and culturally expressive places. Figure 4 illustrates the sequence in which these methods are applied, along with their respective types.

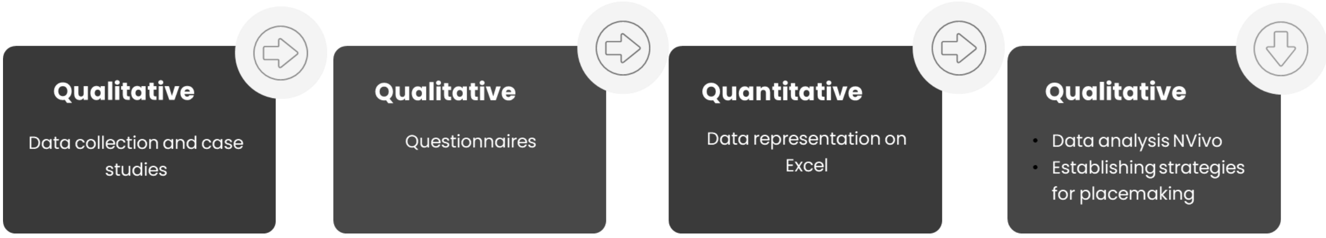

Figure 4. Methodology phases (Author, 2024).

Data collection and Case studies

To examine the current situation of public spaces in Bahrain and establish strategies for inclusivity and cultural expression, collecting data on existing governmental guidelines for designing public spaces is important. This data is found in the governmental building regulations, which present the details on allowable areas, functions, and green spaces (Zoning Regulations for Construction in Various Areas in the Kingdom of Bahrain, 2022). Furthermore, to analyse the current conditions of Bahrain's public spaces, three major public open spaces—Al-Fateh Corniche, Bahrain Fort, and Argan Village—are taken as case studies and assessed based on their physical attributes, such as their location, accessibility, and attractiveness, as well as their abilities to promote inclusivity and cultural expression.

The case studies were selected based on their cultural significance, the type of services and activities they offer, their intended user groups, and the duration of their existence. While Bahrain Fort is an ancient site that primarily offers a cultural experience to tourists and locals alike, Al-Fateh Corniche is a modern development that serves as an open public park for people to hang out, play, engage in sports, or socialize. Both locations cater to a large group of users from diverse demographic backgrounds and often attract people from various areas around Bahrain due to their central location and their functional variety. Additionally, the Argan Village is a new development that offers a range of commercial activities and an open public space for the residents of the Bu-Quwa residential area in Bahrain.

To begin with, Al-Fateh Corniche is one of Bahrain's oldest seaside open spaces, holding a significant cultural and social place in the minds of the Bahraini people. It has been recently developed by the Ministry of Municipalities Affairs and Agriculture to accommodate more functions and offer a more holistic experience for people in Bahrain (*Khalaf Announces the Completion of the Development of the "Al-Fateh Corniche" Walkway*, 2022).

In addition, Bahrain's Fort is the country's oldest and most significant historic site, dating back to 2300 BC. It is a UNESCO World Heritage Site, which offers a rich cultural experience to both locals and tourists in Bahrain (*Qalat Al Bahrain Site and Museum*, n.d.). The site is a part of the collective memory of the people in Bahrain and plays a significant role in defining the country's cultural identity. Surrounded by an open space, a museum, and a café overlooking the ancient ruins and the sea, the area around the fort serves as an attractive spot for people to experience culture, food, and art.

Lastly, the Argan Village site is an example of a smaller-scale, well-designed, local mixed-use development that offers a shared open public space for the residents in the surrounding area (*ARGAN Village*, n.d.). However, the site does not live up to its full potential, as it is rare to see people using either the open public space or the shops and cafes in that area. This case can offer insight into what some public spaces lack in attracting regular users.

The analysis of the case studies is conducted through field observations, which involve visiting the sites and observing people's interaction with their natural environment (Zeisel, 1981). Data is collected to identify the current conditions and physical features of those spaces. This phase is essential for observing the existing conditions of the public spaces, which helps identify areas for improvement and strategies to overcome current issues.

Finally, a comparison is made between the three public spaces to measure their performance in terms of their response to the placemaking qualities that enhance inclusivity and cultural expression in public open spaces. This helps with upgrading the conditions of these public spaces to align with placemaking qualities.

AL-Fateh Corniche, Manama

Al Fateh Corniche is one of Bahrain's oldest waterfront open public spaces (Figure 5). Located in the heart of Manama. The Corniche was recently developed in 2022 to create a longer walkway that extends up to 3 km, as well as the longest biking trail in Bahrain, which spans 2.5 km. The Corniche is now home to four main sports areas, two playgrounds, a fishing area, a larger parking lot, and family areas. It also features green spaces that cover an area of 25,000 sqm. The walkway now leads to Al-Najma Sports Club, which is located close to multiple restaurants and cafes. This new development was done to emphasize the importance of incorporating sports into the lives of the Bahraini youth and encourage them to spend time outdoors (*Khalaf Announces the Completion of the Development of the "Al-Fateh Corniche" Walkway.*, 2022).

In its ongoing effort to enhance the quality of life for young people, the Bahraini government plans multiple sports events in this area to emphasize the benefits of training for both physical and mental health. Furthermore, the corniche is equipped with multiple amenities that enhance the user experience, offering an array of functions that encourage users to spend a longer time in the area. This aligns with some of the placemaking qualities: sociability, uses, and activities (*Khalaf Announces the Completion of the Development of the "Al-Fateh Corniche" Walkway.*, 2022).

Regarding inclusivity, the project provides free access to the Corniche and the open green areas, enabling people from different socioeconomic backgrounds to benefit from the place. The space fosters diversity by providing a safe environment for people from diverse ethnic backgrounds to visit. Moreover, the place is open and features ramps to facilitate easy and free movement for individuals with special needs, making them feel welcome and respected.

Al-Fateh Corniche holds a special place in every Bahraini child's mind, as it is one of the oldest places in Bahrain for playing and enjoying family time. Although it has been extended and developed recently, this has not taken away its cultural identity. Bahrainis still visit this place to remember their childhood days and enjoy the changes made to the site.

Figure 5. Al-Fateh Corniche (Author, 2024).

Bahrain Fort

Bahrain Fort is one of Bahrain's oldest and most significant cultural landmarks. This UNESCO World Heritage Site is approximately 4,500 years old, dating back to around 2300 BC (Figure 6). The site holds a special place in nearly every Bahraini's mind and heart, as it has always been a part of the collective memory of the locals in Bahrain. This magnificent site not only offers beautiful ruins of the past but also features an almost 1 km long path surrounding it and overlooking the seaside, which has become a favoured spot for walking and exercising for both locals and residents in the country (*Qal'at al-Bahrain – Ancient Harbour And Capital of Dilmun*, n.d.).

The intervention in this area is minimal, given that this historic site is a UNESCO World Heritage Site (*Qal'at al-Bahrain – Ancient Harbour And Capital of Dilmun*, n.d.). However, surrounding it is the Bahrain Fort Museum and a café that creates a beautiful link between the past and the present (*Qalat Al Bahrain Site and Museum*, n.d.). The Bahrain Authority for Culture and Antiquities (BACA) often utilizes the site as a canvas for cultural and artistic purposes, bringing culture closer to the people. The ancient site is often revitalized by adding art installations and projections that serve as storytellers of the past, bringing history to life.

In terms of inclusivity, Bahrain Fort's site attracts locals, residents, and tourists from all over the world, reflecting the area's diversity. However, visiting this site could be a challenge to people with special needs, as the fort is not equipped with ramps or elevators to allow them to experience it fully. This is also understandable, given the site's nature, which does not permit major structural or architectural interventions. Moreover, the site is free to enter for everyone, which makes it accessible to people from all backgrounds and levels of society.

Bahrain Fort is a culturally rich site that offers a unique experience into the history of Bahrain. Therefore, people visiting it often express a strong sense of emotional connection, whether they are tourists or expatriates. The fort's site has been utilized multiple times to showcase the story of the fort's past through creative art installations and light projections, which have brought people closer to the site and provided an educational opportunity to learn about Bahrain's culture (*Events and Activities*, 2024).

Figure 6. Bahrain Fort (Author, 2024).

Argan Village

Argan Village is a local mixed-use development located in the Bu-Quwa area in Bahrain (Figure 7). With a built-up area of 11,360 sqm, the project comprises six commercial buildings that can be used for shops, cafes, and an anchor tenant. A green park of 3,146 sqm is located in the centre, which can be utilized as a kids' playground (Figure 8). The design draws inspiration from traditional Bahraini houses to establish a cultural connection with the area (*ARGAN Village*, n.d.).

Argan village, which was built in 2015, currently has a few shops and spaces rented out, while the rest of the development is empty. Despite its sound design, visiting the area at different times of day on various occasions reveals that the place is often underutilized. The car-centric nature of the area could be one of the main issues, as the kids' playground (the park) is directly open to the main road and surrounded by cars on all sides. This limits access to the site to cars and restricts the accessibility and safety of kids. Although the development is located within a residential neighbourhood, it is believed not to be the best location for families to spend time with their kids. Moreover, the high rent in these shops makes it difficult for shop owners to sustain their businesses, forcing them to shut down.

Through observation, the site reflects a shallow emotional or cultural connection with the people of that area. Besides its architectural design inspired by Bahraini houses, no other elements or activities bring people closer to their roots or help them build a cultural bond with the site.

Figure 7. Model of the site (Argan Village, n.d.)

Figure 8. Argan Village open space (Author,2024).

Questionnaires and field observations

Two methods are implemented to holistically understand the current conditions of open public spaces in Bahrain and get feedback from the direct users. First, field observations suggest visiting the sites and observing people's natural interaction with their environment (Zeisel, 1981). This can provide a realistic understanding of people's feelings and behaviour in a spontaneous setting. Second, conducting questionnaires is an effective way to gather information about people's perceptions of a particular place, offering them the freedom to speak their minds and suggest ways to upgrade it.

The questionnaire used in this research is divided into three main types of questions: demographic, Likert scale, and open-ended. While the demographic questions are designed to collect data on the background of visitors to these public spaces, including their age groups, educational levels, gender, ethnic origins, and other information that helps understand the inclusivity of the public space, the Likert scale questions are primarily used to evaluate people's perceptions of the places they visit, allowing them to rate their feelings regarding safety, cultural activities, and sense of belonging in those places. Lastly, open-ended questions are asked to allow people to suggest ways to make places more inclusive, comfortable, and culturally expressive. Figure 9 shows the details of the questions used in the questionnaire.

Questionnaire:

Demographic Questions:

1. Age
2. Gender
3. Education
4. Ethnic origin
5. Marital status
6. Employment
7. Area of residence

Questions about the places:

8. Have you visited Al-Fateh Corniche?
9. Have you visited Bahrain Fort?
10. Have you visited Argan Village?
11. How often do you visit this place:
    a) Daily
    b) Weekly
    c) Monthly
    d) Yearly

Likert Scale Questions:

12. Kindly rate the following statements based on your level of satisfaction with them (agree, strongly agree, neutral, diagree, strongly disagree):

a) The place feels safe to visit
b) The environment is safe and suitable for children to play
c) The place evokes a sense of emotional connection and belonging
d) The place embodies Bahraini culture through its activities, cuisine, and art.
e) The place creates opportunities for social interaction
f) The space accommodates a variety of activities, such as sports, dining, socializing, and walking.
g) You frequently spend hours in this space, engaging in a variety of activities.

Open ended Questions:

13. If you or someone you know has special needs, how would you describe your or their experience in the place, particularly regarding safety and accessibility?

14. If you feel the space is unsafe, what changes would you recommend to enhance its safety?

15. How would you create a stronger sense of belonging in the place, ensuring it reflects and celebrates the local culture, traditions, and community values?

Figure 9. Questionnaire questions (Author, 2024).

Data representation and analysis using Excel and NVivo

The data collected from research papers, questionnaires, and field observations are then analysed to identify common patterns and themes that can be used to develop strategies for placemaking. For this task, NVivo software is used to conduct a thematic analysis by examining the text in the open-ended questions and highlighting the frequency of similar words used by the users. In addition, Excel is used to create charts for the demographic and Likert scale questions to present the findings.

Creating Strategies for Placemaking

The documents investigated provide an understanding of the essential qualities of placemaking, the common issues public spaces face globally and locally, and propose ways to solve them. In addition, they also offer an opportunity to examine in-depth case studies of similar projects worldwide and serve as a learning material for creating a new, coherent model for placemaking in Bahrain. Moreover, when creating patterns and extracting the words most frequently used in the questionnaires, it will be easier to establish strategies inspired by the placemaking attributes and respond to the need for inclusivity and cultural expression in open public spaces.

Furthermore, the data collected through documents, field observations, and questionnaires regarding the three case studies in Bahrain helps to understand the public's needs in Bahrain and how they would like to be involved in the process of designing their public spaces. This helps establish the strategies of placemaking in open public spaces in Bahrain.

Results

The questionnaires were conducted online, and 69 participants participated. They were designed to allow participants to answer questions regarding the place only if they had visited it, which explains why the number of participants is different for each case study. Figure 10 below shows the charts of the participants' demographic information. This indicates the diversity of the people visiting these places, as they comprise various age groups, ethnicities, educational backgrounds, and professional backgrounds.

Figure 10. Demographic information of questionnaire participants (Author, 2025).

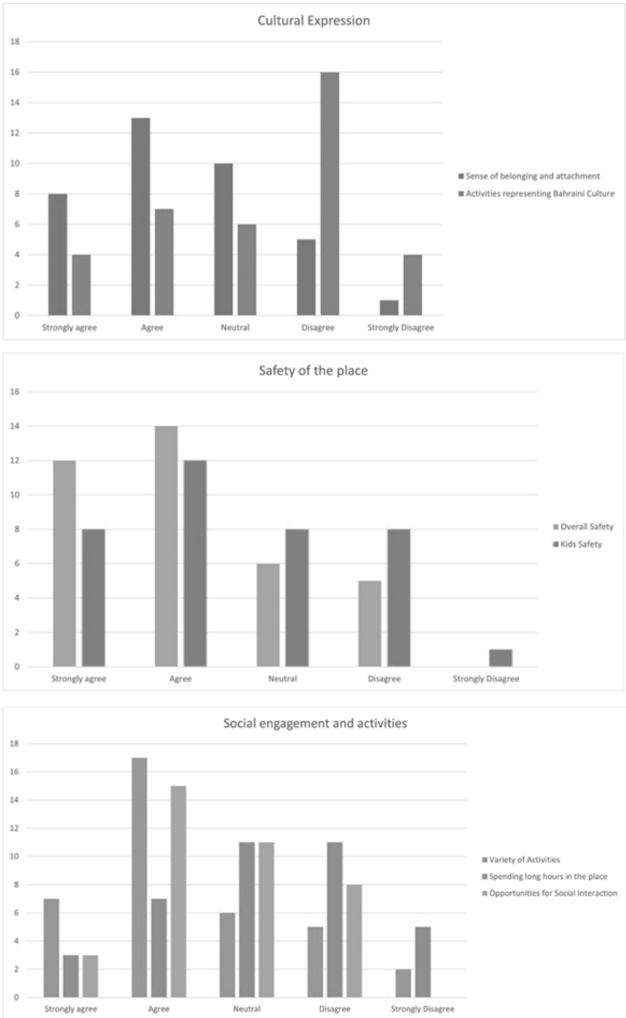

Figure 11. Results for Al-Fateh corniche by Excel (Author, 2025).

Questionnaire results for Al-Fateh Corniche

According to the questionnaire results, 37 out of 69 participants completed the questionnaire about Al-Fateh Corniche. Figure 11 shows the details of the charts based on people's participation in answering questions about cultural expression, safety, inclusivity, and social engagement in the area. Participants were primarily satisfied with the level of safety in the place, and most of them expressed their sense of belonging or attachment to the place. However, many linked their sense of attachment to their childhood memories of this place, indicating that this waterfront open public space does not intentionally reflect the Bahraini identity through activities, events, facilities, or art. This means that the place is primarily used as a hangout spot for families with kids, or as a sports track for walking, running, or biking without interruption for residents. This is also partially reflected in the third chart, which evaluates the type and number of activities available in the space. Most people agree that facilities and amenities are available, but many were also dissatisfied with the types of activities and their lack of diversity.

While the questionnaire results were mostly positive, some open-ended questions offered a deeper insight into how people want to improve the place to create a stronger sense of connection. These responses were entered into NVivo to identify recurring themes and frequently used words. As shown in Figure 12, the most common suggestions (indicated in larger font) were centred around showcasing Bahraini culture through local art installations, cultural events, and activities that celebrate national identity. These elements seem fundamental for creating a stronger bond between the people and this place.

Figure 12. NVivo word cloud for Al-Fateh Corniche (Author, 2025).

Participants also emphasized the importance of using adequate lighting and diverse activities to enhance the sense of safety and encourage visitors to stay longer in the space. Additionally, mentioned less frequently (indicated in a smaller font), several responses suggested reviving traditional crafts and activities, which could involve fishing, pearling, weaving, and other traditional crafts. These suggestions not only serve as fun and engaging activities but also preserve the history of crafts in Bahrain and inspire future generations.

Questionnaire results for Bahrain Fort

Regarding Bahrain Fort, 58 out of 69 participants answered the questionnaire about this iconic structure, since it is one of Bahrain's most prominent landmarks, attracting both locals and tourists alike. As shown in Figure 13, most participants responded positively to questions related to safety and cultural value, expressing satisfaction with the site's preservation and overall experience. However, responses related to the social engagement aspect of the space were more neutral. Many visitors felt that the site lacked interactive activities and local events that could connect the visitors to the local culture.

Participants answering the open-ended questions commended the government's ongoing efforts to maintain and preserve the Fort. At the same time, they raised valid concerns about its limited accessibility for people with special needs and children. The walking paths were sometimes described as uneven and steep, making it difficult for people in wheelchairs or with visual impairments to use them. Additionally, the lack of child-friendly safety features indicates that an adult should always accompany children to ensure their safety.

The NVivo-generated word cloud, shown in Figure 14, highlights these concerns. The most recurring theme, shown in the large font, was related to the need for cultural programming. People suggested adding more cultural activities and events around the Fort to engage people in the experience. Accessibility and safety were also prominent themes, indicated in big, dark font. People suggested improving accessibility and safety to accommodate children and people with special needs and adding adequate lighting to make the area safer at night, especially for women.

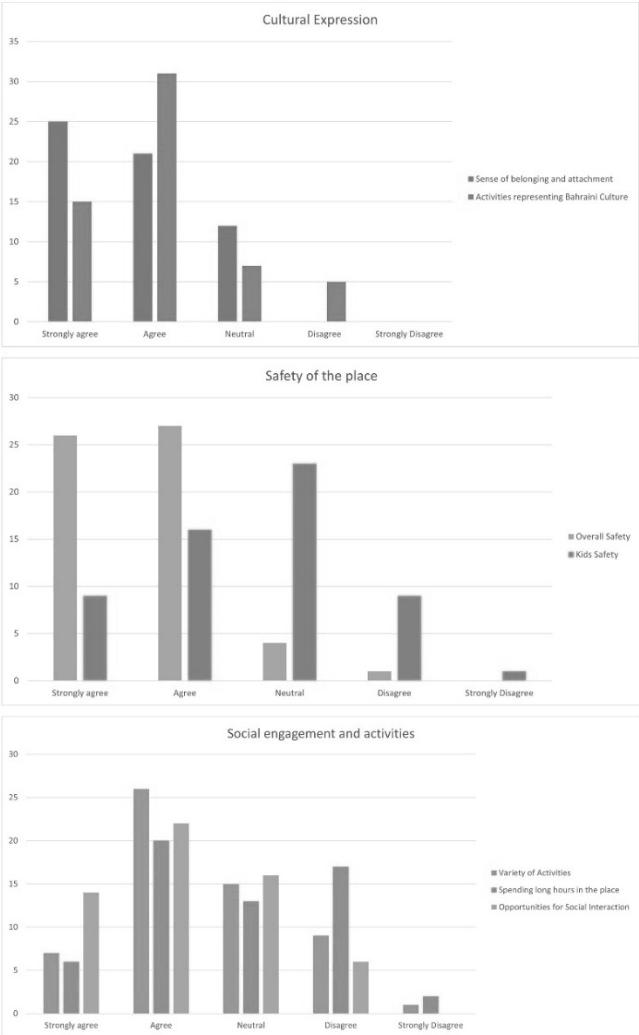

Figure 13. Results for Bahrain Fort by Excel (Author, 2025).

Figure 14. NVivo word cloud for Bahrain Fort (Author, 2025)

Questionnaire results for Argan Village

According to the results of the Argan Village questionnaire, 23 out of 69 participants provided feedback on their experience at this mixed-use development. As illustrated in Figure 15, the overall ratings were generally low across most categories, with the exception of safety, which participants considered adequate.

A recurring suggestion from participants was to pedestrianize the area, making it safer for kids to play and, in turn, encouraging more families to spend time there. Other participants proposed organizing cultural and social activities to bring the community together and enrich the area's cultural aspect. Additional recommendations included periodically hosting exhibits and art activities to promote creative expression and elevate the area's cultural scene.

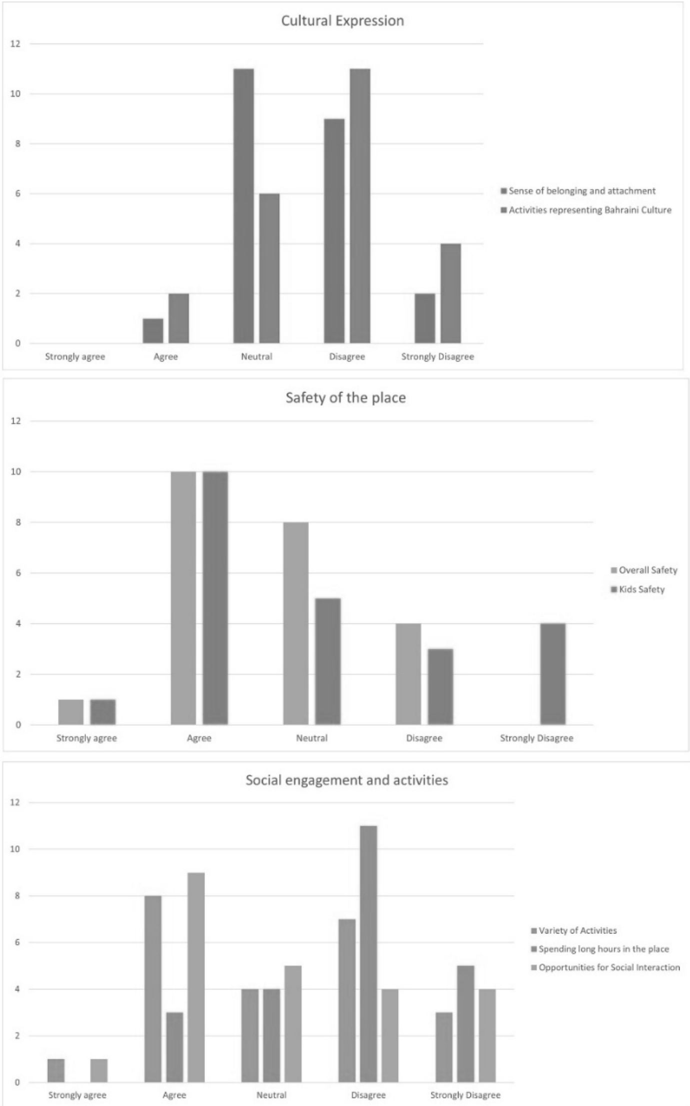

Figure 15. Results for Argan Village by Excel (Author, 2025).

According to NVivo's thematic analysis, most open-ended responses reinforced the previously discussed insights. The most recurring themes revolved around cultural representation and representing local identity through organizing local events and activities, promoting local arts, and supporting local businesses. Others emphasized the importance of enhancing the safety aspects for both adults and children by adding adequate lighting, making outdoor spaces safer for kids to play, and creating a pedestrian-friendly space for walking. In addition, some suggested activating those spaces with multiple activities that bring people together and foster a sense of community (Figure 16).

Figure 16. NVivo word cloud for Argan Village (Author, 2025).

Comparison between case studies

A comparison is made between the three case studies based on people's answers to Likert scale questions in the questionnaire. Table 1 below shows the percentages of the highest votes (strongly agree and agree combined) that each of these case studies received in terms of safety, social engagement, and cultural expression. The overall performance is below average for all sites, despite people's overall satisfaction with some of the sites. However, when asked about the specific aspects of cultural expression, safety, and social engagement through different activities, the answers implied a need for improvement. Generally, Al-Fateh Corniche gets the highest percentages in both safety and social engagement, while Bahrain Fort gets the highest votes for its cultural expression, and Argan Village has the lowest percentage, with the cultural expression aspect being 3.4 %, which indicates the lack of any form of cultural connection with the people in that area. Social engagement is also very low, at 16.7%, and safety scores are 25 %. This makes the Argan Village site the weakest in terms of cultural expression and inclusivity.

Table 1. Comparison between case studies regarding safety, social engagement, and cultural expression.

	Al-Fateh Corniche	Bahrain Fort	Argan Village
Safety	**39.7 %**	**34.8 %**	**25 %**
Cultural expression	**27.6 %**	**41.1 %**	**3.4 %**
Social engagement	**29.9 %**	**28.3 %**	**16.7 %**

Strategies for Placemaking

Although the three chosen public spaces differ in nature and target users, most of the answers suggested similar ideas for inclusivity and cultural expression. These answers, along with the knowledge gained from the literature review, have led to the establishment of some strategies that could serve as guidelines for future developments of more inclusive and culturally expressive public spaces. Table 2 presents the placemaking strategies proposed to create more inclusive and culturally expressive public spaces in Bahrain, aligning with the UN SDG No. 11 indicators, along with the possible barriers for implementing these strategies. The indicators involve providing safe, accessible, and inclusive public spaces that make women, children, the elderly, and people with special needs feel welcome and included. Moreover, one of the indicators for preserving cultural heritage has been used as a basis for establishing strategies for cultural expression (Goal Eleven, n.d.).

Table 2. Placemaking strategies to create more inclusive and culturally expressive open public spaces in Bahrain.

SDG no.11 Targets	Proposed placemaking strategies	Barriers to implementation
Safety	1) Design clear and open public layouts to instill feelings of safety and security amongst users of the space (Loukaitou-Sideris, 2014)	High energy and maintenance costs
	2) Use adequate lighting for the walkways to make the space feel safer at night (Malhotra & Aulakh, 2023)	
	3) Provide wide enough walkways for a comfortable walking experience to allow people to feel a sense of comfort and security (Malhotra & Aulakh, 2023)	
	4) Create safe playgrounds for kids by using the right flooring materials, locating the playgrounds away from cars, and closing off playgrounds to protect kids from running off to the streets	
Accessiblity	5) Provide clean and well-maintained public amenities that allow users of the space to feel comfortable and safe, such as clean restrooms, nursing rooms for mothers, and prayer rooms (*Designing Inclusive Spaces*, 2018).	Requires funding and maintenance costs
	6) Ensure ease of accessibility for all users, particularly women, the elderly, and individuals with special needs, by providing ramps, elevators, rails, braille, and interactive signage, as well as using accessible floor finishes. (Malhotra & Aulakh, 2023; *Designing Inclusive Spaces*, 2018).	

Inclusivity	7) Create platforms for small, low-risk, low-cost community projects to help engage the public in altering their spaces and encourage them to be active members of society.	Requires funding and coordination with public institutions.
	8) Provide multiple functions and activities that cater to people from different age groups, ethnic and social backgrounds to ensure people from all walks of life feel welcome and foster a social cohesion (*8 Lessons to Promote Diversity in Public Places*, 2007)	
	9) Provide spaces to celebrate different cultures through festivals and activities for people from various ethnic backgrounds	
	10) Include people from other cultures, and offer a variety of food options from different cultures, such as Indian, Asian, and Middle Eastern cuisine.	
Cultural Preservation	11) Plan cultural events and festivals in open public spaces to unite people and strengthen social bonds (Sewell et al., n.d.)	Requires funding and coordination with public institutions. Historic sites have some physical constraints and barriers
	12) Plan cultural activities among community members to enrich their knowledge about their culture and create a sense of belonging (Sewell et al., n.d.).	
	13) Integrate art into public spaces by showcasing local artists and performers to empower local talents and connect the public to the city's art scene (Sewell et al., n.d.)	
	14) Use cultural and historic places for public events and activities to enrich people's knowledge about culture and create a stronger bond between the past and the present (Sewell et al., n.d.)	
	15) Provide local experiences by providing local cuisine, showcasing local crafts, and supporting local businesses.	

Discussion and Conclusion

This study builds upon previous research done on placemaking by establishing strategies that can be integrated into policies and guidelines for designing public spaces. These strategies aim to simplify and facilitate the incorporation of placemaking qualities into the design of open public spaces in Bahrain.

This can be achieved by creating measurable actions that integrate seamlessly into the planning system and offer more manageable and more practical ways to assess its performance. One approach is to collaborate with local municipalities to implement year-round cultural and social programs across various areas in Bahrain, ensuring that all programs are activated. Additionally, empowering communities to drive progress in their public spaces through community councils allows residents to propose improvements and act as a point of contact with governmental authorities. Lastly, developing online platforms for public open spaces enables users to suggest ideas, file complaints, and evaluate the quality of their facilities, promoting transparency between the people and their government (Figure 17).

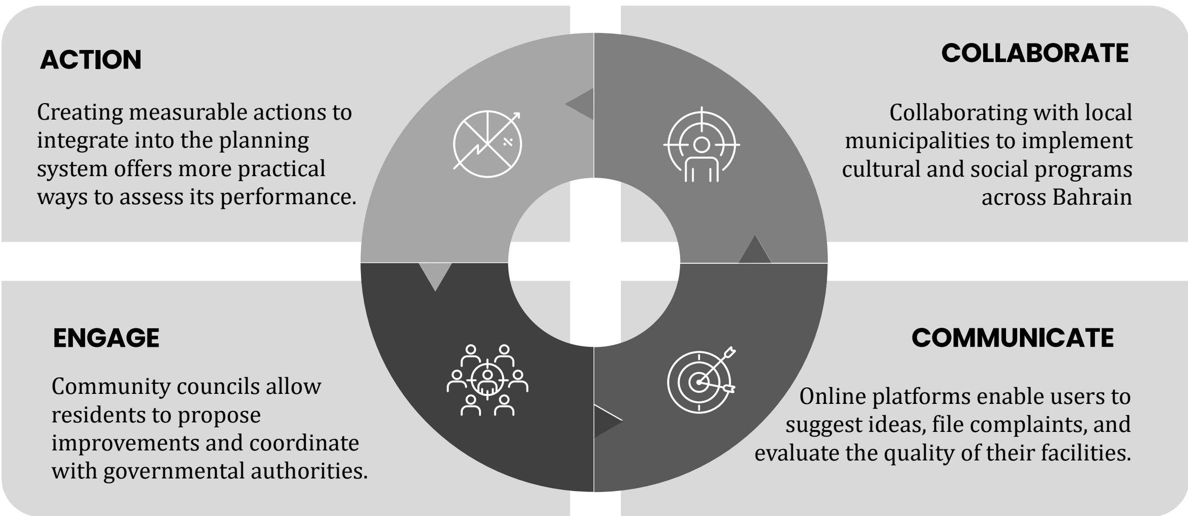

Figure 17. Plan to implement placemaking strategies (Author, 2025).

These strategies can enhance underutilized open spaces, such as Argan Village, by fostering collaboration between the community and governmental institutions. By assessing the current conditions of the place and collaborating with the residents, we can implement some of these strategies to help transform and improve its quality.

Strengths and Limitations

The strength of this research lies in establishing ways to empower people with a sense of ownership over their city, allowing them to become catalysts for change, since they are the direct users of these spaces. By involving the public through questionnaires and surveys, this bottom-up approach to design fosters more realistic and practical changes. Small-scale, low-cost, low-risk projects that can be developed can serve as a model for larger, future interventions.

This study also acknowledges several limitations. A lack of awareness about public space design may lead to misinterpretation of users' experiences. Additionally, a limited understanding of individuals' roles in changing their surrounding environment can result in disengagement. Lastly, the questionnaire sample size is relatively small due to time limitations, which may affect the applicability of the findings.

Barriers to implementation

Although the research proposes strategies for placemaking that could be implemented to enhance the quality of public spaces in Bahrain, some of these strategies may face barriers to their implementation. One of the most challenging issues in Bahrain is the harsh climatic conditions during the summer months, with temperatures reaching up to 47°C and humidity levels exceeding 85% during the warmest months of the year. This affects the functionality of these open spaces, limiting their usability to the cooler months of the year, when the average daytime temperature can reach as low as 20°C and the nighttime temperature is around 15 °C (*Climate and Monthly Weather Forecast Bahrain*, 2024).

Another issue is the funding of some of these projects, which could be a hurdle to implementing these strategies, especially those requiring significant design development and ongoing maintenance. Lastly, coordination with public institutions could slow down the implementation of some of these strategies due to the time required to liaise and obtain approvals from these institutions.

Implications and Future Directions

To enhance future research, a larger sample of participants could cover a broader range of users, producing more precise results. Moreover, incorporating focus groups instead of questionnaires may prove more effective. This approach would provide participants with a better understanding of the project and their role in enhancing their public spaces (O. Nyumba et al., 2018).

Conclusion

Public spaces are more than empty voids in the urban landscape. They are places of rest, leisure, activity, social interaction, and reflection. When designed through a top-down approach, these public spaces risk alienating their main users by focusing only on the physical aspects of design and neglecting the human experience. However, placemaking as an urban design concept involves people in designing their spaces and allowing them to adapt and change over time.

Placemaking is a never-ending process, treating public spaces as living organisms that grow with communities and adapt to people's changing needs. This constant evolution ensures that public spaces constantly respond to environmental shifts and people's needs, keeping this creative process alive and relevant.

To seamlessly integrate placemaking strategies into Bahrain's public spaces design guidelines and align them with Bahrain's 2023 economic vision in response to SDG no. 11, utilizing both a top-down and a bottom-up approach to design is essential. Collaboration among government officials, planners, architects, and the public is vital to creating a process that aligns with the country's values and norms.

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Conflict of Interests

The author(s) declare(s) no conflict of interest.

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Chapter 12

Enhancing Urban Mobility in Cairo A PTV VISSIM-Based Simulation of Salah Salem Corridor

* Mina Samir Sobhy, Husam R. Husain

Introduction

Problem Statement and Research Gap

"Cities have distinctive identities that vary physically according to their geographical location, demographics, culture, environment, and economic factors" (Nafa & Husain, 2021). Cairo in particular suffer from severe traffic congestion is driven by its high population density, limited public transportation, and inadequate road infrastructure. With over 20 million residents, the demand for road space far exceeds supply, pushing many people to use private vehicles or taxis due to gaps in the metro and bus systems (Hegazy, 2020). The city's narrow, outdated roads, initially designed for a much smaller population, have struggled to adapt to the surge in vehicle use. This urban sprawl, often developed without cohesive planning, has led to poorly connected neighborhoods and bottlenecked routes that exacerbate traffic issues (UN-Habitat, 2016). Subsequently, "Rapid urbanization in many parts of the world has resulted in inadequate housing, social segregation and the deterioration of open spaces, all of which have had a negativeimpact on the quality of life for residents" (Husain and Salem, 2024).

Cairo's congestion continues to worsen due to inadequate traffic management practices and cultural driving habits. Drivers frequently ignore signals and lane markings, adding to the gridlock and reducing the effectiveness of existing traffic control measures (Abd El-Rahman & Fathy, 2021). Kadri and Husain indicate that "Egypt's population has grown by 154% over the last 40 years, reaching 105 million people in 2023. Nearly 27% of thispopulation is concentrated in the Greater Cairo Region (GCR), including the governoratesof Cairo, Qalyubia and Giza" (Kadri & Husain, 2024). They further highlight that "The factors needing the most improvement are the cost of living, affordable housing, and adequate public transportation, which received the lowest ratings from the experts" (Kadry & Husain, 2025). According to the Cairo Traffic Index, car users spent an average of 42% extra journey time due to traffic congestion in 2019. Thanks to recent transportation projects and infrastructure developments in Greater Cairo, this number decreased to 40% in 2023. Meanwhile, according to the World Bank (2019) Arab's Voice article, time wasted in traffic in the Greater Cairo Metropolitan Area translates to approximately $8 billion per year, with expectations that this figure will rise to $18 billion by 2030—over three percent of Egypt's total Gross Domestic Product (GDP).

In recent years, urban traffic congestion has become one of the most pressing challenges for cities worldwide, with significant implications for economic productivity, environmental health, and quality of life. In cities like Cairo, where rapid urbanization and high vehicle density have exacerbated traffic issues, congestion often leads to extended travel times and increased pollution. Addressing congestion has therefore become a critical focus for transportation planners, urban policymakers, and researchers. Since traffic congestion is one of the most widely discussed issues in developing countries, Cairo is no exception. The following factors have been identified as key contributors to traffic congestion in Cairo, based on studies conducted over the past decade: Poor public transit system, Lack of intersection management, Heterogeneous traffic conditions, Non-lane-based traffic system, Conflicts between formal and informal modes of transportation, Inadequate street design elements, Shortage of pedestrian walkways and cycling paths, Lack of affordable public transportation, Overcrowded and low-quality public mobility

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services, Poor connectivity, Congested corridors, Traffic delays, Road geometry issues, Limited accessibility, Driver behavior.

Connectivity has been identified as one of the main challenges in large-scale transit networks, as the number of transfers required for a trip is considered a major inconvenience for transit users (Owais et al., 2020). Cairo's transportation network suffers from several issues, including congested corridors, traffic delays, and overcrowded transit vehicles during peak hours. The complexity of the transportation network forces multiple transfers between transit modes, leading public transport users to perceive the system as inefficient. This situation has encouraged a growing preference for private car ownership and use were private cars mandatory in Major arterials like "Salah Salem", which has one of the highest records in term of delay in Travel time according to Google Typical Maps during the year of 2024. Most recent research has linked traffic congestion in Cairo to various theories and perspectives, leading to different proposed solutions, such as road geometry redesign, traffic signal optimization, and public transportation projects. However, the selection of these approaches for specific case studies has not been adequately justified. Despite the extensive literature on transit network design, further research is needed to establish a comprehensive framework for addressing Cairo's congestion challenges. Accordingly, this Thesis is addressing the two major problems mentioned being: the time wasted in Traffic congestion in Cairo as well as the lack of clear vision among urban planners in identifying the main causes behind the traffic congestion phenomena in Cairo.

Significance of the Study

"Approximately 28% of [Egypt's] population is concentrated within the three governorates constituting the Greater Cairo Region (GCR), intensifying the pressure on existing urban infrastructure and resources." (Kadry & Husain, 2025) Which in consequence, makes addressing traffic congestion in Cairo is one of the most critical responsibilities of urban planners, especially in developing cities. As one of the most densely populated cities in the world, Cairo requires effective traffic management to ensure mobility and access to resources for millions of residents. Urban planners play a pivotal role in developing strategies that alleviate congestion while fostering sustainable urban growth.

Studies focused on traffic congestion provide invaluable insights into the underlying causes, patterns, and potential solutions. By prioritizing such studies, urban planners can contribute to creating a more livable city, reducing air pollution, and supporting Cairo's long-term socio-economic development. Traffic congestion in Cairo leads to higher emissions and environmental degradation, as idling vehicles release more pollutants into the air (UN-Habitat, 2016). By designing infrastructure and transportation systems that minimize congestion, planners can contribute to improved air quality and public health. They can also integrate green spaces, pedestrian-friendly areas, and more efficient transit solutions that address both environmental concerns and urban livability (Abd El-Rahman & Fathy, 2021). Understanding the root causes of Cairo's traffic issues allows planners to make informed, sustainable decisions when designing urban spaces that accommodate the city's rapid growth and complex mobility needs. Approaches to addressing the problem and the suggested solutions vary across different studies. However, the majority of studies encourage the use of traffic simulation tools as a method for evaluating different strategies to reduce congestion. In addition, Level of Service (LOS) has been selected as a key performance indicator to assess the effectiveness of each scenario in the corresponding case study. Accordingly, a similar approach will be adopted in this Research, incorporating scenarios from various research studies to provide a broader analytical foundation.

This study explores the potential of advanced traffic simulation tools, specifically PTV VISSIM, to provide innovative solutions to this persistent issue. By simulating and analyzing traffic flow patterns, the study aims to demonstrate how these tools can optimize traffic signal timings, reduce delays, and enhance overall mobility within the city. The findings are expected to provide critical insights for urban planners and policymakers, enabling evidence-based decision-making to address congestion more effectively. Moreover, this research contributes to the growing body of knowledge on the application of simulation technologies in urban traffic management, paving the way for sustainable transportation systems in Cairo and other megacities worldwide. The outcomes hold the promise of improving the quality of life for millions of residents by fostering a more efficient and environmentally friendly transportation network.

Research Question and Objectives

This research investigates the most efficient urban method that can be utilized to reduce time wasted in traffic congestion in Cairo. It aims to identify the most common parameters that cause congestion and its accumulation across consecutive traffic nodes in the city. The study also compares various researchers' perspectives on the most effective methods and tools used over the past decade to reduce congestion-related delays, with a particular focus on their applicability to a selected case study area. Ultimately, the research seeks to provide urban planners with a clear and practical framework for selecting the most efficient approaches to minimizing time lost in traffic, based on specific parameter measurements relevant to different urban contexts. The figure below highlights and clarifies the overall research structure.

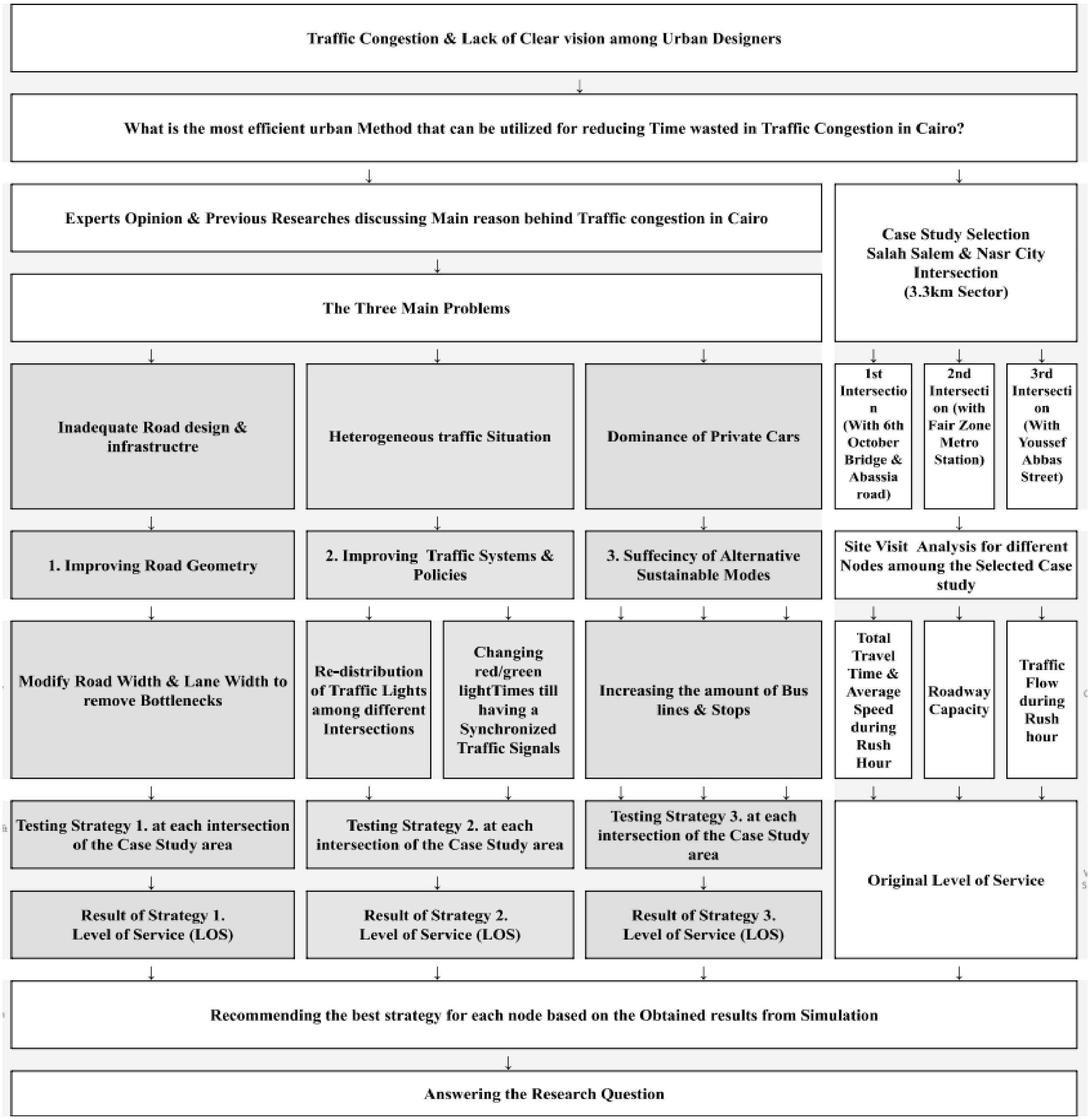


Figure 1. Research Outline.

Material and Methods

The Research is using mixed approach (Quantitative & Qualitative). The primary data collection method employed in this research involved video recordings captured at multiple consecutive nodes within the designated case study area in Cairo. These recordings provided a detailed visual account of traffic conditions, capturing vehicle movements, signal timings, congestion levels, and driver behaviors at various times of the day. Strategic placement of camera ensured comprehensive coverage of key intersections and road segments, enabling accurate documentation of traffic flow patterns and bottlenecks. The collected video data was subsequently analyzed to extract critical parameters such as vehicle counts, delay times, queue lengths, and average travel speeds. This research methodology employs PTV VISSIM software to simulate and optimize urban traffic flow, addressing congestion through three primary Methods: bottleneck mitigation, traffic signal optimization, and public transit enhancement. For the first approach, Bottlenecks, or points of severe congestion due to high traffic demand or inadequate infrastructure, are critical in traffic management as they reduce flow efficiency and increase delays. Using VISSIM's network analysis, locations with high congestion are identified, and potential solutions such as additional lanes, dynamic lane allocation, or ramp metering are tested to reduce time consumed in congestion (Khan et al, 2021). Such interventions have shown to improve throughput and reduce delays in micro-simulation environments by allowing more efficient vehicle movement across critical areas (Zhang et al, 2020).

The second Method involves optimizing traffic signaling and lights to reduce intersection delays and improve traffic flow. Adaptive signal control and coordinated control Methods are tested within VISSIM, which allows for precise modeling of signal timing and coordination to maintain smooth transitions between intersections (Feng et al, 2018). By adjusting these settings, delays at signalized intersections are minimized, improving the overall efficiency of the network. Studies indicate that adaptive signaling can significantly reduce vehicle stops and wait times when well-coordinated, which is essential for high-traffic urban areas where intersections are common (Chen et al, 2019).

Enhancing public transit lines and stations is critical for reducing road congestion by shifting demand from private vehicles to more efficient mass transit. PTV VISSIM's public transport module enables testing of transit priority Methods, including dedicated lanes and signal prioritization at intersections, which increases bus and train efficiency and reduce wait times for passengers. Optimizing public transit can ease congestion on roads and improve travel reliability for users, providing an appealing alternative to private vehicles and helping to reduce overall traffic density. Through these combined Methods, this study seeks a comprehensive approach to urban traffic congestion management.

Finally, two data categories were required for the simulation model at each of these nodes: network geometry and traffic volumes. Site visits have been done by the author to collect the required geometric data such as intersections configurations, lanes alignment, lanes widths, number of lanes of both the major corridor as well as the minor intersected streets and U-turns locations. On the other hand, video observations and traffic counts & Travel Time were obtained via video recording in different days of the week (weekdays & weekends) and during different period of the day (morning & evening), also the selected time periods were chosen using upon the high congested times during the day as shown in Google Typical Traffic flow map. These data are recorded in a 5 min video each to show the traffic flow, capacity and the pass-by Public transportation.

Site Analysis

Case Studies Selection Criteria

In order to ensure that the case study is both relevant to Cairo's unique traffic environment and suitable for in-depth analysis using PTV VISSIM. Proper selection can help illuminate specific urban traffic issues and explore Methods that align with Cairo's urban planning goals. The primary criterion for case study selection is the severity and persistence of congestion at the site. High-traffic areas where congestion leads to significant delays, especially during peak hours, provide the most fertile ground for testing congestion-reducing Methods. Such areas are often central corridors or major arterials, such as Salah Salem Road in Cairo, known for its heavy traffic and strategic importance in connecting different parts of the city. Studying high-congestion areas allows researchers to focus on the most pressing traffic problems and evaluate the potential impact of various Methods on real-world scenarios. According to Litman (2019), targeting high congested zones is essential for maximizing the effectiveness of urban traffic interventions and ensuring that resources address critical needs availability and accessibility of Traffic Data. The study area should experience significant levels of congestion, particularly during peak hours, to ensure that tested interventions address relevant, real-world issues. Comprehensive traffic data availability is also essential, including traffic volumes, vehicle types, and intersection timings, which supports accurate calibration and validation of simulation models. The selected site should exhibit complex traffic patterns, such as intersections and pedestrian crossings, to enable a realistic simulation of Cairo's urban traffic dynamics. Also the feasibility of modeling within the capabilities of simulation tools like PTV VISSIM ensures that the study remains practical and achievable.

A 3.3-kilometer section of Salah Salem arterial road in Cairo aligns well with the selection criteria for a case study on traffic congestion. This corridor experiences severe congestion, particularly during peak hours, and serves as a vital link between key urban areas, accommodating high volumes of daily commuters and public transport vehicles. The road features a variety of traffic interactions, including multiple intersections and pedestrian crossings, which add complexity to traffic flow and allow for comprehensive testing of congestion-mitigation Methods. Furthermore, as a primary route within the city's transportation network, improvements here could have a widespread impact on overall travel times and align with broader urban planning objectives (refer to Figure 4 & 5).

Figure 2. Cairo Map - Salah Salem Road (Google Maps).

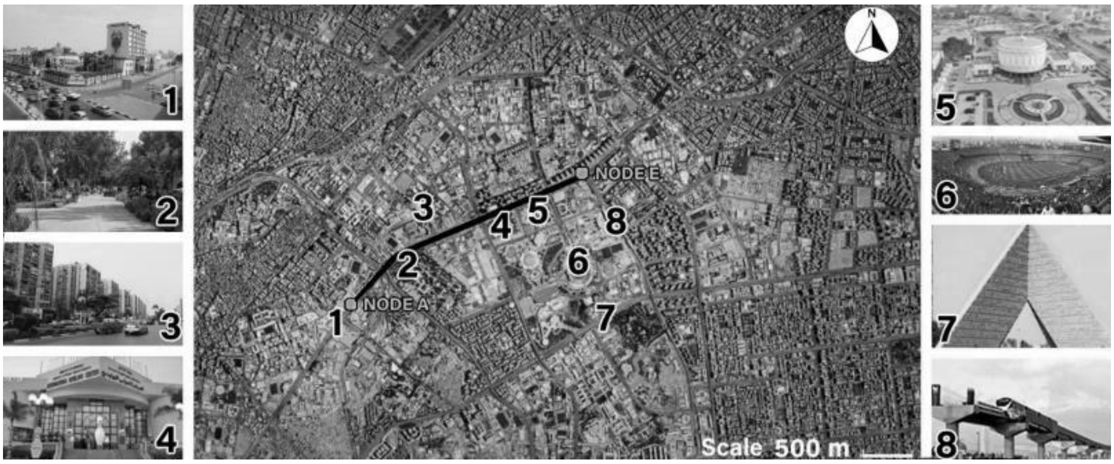


Figure 3. Landmarks around Case study area

1- Vehicles House – (Intersection with El-seka El-beda street)
2- El Ouroba Garden
3- Mixed Use/Commercial Area (El-Obour Buildings)
4- International Bowling Center
5- Panorama 6th October
6- Cairo International Stadium
7- Memorial of the Unknown Soldier
8- Start of Cairo Monorail Line + Stadium Metro Station

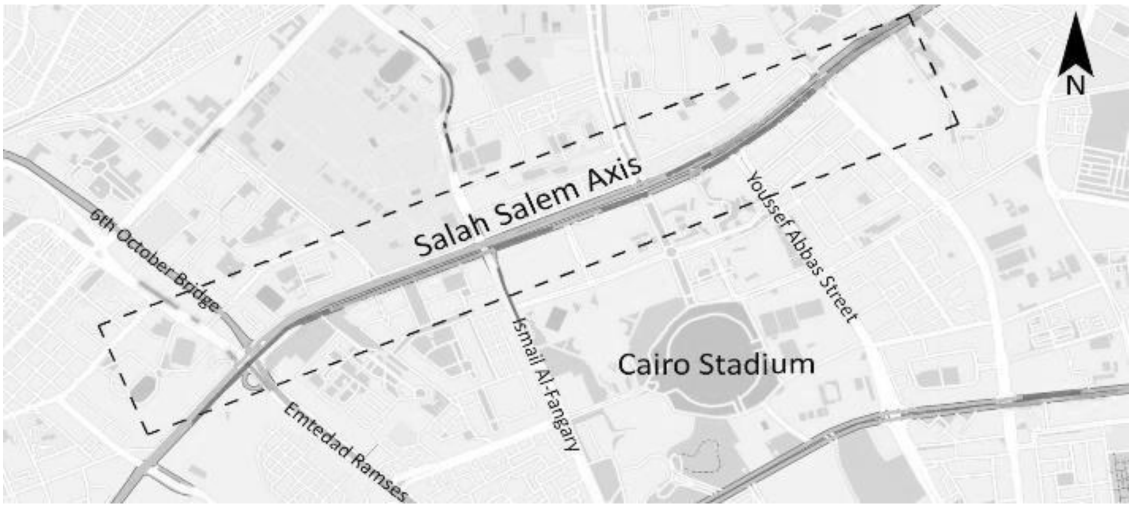


Figure 4. Case Study area Map

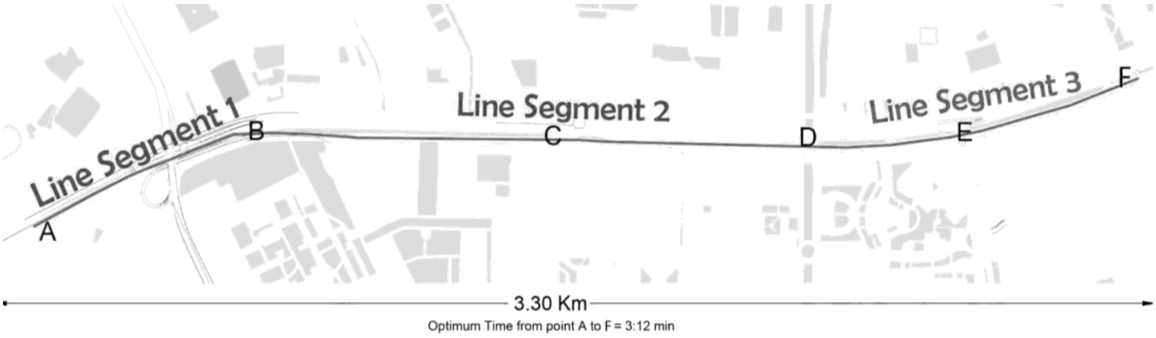


Figure 5. Case study Area boundaries & Segmentation.

Point A (starting of the bridge entering Nasr City) Point B (End of multiple Bridges including 6th October bridge), Point C Ismail el fangary intersection, Point D Fair Zone Metro station, Point E Youssef Abbas street (Stadium Metro and monorail station)

Measurements & Variables

Travel Time & Average speed

Below table shows a sample after a site visit done at 3PM (the most congested Peak hour according to Google maps typical Traffic) on 26th June 2024. the expansion happening in the Travel Time do reflect the reduction in speed of the vehicles thus causing the high traffic congestion at each of the areas (highlighted in Red).

Table 1. Typical Speed & Travel Tima at weekday 2:00 PM

Typical Speed & Travel Time at Weekday 2:00 PM					
Point	A	B	C	D	E
Number of Lanes	3 Lanes	4 Lanes	4 Lanes	3 Lanes	4 Lanes
Distance till next Point (in Km)	0.75	0.85	0.73	0.44	0.5
Speed Limit (Km/h)	60	60	60	60	60
Optimal Time in minutes	0:45	0:51	0:43	0:26	0:30
Typical Time spent in min.	3:00	1:40	0:52	0:34	0:50
Typical Speed at Peak hour (Km/h)	15	30	50	45	35

Road Design & Geometry

Regarding Road Design & Geometry, Google Maps was used as a base for the main map and a site visit has been done by the author in order to validate the online data. such data do include multiple variables that can be examined during the simulation process such as, number of lanes, Road length, U-turn location. Pedestrian areas, pedestrian bridges, ramps. It was noticed that the Number of Lanes does vary starts with 3 Lanes at point A (before the bridge) Then road width increases at Node B and C to become 4 Lanes, then it reduces again to 3 Lanes at point E (Intersection with Youssef Abbas street), then returns to 4 Lanes at point F.

Traffic Volume

Traffic volume was observed via recorded videos by author including Car count at during week days & weekends. First a primary data has been taken from Google Typical Maps (refer to table 2) showing the rate of flow of the Traffic. At which green is the free flow, Orange is the medium flow, Red is Congested and Dark red the most congested Time (2:00 to 4:00 PM at Weekdays). Videos has been recorded by the author during different Times and Days of the week in order to observe the Traffic flow as well as taking counts of Private vs Public Vehicles. The videos were taken at each node during the following Times on: Saturday 22nd June 2024 - 2:00 PM and 8:00 PM, Wednesday 26th June 2024 - 2:00 PM and 8:00 PM, Tuesday 9th July 2024 - 2:00 PM and 8:00 PM. Then the counted numbers are inserted inside Table 3 and 4 in order to show the amount of Passing by cars at each node. Positive Numbers are the number of Cars passing by the Node and negative numbers are the number of Cars leaving the Node (refer to Table 3).

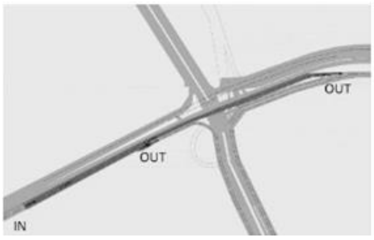
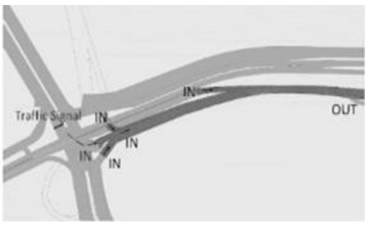
Table 2. Typical Traffic flow according to Google Maps at the 3 selected nodes during Weekday & Weekend day.

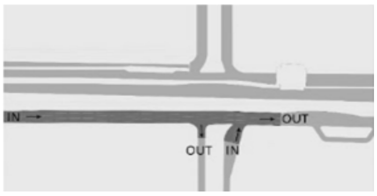
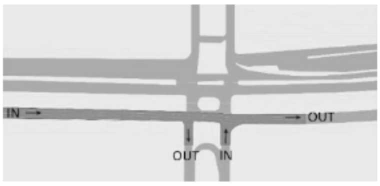
		Typical Traffic flow according to Google Maps at the 3 selected nodes during Weekday & Weekend days								
		6AM - 8AM	8AM - 10AM	10AM - 12PM	12PM - 2PM	2PM - 4PM	4PM - 6PM	6PM - 8PM	8PM - 10PM	10PM - 12AM
Weekday	A									
	C									
	E									
Weekend	A									
	C									
	E									

Table 3. Typical Traffic count at Weekday 2:00 PM.

Typical Traffic count at Weekday 2:00 PM					
Point	**A**	**B**	**C**	**D**	**E**
Number of pass-by Vehicles	4356	3684	5268	5396	4484
	-672	630	528	72	960
		738	-400	-984	132
		108			-72
		108			
Typical Traffic Count	**3684**	**5268**	**5396**	**4484**	**5504**

Table 4. Vehicle routing as recording by the Author at each node.

Node	Plan	Vehicle routing (In)	Vehicle routing (Out)
A		Salah Salem (4356) = 3 Lanes 100%	Bridge (SS) (3684) = 2 Lanes 83% Secondary Road (-672) = 2 Lanes 17%
B		Bridge (SS) (3684) = 2 Lanes 66% October Bridge (+630) = 2 Lanes 13% Emtedad Ramses (+730) = 2 Lanes 16% Ramses Road (+108) = 2 Lanes 3% U-Turn (+108) = 1 Lane 3%	Main Road (5268) = 4 Lanes 100%

C		Main Road (5268) = 4 Lanes 91% Secondary Road (+528) = 2 Lanes 9%	Main Road (5396) = 4 Lanes 85% Secondary Road (-400) = 2 Lanes 15%
D		Main Road (5396) = 4 Lanes 97% Secondary Road (+72) = 2 Lanes 3%	Main Road (4484) = 3 Lanes 90% Secondary Road (-984) = 2 Lanes 10%
E		Main Road (4484) = 3 Lanes 85% U-Turn (+960) = 1 Lanes 13% Secondary Road (+132) = 2 Lanes 15%	Main Road (5504) = 4 Lanes 85% Secondary Road (-72) = 2 Lanes 15%

Traffic Signaling

This Parameters do include all of the data related to Traffic system at each node such as, Traffic Signal location, Speed limit, stopping period, Bottle necks, Speed bumpers and obstacles in Asphalt (if any). As per the site visit of the Case study area, 2 Traffic light have been indicated at between points A & B with approx. 30 second headway.

Public Transportation

This Parameter is addressing the location of Public transportation stations, the amount of bus stops within a walkable area, below Table do illustrate the quantity of passing by Vehicles type at each of the case study nodes and as per recorded videos done by the author at the most congested time of the week. The amount of Formal Public Transportation passing by (Buses and Minibuses) has been counted during Peak hour, around 50 Bus counted at each node (refer to Table 5). In addition, Bus lines have been summarized in the below table as mentioned in the official Website of the Egyptian Public transportation lines (2024): https://www.cairo.gov.eg/ (refer to Table 6 and Figure 11) which shows that there should be 57 Buses and/or Minibuses passing by during peak hour (assuming that each bus passes by each 20 min. (approx. 3 cycles for each line per Hour).

Table 5. Capacity of Public Transportation Vs Capacity of Private Vehicles from videos recorded by Author.

Ratio of Public Transit to Private Vehicles at Weekday 2:00 PM					
Point	**A**	**B**	**C**	**D**	**E**
Number of Private Vehicles	3540	5040	5120	4244	5252
Microbuses	144	180	228	192	192
Buses		48	48	48	60
Typical Traffic Count	**3684**	**5268**	**5396**	**4484**	**5504**

Table 6. Public Buses/ Minibuses Lines passing by the Case study area - Developed by Author taken from website https://www.cairo.gov.eg/

#	Route	Type	No. of Bus lines	No. of passing by Buses during Peak Hour	Capacity (No. of Passengers pe bus)
1	Abbasiya - Salah Salem – Youssef Abbas Street	Bus (50 Passenger)	1	3	200
2	Emtedad Ramses - Salah Salem - El-Tayaran	Bus (50 Passenger)	2	6	400
3	Abbasiya - Salah Salem	Bus	7	21	1400

	- El-Tayaran	(50 Passenger)			
4	Abbasiya - Salah Salem - El-Tayaran	Mini Bus (27 Passenger)	7	21	756
5	Hadayek El-Quba - Fare Zone - Salah Salem - El-Tayaran	Mini Bus (27 Passenger)	2	6	216
	Total		19	57	2972

In addition, the amount of informal public transportation (Microbuses) has been counted (refer to Table 5). Which concludes that on average, around 185 Microbuses passes by the Cases study axis. The mentioned Microbuses are the 14 Passenger ones which means that the passengers' capacity of Microbus users during peak hour can be calculated as below:

185 x 14 = 2590 passenger

While the Total amount of Private Cars continued from A to point B (refer to Table 4) = 5040 Car

- Capacity of existing Public Transit (Formal + Informal) = Buses/Minibuses + Microbuses = 2972 + 2590 = 5562 Passenger
- Total Amount of Car users = Car count x average number of passengers (3) =

5040 x 3 = 15,120 Passenger

Ratio between Public Transit & Private Car users/ passengers = 5562: 15,120 ~ 2:5

Site Analysis illustration

As shown below at the first Line segment of the selected Case study area, Cars coming from point A (4 Lanes) will have to pass by a 2-Lane Bridge in order to continue on Salah Salem Street (Airport direction). According to the site Analysis and multiple videos recorded by the Author in June 2024 during Peak hours, around 87% of the passing-by Vehicles do take this route while the rest do not take that bridge and go toward the other Lane (toward Emtedad Ramses Street) creating a major Stop at the start of the bridge that continues till reaching point C; creating a huge Queue line along Line segments 1 & 2.

Figure 6. Line Segment 1 analysis - Developed by Author.

In addition, the road underneath the Bridge, do also contain 2 manual Traffic lights as shown in the below Figure, where each Traffic Light have both Red and Green Lights (30 seconds each) in order to monitor the Cars coming from Abbassia and Emtedad Ramses direction. Around 35% of the passing-by Vehicles coming from Traffic Signal 1 go toward point B (2 Lane Curve), while 45% of the passing-by vehicles coming from Emtedad Ramsis Street do go toward point B (2 Lane Curve). With all of these Inputs (2 Lanes from Abbasia Street, 2 Lanes from Emtedad Ramsis Street, 2 Lanes from the bridge coming from Point A, as well as 2 Lanes from October Bridge = 8 Lanes) this leads to large queue of a completely stopping Vehicles at point B (Only 4 Lanes). Below 3rd illustration is done by PTV VISSIM and Adobe Photoshop in order to highlight the Heterogeneous traffic at this Line segment.

Regarding Line segment 2 and as shown in Figure 15, The Majority of passing-by Vehicles do go in a straight line from Point B to Point D, however the number of Lanes does decrease at point D, forming another Bottleneck at which a Queue of Stopping vehicles at this line segment. Point C can be considered an essential stop as it is located beside Fair Zone Metro station. Another observed point during the Recorded videos of this line segment is that

Buses/ Microbuses coming from both Emtedad Ramsis and Abbasia street do stop at point C (under the bridge) with no safe way to pass the street for pedestrians nor enough seating area for pedestrian. which might be a reason for people preferring to use Private cars over Public buses / microbuses.

Figure 7. Line Segment 2 analysis (Developed by Author).

Regarding Line segment 3 and as shown in figure 17, The Majority of passing-by Vehicles do go in a straight line from Point D to Point F, however an additional Lane comes in the middle from the U-turn, this added Lane is then overlap the existing lanes forming another Bottleneck at which a Queue of Stopping vehicles at this line segment. It is also worth mentioning that the start of the Stadium Metro station as well as the new Monorail Station Line coming (Stadium Monorail station) located at Youssef Abbas street is currently under construction and is 650m away from point E.

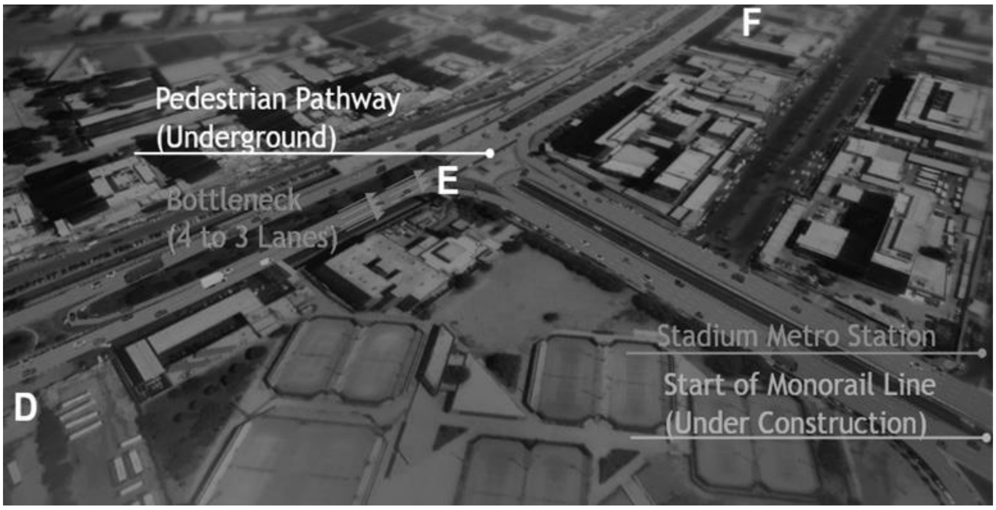


Figure 8. Line Segment 3 analysis (Developed by Author).

Model Making "Model 0"

PTV VISSIM software is selected as a Traffic simulation tool that is used as an easy way to optimize each of the related parameters. (Travel Time, Traffic count, Level of service, Road geometry, Traffic signals, Capacity of accessible Public transportation vehicles). Main steps for using the software are:

1. Inserting Road geometry (source: Google map & Site visit)
2. Inserting Traffic volume (Recorded Videos by Author)
3. Inserting Signal Heads (Traffic Lights shown in recorded videos)
4. Inserting Public Transport Lines & Stops (Recorded Videos by Author + Official websites of bus lines)
5. Model Calibration & Validation: Examining the different parameters (according to the 3 Methods mentioned in the Literature review for each node.)
6. Observing the best results: (Least Travel time, and highest Level of Service LOS)

Results and Discussion

Simulation Model #1: Bottlenecks Removal

During the Site analysis, Multiple Bottlenecks were observed as result of the non-linear road width changes from one zone to the other, which could be potentially one of the main reasons behind Traffic congestion. This Method aim is to try to fix the road design from the Geometrical perspective in order to maintain the flow of the Cars uninterrupted as much as possible, while also providing the highest possible safe area for non-car users (Pedestrian & cyclist).

Figure 9. Existing Number of Lanes.

Figure 10. Updated Number of Lanes (Method 1)

Below Map showing the Typical traffic during peak hour according to Google Maps (Wednesday at 3:00 PM) which is directly reflecting the changes happening in the Road width. Accordingly, it was recommended to check the LOS of each Node as well as total traveling time before and after road width updates done in this Method via PTV VISSIM.

Method 1:

Step 1: Road geometry was modified in PTV VISSIM through changing the number Lanes using the "Links" Tool at the high congested nodes that have a smaller number of Lanes (Point C & E) in order to remove all Bottlenecks.

Step 2: The area taken from the Curb (highlighted in Red in Figure 42 & 43.) is recommended to be relocated along the case study area and enhanced as a Pedestrian area with greenery and shading in order to provide a sufficient and safe alternative for car and to avoid induced demand Gabe Klien (2012).

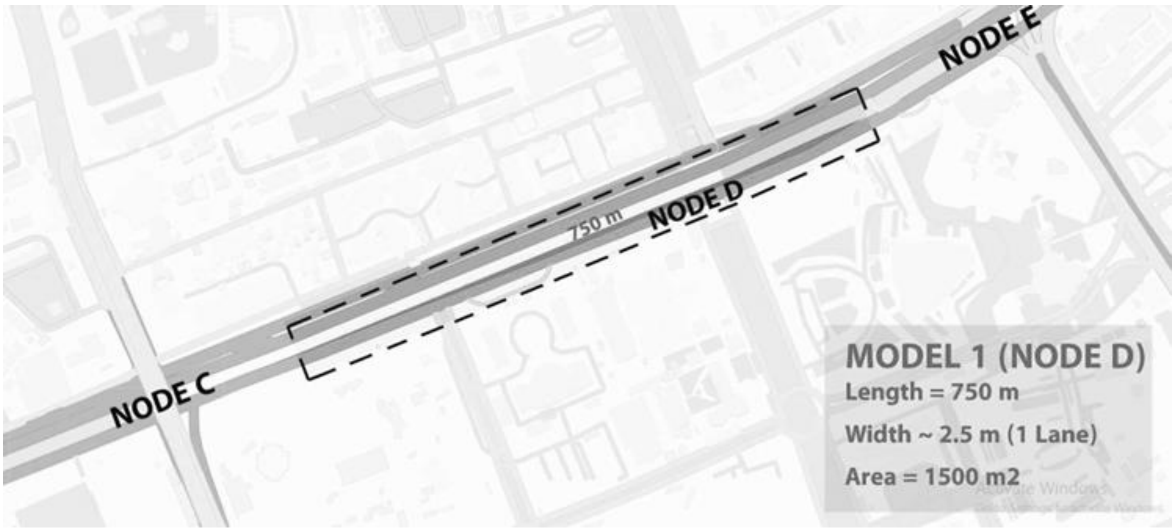


Figure 11. Intervention area around Node D (Sidewalk to Asphalt).

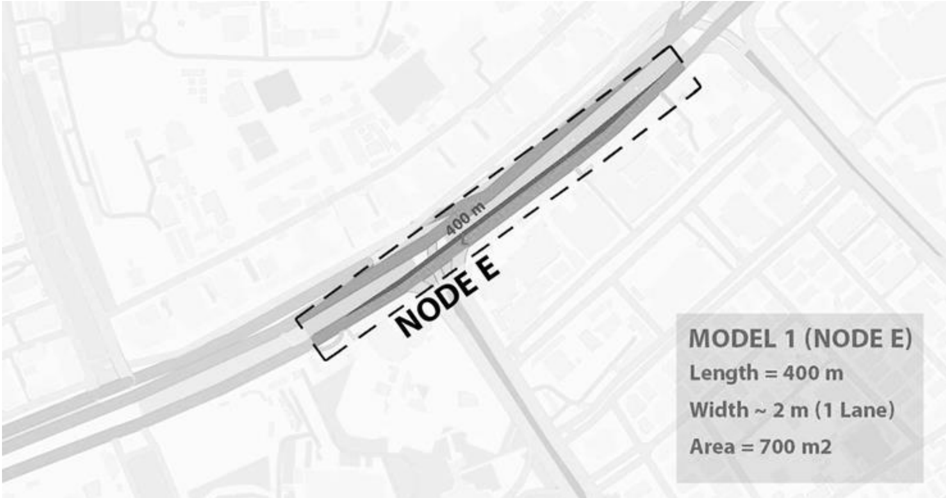


Figure 12. Intervention area around Node E (Sidewalk to Asphalt).

Simulation Model #2: Traffic signaling Optimization

During the Site analysis, it was observed that there are 2 Manual Traffic Signals between Node A & B. Each of these two Traffic signals includes approx. 30 Seconds Green Light and 30 Seconds Red Light. The Car flow coming from those two Traffic signals is directly interesting Node B from:

"Abassia" (Traffic Signal 1) & "Emtedad Ramsis" (Traffic Signal 2)

This Method does study the impact of Optimizing the Traffic lights duration in order to check whether the Traffic signaling is impacting the Traffic congestion and to what extent. Thus, different the Total Travel time as well as LOS at each node are calculated using PTV VISSIM software before and after each iteration.

Method 2:

Signal Timing sequence was modified to different timing iterations (0, 30, 60, 90, 120, 150, 180) and the result of LOS & Travel time was inserted in the below Table Figure 10.

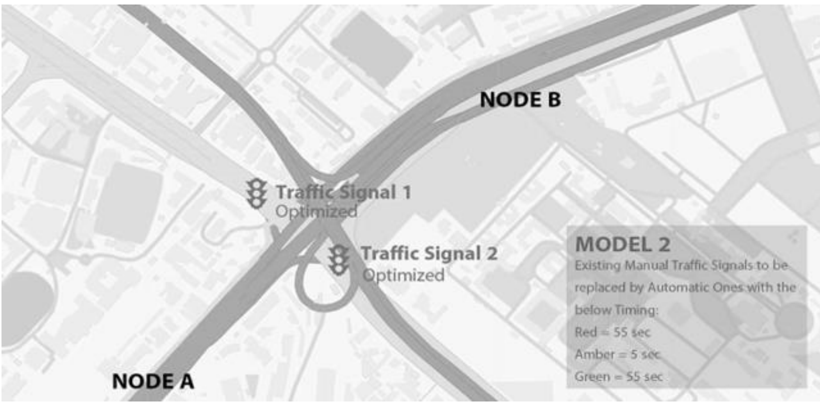


Figure 13. Method 2 Traffic signaling Optimization (Developed by Author).

Simulation Model #3: Public Transportation Revitalization

The amount of Formal Public Transportation passing by (Buses and Minibuses) has been counted during Peak hour, around 50 Bus counted at each node (refer to Table 4). In addition, Bus lines have been summarized in the below table as mentioned in the official Website of the Egyptian Public transportation lines: https://www.cairo.gov.eg/ (See Table 5) which shows that there should be 57 Buses and/or Mini-buses passing by during peak hour (assuming that each bus passes by each 20 min. (approx. 3 cycles for each line per Hour)

This Method aim is to show the impact of increasing Public Transit lines on the existing Traffic situation, (Assuming that the new Public Transit lines are running at full capacity). For the purpose of this study, the amount of Buses is increased in order to accommodate the difference between Private and Public Transit users till reaching the 1:1 ratio in order to see the impact of such concept on the Total Travel time as well as the level of service. Total amount of Passengers in the Case study area = 13,740 + 5562 = 19,302 Passenger

Targeted number of Passengers for the new Public transit lines (19,302 / 2) - 5562 = 4089 Passenger

Which means that almost double the existing number of buses is needed to accommodate the difference

Method 3:

Step 1: Calculate the needed amount of the extra public Buses at peak hour that will replace the Private Cars.

4089 / 3 = 1363 Cars
4089 / 50 = 81 Bus

Step 2: Replacing the existing extra Car counts (1363) with the new Buses (81) inside the PTV VISSIM software with the same stop location using the Public Transport Line / Stop tool.

Step 3: Calculate the Total Travel Time & LOS at each point.

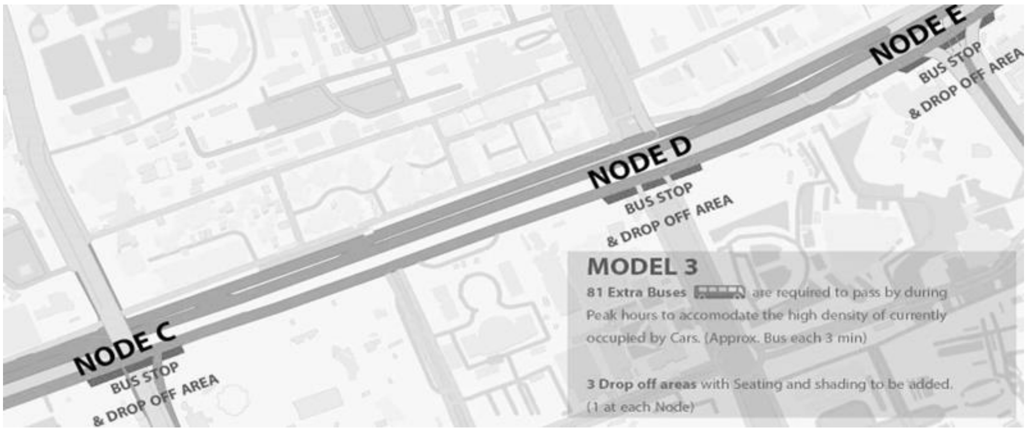
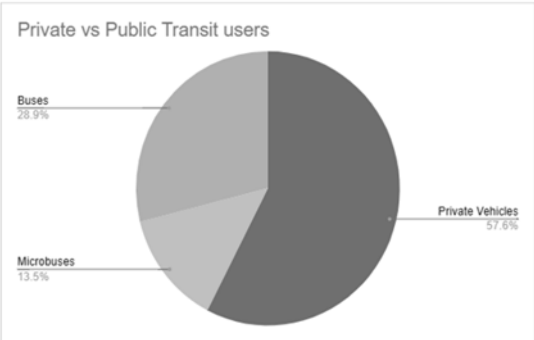


Figure 14. Method 3 Public Transportation Revitalization (Developed by Author).

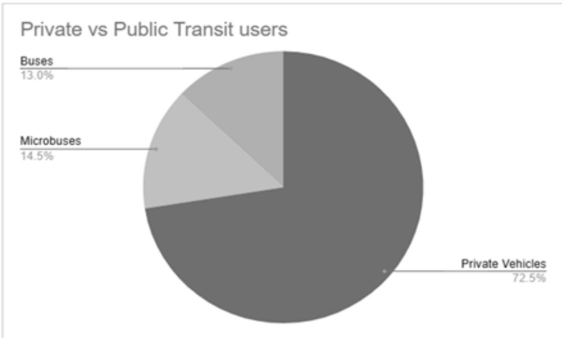
Public Transportation vs Private Vehicles ratio (Proposed)

Vehicle Type	Count durin Peak hour	Capacity	No. oF users	
Private Vehicles	2856	3	8568	- 500 Cars
Microbuses	144	14	2016	
Buses	86	50	4300	+ 50 Bus



Public Transportation vs Private Vehicles ratio (Existing)

Vehicle Type	Count durin Peak hour	Capacity	No. oF users
Private Vehicles	3356	3	10068
Microbuses	144	14	2016
Buses	36	50	1800



Observed outputs

According to PTV VISSIM result for the first Scenario, The Total Travel time has been decreased by 48% (4.13 min instead of 8.08) while the number of passing by Vehicles has been increased to 3868 instead of 3277, it was shown that the Level of Service of NODE A has been boosted became A instead of E. For point B, it was shown that the Level of Service has been boosted to become A instead of C, while also the number of passing by Car has been increased (5226 instead of 4546), for point C, it was shown that the Level of Service has been boosted to become B instead of D, while the car count has been also increase to become 5286 instead of 4448. For Node D the LOS has been boosted to B instead of D, while in NODE E the Level of Service has remained the same (D). According to PTV VISSIM result for the second Scenario, the Total Travel time has been decreased by just 5% (7.45 instead of 8.08 min) while the number of passing by Vehicles has been increased to 3357 instead of 3277, it was shown that the Level of Service of NODE A has been boosted to became C instead of E. For point B, it was shown that the Level of Service has not been affected (remains C), while also the number of passing by Car has been increased (4617 instead of 4546), for point C, it was shown that the Level of Service has remained as it is (D), while the car count has also remained the same (4448). For Node D & E the Level of Service has also remained as it is (D) and the amount of passing by cars has a very minor increase (4474 instead of 4428).Regarding the result for the Third Scenario, The Total Travel time has been decreased by 43% (4.38 min instead of 8.08) while the number of passing by Vehicles has been increased to 2766 instead of 3277, it was shown that the Level of Service of NODE A has been boosted became A instead of E. For point B, it was shown that the Level of Service has been boosted to become A instead of C, while also the number of passing by Car has been increased 4173 instead of 4546), for point C, it was shown that the Level of Service has a minor boost to become C instead of D, while the car count has been also increase to become 4196 instead of 4448. For Node D & E the Level of Service has been boosted to become C instead of D and the amount of passing by cars has also increased (4168 instead of 4428). Regarding the result for the Scenarios Combined, The Total Travel time has been decreased by 49% (4.06 min instead of 8.08) while the number of passing by Vehicles has been increased to 3273 instead of 3277, it was shown that the Level of Service of NODE A has been boosted became A instead of E. For point B, it was shown that the Level of Service has been boosted to become A instead of C, while also the number of passing by Car has been increased 4588 instead of 4546, for point C, it was shown that the Level of Service has been boosted to become A instead of D, while the car count has been also increase to become 4620 instead of 4448. For Node D & E, the Level of Service has been boosted to become A instead of D and the amount of passing by cars has also increased (4679 instead of 4428).

Conclusion

Research Summary

As Traffic congestion became a critical issue that affects Cairo in different scales being the time wasted by Private Car users as well as a significant Loss in Egypt's GDP. It was essential to find the main reasons causing such phenomena from the various possibilities suggested in the prior researches / studies. Thus, a consolidated framework has been developed in this Research for urban designers to diagnose the primary causes of traffic congestion and select the most effective solutions using traffic simulation tools. Salah Salem Axis, one of Cairo's most congested roads, was chosen as the case study. PTV VISSIM software was used to simulate traffic flow, with key parameters such as network geometry, traffic volumes, and travel times recorded and analyzed. Three Scenarios has been chosen according to the Literature review and all of those Scenarios had been simulated inside the Traffic simulation software. After running the Simulation Model for 1 hour after implementing each Method inside the Traffic simulation Tool, it was observed that, Method no.1 (Enhancing the road geometry) had the most impact in reducing total Travel time "4:13 min" which is 48% less of the existing situation "8:08 min", as well as the Best Value for the LOS at NODE B & C. Which reflects how drastic the road design in causing Traffic congestion, hence resulting in a significant delay in Travel Time.

On the other hand, Method no.2 (Traffic Signals optimization) had the least impact on the total Travel time "7:45 min" which is just a 5% reduction of the existing Travel Time, which reflects how poorly the development of Traffic Lights affect the flow of the cars at that area. For Method no. 3, the Travel time has also a significant reduction of "4:38 min" which is 43% less of the existing Travel time. In term of NODES, For Node A, B, C the most efficient Method used was the third approach to increase the Public Transport reliance. For Node D The most effective approach to solve the Bottleneck. 2nd Approach (Optimizing the Traffic Signals) was the least effective Method.

Table 7. Analysis Results - LOS (Level of Service) vs Travel Time according to PTV VISSIM software.

NODE	Original Case	Bottlenecks removal	Traffic Signals	Public Transit	3 Scenarios Combined
NODE A	E	A	C	A	A
NODE B	C	A	C	A	A
NODE C	D	A	D	C	A
NODE D	D	B	D	C	A
NODE E	D	D	D	C	A
Travel Time in Min.	**8.08**	**4.13**	**7.45**	**4.38**	**4.06**

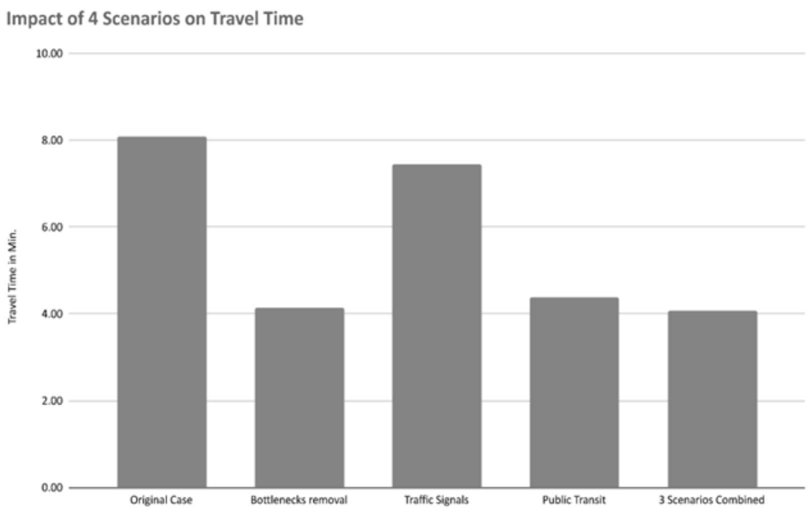


Figure 15. Impact of the 4 Scenarios on Travel Time.

Regarding the Research question, “What are the most efficient urban Methods and Tools that can be utilized for reducing Time wasted in Traffic Congestion in Cairo?” it was concluded that all of the three mentioned Methods have different implication among different nodes, however for the purpose of this Research and with the selected case study area, Method no. 1 “Road Geometry enhancement” was the most efficient and impactful Method in term of Travel Time and Level of Service (LOS) at the multiple intersections. In addition, the results came out of the PTV VISSIM can be reliable however the parameters identification are needed to be observed as already done by the author at site analysis, thus this Master Research should be provided as a consolidated a step by step framework/guide for Urban Designers and planners for future studies before committing to Design, which do satisfy the recommendation done in the previous researches. However, as already mentioned in the (M. Abdel Wahed and N. Abd El Monem, 2020). Urban Planning is about having a continuous check and revise over the existing Master plan in order to validate if the current design can accommodate the continuous changes and updates happening by the people.

For future studies, researchers could explore the impact of different time-of-day traffic patterns. Extending data collection methods to include more advanced technology, like drone footage and AI-based video analysis, could provide a more comprehensive view of traffic flow and driver behavior. Additionally, future studies could benefit from a multi-arterial approach to better understand network-wide traffic dynamics. Examining the effect of specific interventions, such as dedicated lanes for public transport or signal prioritization for buses, could also positively affects the Traffic flow as already suggested in previous studies. Further research might also investigate driver’s behavior and preferences, which could inform targeted awareness campaigns. In addition, long-term monitoring and evaluation of the implemented recommendations would be essential for measuring impact and making continuous improvements based on real-world data. It is also recommended that different Case studies areas be done using the same approach as this study, in order to have a wider ground and have a better approach among different patterns of the selected parameters. Another recommendation is to keep in consideration the surrounding Transportation projects. Another recommendation is that, urban planners should consider integrated Methods that prioritize public transport, non-motorized options, and modernized infrastructure. Expanding the public transportation network, including bus rapid transit systems and dedicated lanes, could mitigate, road congestion while reducing dependency on private vehicle.

Limitations

One of the primary issues is data availability and quality. Traffic simulation relies heavily on accurate, detailed, and current data, yet in Cairo, obtaining comprehensive data on traffic flow, signal timings, vehicle counts, and travel times can be difficult. Often, online data may be incomplete or inconsistent. Thus, the Author has relied on the Site visit done as well as some Traffic data from Google typical maps. In addition, one of the parameters that do affect the Traffic congestion worldwide in developing countries such as Cairo is Driver behavior. Such parameters have been ignored in this study as is a very wide term and it will be very difficult to assess all of the possibilities because of the random factor that comes with this parameter. Cairo’s traffic involves unique behavioral factors, including frequent lane changes, sudden stops, and aggressive driving that are hard to quantify in simulation terms. VISSIM typically uses standard behavioral models, which might not capture the nuances of local driving habits effectively. Calibration and validation of the model to ensure accuracy is a critical, yet time-intensive, process, particularly with these behavioral differences. Another limitation lies in impact measurement. Evaluating the effectiveness of various congestion-reducing Methods can be challenging, as traffic systems are complex, and isolating the effect of each Method from other influencing variables is often difficult. Additionally, implementing and validating Methods may require cooperation from local stakeholders, including traffic authorities or urban planning departments.

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Conflict of Interests

The author(s) declare(s) no conflict of interest.

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