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CRITICAL ANALYSIS OF DESIGN PARADIGMS IN ISLAMIC ARCHITECTURE: A STUDY OF INTERIORITY, VERSATILITY AND CELLULARITY

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Abstract. This paper analyzes traditional design principles in Islamic architecture, contextualizing them within broader cultural, social and environmental frameworks. The study develops a critical analysis framework that is both interpretative and descriptive, clustering Islamic architectural design features under the three paradigms of Interiority, Versatility and Cellularity. Traditional design elements are still present and can be distinguished across different scales, from individual homes and workplaces to entire neighborhoods and cities. Despite this, traditional design features have often been interpreted superficially, focusing mainly on the distinctive decorative compositions that define the external image of Islamic architecture. The analytical approach of this study shifts the discourse from a focus on architectural aesthetics to an exploration of compositional and environmental design values that remain as relevant in contemporary design as they were centuries ago. It adopts an analytical framework that integrates the basic architectural design principles of interiority, versatility and cellularity. The research examines how these principles have been embodied in traditional Islamic architecture's functional and spatial characteristics. The study highlights the complex relationship between private and public spheres in Islamic architecture, demonstrating how these essential qualities continue to shape and enrich contemporary architectural practices.

1.　Introduction

Islamic architecture and decorative styles provided a rich visual and geometric vocabulary that developed independently and interdependently across vast regions of Africa, Asia and southern Europe. The regional cultures and arts that preceded Islam expressed their unique histories and identities within a new architectural framework. Consequently, Islamic architecture in Iran differs markedly from its counterparts in Andalusia, Egypt and Syria, as each society developed distinctive architectural qualities that integrated indigenous cultures and histories into uniquely Islamic forms. Figure 1 provides an exposition of various examples of Islamic monuments, illustrating the diversity and adaptability of these styles (https://www.gettyimages.com/). These examples are not exhaustive or fully representative of Islamic architectural styles but serve as a collage highlighting the forms that have most significantly shaped the distinct

character and styling of Islamic Architecture. The distinctiveness of Islamic architecture across different regions can be attributed to several factors. In Iran, for instance, the use of intricate tile work, elaborate muqarnas and soaring minarets reflects a blend of Persian artistic traditions with Islamic design principles. This results in a visual and structural complexity that is both aesthetically pleasing and symbolically rich (O'Kane, 2021). In contrast, the architecture of Andalusia, particularly exemplified by the Alhambra, incorporates elements such as courtyards, water features and intricate stucco work, reflecting the interplay of Islamic and local Spanish influences (Barrucand *et al.*, 1992). Egyptian and Syrian Islamic architecture often emphasizes monumentalism and functionality, as seen in the grand mosques and madrasas that serve as religious and educational centers. The use of robust stone constructions, geometric patterns and calligraphic inscriptions in these regions underscores the importance of durability, artistry and religious devotion (O'Kane, 2016; Abouseif, 1989).

2. Research Methodology and Critical Discussions

This research employs a qualitative approach rooted in critical analysis to underline key design characteristics of traditional Islamic architecture. The research utilizes secondary data drawn from various scholarly sources, including books, peer-reviewed articles and case studies focusing on historical analyses of significant Islamic architectural movements. In addition to textual analysis, the study incorporates rich visual data encompassing various examples of traditional architectural developments spanning hundreds of years from medieval to contemporary times. The study develops a critical analysis framework that is both interpretive and descriptive, clustering Islamic architectural design features under the three paradigms of Interiority, Versatility and Cellularity. Despite the overlap between these design clusters, this organizational framework offers a nuanced understanding of Islamic architectural design values. Interiority denotes an emphasis on interior spaces rather than exterior forms. It is evident in the design of courtyards, gardens and interior rooms that provide privacy, comfort and a connection to nature. The focus on interiority creates sanctuaries within urban environments, offering respite from the outside world while fostering a sense of community. Versatility is evident in using spaces that can serve multiple purposes depending on the time of day, season or social occasion. The flexible use of space reflects a profound understanding of the need for environments that can accommodate various activities and social interactions. Cellularity refers to the use of modular units or cells that combine to form larger compositions (Abdelsalam & Ibrahim, 2020). It is visible in the design of residential neighborhoods, where individual homes form cohesive urban blocks and in the intricate patterns of surface ornamentation, where geometric motifs repeat and interlock to create complex, harmonious designs. Self-similar geometries have been employed at all levels of development, from macro-urban areas to neighborhoods, buildings and surface ornaments. The concept of microcosmic units replicating the structure and geometry of larger compositions has played a defining role in the evolution of diverse spatial, architectural, decorative and linear arrangements in Islamic architecture (Bokhari *et al.*, 2020; O'Kane, 2016; Kashef, 2010, 2017). These principles and patterns have manifested themselves across various developments, including urban blocks, mosques, commercial establishments, homes, courtyards, gardens, domes, arches, minarets and the renowned muqarnas units. Additionally, they have been extensively applied in surface geometries and inscription bands using materials such as stone, brick,

wood and tiled mosaics. Figure 2 provides a theoretical framework of the qualities associated with each of the three primary design values integrated in subsequent study analyses.

Iran - 17th Century AD

Andalusia, Spain - 8th till 14th Century AD

Cairo, Egypt - 14th & 15th Century AD

Abu Dhabi, UAE - Twenty First Century AD

Figure 1. Islamic architecture examples from around the world
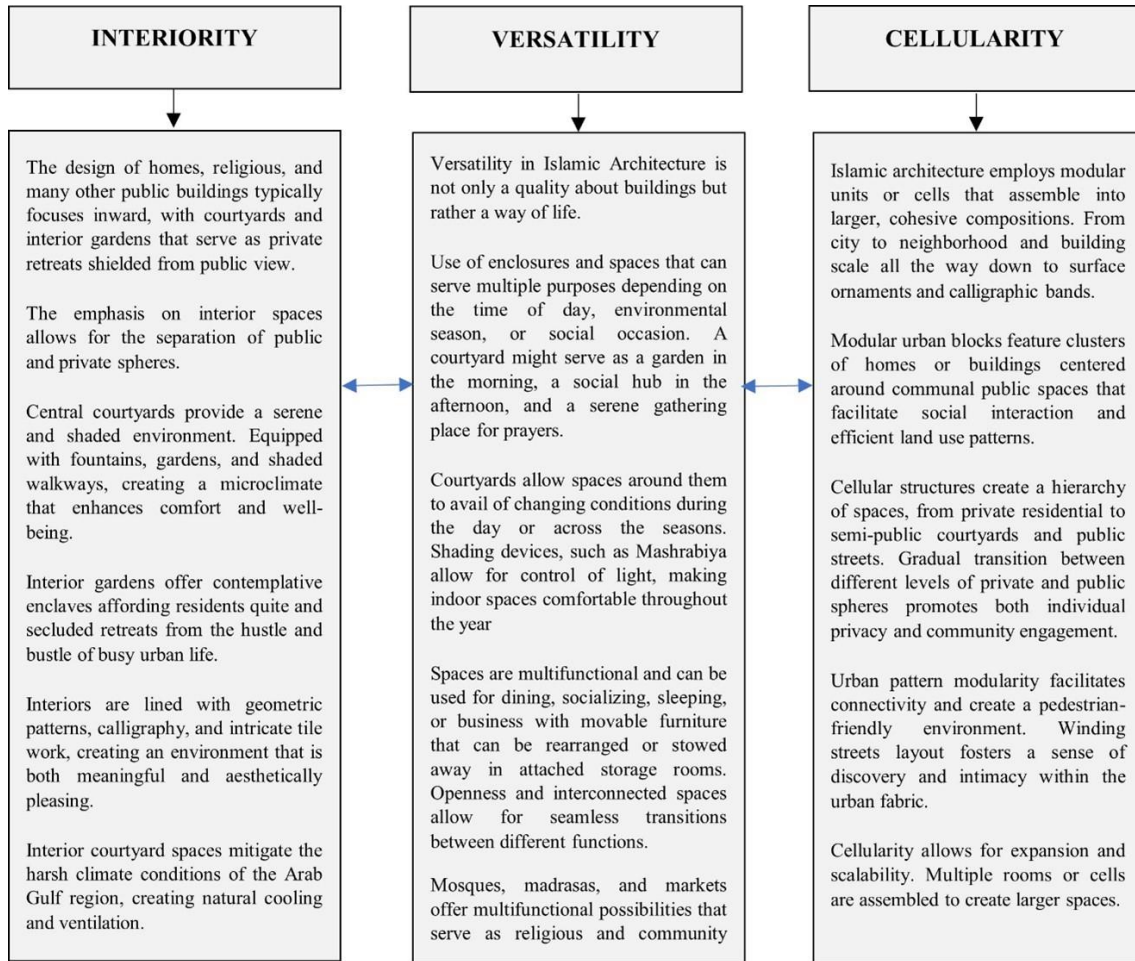**Source:** https://www.gettyimages.com/

INTERIORITY	**VERSATILITY**	**CELLULARITY**
The design of homes, religious, and many other public buildings typically focuses inward, with courtyards and interior gardens that serve as private retreats shielded from public view. The emphasis on interior spaces allows for the separation of public and private spheres. Central courtyards provide a serene and shaded environment. Equipped with fountains, gardens, and shaded walkways, creating a microclimate that enhances comfort and well-being. Interior gardens offer contemplative enclaves affording residents quite and secluded retreats from the hustle and bustle of busy urban life. Interiors are lined with geometric patterns, calligraphy, and intricate tile work, creating an environment that is both meaningful and aesthetically pleasing. Interior courtyard spaces mitigate the harsh climate conditions of the Arab Gulf region, creating natural cooling and ventilation.	Versatility in Islamic Architecture is not only a quality about buildings but rather a way of life. Use of enclosures and spaces that can serve multiple purposes depending on the time of day, environmental season, or social occasion. A courtyard might serve as a garden in the morning, a social hub in the afternoon, and a serene gathering place for prayers. Courtyards allow spaces around them to avail of changing conditions during the day or across the seasons. Shading devices, such as Mashrabiya allow for control of light, making indoor spaces comfortable throughout the year Spaces are multifunctional and can be used for dining, socializing, sleeping, or business with movable furniture that can be rearranged or stowed away in attached storage rooms. Openness and interconnected spaces allow for seamless transitions between different functions. Mosques, madrasas, and markets offer multifunctional possibilities that serve as religious and community	Islamic architecture employs modular units or cells that assemble into larger, cohesive compositions. From city to neighborhood and building scale all the way down to surface ornaments and calligraphic bands. Modular urban blocks feature clusters of homes or buildings centered around communal public spaces that facilitate social interaction and efficient land use patterns. Cellular structures create a hierarchy of spaces, from private residential to semi-public courtyards and public streets. Gradual transition between different levels of private and public spheres promotes both individual privacy and community engagement. Urban pattern modularity facilitates connectivity and create a pedestrian-friendly environment. Winding streets layout fosters a sense of discovery and intimacy within the urban fabric. Cellularity allows for expansion and scalability. Multiple rooms or cells are assembled to create larger spaces.

Figure 2. Traditional design paradigms in Islamic Architecture
Sources: Holod (1984), Abu-Lughod (1987), Abouseif (1989), Cerasi (1989), Lane (2004), Raymond (2005), Spahic (2008), Hamouche (2009), Kashef (2010; 2017), O'Kane (2016), Bokhari et al. (2020)

Architects of contemporary projects in the Arab Gulf Region, for example, draw inspiration from traditional Islamic forms and motifs, integrating them into new constructions that cater to modern needs while preserving cultural heritage. The Msheireb Downtown project in Doha exemplifies versatility through its mixed-use urban development, which integrates residential, commercial and cultural spaces. It is a pioneering urban regeneration project that draws from traditional Qatari and Islamic urban patterns. Many buildings, whether residential or commercial, are designed around functional courtyards that act as central gathering spaces, naturally ventilated and shaded to relieve the hot climate (Figure 3a). These courtyards serve multiple purposes, from social interaction spaces to natural cooling systems, thus embodying both cultural and environmental considerations (Al-Hammadi, 2022). The Louvre in Abu Dhabi, designed by Jean Novel, incorporates internal courtyards that are functional, aesthetic spaces with climate control features (Figure 3b). The courtyards, nestled under the iconic dome, provide visitors with shaded, tranquil areas that break up the exhibition spaces, mimicking the traditional role of courtyards as gathering or transition spaces. These internal courtyards help to moderate the harsh sunlight and heat, enhancing the visitor experience

while reinforcing the architectural dialogue between interior and exterior spaces (Musfy *et al*., 2021; Kashef, 2022).

a) Msheireb Downtown   b) Louver Museum, Abu

Figure 3. Contemporary projects in the Arab gulf region
Source: https://www.gettyimages.com/

3.   Interiority

The concept of interiority in Islamic architecture should not be confused with social introversion or reclusiveness. Instead, it refers to a sophisticated spatial configurational approach that responds to societal norms and lifestyle choices. Traditional Islamic communities were socially active within and across the borders of private and public realms, yet they invariably preferred a level of exclusivity (Raymond, 2005). This preference led to a distinct spatial pattern evident across all scales of development, from individual buildings to the urban fabric (Hamouche, 2009). It was manifested in hierarchical spatial enclosures and compact agglomerations penetrated by strategically located courtyards within buildings, neighborhoods and city centers.

3.1. Spatial Enclosures

Spatial enclosures in Islamic Architecture involve the creation of private, inward-focused spaces that provide a sense of security and privacy. This principle is evident in the design of homes, courtyards and even urban spaces (Holod, 1984). Homes are designed with minimal exterior openings, focusing attention inward toward private courtyards and gardens. This ensures privacy and creates a tranquil, secure environment for family life. Central courtyards serve as the heart of the home, providing a private outdoor space for relaxation, socializing and daily activities. These courtyards are often lush with greenery and water features, enhancing the sense of enclosure and comfort (Spahic, 2008; Abu-Lughod, 1987). The concept of enclosure is reflected in the layout of neighborhoods and public spaces. Narrow, winding streets create a sense of intimacy and enclosure, shielding the inhabitants from the harsh exterior climate and bustling public life. The hierarchical organization of spaces in Islamic architecture is crucial for maintaining social order and facilitating various levels of interaction (Figure 4). Within homes, spaces are arranged hierarchically from public reception areas to private family quarters. This layout ensures that visitors can be received without intruding on the private areas of the home, respecting the family's privacy. At the neighborhood level, a hierarchy

is established through the placement of communal spaces such as mosques, markets and public squares. These spaces are centrally located and easily accessible, serving as focal points for community life. The urban fabric is hierarchical, with main thoroughfares leading to secondary streets and then to narrow alleys. This hierarchical arrangement facilitates movement while maintaining order and privacy (Eltrapolsi *et al*., 2022; Hakim, 1994).

3.2. *Compact Agglomerations and Hierarchical Enclosures*

This refers to the clustering of buildings and spaces in a compact, cohesive manner that enhances social interaction, resource efficiency and environmental sustainability. In residential neighborhoods, communal courtyards enhance social interaction among multiple households, provide shared amenities and create a microclimate that improves comfort and livability. On the city scale, the agglomeration principle is evident in the dense arrangement of commercial, religious and public buildings. This clustering creates vibrant urban centers that support diverse activities and services, making cities more dynamic and functional. Figure 4 illustrates reconstructed maps and aerial images of various traditional Islamic cities, highlighting the three related design constructs of Enclosure, Hierarchy and Agglomeration. Enclosed spaces create environments that simultaneously enhance exclusivity and foster a sense of community. The hierarchical organization of spaces ensures that different social functions are effectively accommodated while supporting both private and public life. Compact agglomerations and developments enhance social cohesion and resource efficiency, making traditional Islamic cities resilient and sustainable (Eltrapolsi, 2022; Hakim, 1994).

3.3. *Sociospatial Perspective of Spatial Enclosures in Islamic Architecture*

Many studies presume that the courtyard house by its introverted character and confined spatial enclosure aimed to fulfill religious precepts and the reclusive private life of Muslim communities (Rashid, 2020; Bokhari *et al*., 2020; Malik *et al*., 2016; Spahic, 2008). They support such arguments with descriptive interpretations of house components such as window privacy screens overlooking the public realm, courtyard enclosures around which home spaces are organized, zigzagged or bent vestibules that ensure home privacy, etc. However, primary accounts of traditional communities depicted a much richer and more active social life that negated such religious and reclusive considerations (Lane, 2004). Edward Lane's account of traditional life in Cairo (first published in 1836) underlined the dynamic social structure and activity patterns that took place in streets, private courtyards and city public squares. The home courtyard figured in Lane's accounts as a semi-private/public enclosure with an animated social life for family members and non-family member guests shielded away from the prying eyes of street passersby. Lane's assertions are corroborated by various spatial, functional and design components of traditional homes. Male guest entertainment spaces in traditional homes (Mandara-Maqaad-Takhtaboush) were designed to avail of the lush environment of inner courtyards that have been systematically characterized as the private inner domain of family members. Tightly designed screens were applied equally to windows overlooking the streets and the internal courtyards. Furthermore, some private family rooms that have been primarily designated for women in traditional homes were oriented to the street space rather than the courtyard, the presumed private and reclusive enclave of the family. This bespeaks the spatial flexibility of traditional home
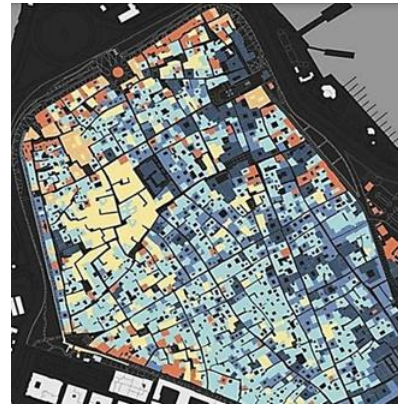
spaces and social dynamism in traditional communities. Mashrabiyas were largely used to screen the residents from the view of strangers, while at the same time allowing them to see the outside world.
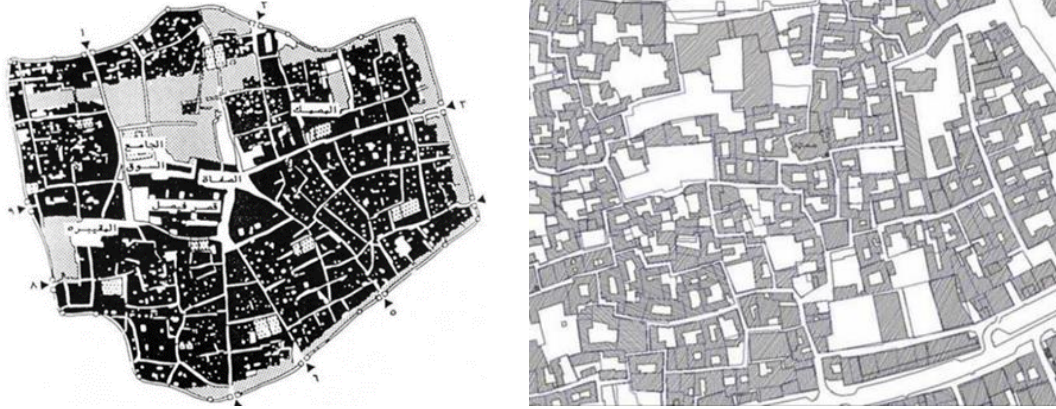
a)   **Source:** https://www.csbe.org, Abu-Lughod (1987)

b) **Source:** Hakim (1994)

c) **Source:** Eltrapolsi et al. (2022)

d) **Source:** Eltrapolsi et al. (2022)

Figure 4. Enclosure, hierarchy and agglomeration in traditional Islamic cities
a) Old Cities of Riyadh, KSA (Left) and Manama, Bahrain (Right);
b) Map of the city of Hofouf 100 years ago, KSA;
c) Reconstructed map of the Old city City of Tripoli, Libya;
d) Reconstructed aerial image of the old City of Tripoli, Libya.

The home courtyard was sort of a privatized fragment of the public realm that could be exclusively enjoyed by home residents, extended family and non-family guests (Kashef, 2010; Abouseif, 1989; Cerasi, 1998). As a resource for openness, aesthetics, entertainment and social activity, spatially defined open space enclosures across the entire hierarchy of development (building, street, neighborhood, city), served as temperature regulators for traditional compact urban agglomerations (Figures 5, 6).

The great difference between daytime and night-time temperatures in hot climates allowed colder air to accumulate in the narrow streets and the well-like interiors of private courtyards and open public spaces. Building walls located across the contrasting geometries of narrow streets and spacious private courtyards and public open spaces are subject to differential solar radiation and ambient temperatures. This generates dynamic air convection currents that move across building interior rooms, courtyards and public open spaces throughout the daytime and the early hours of nighttime (Kashef, 2010; Abdelkader & Park, 2018). Such traditional, yet innovative environmental solutions have been adapted to contemporary architecture and are currently designated "solar chimneys". Other environmental devices have been incorporated into buildings to fight heat extremes and make their rooms cooler and more appropriate for habitation.
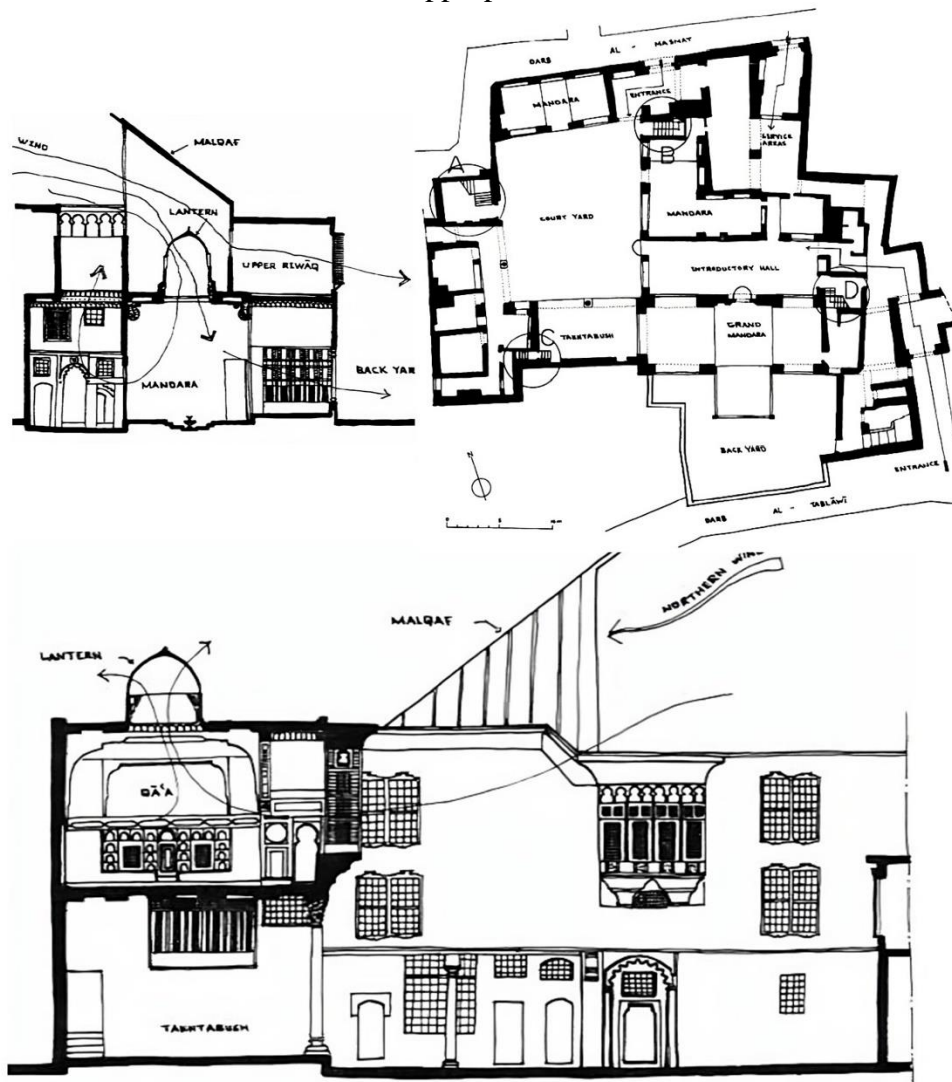
Figure 5. Traditional courtyard house spatial and environmental adaptations

The windcatcher (Malqaf) was a standard feature in traditional homes. It is a rectilinear air scoop, facing north and configured to capture desirable cooling northern winds. A sophisticated system of rectangular ducts connected with windcatchers channeled the air into the house's different rooms. Another interesting device termed "Shukhshaykha" was a narrow-domed opening (lantern or cupula) typically surmounting the ceiling of major living spaces. Small openings in the drum of the lantern provided further daylight and enhanced air circulation in living spaces while allowing hot air to escape (Kashef, 2010).

As much as Irregular and narrow street networks have been romanticized and celebrated in literature as the defining feature of traditional cities, they did not form the skeletal organizational structure of traditional built environments. Traditional urban geography consisted of separate alleys rather than a single network of intersecting streets. The widest open-ended thoroughfares were lined up with major public spaces and laterally surrounded by compact agglomerations interspersed by dead-end lanes and a gradient hierarchy of neighborhood open spaces and private courtyards (Raymond, 2002). The principal arteries of eighteenth-century Cairo were known as "Shari" (avenue), the branch streets were called "Darb" (route) and the dead-end lanes were defined by several names, "Atfa", "Zuqaq" or "Sikka" (Lane, 2004). He also emphasized that the primary constituent that identified different parts of the city was the "Hara", which signifies an urban quarter or neighborhood. The "Harat" or quarters appeared in various historical sources referring to clusters or organizational units of the urban fabric traversed by some routes and dead-end lanes. Maqrizi (Medieval historian) cited thirty-seven Harat which were distributed in all parts of Medieval Cairo. He underlined the role of the "Hara" agglomeration as the primary structural unit of the city (1442). The Hara may be seen as a microcosm of the city where different classes and social groups lived together (Figure 5). Figures 7 and 8 depict the interior of the 18th century home in Cairo and the revitalized Souq Waqif in the Qatari capital of Doha.

Figure 6. Old city of Damascus: City map and urban block pattern
Sources: Pascual (1983), Sack (1989), Chamberlain (1994), Raymond (1984, 2002)

Figure 7. Home Interiority: Courtyard of Bayt Al-Suhaimi, Cairo (18th Century)
Source: Gerhard Huber, https://global-geography.org/af/Geography/Africa/Egypt/Pictures/Cairo/Khan_el-Khalili_-_Bayt_Al-Suhaymi_Courtyard

Figure 8. Urban Hierarchical Spatial Enclosures (Doha, Qatar) – Contemporary retrofitting and revitalization of traditional

4. Versatility

Traditional Islamic architecture embraced functional and spatiotemporal versatility, which was evident across various building types and urban scales, from residential buildings to commercial and religious institutions, as well as neighborhoods and community spaces. Such versatility ensured that structures could meet diverse and evolving needs over time.

4.1. Functional Versatility

Traditional Islamic homes were designed to serve multiple functions throughout the day. During the daytime, living and entertainment spaces accommodated family activities and social gatherings. At night, these areas transformed into sleeping quarters, with bedding stored in adjoining storage rooms (Lane, 2004). This multifunctional use of space maximized the utility of limited floor areas, reflecting an efficient and pragmatic approach to living. Merchants often conducted business from their homes, transforming entertainment and guest reception areas into workspaces. This dual functionality allowed for seamless integration of domestic life and economic activities. Small rooms adjoining primary home spaces and private family quarters were used to store movable furniture. These storage areas enabled residents to adapt rooms for different purposes and occasions, showcasing the functional versatility inherent in traditional Islamic homes (Lane, 2004).

4.2. Spatiotemporal Versatility

The central courtyard (Sahn) of traditional homes served as the main source of lighting and ventilation for interior spaces. Additionally, it functioned as a living and entertainment space for residents and their guests. This multifunctional courtyard exemplifies spatial versatility, providing a private outdoor area that enhances the overall livability and comfort of the home. Rooms within traditional Islamic homes were often designed with flexibility in mind. Large, open spaces could be subdivided using curtains, screens or movable partitions, allowing for adaptable spatial configurations that meet various needs and activities. Homes were designed with open spaces facing desirable

wind direction to avail themselves of cooler air during harsh summers. Courtyards were also equipped with outdoor fountains, trees and retractable shading that created agreeable sitting and entertaining outdoor spaces. Other spaces faced the south direction to provide users with warmth during cold winters. This temporal adaptability ensured comfort and functionality throughout the year. Holod (1984) emphasized that flexibility and adaptability in traditional Islamic architecture extended beyond residential functions to include commercial and religious spaces. For instance, traditional mosques and madrasas were designed with flexible layouts that allowed primary spaces to accommodate prayers and teaching classrooms in between scheduled prayer times. Sultan Hassan Complex, built around 1356 AD in Cairo, exemplified functional and spatiotemporal flexibility. It housed residential cells for students and scholars on the upper floors, overlooking the central courtyard that unified various functions. This courtyard provided light and ventilation for prayer halls and rooms, enhancing the overall ambiance of the interior (Iwans). The complex design allowed for a seamless blend of educational, residential and religious activities (Figure 9). Major commercial establishments, known as "Wekala" or "khan" were designed to accommodate market stalls, various shop sizes and workspaces on the lower floors. The upper floors provided hotel accommodation. This flexible configuration allowed for mixed-use arrangements that adapted to seasonal variations and trade events (Figure 10). Such adaptability ensured that commercial spaces remained vibrant and functional throughout the year. Traditional Islamic cities featured mixed-use neighborhoods where residential, commercial and public spaces coexisted harmoniously. This blend of uses within a compact urban fabric facilitated social interaction, economic activity and community cohesion. Urban spaces were designed to accommodate different activities at various times of the day and year. Markets and public squares transformed into spaces for festivals, religious events and social gatherings, reflecting the temporal versatility of the urban fabric. Narrow, winding streets created intimate and pedestrian-friendly environments, facilitating both private and public life. The street layouts allowed for easy adaptation to changing social and economic needs, ensuring the city's resilience and longevity (Lewcock, 1988).
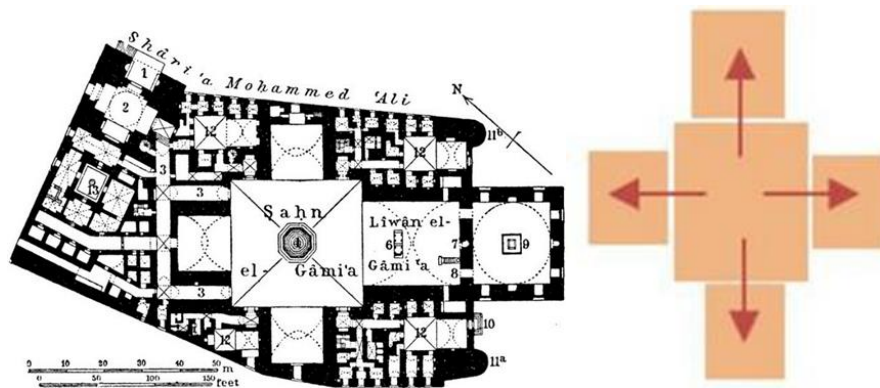

Figure 9. Sultan Hassan Madrasa, Cairo 1356 AD
Sources: https://dome.mit.edu (Left); Abdelsalam and Ibrahim (2019)

Figure 10. Functional Versatility in Sultan Hassan Madrasa, 1356 AD (Left) and
Wekala AL Ghori, 1505 AD, Cairo (Right)
Sources: https://www.archnet.org/ https://dome.mit.edu

4.3. City-Wide Versatility

Though city thoroughfares and neighborhood streets were narrow and primarily designed for foot traffic and camel passing, outdoor sitting benches were invariably fitted beside the buildings' main entryways. This created semipublic social nodes along public streets that allowed building occupants to occasionally interact with friends and passersby and conduct business transactions. Significant public open spaces were commonly attached to mosques and served as extended prayer grounds during weekly Friday prayers, marketplaces on specific weekdays and sociocultural incubators for the community on other days. Major public spaces were centrally located in the urban fabric near important government functions and provided opportunities for official and public parades. They also served as open grounds that accommodated large crowds during Eid prayers and other community festivals (Raymond, 1984, 2005; Jayyusi, 2008; Kashef, 2010). Lewcock (1988) referenced an interactive sociospatial dynamic between buildings and streets in traditional cities that afforded homeowners to utilize public space as an extension of their private properties. Neighborhood residents were allowed to hold major weddings and other festivities in the public realm, thereby extending private functions into the street and city open spaces temporarily. These practices have thrown families and their extended circle of relatives, friends and other neighborhood or city-wide residents in close contact, which enhanced community social cohesion and provided a level of functional and spatial flexibility rarely encountered in other contexts.

5. Cellularity

The term cellularity refers to traditional geometries that incorporate compositions with infinite replication possibilities and modular configurations. Rhythmic, aperiodic and fractal geometries were applied constructively in residential, religious and commercial buildings as well as ornamentally as carvings, tiles or stylized calligraphy moldings. Fractal geometries refer to a process of generating self-similar forms at different scales leading to complex substantial compositions that are similar to the smallest cellular units of the formation. Complex and intricate cellular designs have been manifested in both interior space design and exterior forms as well as surface ornaments

including the use of different styles of Arabic calligraphy (Al-Tawil, 2013; Gharipour & Schick, 2013).

5.1. Mathematical Proportions in Islamic Architecture

In-depth mathematical analyses of traditional courtyard houses pointed to a general formula that architects used to determine the overall proportions of principal living spaces commonly termed "Qa'a or Mandara" (Figure 11). The dimensional proportions between the lengths and widths of such spaces approximated the well-known ratio of pi (3.14) (Kashef, 2010). This particular space was subdivided into three smaller units, the central area "Durqa'a" is widely opened to two opposite "Iwans" or living rooms. The result is three volumes lined along one axis, each serving a different purpose and providing versatile space for daytime entertainment and nighttime slumbering. The Iwans were commonly elevated by one or two steps separating them from the central space, which has a square geometry and is adorned by a drizzling fountain and intricately designed marble floors. Dimensional relations of other spaces in courtyard homes approximated the alpha quotient with lengths, widths and general room proportions following the golden ratio (Sultan, 1980). The courtyard was a key element in shaping the spatial composition of the house. Though primary spaces opened directly onto the courtyard, the overall disposition of the house followed pragmatic considerations related to the street network, building orientation and relationship to adjoining properties. Hence, there have been various compositional arrangements for the Location of Courtyards vis-a-vis other house Components (Figure 12). Modular proportion systems and cellular design elements were followed in religious and commercial buildings. Traditional mosque layouts generally exhibited cellular square geometries that originated in the dominant central courtyard and branch out into smaller square spaces that accommodate various functions based on the time of day, activity patterns and prayer schedule.

Figure 11. The Qa'a of Hassan Kashef House, eighteenth century, Cairo
Source: Commission des sciences et arts d'Egypte and Napoleon (1809)
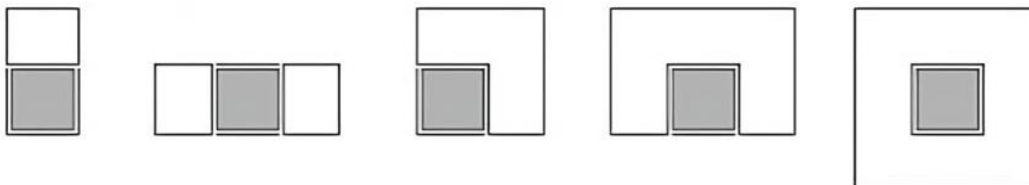

Figure 12. Compositional variations for Courtyards vis-a-vis other House Components
Source: Abdelkader (2018)

The courtyard of Sulaymaniyah Mosque in Istanbul, Turkey (1550) has a rectangular geometry with proportional dimensions of width to length 1-1.4, which approximates the Golden Ratio (Figure 13). The interior space of the mosque offers a complex modular geometry with nested square and rectangular layout arrangements. The central dome is flanked by two semi-domes along the East-West axis thus creating a rectangular space of width-to-length proportions of 1-2. The square layout of the central dome is nested within the larger square of the prayer hall with relative area proportions between both approximating the golden ratio as well. The overall mosque configuration boasts a rich cellular interplay of proportional solids and voids, from additions and subtractions and rhythmic design patterns along its horizontal and vertical mass development (Figure 14). Self-similarity is not about sameness or tedious repetitions. Self-similar but nonidentical geometries are reproduced within a hierarchical structure of scales and dispositions, thereby creating a fractal canvas with distinct and enduring qualities (Eilouti, 2017).
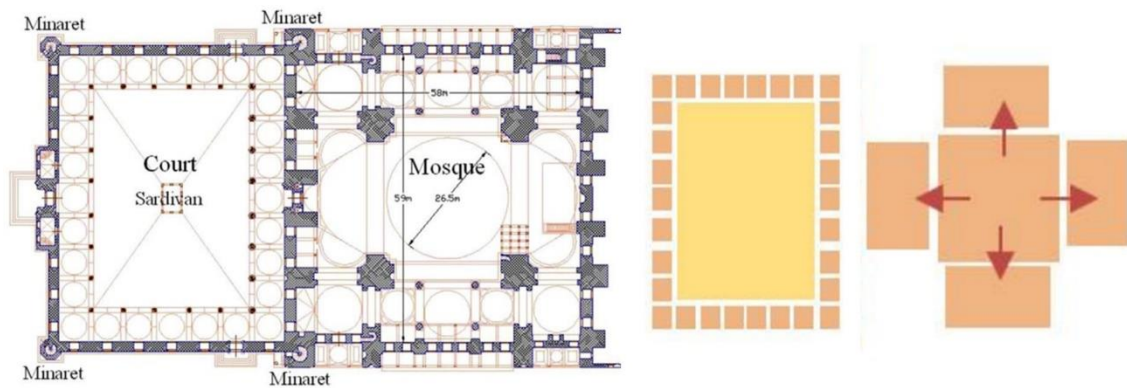

Figure 13. Proportional geometries of the Sulaymaniyah mosque, Istanbul, Turkey, 1550
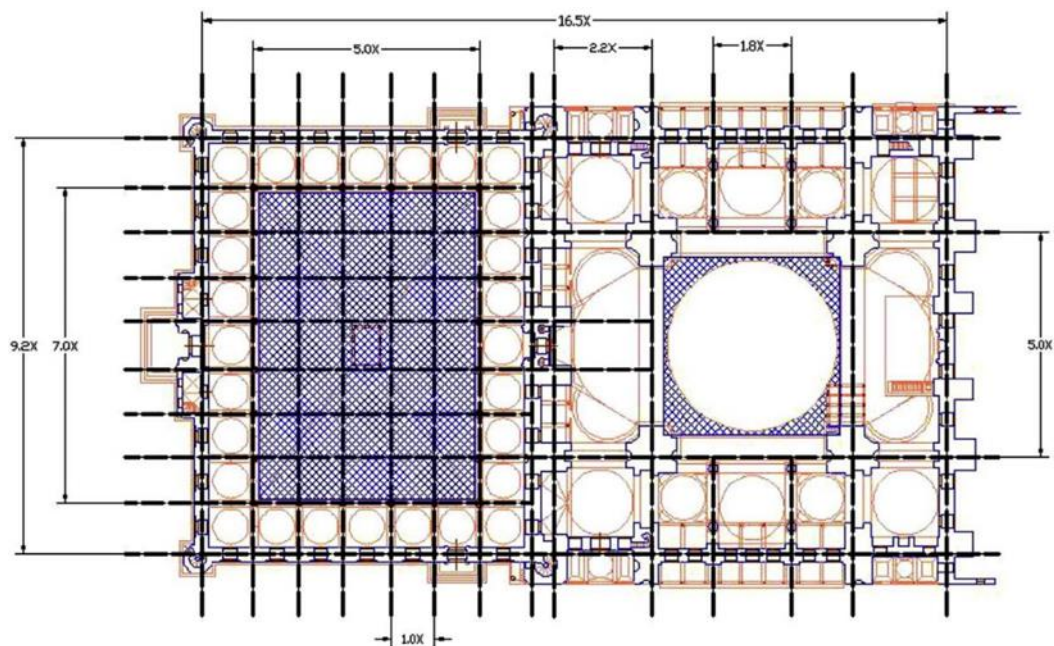**Sources:** Eilouti (2017) (Left); Abdelsalam and Ibrahim (2019) (Right)

Figure 14. Proportional geometries of the Sulaymaniyah mosque, Istanbul, Turkey, 1550
Sources: Eilouti (2017)

5.2. *Fractal and Aperiodic Geometries in Islamic Architecture*

Fractal and quasi-fractal geometries have been manifested in traditional cities from the urban scale down to Muqarnas configurations and the intricate mosaic patterns that adorned the interior and exterior surfaces of buildings. The tree-like geometry of traditional city fabric and the incremental process of urban development precipitated an infinite variety of nested self-similar geometries within an overall structured hierarchy and cellular compositions (Figure 15). This was evidenced in the distribution and hierarchical volumes of courtyards and open spaces within homes, mosques, commercial establishments, neighborhoods and along major thoroughfares (Bokhari *et al*., 2020). The tree-like structure of streets offered another self-similar hierarchical composition and changed in width, spatial proportions and directional characteristics concerning different courtyards and open spaces. The urban fabric of traditional cities grew incrementally and was continuously subdivided into various scale cellular compositions that create distinct spatial, functional and visual overlays.
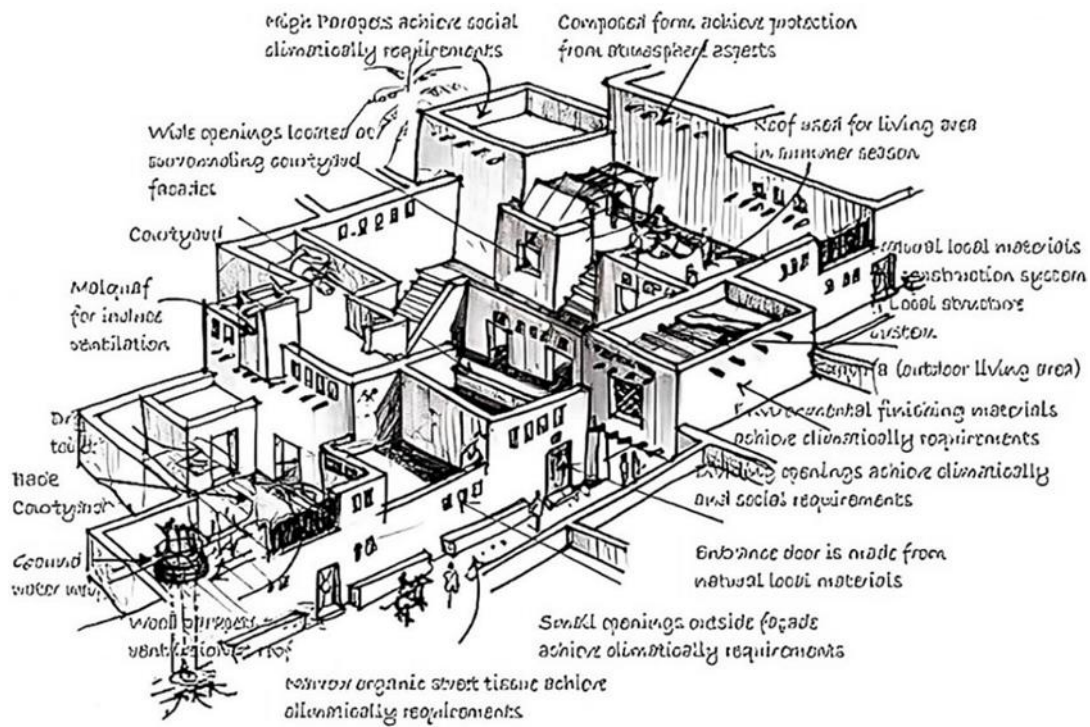

Figure 15. Massing and Geometric Modularity of Traditional Homes in Baha, KSA
Source: Bokhari et al. (2020)

5.3. *Muqarnas configurations*

These provide the most vivid and striking expression of cellular designs and self-replicating units that vary in size, position and detail but fit together well thanks to the ingenious geometric logic and mathematical precision of their design and construction. They are characterized by multiple layers of niches, often found in transitional areas between walls and domed ceilings and were later incorporated as decorative bands on building facades. The muqarnas design process involves a sophisticated understanding of geometry, symmetry and proportions. Microcosmic and self-replicating geometric formations are assembled into larger and more complex compositions that reflect the

spatial character and details of the smaller units (Figure 16). This recursive arrangement not only enhances visual complexity but also demonstrates the ability to use complex geometric and mathematical principles to create fractal compositions, where self-similar patterns occur at different levels and placement within the overall composition. Muqarnas exemplifies the concept of cellular geometry with a three-dimensional lattice or network of interconnected cells. These cells are formed by the interlocking and overlapping of the replicated units, creating a visually captivating and structurally stable architectural element (Yaghan, 2011).
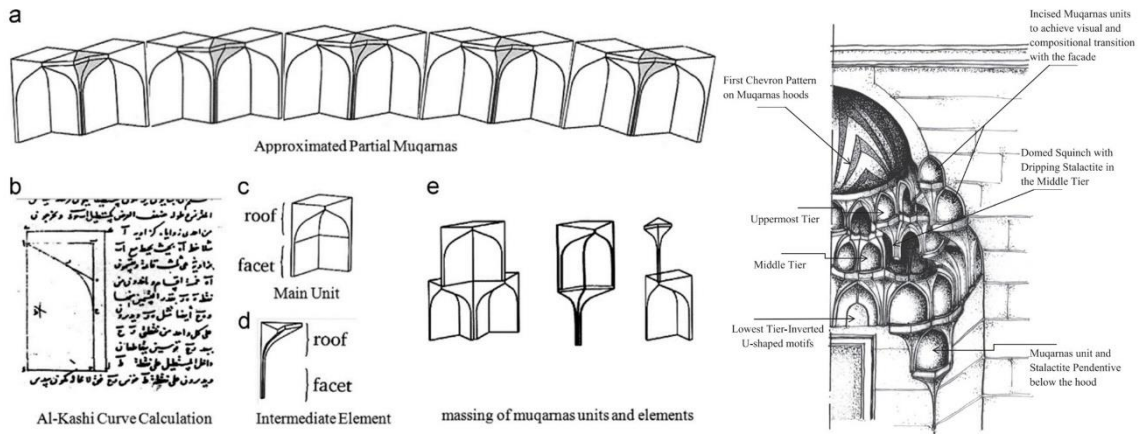

Figure 16. Muqarnas Configuration, Structure and Process of Erection
Source: Kashef (2017)

6. Reflective Discussion

The legacy of Islamic architecture is much broader than the scope analyzed in this study. However, the three design values (interiority, versatility and cellularity) addressed here have had a profound impact on the development of design patterns and urban typologies. While these values represent only a fraction of the rich tapestry of Islamic architectural principles, they are foundational and emblematic of the broader architectural tradition. These design principles not only define the essence of traditional Islamic architecture but also continue to shape contemporary design values within and outside the Islamic world. The principle of versatility refers to the nuanced and multifaceted conceptual framework that underpins the design of spaces within Islamic architecture. The research placed a strong emphasis on the versatile nature of interior spaces, highlighting their ability to cater to a myriad of purposes and seamlessly respond to the diverse needs of users, whether over different times of the year, month or day. The design principles of versatility and interiority in Islamic architecture are highly intertwined and a discussion of one inevitably involves the other. The central courtyard assumed a paramount role as the primary organizational nucleus within the house, affording a remarkable degree of functional versatility. It seamlessly accommodated an array of activities, encompassing social gatherings, entertainment, repose, prayer and the orchestration of the homeowner's business endeavors (Abouseif, 1989). Beyond its multifunctional role, the courtyard functioned as a climate regulator, exerting influence over the entire dwelling by moderating heat extremes and channeling both fresh air and natural light into different rooms of the residence (Kashef, 2010). Interior spaces were thoughtfully conceived as dynamic modules, designed for effortless reconfiguration and

repurposing. This inherent adaptability empowered residents to tailor their living environment to suit momentary requirements, be it the hosting of family gatherings, the entertainment of guests or the creation of a serene sanctuary for contemplation. Movable partitions or screens commonly referred to as "mashrabiyas" were used to balance privacy and social dynamics for different uses while maintaining airflow and communication possibilities across the boundaries of different functions (Lane, 2004). Likewise, the courtyard played a central role in Mamluk mosques and madrasas. The open courtyard surrounded by four partially enclosed iwans provides versatile spaces capable of accommodating a large congregation during Friday prayers and special occasions. However, each of the four iwans accommodates smaller gatherings for daily prayer and religious teachings. Mosque and madrasa buildings often include multi-purpose rooms for overnight accommodation of scholars and students, community gatherings, educational activities and social events (O'kane, 2016). These spaces were highly adaptable and were used for a variety of functions that promoted community engagement. Commercial establishments, known as Bazaars, Wekalas, Souks or Caravanserais, exemplified a sophisticated architectural approach characterized by modular stall configurations. This design facilitated adaptability, enabling small-scale merchants to lease or own one or two stalls, while allowing larger traders to amalgamate numerous modular units, thereby fashioning expansive trading centers. Outdoor and indoor spaces were seamlessly integrated and punctuated by courtyards and arcaded walkways, thereby nurturing a sense of interconnectivity and adaptability, capable of accommodating trade and social interaction in diverse weather conditions. The synergy of multi-functionality and modularity, complemented by the judicious use of moving components, has generated rich compositional possibilities, deftly matching evolving needs while contributing to the rich tapestry of Islamic cultural and architectural traditions (Abouseif, 1989; Raymond, 1980).

The principle of versatility addressed in this study transcends the external appearance of buildings or the surface ornaments inside homes, mosques and commercial establishments. It primarily refers to the functional and social versatility aspects that allowed different building typologies and components to accommodate a myriad of functions and social practices that found vivid expressions in diverse compositions and textures that displayed distinct regional characteristics. The complex geometric patterns and tile work of the Alhambra in Spain differ from the floral stone carving patterns and wood inlays of Egypt and Syria, as well as the colorful marble tiles and inlays of the Taj Mahal. The design value of interiority in Islamic architecture was evident in the creation of lush, meditative interiors, which used natural light and air to create unique spatial qualities and micro-climatic conditions with a sense of calm and contemplation. Intricate, tightly carved wooden screens, known as mashrabiyas, covered windows and allowed for a rich interplay between privacy and openness in interior spaces. Inhabitants could gaze upon the bustling street while maintaining a coveted sense of privacy, shielding their interiors from prying eyes. These features in Islamic architecture transcend superficial beauty; they symbolize the complex relationship between the built environment, the individual and the spiritual world and embody a profound harmony between private and public realms.

The concept of "cellularity" permeated diverse architectural forms and typologies, offering compositions marked by infinite replication possibilities and modular configurations. These geometric patterns were applied in residential, religious and commercial buildings, both in interior and exterior designs, as well as ornamental

elements such as carvings, tiles and calligraphy moldings. The geometric proportions of courtyards and key living spaces closely approximated the mathematical constant pi (3.14) and adhered to the golden ratio across various room dimensions (Sultan, 1980). The courtyard emerged as the primary organizational space, around which essential functions and rooms were strategically arranged. These placements were carefully considered, taking into account their intended use and the desired exposure to sunlight and breeze, varying with different seasons and times of the day. The layout of most buildings showcased fractal compositions, where smaller rooms repeated the proportions of larger spaces. Design modularity may have contributed to seamless construction and functionality across different building types. The mosque layout featured cellular square geometries, centered around a dominant courtyard, leading to smaller square spaces (Iwans) accommodating various activities based on the time of day and prayer schedules. It expressed an interplay of proportional solids and voids, characterized by rhythmic design patterns in both horizontal and vertical mass development (Abdelkader, 2018; Eilouti, 2017).

The use of geometric patterns and self-replication of elements extended to other structural and decorative elements such as arches, domes and muqarnas configurations. The judicious repetition of these elements at different scales on building exteriors created visual harmony and enriched wayfinding through the labyrinth of the narrow, irregular streets of Islamic cities. Cellularity extended beyond individual buildings to the scale of neighborhoods and entire cities. The urban fabric featured a network of narrow streets, quasi cul-de-sacs and courtyards, mirroring the modular and cellular organization seen in architectural elements (Eltrapolsi, 2022; Hakim, 1994; Pascual, 1983; Sack, 1989; Chamberlain, 1994). Every neighborhood was designed as a microcosm of the city with a mix of social classes, affording its residents a central public space, a small mosque and a market in addition to other ancillary facilities. This urban typology fostered a strong sense of community and promoted some camaraderie and a desire to outperform other neighborhoods through excellence in the production of arts, crafts, buildings and community services.

7.   Conclusion

This study has raised critical considerations regarding the design principles of Islamic architecture that extend beyond mere aesthetics of design, ornamentation and even advanced forms of calligraphy. At the risk of taking a reductionist approach, the study focused on three core design values, identified as versatility, interiority and cellularity, which have not only shaped the traditional architectural landscape but continue to influence contemporary design paradigms within and beyond the Islamic world. The principle of versatility was manifested in the dynamic, multi-functional spaces meticulously designed to meet diverse needs, from family gatherings to moments of contemplation. A delicate balance has been created between the need for privacy and the desire to engage in rich social practices inside and outside the building's premises. The concept of interiority was exemplified by the serene and meditative atmospheres within Islamic architectural spaces, emphasizing the symbiotic relationship between natural light, air and human experience. The designers crafted a network of expansive open areas alongside more intimate, partially enclosed spaces. This meticulous design not only facilitated a continuous flow of desirable breezes throughout the living spaces but also orchestrated a seamless transition from brilliantly illuminated rooms to those

artfully dappled and shaded with intricate wooden screens. This deliberate arrangement resulted in striking, dynamic light patterns, adding a touch of drama and sophistication to the living experience. The interplay of light and shadow and the contemplative courtyards all contributed to an integrative blend of private and public realms, fostering a connection between private individual or family life and city social spaces. Cellularity as a core design value, found expression in the self-replication and modular configurations of geometric patterns, arches, domes and various architectural elements. This approach permeated not only structural and ornamental moldings on buildings' interiors and exteriors but also the fabric of neighborhoods and entire cities. In essence, Islamic architecture goes beyond the physical realm; it embodies a holistic philosophy where design serves as a conduit for social interaction, sociality, spirituality and communal harmony. The enduring design principles of versatility, interiority and cellularity continue to inspire contemporary architects, underscoring the rich Islamic cultural and architectural heritage. A comprehensive exploration and rigorous analysis of Islamic architectural principles are imperative. Many books and research publications have rigorously addressed crucial facets of Islamic architecture, urban planning and culture and certainly enriched the debates of this paper. There is still a need for more future research that goes beyond the commonplace fixation on surface-level ornamentation and delving into the deep-rooted essence of Islamic architecture, space conceptualization and critical urban planning issues. With more in-depth analytical considerations of the design principles of Islamic architecture, a rich architectural vocabulary can be developed and would be an important resource for enriching contemporary architecture and design theory.

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Glossary of Terms:

Mandara: An enclosed male reception space in traditional Islamic homes, typically located on the ground floor and opening off the courtyard. It is designed to face the northern desirable wind direction for optimal ventilation.

Takhtaboush: A semi-open, multi-purpose reception and family space, typically elevated one floor and opening off the main courtyard. It is designed to face the northern desirable wind direction, providing both comfort and ventilation.

Maqaad: A semi-open, multi-purpose reception and family space, typically elevated one floor and opening off the main courtyard. Like the takhtaboush, it is designed to face the northern desirable wind direction for ventilation.

Mashrabiya: Turned wooden screens placed over house windows with tight openings. These screens allow residents to observe the outside without being seen, providing both privacy and ventilation.

Malqaf: A wind catcher placed above the house roof, oriented towards the desirable northern wind. It channels outside air into the primary living spaces, enhancing ventilation.

Shukhshaykha: A dome lantern with openings that pierce through the roof of main reception and family spaces. It channels hot air generated inside the home to the outside, promoting effective ventilation.

Sharie: A main street or avenue that cuts through the city, serving as a primary thoroughfare.

Darb: A route or secondary street branching off from main streets, providing access to different areas.

Atfa, Zuqaq or Sikka: Synonyms for dead-end access lanes that branch off from the Darb, typically providing access to residences or specific areas within a neighborhood. Hara: A term that signifies a well-defined part of the city, such as a quarter or neighborhood.

Qa'a: A primary hall for family gatherings inside the house, which can also signify an important room in other establishments.

Iwan: A semi-open functional space that opens off courtyards in mosques or primary halls in homes. It is typically elevated one step from the courtyard or the central part of the space.

Durqa'a: The central area of primary halls in houses or other establishments, typically flanked on two or three sides by semi-open spaces (iwans) that are elevated one step from the central area.

Souq: A central space in an Islamic city that houses market stalls. It can be partially or fully enclosed, with many shops and stalls extending into the open street space.

Wekala or Khan: Both terms refer to a marketplace in a traditional Islamic city. They are typically used to denote specialized marketplaces devoted to specific merchandise, such as spices, essences or gold.

Muqarnas: A modified vault form used both structurally and decoratively in Islamic architecture. Structurally, it transitions from square room layouts to circular dome configurations. Decoratively, it consists of three-dimensional, honeycomb-like ornaments that adorn the undersides of domes, arches and vaults.