The Journal of Transport and Land Use jtlu.org
Vol. 16 No. 1 [2023] pp. 189–214

Making religious buildings more accessible: The case of mosques in Abu Dhabi's and Dubai's neighborhoods

Khaled Alawadi (corresponding author)
Khalifa University
khaled.alawadi@ku.ac.ae

Nour Alkhaja
Khalifa University
nour.alkhaja@ku.ac.ae

Mariam Ahmed Alazab Alhadhrami
Khalifa University
100045561@ku.ac.ae

Sara Omar Mustafa
Khalifa University
100058287@ku.ac.ae

Abstract: More than a house of worship, religious buildings have a critical and authoritative role in the social and political life of people. Yet, such places of divine and spirit have received limited attention in transportation and urban planning research. This research evaluates accessibility to one kind of religious institution: mosques. The article studies the ease of access to mosques at walkable distances of 400 m and 800 m radii in twelve selected neighborhoods in Abu Dhabi and Dubai. Analysis uses the gravity metric under two network scenarios: streets only, and the combined network of streets and alleys. Gravity values demonstrate three types of accessibility to mosques: plots without access, plots with minimum access to one mosque, and plots with choice access to more than one mosque. Findings show neighborhoods have experienced an erratic decrease in accessibility to mosques. In both cities, percentages of plots with an overall accessibility to mosques, (sum of both minimum and choice), were higher in the pre- and-early-suburban phases. With the inclusion of alleyways, the overall accessibility percentages increased in many cases. The study reveals that good pedestrian accessibility results from an effective interplay between street design, plot densities, network intersection density, strategic placement of alleys, and mosques' ratio and spatial distribution.

Keywords: Accessibility, urban form, neighborhood, urban network analysis, mosques

Article history:
Received: September 14, 2022
Received in revised form: April 7, 2023
Accepted: April 14, 2023
Available online: June 22, 2023

1 Introduction

Urban morphology is a broad field concerned with studying the elements of urban form (Moudon, 1997). Urban form refers to the patterns of street networks in terms of design, urban blocks in terms of size and configuration, plots in terms of density, and land uses in terms of diversity and distribution (Handy, 1996; Lynch, 1981). Jabareen (2006) identified active transportation, such as walking and cycling, as critical concepts in the assessment of sustainable built environments. The two common

http://dx.doi.org/10.5198/jtlu.2023.2277
ISSN: 1938-7849

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

types of trips originating from residential locations are work and non-work trips. Spinney et al. (2012) found that travel to-entertain is more common than travel to-work. Those common types of non-work trips were towards daily services such as grocery stores, banks, and other utilitarian destinations. Many urban studies associate destination-oriented walkability with both the attributes of physical form (Owen et al., 2004; Saelens et al., 2003; Shay et.al, 2003) and the availability of civic and commercial facilities (Brownson at el., 2009). Handy (1996) found that urban form impacts the choice to walk to a destination, with distance being the most critical factor. Similarly, Jenks (2005) points out that "if appropriate local facilities are located within walkable distances from home, the necessity of owning and using private cars is diminished" (p. 313). Other studies inspected how specific physical attributes contribute to increased walkability. For example, Moudon et al. (2006)found that walkable suburban neighborhoods have specific attributes such as: higher residential density, smaller blocks, and shorter distances to retail destinations. Randall and Baetz (2001) found that certain street patterns, in terms of topology and connectivity in suburbs, impacted walkability. These studies pertain to a principal concept in sustainable urbanism: accessibility, which is concerned with evaluating the ease of accessing nearby opportunities (Handy et al., 2002; Talen, 2003). Residents in highly accessible neighborhoods are more likely to use nonmotorized transportation to access destinations at reasonable distances (Jabareen, 2006). Therefore, physical design elements such as: street layouts, parcel division (density), and allocation of activities (land use), impacts accessibility levels. Studies examining the impact of mixed land uses on accessibility in suburbs rely on trips generation models that are concerned mainly either with utilitarian, leisure, or work trips (Cervero & Kockelman, 1997; Frank & Pivo, 1994). Non-work trips in urban literature often entail generic retail uses such as supermarkets, groceries, drugstores, dry cleaners, and shopping centers. Those are used for example in Handy's (1996) study which concluded that residents, with higher accessibility levels to local services and regional shopping centers, are more likely to walk. Other studies focused on specific types of land use such as schools (Rodriguez et al., 2006), and public facilities like museums and libraries (Witten et al., 2011).

Fewer studies addressed accessibility to religious facilities, including mosques, churches, synagogues, and temples. Religious buildings are distinctive types of public facilities within residential neighborhoods and urban centers. Aside from being places for worship, they fulfill other civic and social functions (Al-Hemaidi, 2001; Williams, 2007). Religious facilities found in historical parts of cities usually occupy prominent locations (Ayhan & Cubukcu, 2010). A study conducted in historical quarters of Iranian cities indicated that high housing density, mixed-use development, and interconnected streets and public spaces were essential elements in boosting walkability to mosques (Jamei et al., 2021). Rahman and Nahiduzzaman's (2019) studied walkability in Dhahran, Saudi Arabia, and found that mosques are regarded as a key daily destination. Although they are positioned at an average walkable distance of 242 m from residential plots, residents were reluctant to walk due to obstructed sidewalks or the harsh climate. Al-Shareef and Al-Joufie (2020) studied factors impacting walkability in Jeddah, Saudi Arabia, neighborhoods and confirmed that mosques are the most significant attractor for daily walking trips. This is because residents prayed five times a day and constantly attended the mosques on daily basis. Islamic principles require Muslims, in general, to have frequent daily visits to mosques to perform prayers. Worshipers are expected to walk to mosques, and this act has religious and social significance (Mazumdar & Mazumdar, 2004). Therefore, the selection of a mosque's site that is conveniently accessible to the public was emphasized in both historical and modern planning practices (Abdullah et al., 2013; Kahera et al., 2009). Such aspects are consistent with the criteria used to describe factors impacting accessibility in the literature, where good accessibility "is determined by the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude,

quality, and character of the activities found there" (Handy & Niemeier, 1997, p. 1175). When key destinations, like mosques, are expected to generate daily frequent visits, their presence at a reasonable distance and intensity to ensure proximity to residents becomes critical. Increased intensity, or magnitude, is also associated with "choice" (Handy & Niemeier, 1997) since "the more destinations, and the greater the variety, the higher the level of accessibility" (p.1175). In this study, accessibility is assessed not only from proximity perspective but also from choice standpoint, which refers to evaluating the degree of choice availability at a walkable distance. Given the similarity of contexts between Jeddah, Abu Dhabi, Dubai, and other Islamic cities, it can be argued that mosques have equal significance in residential neighborhoods, where the decision of which mosque to walk to is subject to proximity and choice availability.

Although the planning systems of Abu Dhabi and Dubai are similar, the two cities' neighborhoods have distinct physical patterns and have had dramatic shifts in their urban form during their growth, which impacted pedestrian accessibility. This study employs an integrated approach that uses morphological mapping and mathematical network analysis to analyze the physical design elements shaping walkability to mosques in each city. Additionally, different levels of accessibility are identified to provide an in-depth understanding of how accessibility to mosques are impacted, not only by the physical attributes of the built environment but also by the availability and the spatial distribution of such destinations. The centrality measure of Gravity is used to assess pedestrian accessibility to mosques using local scale radii of 400 m and 800 m in two scenarios; one considers the street network only, and the other considers the combined network of streets and alleys. This research attempts to answer four questions: How pedestrian accessibility to mosques changed throughout the urban evolution of Abu Dhabi and Dubai? How morphological attributes and land-use distribution have impacted pedestrian accessibility to mosques? What is the contribution of alleys in enhancing pedestrian accessibility to mosques? Do existing neighborhood designs in Abu Dhabi and Dubai support accessibility choices to more than one local mosque for pedestrians? Findings aid in identifying which physical planning attributes can maximize local accessibility to religious destinations, thus assessing planning practice and policy in enhancing and the planning of future neighborhood design.

2 Literature review

2.1 Religious buildings in cities

Religious buildings are crucial components of the urban landscape, and they evolve in tandem with the population (Baker & Holt, 2004; Myint, 2008). They are typically found in residential areas (Hancock & Srinivas, 2008) and employment zones (Agrawal, 2009). Regardless of economic development, land ownership, and rigid legal constraints on land-use changes, places of worship are enduring and perpetual, distinct from other built landscapes (Abdullah et al., 2013). Historically, the density and location of religious buildings was a physical manifestation of authority (Bennison, 2007), signifying the collective beliefs of communities (Kowalewski & Królikowska, 2016). In traditional Islamic cities mosques had a significant location in the urban landscape (Williams, 2007), where the Great Mosque was first to be laid at the center, while smaller local mosques served clusters of residential quarters (Bianca, 2000, p. 37). Bianca (2000) described traditional Arab muslim cities as "usually focused on a multifunctional core structure enveloping or at least partially surrounding the central mosque by different layers of interconnected suqs" (p. 142). The distribution of local mosques is intended to be scattered and fully decentralized for greater accessibility (AlHemaidi, 2001; Baker & Holt, 2004). For example, in traditional Saudi Arabian cities, local mosques were uniformly spaced across the neighborhoods by an average spacing of roughly 100 meters, serving various residential clusters (Al-Hemaidi, 2001). Mosques are therefore, morphologically and functionally, integrated within the urban fabric of traditional Islamic cities whose layout follows a cellular organic topology, and whose hierarchy is defined by an intricate access system mediating between public functions and more private residential quarters (Bianca, 2000). The mosque's role is further augmented into public life by assuming multiple functions, beyond its religious designation, that may include: hosting social, legal, educational, charity, and political activities (BenAicha, 1986; Al-Krenawi, 2016).

In modern Islamic cities, globalization and increased population led to suburbanization and urban sprawl. Accordingly, many cities faced issues of deteriorated pedestrian accessibility and segregation of urban zones. The reliance on motorized transport infrastructure reduced outdoor walking and cycling activities to daily destinations such as mosques (Harb, 2015; Radwan, 2021). Although mosques are still an integral component of Muslims' lives in modern cities, current planning ideals, have drastically changed how they are distributed and accessed. Mosques are no longer the center of Islamic city planning. They lost their dominance in being central and having a location advantage over other land uses. This can be attributed to the gradually diminishing role of modern mosque in serving different functions. Mosques are now planned in isolation from the city's urban fabric, thus restricting their function to worship only.

Also, the rise of institutions that cater for specialized social functions, such as education and disputes settlements, with designated buildings like courts and schools have contributed to the reduction in mosque's role and presence (Radwan, 2021). Moreover, decreased urban density, fragmented street layouts, and large public right of ways limited the walking experience and accessibility to mosques in modern Islamic cities (Sharifi & Murayama, 2013).

2.2 Growth phases of Abu Dhabi & Dubai

Urban forms of Abu Dhabi and Dubai have gone through successive periods of transformation, reflecting changes in each city's planning ideologies. Various street patterns, densities, and land-use systems caused the emergence of diverse neighborhood forms. The current body of research splits Abu Dhabi and Dubai's urban development into three distinct phases: the Pre-suburban Phase (up to 1970), the Early-suburban Phase (1970–1985), and the New-suburban Phase (1985–Present). Both Abu Dhabi and Dubai were built for compactness during the Pre-suburban phase, influenced by the harsh climate and the necessity for easy access to everyday facilities. Pre-suburban periods had higher plot density, more connected streets, and a mixed-use and decentralized land-use system. Then, the two cities' economic wealth drove them toward dispersion throughout the Early-suburban phase (1970-1985) and the New-suburban phase (1985-Present). This resulted in centralized land-use systems, fragmented streets, and lower plot densities. Rejection of the Pre-suburban planning ideals resulted in the spread of automotive culture and the decline of pedestrian accessibility to daily destinations such as mosques. Both of Abu Dhabi and Dubai are considered Islamic cities where Muslim residents visit mosques few times per day, on Fridays, and throughout the holy month of Ramadan. Therefore, mosques of varied sizes and architectural magnificence are seen in Abu Dhabi and Dubai (Qamhaieh & Chakravarty, 2020). Planning regulations in both cities specify guidelines for the location and distribution of mosques (Abu Dhabi Urban Planning Council, 2020; Dubai Development Authority, 2019); however, the implications of such policies on walkability to mosques in the UAE or other Islamic cities received little attention. Therefore, a study assessing pedestrian accessibility to mosques is significant for promoting more walkable environments in Islamic cities.

2.3 Morphological attributes and accessibility

In its simplest form, accessibility has been defined as the ease of accessing a destination (Handy & Niemeir, 1997). However, Handy and Clifton (2001) identified the basic features of this concept as being: "determined by attributes of both the activity patterns and the transportation system in the area. The spatial distribution of activities as determined by land development patterns and their qualities and attributes are important components of accessibility, as are the qualities and attributes of the transportation system that links these activities" (p. 68). Accessibility also entails examining the interconnection between the nature of the destination in terms of the anticipated number of generated trips (Handy & Niemeir, 1997; Mitchell & Rapkin, 1954), and the network's design and topology (Marshall et al., 2018). Travel mode decisions (Silva et al., 2017) and the choice of routes (Hillier & Iida, 2005) are impacted by physical attributes such as density (Carl, 2000), land-use diversity, and distribution of services (Cervero & Kockelman, 1997; Ewing, 1995). Literature on measuring accessibility points to different destinations, quantifies the association between morphological attributes and facilitated trips to destinations. Therefore, most accessibility measures address two aspects: one that is relevant to the urban network used for travel in terms of travel ease, and the other is related to the activity itself in terms of distribution and the characterization of the destination (Handy & Niemeier, 1997, p. 1176).

Graph theory has been utilized to represent the urban form by reducing it into a set of nodes and segments. Its implementation is concerned with measuring accessibility in terms of spatial separation between nodes either topologically or by using the metric distance. Therefore, two distinct types of graphs can be identified, the first is the dual in which the street segments are abstracted into nodes whereas links are formed connecting the streets' intersections; this methodology is known as the "Space Syntax" (Hillier et al., 1976). It provides an insight into the impact of the network's morphology on movement by measuring the degree of integration between street segments (Penn, 2003). However, because it relies on topological separation it fails to capture how trips are impeded by distance. Conversely, the primal graph, used in the Multiple Centrality Assessment (MCA), which was developed by Sergio Porta and his colleagues, introduces the street network as links and their intersections as nodes, thus accounts for the actual network distance. Additionally, the abstraction of buildings/plots into nodes returns information relevant to their location within the city. Metrics used in this methodology link estimations of travel with the urban form and distance factors (Porta et al., 2006). MCA reveals hidden mathematical characteristics of urban networks such as clustering and nodes' hierarchies. The resiliency of this theory also enables network assessment at different scales. For example, evaluating accessibility on a local scale includes searching for nearby facilities that can be accessed within a 5,10-, or 15 min walking distance. While global scale would entail evaluating accessibility at longer distances usually via automobiles. The implementation of the MCA analysis warrants the possibility to characterize the geometry of the urban form (Sevtsuk, 2010) and the activity at specific locations (Crucitti et al., 2006). It introduces a powerful set of measures that can return a comprehensive quantification of accessibility at different scales. In this study, MCA's Gravity index (Sevtsuk & Mekonnen, 2012) is used to evaluate mosques' accessibility, within the cities of Abu Dhabi and Dubai. This index is "based on the intuition that centrality is inversely proportional to the shortest path distance" (Sevtsuk & Mekonnen, 2012, p. 295). It returns the count of nearby opportunities, reachable at a shortest distance within a search radius, while considering the distance decay effect. Therefore, insights gained from the index can be used to describe the spatial distribution of mosques in terms of quantity and proximity to residential plots. Moreover, design and policy conclusions can be inferred when the morphological attributes are cross referenced with the Gravity results.

2.4 Using gravity measure to estimate accessibility

Numerous studies have utilized Gravity-based models to evaluate active accessibility to different destinations such as retail locations (Arranz-Lopez et al., 2019), open public spaces (Giles-Corti et al., 2005), and urban parks (Chang et al., 2019). Gravity index has proved to be one of the most popular indices used in accessibility studies that can capture the impact of decayed accessibility chances as distance increases (Kwan, 1998; Sevtsuk, 2014; Talen & Anselin, 1998). Gravity as an index showed high sensitivity to physical attributes; for example, Sevtsuk et al. (2016) measured pedestrian accessibility in gridded layouts and concluded that plot dimension, street width and block length, impact walkability and accessibility in such settings. Rajamani et al. (2003) also utilized urban form measures along with the Gravity index to study non-work travel in Portland, OR, area; the study concluded that locations of higher land-use diversity and residential density encouraged walking and shared mobility, while other attributes such as street networks with cul-de-sacs discouraged walking. The concept of estimating accessibility using Gravity was first introduced by Hansen (1959) and has been utilized by many studies to return the count of activities discounted either by travel time or distance. Levinson's study (1998) for example explained that Hansen's concept of Gravity introduces accessibility as "a continuous variable which is measured by counting the number of activities (e.g., jobs) available at a given distance from an origin (e.g., the home), and discounting that number by the intervening travel time (Hansen, 1959)" (p.12). Although cumulative measures are typically used to return the count of accessible opportunities, Gravity measures can serve similar purpose while also accounting for the decayed accessibility bounded either by travel time or distance. Páez et al. (2010) explained that in a general form, Gravity and cumulative opportunity measures return "the direct count of opportunities" (Páez et al., 2010). They also indicated that "measures in the gravity and cumulative opportunities families are more similar to each other than to other types of indicator" (Páez et al., 2010, p. 1418). Therefore, in this study the Gravity metric calculates the count of accessible mosques by summing weights returned from entrances, considering the distance decay effect.

3 Methodology

3.1 Selection of neighborhoods and morphological analysis

This article analyzes twelve different neighborhoods representing different growth periods in Abu Dhabi and Dubai: Pre, Early and New-suburban phases (see Figure 1). As it has been highlighted, the successive growth phases, in Abu Dhabi and Dubai, featured different physical attributes and were gradually becoming sparser and more fragmented; therefore, and in order to evaluate how mosques' accessibility has been impacted as the cities grew, neighborhoods from each phase were selected. The selected ones are representative of the dominant urban pattern of each of three morphological periods. Certain forms and patterns have been used constantly for generations until other dominant forms took their place. For the

Pre-suburban phase, West Island and Dubai Creek are the only two neighborhoods belonging to that phase. For the Early-suburban phase, Baniyas is the selected neighborhood in Abu Dhabi to represent that phase, while in Dubai three neighborhoods are selected: Al Satwa, Al Rashidyia, and Al Qouz. For the New-suburban period, four neighborhoods are selected from Abu Dhabi: Khalifa City, Al. Bahya, Mohammed Bin Zayed City (MBZ), and Al Falah; while in Dubai, two neighborhoods are selected: Jumeirah and Al Warqa. The selection of neighborhoods shows areas that are representative of the dominant forms belonging to that phase. A mapping exercise identifies key morphological attributes of the selected neighborhoods including: street layouts, land uses (mosque to residential ratio), plot densities, street densities, alley densities, and network intersection densities (see Table 1). The majority of the twelve neighborhoods are single-family housing neighborhoods with diverse densities and street typologies. To map changes in neighborhood patterns over time, the study uses aerial photos and geospatial data obtained from the Abu Dhabi Department of Municipalities and Transportation (DMT) and Dubai Municipality (DM). Numerous studies traced urban transformation by quantifying changes in cities' physical and spatial elements which include density, street layout, land use, land parcel size, block typology, and building forms (Southworth & Owens, 1993; Wheeler, 2015). It is argued that planners must study the trend of urban evolution before providing new policies and design interventions (Moudon, 1997).

3.2 Network analysis: Gravity

This study utilizes Urban Network Analysis (UNA) toolbox within Rhinoceros 3D software to analyze the accessibility levels in the selected neighborhoods. The analysis has two scenarios– 1) considering the streets network only, and 2) considering the combined network of streets and alleys. Subsequently, the contribution of alleyways in enhancing accessibility is determined. This study uses one centrality measure, namely Gravity, to evaluate accessibility to mosques at walkable distances. Gravity index is calculated using the following formula:

$$Gravity\ [i]^r = \sum_{j\ \in G-\{i\}, d[i,j]\leq r} \frac{W\ [j]^a}{e^{\beta . d[i,j]}} \tag{1}$$

Where $Gravity\ [i]^r$ is the Gravity index that return a count of accessible opportunities, that are associated with each origin i, within a specified search radius r. $d[i,j]$ is the geodesic distance between locations i and j, and β is the exponent for adjusting for the distance decay effect (Sevtsuk, 2018). The negative impact of the distance is known as the distance decay effect and the shape of this association, between decreased accessibility and distance, is controlled by the Beta factor (B). Such value is a context-sensitive factor that exponentially increases the distance decay effect in warmer climates. Considering the hot arid climate of the cities, that are the subject of this study, the Beta value was set to (0.004). This is based on guidelines recommended by the UNA toolbox manual, such value was used to evaluate walkability in Singapore, a city with a climate similar to the studied region. Although the Gravity tool enables the option of weighing destinations proportionally to their attractiveness, this was avoided for two reasons: the first is the lack of empirical data linking mosque choice with the user preference (e.g. mosque size), the other is the study's objective in solely evaluating the impact of the built-environment morphological attributes on accessibility. Therefore, equal default weights for all the mosques' entrances are maintained. Nodes representing non mosques plots' centroids are used as origins and all existing mosques' entrances are added and used as destinations. This produces more accurate and realistic simulation of accessibility to mosques, within the Gravity tool, since trips will be routed to the extra entrances using all available routes. Network analysis is performed along two network scenarios: using the streets only and the combined segments of streets and alleyways. This would highlight the role of alleyways in improving accessibility to such destinations. Considering accessibility to mosques within walkable distances, two search radii of 400 m and 800 m, are used as inputs when running the analysis for each network scenario.

Those two radii correspond to 5- and 10 minutes walking distance respectively and are frequently used in accessibility studies (Wittowsky et al., 2020; Xiao et al., 2016). Municipality guidelines in Abu Dhabi (Department of Municipalities and Transport, 2021) specify a maximum catchment area of a mosque to be within a radius of 350 meters, and in Dubai (Dubai Development Authority, 2019) the radius of the catchment area shouldn't exceed 500 meters. When a residential plot is being evaluated, all the mosques' entrances falling within the specified search radius would be allocated as equally weighted destinations. Their initial assigned weights are all equal to (1) and those weights get discounted as the distance to the target plot increases. Thus, Gravity values diminish significantly as the distance grows to reflect the difficulty of accessing mosques. The returned Gravity value, for the residential plot being evaluated, would be the sum of all the accessed entrances. However, one limitation of the implemented tool is that it doesn't allow for a sharp distinction between the returned Gravity values in terms of their source (e.g., returned from which destination). The summed Gravity values, therefore, could be returned from multiple entrances belonging to more than one mosque. However, considering that mosques in both of Abu-Dhabi and Dubai share similar features (Abu Dhabi Urban Council, 2020; Dubai Development Authority, 2019) in terms of plot size and count of entrances, which ranges between 2 and 4, it's possible to discern whether the summed Gravity value results from one or more mosques. To determine the degree of accessibility, cutoff points are used to distinguish the count of accessible mosques. This is based on calculating the summed Gravity values that would be returned from a hypothetical mosque, with 3 entrances, located at different distances. The summed Gravity value returned from all entrances of such mosque when located at an increasing distance of (150 m, 200 m, 250 m, 300 m, 350 m, 400 m, and 450 m) are respectively (1.501, 1.270, 1.040, 0.851, 0.697, 0.571 and 0.467).

Plots with summed Gravity values less than (0.5) are regarded as without an accessibility to a local mosque. Plots with summed Gravity value that range between (0.5 and 1.5) are classified as locations with Minimum accessibility to a local mosque. Within the 400- m search radius, minimum accessibility results from having accessibility to one mosque at a distance between 200 to 400 m. For the 800 m search radius, the tool might locate more than one mosque, one at a distance lower than the 400 m threshold and another distant one. In that case, if all of the entrances of the two mosques are accessible, then their summed Gravity value would exceed 1.5 reflecting choice accessibility. Otherwise, if all of the entrances of one mosque are accessible within the 800 m search radius threshold and the entrance of the other mosque aren't, then their returned summed Gravity value would be below 1.5, suggesting minimum accessibility to one mosque only.

Choice accessibility reflects summed Gravity values of 1.5 or higher, where more than one mosque is accessible. This concept works for the two search radii; for example, when the 400 m search radius is applied, if more than one mosque is found, then their summed Gravity values would exceed 1.5. When the 800 m search radius is applied, the tool is likely to find mosques with entrances at distances (lower than 400 m), those would yield a Gravity value between (0.5 and 1.5), and mosques with entrances at distances (greater than 400 m), those would yield a Gravity value below (0.5). The returned Gravity value would be the sum of values returned from mosques captured within the 800 m search radius. Choice accessibility for the two search radii, therefore, can be defined as having a choice to access two or more local mosques. However, it should be noted that Gravity values of 1.5 or higher for few plots is caused by an accessibility to a single mosque with close proximity (at distances lower than 200 m). The percentages of those plots were identified by locating them within the 200 m catchment area of each mosque. Results are then used to illustrate the changing accessibility levels at the two successive radii for each network scenario. Figures 2 and 3 show accessibility results where plots with the three levels are denoted in the following colors: blue color is used for the plots without an accessibility, yellow for the plots with minimum accessibility, and red for the plots with choice accessibility.

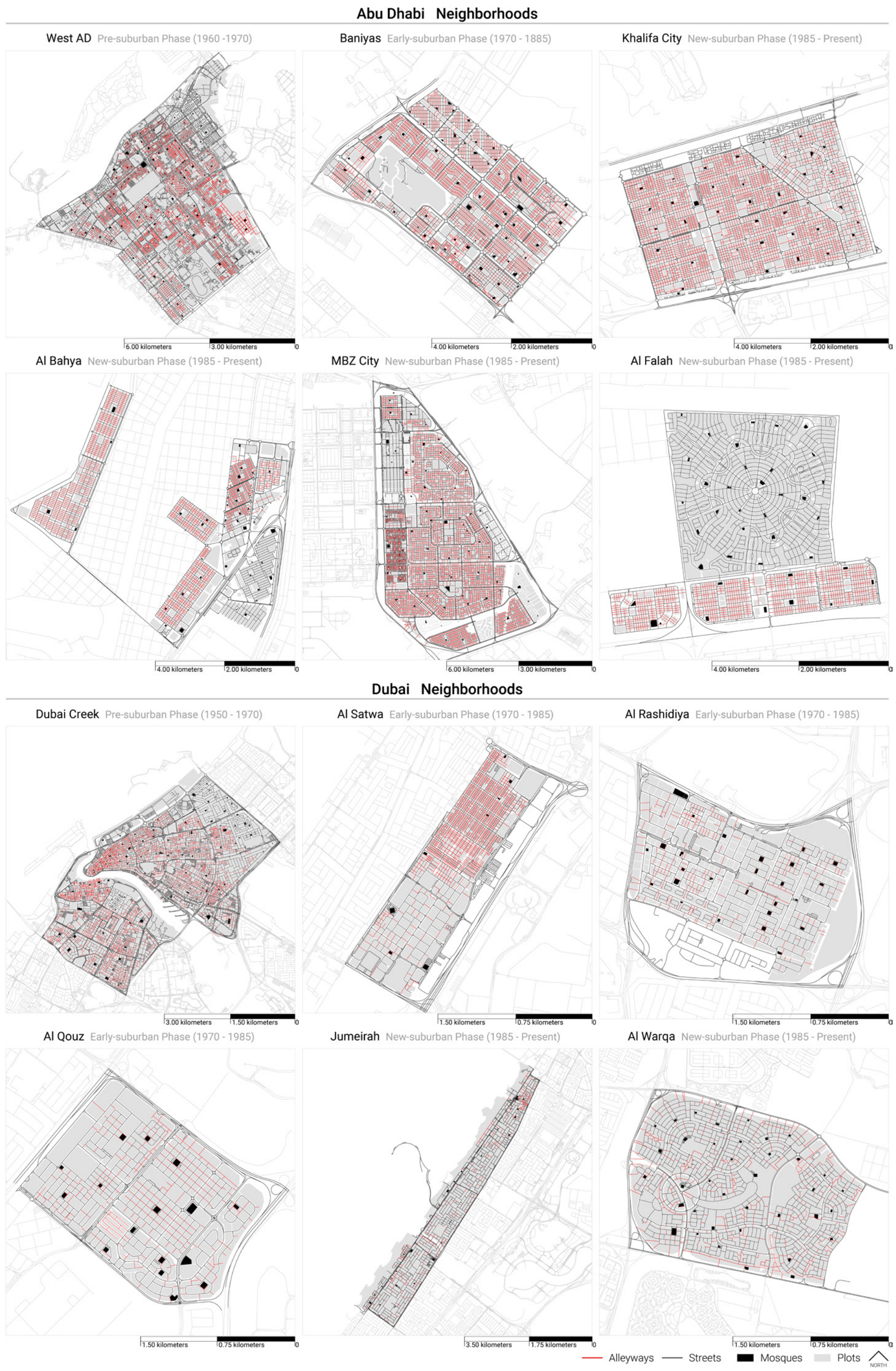

Figure 1. Collage showing mosques distribution in Abu Dhabi's and Dubai's neighborhoods

Table 1. Characteristics of selected Abu Dhabi and Dubai neighborhoods

City	Growth Phase	Neighborhood Name	Area (Hectares, Ha)	Street Layout	Plot Density (Plots/Ha)	Mosque to Residential Ratio (1|100 Plots)		Streets + Alleys Density (Km/Ha)	Streets Intersection Density (Intersection/Ha)	Streets + Alleys Intersection Density (Intersection/Ha)
Abu Dhabi City	Pre-suburban (1960 - 1970)	West Island	3,639	Combination of networks: grid, semi-grid, cul-de-sac, and fragmented parallel	2.65	2.50	0.25	0.40	3.28	4.90
	Early-suburban (1970 - 1985)	Baniyas	1,737	Combination of networks: semi-grid, and fragmented parallel	2.41	1.70	0.24	0.36	0.42	3.80
	New-suburban (1985-Present)	Khalifa City	2,534	Interlocked fragmented parallel	2.04	0.90	0.14	0.29	0.68	2.73
		Al Bahya	1,432	Interconnected gridiron	1.32	1.90	0.12	0.21	1.32	2.13
		Mohammed Bin Zayed City, MBZ	5,559	Combination of networks: fragmented parallel, and loops	1.81	1.40	0.14	0.23	0.69	2.06
		Al Falah	2,151	Combination of networks: interconnected radial grid, and fragmented parallel	3.31	0.80	0.13	0.17	0.58	1.03
Dubai City	Pre-suburban (1950 – 1970)	Dubai Creek	2,081	Compact organic	7.05	0.98	0.30	0.41	2.99	7.81
	Early-suburban (1970 - 1985)	Al Satwa	261	Interconnected gridiron	10.05	0.31	0.19	0.42	1.31	8.79
		Al Rashidiya	575	Combination of networks: fragmented parallel, and loops	4.16	1.10	0.20	0.23	1.77	1.97
		Al Qouz	349	Combination of networks: fragmented, grid (center), and wrapped parallel (at edge).	5.64	0.82	0.26	0.32	1.42	3.02
	New-suburban (1985-Present)	Jumeirah	801	Combination of networks: fragmented parallel, and loops	3.76	0.77	0.20	0.23	2.00	2.74
		Al Warqa	1,691	Combination of networks: wrapped loops, and fragmented loops.	4.08	0.54	0.13	0.14	0.62	1.17

4 Results

4.1 Abu Dhabi

Gravity results in Abu Dhabi are summarized in Figure 2 and Table 2. The general trend indicates that the West Island, a Pre-suburban neighborhood, and Baniyas, an Early-suburban neighborhood, have the highest percentages of plots with an overall accessibility to mosques. Whereas Mohammed Bin Zayed City and Al Falah, New-suburban neighborhoods, have the lowest. Those trends are consistent for the two network scenarios: streets only and streets with alleyways, and within the two distance thresholds 400 m and 800 m radii. Percentages indicating choice accessibility are significantly higher in the West Island and Baniyas in comparison with other neighborhoods. Although the inclusion of alleyways increases those percentages for all the neighborhoods, the improvement in Baniyas and Khalifa City choice percentages is most evident. However, in all the studied neighborhoods, a small portion of choice accessibility percentage points are resulting from plots within a close vicinity to mosques (at distances lower than 200 m), causing their summed Gravity values to exceed 1.5 (Appendix 1). When the streets' network is evaluated, those percentage points are between 0.9, in the West Island, and 5.7, in Baniyas. When alleyways are included, those percentage points drop to 0.6 in the West Island and 3.2 in Baniyas. Those percentage points, pertaining to plots with higher Gravity values and accessibility to a single mosque at distances of 200 m or less, drop upon the inclusion of alleyways because of their increased accessibility to more mosques, since alleyways provide additional routes to more destinations at shorter distances.

4.1.1 Gravity, Abu Dhabi: Streets

When streets are only considered, results show that accessibility to mosques decreases over time. This is evident from the considerable increase in the percentage of plots without accessibility to mosques. For example, within the 400 m radius, the percentage of plots without accessibility to mosques increased from 26% in the West Island, the first planned neighborhood, to 62% in Al Falah, one of the most recently built neighborhoods. Mosques in the West Island are distributed within the superblocks at a ratio of 2.50/100 plot, the highest in Abu Dhabi. The West Island Gravity results indicate the highest overall accessibility percentage at the two radii. At 400 m radius, the percentage of plots with overall accessibility is at 74%. The Superblocks' physical attributes in the West Island, of fairly high street intersection density at 3.28 (intersection/ha) and a relatively high plot density at 2.65 (plot/ha), contributed to higher accessibility to mosques than other Abu Dhabi neighborhoods. Baniyas, an Early-suburban neighborhood, has the second highest percentage of the overall accessibility to mosques at both radii. Within 400 m radius, the percentage of plots with overall accessibility is 58%. Despite having a relatively high plot density at 2.41 (plot/ha), the low street intersection density at 0.42 (intersection/ha), and the low distribution of mosques at a ratio of 1.70/100 plot, resulted in lower accessibility values in Baniyas. In the New-suburban phase, Gravity results drop even more. For example, Al Bahya's overall accessibility is at 55% within the 400 m radius. Even though Al Bahya has an interconnected grid street system with a higher street intersection density and mosque ratio than Baniyas, accessibility percentages were lower. This can be attributed to Al Bahya's low plot density at 1.32 (plot/ha), the lowest among the studied neighborhoods, to the increased spacing between street intersections due to the large superblock size at around 400 m × 500 m. The rest of the studied neighborhoods registered very low percentages. For example, at 400 m radius, Khalifa City and MBZ City have close values of overall accessibility at 41% and at 40% respectively. Nevertheless, choice, and minimum accessibility percentages are different; choice percentage is considerably higher in MBZ City than in Khalifa City (14% and 9% respectively), and the opposite is true for the minimum accessibility percentage. A similar trend is found at the 800 m radius. This is attributed to the slightly higher mosque ratio in MBZ City at 1.40/100 plot than in Khalifa City at 0.90/100 plot. In general, both neighborhoods have relatively low accessibility values due to their physical attributes: both have considerably large superblock sizes (960 m × 736 m in MBZ City, 800 m × 640 m in Khalifa City), low street intersection density at around 0.68 (intersection/ha), and relatively 20 low plot densities. Similarly, Al Falah is found to have low percentage of plots in terms of the overall accessibility to mosques. For example, within the 400 m, the overall accessibility percentage is at 38%. Although Al Falah has the highest plot density among the studied neighborhoods in Abu Dhabi (3.31 plot/ha), its accessibility to mosques is impacted by the low street intersection density (0.58 intersection/ha), and the low mosque ratio at 0.80/100 plot.

4.1.2 Gravity, Abu Dhabi: Streets and alleyways

When alleyways are included in the analysis, results indicate an overall improvement in accessibility to mosques, although this improvement varies between neighborhoods. The contribution of alleyways to accessibility is higher at the 400 m radius than the 800 m. Alleyways in Baniyas has the highest contribution to increased mosque's accessibility at the 400 m radius, where the overall accessibility increases by 18 percentage points, whereas at the 800 m, they contributed with the second highest increase by 14 percentage points. However, this improvement is in favor of increased choice accessibility at both radii. For example, at the 400 m radius, the percentage of choice accessibility significantly increases from 24% to 40%. This can be attributed to the enhanced route continuity since alleyways are significantly reducing the average block size from (240 m × 100 m) to (65 m × 39 m) and increasing the count of 4-way intersections. In Khalifa City, alleyways contribution is the second highest at the 400 m radius, and the highest at the 800 m radius where overall accessibility increases by 9 percentage points and by 17 percentage points at both radii respectively. It should be noted that improvement is in favor of increasing the minimum accessibility rather than choice accessibility at both radii. This can be attributed to the low mosque ratio at 0.90/100 plot and the spatial distribution of mosques, which limits the availability of mosques to one per superblock. Moreover, superblocks are separated by collectors, thus limiting accessibility to additional mosques. In MBZ City, alleyways contribution in increasing the overall accessibility is the third highest at both radii. The overall accessibility to mosques improves by five percentage points and by eight percentage points at the 400 m and 800 m radius, respectively. This improvement is observed to be towards the percentage of plots with minimum accessibility. For example, at the 800 m radius the minimum accessibility increases from 34% to 40%. This is attributed to the distribution of mosques to one per superblock, and to the relatively low mosque ratio at 1.40/100 plot. In the West Island, the improvement in the overall accessibility percentages is less than 10% at both radii. However, it can be observed that the choice accessibility percentage increases significantly. For example, within the 400 m radius, it increases from 39% to 47% while minimum accessibility remains the same. This is attributed to the increased intersection density at 4.90 (intersection/ha) and the improved network continuity since alleys are turning most intersections from T-junctions to four-way intersections and long blocks into shorter blocks. Consequently, more local mosques can be accessed at shorter distances resulting in greater choice accessibility percentages. Both Al Bahya and Al Falah have the lowest improvement percentages (lower than three percentage points at both radii). Although alleyways, in Al Bahya, are reducing the block size from (230 m × 215 m) to (90 m × 55 m) and increasing the intersections density from 1.32 to 2.13 (intersections/ha), accessibility is still impacted by the low plot density at 1.32 (plot/ha), and by the relatively low mosque ratio at 1.90/100 plot. Al Falah plots' accessibility to mosques are found to have been impacted the least by alleyways, since only a small area (903 ha out of 2151 ha) of the neighborhood is supplemented by alleyways.

Table 2. Gravity results of Abu Dhabi neighborhoods

City	Growth-Phase	Neighborhood Name	Gravity 400m – Streets				Gravity 400m – Streets + Alleys				
			% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	Overall accessibility improvement (percentage point)
Abu Dhabi City	Pre-suburban (1960 - 1970)	West Island	26	35	39	74	18	35	47	82	8
	Early-suburban (1970 - 1985)	Baniyas	43	35	23	58	24	36	40	76	18
	New-suburban (1985-Present)	Khalifa City	59	32	9	41	50	41	9	50	9
		Al Bahya	45	32	24	55	42	34	24	58	3
		Mohammed Bin Zayed City, MBZ	61	26	14	40	55	28	17	45	5
		Al Falah	62	29	9	38	61	30	9	39	1
	Growth Phase	Neighborhood Name	Gravity 800m – Streets				Gravity 800m – Streets + Alleys				
			% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	Overall accessibility improvement (percentage point)
Abu Dhabi City	Pre-suburban (1960 - 1970)	West Island	8	27	65	92	4	23	73	96	4
	Early-suburban (1970 - 1985)	Baniyas	18	43	40	82	4	37	58	96	14
	New-suburban (1985-Present)	Khalifa City	41	48	11	59	24	62	14	76	17
		Al Bahya	24	40	37	76	22	42	37	78	2
		Mohammed Bin Zayed City, MBZ	46	34	20	54	39	40	22	62	8
		Al Falah	36	50	15	65	35	51	15	66	1

Figure 2. Collage showing mosques accessibility distribution in Abu Dhabi's neighborhoods

4.2 Dubai

Gravity analysis in Dubai is summarized in (Figure 3 and Table 3). The general trend indicates that Al Rashidiya and Al Qouz, Early-suburban neighborhoods, have the highest percentages of plots with an overall accessibility to mosques, along with Creek, a Pre-suburban neighborhood. Whereas Jumeirah, a New-suburban neighborhood, has the lowest. Those trends are almost consistent for the two network scenarios: streets only and streets with alleyways and within the two distance thresholds of 400 m and 800 m. Choice accessibility percentages, when streets' network is evaluated, are the highest in the Pre-suburban neighborhood, Creek, and the lowest in the New-suburban neighborhoods, Jumeirah, and Al Warqa. When alleyways are considered, Al Rashidyia, an Early-suburban neighborhood, reports the highest percentage of choice accessibility followed by Creek, while Jumeirah, remain the lowest neighborhood with such percentage. Few percentage points of choice accessibility are attributed to plots with accessibility to multiple entrances of one mosque only at distances lower than 200 m (Appendix 1). Those percentage points range between 0.5, in Jumeirah, to 10.9, in Al Satwa. This is prior to the inclusion of alleyways, but once added, those percentage points drop to become between 0.4 in Jumeraih and 7.1 in Al Satwa. Those percentage points drop upon the inclusion of alleyways because they provide additional routes to more destinations at shorter distances.

4.3 Gravity, Dubai: Streets

When streets are only considered, Gravity results show that Al Rashidiya, an Early-suburban area, has the highest percentage of plots with an overall accessibility at both radii. For example, the overall accessibility percentage at the 400 m radius is 82% and 98% at the 800 m radius. Many factors are contributing to Al Rashidiya's high accessibility to mosques: it has the highest mosque ratio at 1.10/100 plot among studied sites in Dubai, a decentralized mosque distribution, and a relatively high plot density at 4.16 (plot/ha). This suggests that the looping fragmented network of Al Rashidyia, despite the relatively low intersection density, provides high mosque accessibility when adequate plot density, and count and distribution of mosques are present. At the 400 m radius, Creek, a Pre-suburban area, is reporting both the second highest percentage of the overall accessibility to mosques at 79% and the highest percentage of plots with choice accessibility at 68%. Accessibility in Creek is impacted by the dense organic topology of its network. At the 800 m radius, Al Qouz, an Early-suburban area, shows the second highest percentage of the overall accessibility to mosques, and the third highest within the 400 m radius at 69%. Al-Qouz's network morphology is composed of two different systems: fragmented grid at the center, and warped parallels at the edge. When Al Qouz is compared with Al Rashidiya's urban form, it appears that the two neighborhoods share common morphological similarities. For example, both have approximately similar blocks sizes (152 m × 78 m in Al Qouz, 142 m × 68 m in Al Rashidiya), and similar street densities (0.20 Km/Ha in Al Rashidiya, 0.26 Km/Ha in Al-Qouz). Although Al Rashidiya and Al Qouz have close percentages in terms of the overall accessibility at 800 m radius, 98% and 95% respectively, the breakdown of these percentages is different. In Al Qouz, the percentage of choice accessibility is lower (at 66%) than in Al Rashidiya (at 88%). This is attributed to a key morphological difference: the ratio of mosques in Al Qouz at 0.82/100 plot is lower than in Al Rashidiya at 1.10/100 plot. Al Satwa Gravity results are moderately lower than the rest of the Early-suburban neighborhoods. Its overall accessibility percentage at the 400 m radius is 52%. In theory, Al Satwa's fine-grain grid network should support good accessibility, but results indicate that it has lower overall accessibility to mosques. Accessibility values in Al Satwa are impacted by the low mosque ratio at 0.31/100 plot, despite having the highest plot density (9.77 plot/ha) among the studied neighborhoods. In the New-suburban phase, Gravity results drop. For example, Gravity values in Al Warqa, with its looping fragmented network, show an overall accessibility of 49%. Accessibility in Al Warqa is impacted by multiple factors: a large average block size at (259 m × 94 m), a low plot density at 4.08 (plot/ha), a low intersection density at 0.62 (intersection/ha), and low mosque ratio at 0.54/100 plot. These attributes are resulting in longer and less-direct routes to mosques. The lowest Gravity results, at both radii, within this network scenario is reported by Jumeirah. The percentage of plots in terms of the overall accessibility to mosques is at 26% within the 400 m. Jumeirah also reported the lowest percentages of choice accessibility at both radii. Accessibility, in Jumeirah, is impacted by the spatial distribution of mosques. Since this neighborhood extends linearly along the coast, mosques concentration at the edges leaves the central part without being served by local mosques. Moreover, Jumeriah has inconsistent plots sizes varying between (57 m × 30 m) to (238 m × 126 m), thus when coupled with the uneven distribution of mosques and the moderate mosque ratio at 0.77/100 plot, accessibility is impacted.

4.4 Gravity, Dubai: Streets and alleyways

When alleys are included in the analysis, an overall improvement in accessibility to mosques is reported, although this improvement varies between neighborhoods. The contribution of alleyways in most neighborhoods is higher at the 400 m radius than the 800 m. In Jumeirah, alleyways have the highest impact on increasing accessibility at both radii, where the overall accessibility has improved by 8 and 14 percentage points within the 400 and 800 m respectively. At 400 m radius, choice accessibility increases from 6% to 34%, while at 800- m radius, it increases from 7% to 48%. Although the impact of alleys in improving accessibility is the highest, the percentages of the overall accessibility to mosques, are less than 50%. This modest result is attributed to the restricted impact of alleys due to being localized around mosques. This explains why the improvement was in favor of increasing percentages of accessibility to one mosque. In Al Qouz, alleyways have contributed to improving the overall accessibility to mosques at the 400 m radius more than 800 m radius, by 12, and 4 percentage points, respectively. Yet, upon closer inspection, percentages of choice accessibility have increased significantly in comparison with the previous scenario (from 39% to 56% and from 66% to 81% at the 400 m and 800 m radius respectively). The improved accessibility in Al Qouz is attributed to the increased intersection density (from 1.42 to 3.02 intersection/ha), thus creating shorter routes by reducing the block sizes from (152 m × 78 m) to (77 m × 65 m). Gravity results in Al Satwa, when alleyways are considered, show moderate contribution to accessibility, 6 and 2 percentage points within the two consecutive radii respectively. The limited impact of alleys is likely attributed to the low mosque ratio at 0.31/100 plot. Alleyways in Al Rashidiya have improved accessibility at the 400 m radius only, where the overall accessibility increases by 9 percentage points, while at the 800 m radius the percentage of the overall accessibility to mosques remained the same. This indicates that the extra routes created by alleyways provided shorter route options, reduced the average block sizes from (142 m x 68 m) to (64 m x 44 m), and modestly increased the intersection density from 1.77 to 1.97 intersection/ha. Al Warqa's overall accessibility percentages at both radii show a marginal improvement (less than 4 percentage points). The minimum impact of alleyways in Al Warqa is attributed to the uneven distribution of alleys in the network; they are scattered without solving deficiencies in the street layout, such as enhancing route continuity or increasing 4-way intersections. For the Creek neighborhood, alleyways have had limited impact on improving accessibility at the 400 m radius, while at the 800 m the overall accessibility percentages remain the same. This is mainly attributed to the fact that the organic network itself already ensures relatively adequate accessibility; therefore, adding more routes would produce limited impact when also considering the modest mosque presence at a ratio of 0.98/100 plot.

Table 3. Gravity results of Dubai neighborhoods

City	Growth Phase	Neighborhood Name	Gravity 400m – Streets				Gravity 400m – Streets + Alleys				
			% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	Overall accessibility improvement (percentage point)
Dubai City	Pre-suburban (1950 – 1970)	Dubai Creek	21	11	68	79	20	10	70	80	1
	Early-suburban (1970 - 1985)	Al Satwa	48	13	39	52	42	12	46	58	6
		Al Rashidiya	18	16	66	82	9	18	73	91	9
		Al Qouz	31	30	39	69	19	25	56	81	12
	New-suburban (1985-Present)	Jumeirah	74	20	6	26	66	27	7	34	8
		Al Warqa	51	21	28	49	49	22	29	51	2
			Gravity 800m – Streets				Gravity 800m – Streets + Alleys				
	Growth Phase	Neighborhood Name	% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	% of plots without accessibility to any mosque	% of plots with minimum accessibility (one mosque)	% of plots with choice accessibility (to more than one mosque)	% of plots with overall accessibility (to one or more mosques)	Overall accessibility improvement (percentage point)
Dubai City	Pre-suburban (1950 – 1970)	Dubai Creek	7	12	81	93	7	10	83	93	0
	Early-suburban (1970 - 1985)	Al Satwa	11	23	66	89	9	23	68	91	2
		Al Rashidiya	2	10	88	98	2	4	94	98	0
		Al Qouz	5	29	66	95	1	18	81	99	4
	New-suburban (1985-Present)	Jumeirah	66	27	7	34	52	40	8	48	14
		Al Warqa	19	41	40	81	16	39	45	84	3

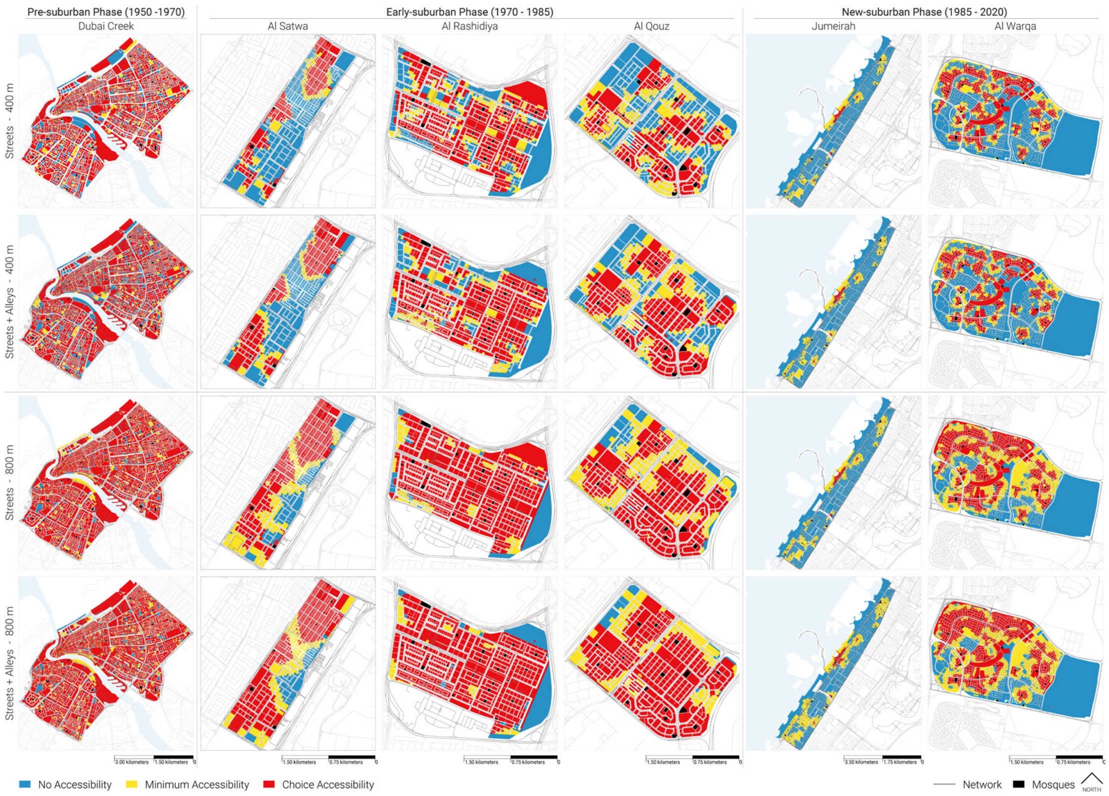

Figure 3. Collage showing mosques accessibility distribution in Dubai's neighborhoods

5 Discussion

This study analyzed accessibility to mosques in 12 neighborhoods from Abu Dhabi and Dubai. The selection of neighborhoods from different growth phases has served two goals: exploring how accessibility to local mosques has changed during each city's evolution, and how different morphological attributes have impacted accessibility to mosques. Since the study is focused on assessing accessibility at walkable distances, the inclusion of alleyways was critical. Therefore, analysis comprised measuring Gravity in two network scenarios: streets only and streets with alleyways. The analysis also evaluated the impact of destinations availability in terms of spatial distribution and intensity on accessibility. When trips from each residential plot towards mosques are evaluated, three different levels of accessibility are identified as per the cumulative count of accessed mosques: plots without accessibility, plots with minimum accessibility denoting availability of one local accessible mosque, and choice accessibility denoting accessibility of plots to more than one local mosque. Results revealed disparities in terms of accessibility between neighborhoods belonging to different growth phases in each city, where earlier neighborhoods featuring higher plot densities and grided networks yielded higher overall accessibility levels. Disparities in accessibility levels are also evident between the two cities, highlighting the intrinsic differences between the adopted urban forms in each city and their impact on accessing mosques. For example, Dubai neighborhoods reported a higher percentage of plots with choice accessibility than Abu Dhabi due to their higher network and plot densities. This is despite the gridded network layouts of Abu Dhabi's neighborhoods, higher mosques ratio and higher intersection and alleyways densities than Dubai, highlighting the importance of compactness in accessibility.

This gave further insights towards the collective impact of multiple physical attributes on accessibility rather than one deterministic attribute. Gravity results indicate that percentages of overall accessibility are consistently higher for the Pre and Early-Suburban phases at the two radii and within the two network scenarios. When alleyways are considered, accessibility increases at various rates for all neighborhoods. Results indicated that local accessibility to mosques has declined as the cities further evolved and expanded. For example, in Dubai Creek, a Pre-suburban neighborhood, and Al Rashidiya, an Early-suburban neighborhood, have higher overall and choice results than Al Warqa and Jumeirah, New-suburban neighborhoods. Similarly, in Abu Dhabi, the West Island, a Pre-suburban neighborhood, and Baniyas, an Early-suburban neighborhood, have higher Gravity results than New-suburban neighborhoods of Al Bahya and Al Falah. Earlier neighborhoods in Abu Dhabi have higher mosque ratio and network intersection density than later ones. The West Island for example reported significantly higher percentages of plots with overall accessibility to mosques than Al Bahya. This can be attributed to higher mosque ratio and intersection density in the West Island (2.50 mosque/100 plot, 4.90 intersection/ha) than in Al Bahya (1.90 mosque/100 plot, 2.13 intersection/ha). In Dubai, earlier neighborhoods have higher plot densities and network intersection densities than later ones. The plot and intersection density in Creek (7.05 plot/ha, 7.81 intersection/ha) is higher than in Jumeirah (3.76 plot/ha, 2.74 intersection/ha). Those observed attributes in earlier phases are contributing towards reducing distances to mosques. Moreover, in Dubai, five out of the six selected neighborhoods have percentages of plots with an overall accessibility higher than 80% at the 800 m radius in the two network scenarios. On the other hand, only two neighborhoods in Abu Dhabi have reported results higher than 80% at the same radius and within the two network scenarios. This suggests that Dubai neighborhoods have certain morphological attributes that support better accessibility to local mosques over Abu Dhabi. It can also be noted that percentages of choice accessibility are much higher in Dubai than in Abu Dhabi. It is found that Dubai on average has higher street and plot densities than Abu Dhabi, whereas Abu Dhabi on average has higher alleyways and network intersection densities, and higher mosque ratios. In terms of network topologies, Dubai neighborhoods have more curvilinear and fragmented networks, whereas Abu Dhabi neighborhoods have more orthogonal grids. These observations indicate that good accessibility does not rely on one physical design ideal, like density, but rather on a combination of morphological attributes (Figures 4 and 5).

Gravity results revealed that some of the favorable morphological attributes that contribute to better accessibility include high plot and intersection density, an interconnected street layout, and an adequate land-use system. Additionally, sufficient ratios of mosques that are evenly distributed within the neighborhoods result in better accessibility for a larger percentage of plots. An example of this is found in Al Satwa. Although Al Satwa has an interconnected grid-iron network and the highest plot and network intersection density (10.05 plot/ha, 8.79 intersection/ha), results show that it has lower overall and choice accessibility percentages than Al Rashidiya, which has fragmented and looping networks and with lower plot and intersection density (4.16 plot/ha, 1.97 intersection/ha). This is because Al Rashidiya has a higher mosque ratio (at 1.10 /100 plot) than Al Satwa (at 0.31 /100 plot). Yet, higher mosque ratios are not necessarily associated with better accessibility. Results show that not every grid system is perfect, meaning, other physical attributes supporting shorter travel distances must be present. For example, when Al Bahya with a gridiron network and a relatively high mosque ratio (1.90 /100 plot) is compared against Baniyas's segmented fragmented layout and lower mosque ratio (1.70 /100 plot), it is found that Baniyas has higher overall mosques' accessibility than Al Bahya. This is because Baniyas has higher plot and intersection density (2.41 plot/ha, 3.80 intersection/ha) than Al Bahya's super grid system (1.32 plot/ha, 2.13 intersection/ha). With intersections placed at larger intervals in Al Bahya, travel distances to nearby mosque increase.

Other critical aspects that impacted accessibility are: route continuity and the type of intersections present within the network. The organic grid in the Creek has significantly high plot and intersection density (7.05 plot/ha, 7.81 intersection/ha). However, it reported lower accessibility percentages than Al Qouz which has lower plot and intersection density and with a lower mosque ratio than the Creek. This is mainly attributed to the lack of clear continuous routes in the Creek due to its irregular network, which often meet at 3-way junctions. The analysis also evaluated the role of alleyways in improving local accessibility to mosques. When accessibility to mosques is evaluated using the streets and alleyways, it is found that the contribution of alleys depends on the street system attributes. When networks are providing good opportunity for accessibility at walkable distances, by having high frequency of intersections at shorter intervals, continuous routes, and appropriate blocks configuration, alleys would provide marginal value in improving accessibility. For example, the superblocks in the West Island have semi-grid networks with relatively high street intersection density. Although alleys increase the intersection density (from 3.28 to 4.90 intersection/ha), the improvement in the percentage of plots, with an overall accessibility to mosques, does not exceed 10%. Nevertheless, when networks have drawbacks like fragmented topology, dead ends, and large blocks, alleys are found to have more significant impact in improving accessibility. In Khalifa City for example, alleyways have reduced the block size from 124 x 500 m to 70 x 95 m, thus improving the percentage of plots with an overall accessibility to mosques by more than 20% at the two radii. However, this improvement is in favor of increasing minimum rather than choice accessibility because Khalifa City has one of the lowest mosque ratios in Abu Dhabi. In another example, alleys in Al Qouz improved the route continuity and increased the count of the 4-way junctions. This has resulted in improving accessibility to further destinations as evident from the increase in the percentage of plots with choice accessibility at the two radii. The implementation of alleys, in terms of their layout, also pose a challenge to planners. Results show that when alleys have an uneven concentration, or when they fail to resolve the street network deficiencies, they result in marginal accessibility improvement. In Al Warqa, alleys improved the overall accessibility by only 5%. Alleys failed to compliment the street system topology due to its fragmented layout and low density (at 0.01 km of alleys/ha). The looping fragmented street system of Al Warqa could have benefited from a more strategic placement of alleys that reduce block sizes, resolve 3-way junctions, and enhance route continuity.

In terms of the adopted planning guidelines in the studied cities, results show that mandating a catchment area with a specified radius around mosques should take into consideration certain physical planning attributes such as the plot density, street patterns, the availability of alleyways, and designated pedestrian routes. Curvilinear street networks with lower plots and alleyways densities would require an allocation of mosques that would reduce the actual traveled distance rather than relying on specified radius. Improving local accessibility to mosques shouldn't depend on one physical design strategy but rather on an integration of several attributes. First, design policies should allocate sufficient count of mosques with a reasonable spatial distribution from origins or plots. Distribution should take into considerations walkability limitations in terms of street hierarchy, alleyways availability, and average block sizes. Second, higher plot densities proved to impact accessibility positively despite the presence of non-orthogonal grids. This is because higher dentists, when coupled with appropriate level of diverse land uses, can produce more compact forms where distances between locations are minimized. Third, street network layouts leading to mosque locations should have: efficient interconnected layout, sufficient density of 4-way intersections, and continuous routes to ensure travel at shorter distances. This can be achieved by adopting fine-grain interconnected patterns than large superblocks with low intersections. Fourth, alleyways should assist in solving street network limitations. If alleys are implemented strategically in terms of layout and concentration within the network, they assist in: reducing block sizes, providing alternative routes, increasing intersections density, and enhancing route continuity.

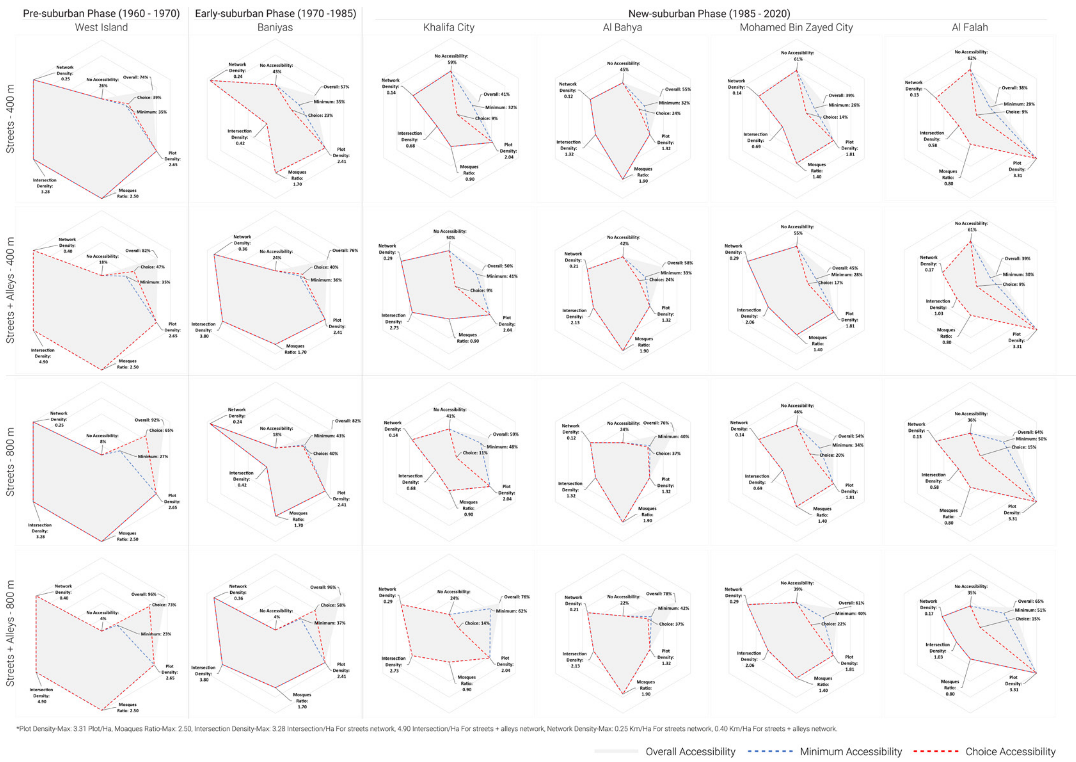

Figure 4. Collage of radial chart showing the connection between physical attributes and mosques accessibility of Abu Dhabi's neighborhoods within two radial (400, 800) using two network scenarios

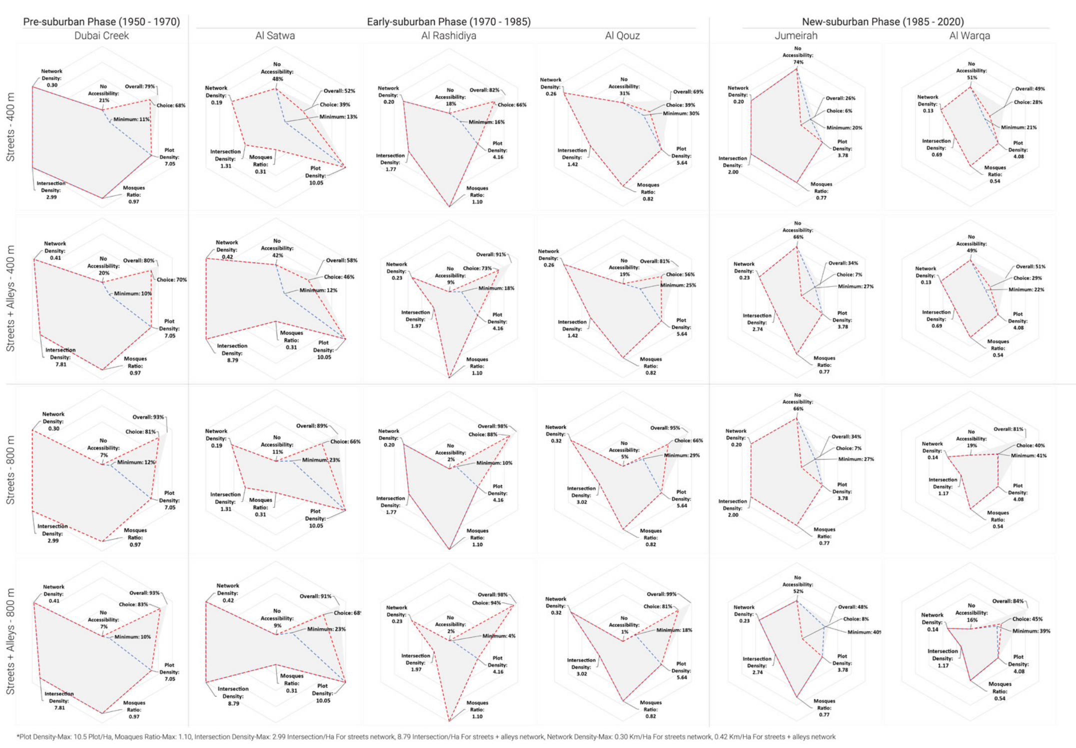

Figure 5. Collage of radial chart showing the connection between physical attributes and mosques accessibility of Dubai's neighborhoods within two radial (400, 800) using two network scenarios

6 Conclusion

In both cities, neighborhoods belonging to earlier phases reported lower percentages of plots without accessibility to mosques than later ones. This indicates that accessibility to local mosques has declined with time due to the change of prevalent morphological features in every growth phases. For example, earlier neighborhoods in Abu Dhabi have higher mosque ratios and intersection densities than newer neighborhoods built during the suburbanization process. Therefore, plots, within those neighborhoods, not only have the advantage of accessing local mosques at shorter distances but also the choice to access other mosques within the search radii. Disparities in attributes are not only found between neighborhoods belonging to different phases within each city, but also between the two cities. Dubai has higher plot and street densities with looping and fragmented network topologies, while Abu Dhabi has higher intersection and alleys' densities with more orthogonal streets. When Abu Dhabi and Dubai results are compared, it is found that Dubai's neighborhoods tend to have significantly higher accessibility percentages. Analyses demonstrate that good accessibility is conditional to having an integration between a multitude of physical design elements (e.g., plot density, intersections type and density, mosques ratios and distribution, network topology, and strategic placement of alleys). Findings show that when higher plot and intersection densities are present, accessibility would still be impacted by the ratio and distribution of mosques, the topology of the network, and the type and frequency of intersections. Results also show that when alleyways are strategically implemented, they can significantly enhance accessibility. In some cases, alleys rectified the streets network shortcomings by connecting dead ends, enhancing route continuity, converting T-junctions into 4-way, and by reducing block sizes. However, alleys are found to have minimal impact when they have inconsistent layout and concentration, thus failing in resolving the street network deficiencies. This research only captures the impact of physical design attributes on accessibility; it lacks consideration of other aspects such as travel behavior and movement. Pedestrians' movement do not necessarily follow the orders of certain urban forms, but rather it is grounded on other several factors, such as the location advantage of attractions, the conditions and quality of the walking infrastructure, cultural traditions, climatic conditions, and other behavioral factors (Hillier et al., 1993). For that reason, a follow up qualitative study would be necessary to determine the real situation on the ground and how these streets shape residents' actual daily trips to mosques. Future research could also provide a comprehensive analysis of routes utilized for daily travel towards mosques; one possible way would be studying and differentiating routes by traffic flow and frequency, routes for pedestrians only, and roads with a mixed flow of pedestrians and motorized vehicles. Primary and prioritized travel routes could therefore be identified/quantified, and thus evaluated qualitatively. Another possible future research trajectory could explore the impact of weighing mosques differently with respect to their size, people's preferences, design, and other physical conditions and behavioral aspects. Analysis in future studies should also mitigate current limitations with regard to the analysis tool by finding a method on how returned Gravity values can be associated with specific sources. Therefore, such research approach can inform better planning and policy frameworks with regard to: locating religious facilities in residential neighborhoods, and the factors impacting pedestrian movement to such destinations in terms of distance and physical design of pathways.

Acknowledgment

This work was supported by the [Khalifa University] under Grant [number 8474000184].

References

Abdullah, I. C., Yusof, F., Kamaruddin, S. M., & Rasam, A. R. (2013). Travel behavior and land-use planning: The planning of mosque in Shah Alam, Selangor. *Procedia — Social and Behavioral Sciences, 105,* 723–733.

Abu Dhabi Urban Planning Council. (2020). *Plan Abu Dhabi 2030 urban structure framework plan.* Government of Abu Dhabi. Retrieved from https://jawdah.qcc.abudhabi.ae/en/Registration/QCC-Services/Services/STD/ISGL/ISGL -LIST/DP-301.pdf

Agrawal, S. (2009). New ethnic places of worship and planning challenges. *Plan Canada, 48,* 64–67.

Al-Hemaidi, W. K. (2001). The metamorphosis of the urban fabric in Arab muslim city: Riyadh, Saudi Arabia. *Journal of Housing and the Built Environment, 16*(2), 179–201.

Al-Krenawi, A. (2016). The role of the mosque and its relevance to social work. *International Social Work, 59*(3), 359–367.

Al-Shareef, F., & Aljoufie, M. (2020). Identification of the proper criteria set for neighborhood walkability using the fuzzy analytic hierarchy process model: A case study in Jeddah, Saudi Arabia. *Sustainability, 12*(21), 9286.

Arranz-Lopez, A., Soria-Lara, J. A., & Pueyo-Campos, A. (2019). Social and spatial equity effects of non motorized accessibility to retail. *Cities, 86,* 71–82.

Ayhan, I., & Cubukcu, K. M. (2010). Explaining historical urban development using the locations of mosques: A GIS/spatial statistics-based approach. *Applied Geography, 30*(2), 229–238.

Baker, N., & Holt, R. (2004). Urban growth and the medieval church: Gloucester and Worcester. Abingdon, UK: Routledge.

BenAicha, H. (1986). Mosques as libraries in Islamic Civilization, 700–1400 AD. *Journal of Library History, 20*(4), 253–260.

Bennison, A. K. (2007). Power and the city in the Islamic west from the Umayyads to the Almohads. In *Cities in the pre modern Islamic world*. Abingdon, UK: Routledge.

Bianca, S. (2000). *Urban form in the Arab world: Past and present* (Vol. 46). London: Thames and Hudson.

Brownson, R. C., Hoehner, C. M., Day, K., Forsyth, A., & Sallis, J. F. (2009). Measuring the built environment for physical activity: State of the science. *American Journal of Preventive Medicine, 36*(4), S99–S123.

Carl, P. (2000). Urban density and block metabolism. Architecture, city, environment. *Proceedings of PLEA, 2000,* 343–347.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment, 2*(3), 199–219.

Chang, Z., Chen, J., Li, W., & Li, X. (2019). Public transportation and the spatial inequality of urban park accessibility: New evidence from Hong Kong. *Transportation Research Part D: Transport and Environment, 76*, 111–122.

Crucitti, P. Latora, V., & Porta, S. (2006). Centrality in networks of urban streets. *Chaos: An Interdisciplinary Journal of Nonlinear Science, 16*(1), 015113.

Department of Municipalities and Transport. (2021). *Abu Dhabi mosque development regulations.* Abu Dhabi: Department of Municipalities and Transport.

Dubai Development Authority. (2019). *Master planning guidelines. Dubai Development Authority*. Retrieved from https://dda.gov.ae/Guidelines/MasterPlanning-Guidelines.pdf

Ewing, R. (1995). Beyond density, mode choice, and single-purpose trips. *Transportation Quarterly, 49*(4), 15–25.

Frank, L. D., & Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: Single-occupant vehicle, transit, and walking. *Transportation Research Record, 1466*, 44–52.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., ... & Donovan, R. J. (2005). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine, 28*(2),169–176.

Hancock, M., & Srinivas, S. (2008). Spaces of modernity: Religion and the urban in Asia and Africa. *International Journal of Urban and Regional Research, 32*(3), 617–630.

Handy, S. L. (1996). Urban form and pedestrian choices: Study of Austin neighborhoods. *Transportation Research Record, 1552*(1), 135–144.

Handy, S. L., & Clifton, K. J. (2001). Evaluating neighborhood accessibility: Possibilities and practicalities. *Journal of Transportation and Statistics, 4*(2/3), 67–78.

Handy, S. L., & Niemeier, D. A. (1997). Measuring accessibility: An exploration of issues and alternatives. *Environment and Planning A, 29*(7), 1175–1194.

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: Views from urban planning. *American Journal of Preventive Medicine, 23*(2), 64–73.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners, 25*(2), 73–76.

Harb, D. (2015). Walkability potential in the built environment of Doha City. In *12th International Post-Graduate Research Conference, 2015 Proceedings,* 94–108.

Hillier, B., & Iida, S. (2005, September). Network and psychological effects in urban movement. In *International Conference on Spatial Information Theory,* 475–490.

Hillier, B., Leaman, A., Stansall, P., & Bedford, M. (1976). Space syntax. *Environment and Planning B: Planning and Design 3*(2), 147–185.

Hillier, B., Penn, A., Hanson, J., Grajewski, T., & Xu, J. (1993). Natural movement: Or configuration and attraction in urban pedestrian movement. *Environment and Planning B: Planning and Design, 20*(1), 29-66.

Jabareen, Y. R. (2006). Sustainable urban forms: Their typologies, models, and concepts. *Journal of Planning Education and Research, 26*(1), 38–52.

Jamei, E., Ahmadi, K., Chau, H. W., Seyedmahmoudian, M., Horan, B., & Stojcevski, A. (2021). Urban design and walkability: Lessons learnt from Iranian traditional cities. *Sustainability, 13*(10), 5731.

Jenks, M. (2005). *Future forms and design for sustainable cities.* Abingdon, UK: Routledge.

Kahera, A., Abdulmalik, L., & Anz, C. (2009). *Design criteria for mosques and Islamic centers.* Abingdon, UK: Routledge.

Kowalewski, M., & Królikowska, A. M. (2016, December). Politics of sacred spaces. Nation, memory and urban sacrum. In *Transforming urban sacred places in Poland and Germany* (pp. 13-40). Baden-Baden, Germany: Nomos Verlagsgesellschaft mbH & Co.

Kwan, M. P. (1998). Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework. *Geographical Analysis, 30*(3), 191–216.

Levinson, D. M. (1998). Accessibility and the journey to work. *Journal of Transport Geography, 6*(1), 11–21.

Lynch, K. (1981). A theory of good urban form. *American Institute of Planners, 24*(4), 201–214.

Marshall, S., Gil, J., Kropf, K., Tomko, M., & Figueiredo, L. (2018). Street network studies: From networks to models and their representations. *Networks and Spatial Economics, 18*(3), 735–749.

Mazumdar, S., & Mazumdar, S. (2004). Religion and place attachment: A study of sacred places. *Journal of Environmental Psychology, 24*(3), 385–397.

Mitchell, R. B., & Rapkin, C. (1954). *Urban traffic.* New York: Columbia University Press.

Moudon, A. V. (1997). Urban morphology as an emerging interdisciplinary field. *Urban Morphology, 1*(1), 3–10.

Moudon, A. V., Lee, C., Cheadle, A. D., Garvin, C., Johnson, D., Schmid, T. L., ... & Lin, L. (2006). Operational definitions of walkable neighborhood: Theoretical and empirical insights. *Journal of Physical Activity and Health, 3*(S1), S99–S117.

Myint, S. W. (2008). An exploration of spatial dispersion, pattern, and association of socio-economic functional units in an urban system. *Applied Geography, 28*(3), 168–188.

Owen, N., Humpel, N., Leslie, E., Bauman, A., & Sallis, J. F. (2004). Understanding environmental influences on walking: Review and research agenda. *American Journal of Preventive Medicine, 27*(1), 67–76.

Páez, A., Mercado, R. G., Farber, S., Morency, C., & Roorda, M. (2010). Relative accessibility deprivation indicators for urban settings: Definitions and application to food deserts in Montreal. *Urban Studies, 47*(7), 1415–1438.

Penn, A. (2003). Space syntax and spatial cognition: Or why the axial line? *Environment and Behavior, 35*(1), 30–65.

Porta, S., Crucitti, P., & Latora, V. (2006). The network analysis of urban streets: A primal approach. *Environment and Planning B: Planning and Design, 33*(5), 705–725.

Qamhaieh, A., & Chakravarty, S. (2020). Drive-through cities: Cars, labor, and exaggerated automobilities in Abu Dhabi. *Mobilities, 15*(6), 792–809.

Radwan, A. H. (2021). The mosque as a public space in the Islamic city: An analytical study of architectural and urban design of contemporary examples. *Journal of Architecture, Arts and Humanistic Science, 6*(30), 18.

Rahman, M. T., & Nahiduzzaman, K. (2019). Examining the walking accessibility, willingness, and travel conditions of residents in Saudi cities. *International Journal of Environmental Research and Public Health, 16*(4), 545.

Rajamani, J., Bhat, C. R., Handy, S., Knaap, G., & Song, Y. (2003). Assessing impact of urban form measures on nonwork trip mode choice after controlling for demographic and level-of-service effects. *Transportation Research Record, 1831*(1), 158–165.

Randall, T. A., & Baetz, B. W. (2001). Evaluating pedestrian connectivity for suburban sustainability. Journal of Urban Planning and Development, 127(1), 1–15.

Rodríguez, D. A., Khattak, A. J., & Evenson, K. R. (2006). Can new urbanism encourage physical activity? Comparing a new urbanist neighborhood with conventional suburbs. Journal of the American Planning Association, 72(1), 43–54.

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine, 25*(2), 80–91.

Sevtsuk, A. (2010). Path and place: A study of urban geometry and retail activity in Cambridge and Somerville, MA (Doctoral dissertation), Massachusetts Institute of Technology, Cambridge, MA.

Sevtsuk, A. (2014). Location and agglomeration: The distribution of retail and food businesses in dense urban environments. Journal of Planning Education and Research, 34(4), 374–393.

Sevtsuk, A. (2018). *Urban network analysis for rhinoceros 3D: Tools for modeling pedestrian and bicycle trips in cities.* Cambridge, MA: City Form Lab.

Sevtsuk, A., & Mekonnen, M. (2012). Urban network analysis. *Revue Internationale de Géomatique, 287,* 305.

Sevtsuk, A., Kalvo, R., & Ekmekci, O. (2016). Pedestrian accessibility in grid layouts: The role of block, plot and street dimensions. *Urban Morphology, 20*(2), 89–106.

Sharifi, A., & Murayama, A. (2013). Changes in the traditional urban form and the social sustainability of contemporary cities: A case study of Iranian cities. *Habitat International, 38*, 126-134.

Shay, E., Spoon, S. C., Khattak, A. J., & Center, S. T. (2003). *Walkable environments and walking activity* (Final report for seed grant). Knoxville, TN: Southeastern Transportation Center, University of Tennessee.

Silva, M., Oliveira, V., & Leal, V. (2017). Urban form and energy demand: A review of energy-relevant urban attributes. *Journal of Planning Literature, 32*(4), 346–365.

Southworth, M., & Owens, P. M. (1993). The evolving metropolis: Studies of community, neighborhood, and street form at the urban edge. *Journal of the American Planning Association, 59*(3), 271–287.

Spinney, J. E., Miliward, H., & Scott, D. (2012). Walking for transport versus recreation: A comparison of participants, timing, and locations. *Journal of Physical Activity & Health, 9*(2), 47.

Talen, E. (2003). Neighborhoods as service providers: A methodology for evaluating pedestrian access. *Environment and Planning B: Planning and Design, 30*(2), 181–200.

Talen, E., & Anselin, L. (1998). Assessing spatial equity: An evaluation of measures of accessibility to public playgrounds. *Environment and Planning A, 30*(4), 595–613.

Wheeler, S. M. (2015). Built landscapes of metropolitan regions: An international typology. *Journal of the American Planning Association, 81*(3), 167–190.

Williams, T. (2007). The city of Sultan Kala, Merv, Turkmenistan: Communities, neighborhoods and urban planning from the eighth to the thirteenth century. In A. K. Bennison & A. Gascoigne (Eds.), *Cities in the pre modern Islamic world: The urban impact of religion, state and society* (pp. 42–62). Abingdon, UK: Routledge.

Witten, K., Pearce, J., & Day, P. (2011). Neighborhood destination accessibility index: A GIS tool for measuring infrastructure support for neighbourhood physical activity. *Environment and Planning A, 43*(1), 205–223.

Wittowsky, D., Hoekveld, J., Welsch, J., & Steier, M. (2020). Residential housing prices: Impact of housing characteristics, accessibility and neighboring apartments–a case study of Dortmund, Germany. *Urban, Planning and Transport Research, 8*(1), 44–70.

Xiao, Y., Orford, S., & Webster, C. J. (2016). Urban configuration, accessibility, and property prices: A case study of Cardiff, Wales. *Environment and Planning B: Planning and Design, 43*(1), 108–129.