Research Paper

Analysis of Built Environment Factors on Walkability at Three Doha Metro Stations

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Abstract

Many factors contribute to people's decisions for using public rail transit in an urban network. However, the lack of a cohesive and integrated relationship between the built environment and the transport system is one of the most significant factors. It is fundamental for architects, urban designers, town planners, and policymakers to understand the design and planning factors that promote or deter pedestrian behavior in the urban environment. The paper examines four (4) urban connectivity and walkability criteria for three different Doha Metro stations (Al Ziziyah, Hamad Hospital, and West Bay), including pedestrian sheds, block sizes, ground-level land uses, and connectedness within the pedestrian network, which represent a small part of a more extensive, on-going study. The paper argues that these three neighborhoods and metro stations are representative of diverse neighborhood types in Doha: relatively compact but expansive for the Al Saad/Hamad Hospital Station area, metric and topologically restriction due to the poor planning and the peninsular location of the West Bay area, and expansive but shallow reliant on attraction for the transportation corridor associated with Al Waab Road, Sports City, and Al Ziziyah Station. The paper's analysis can help us better calibrate the design and planning strategies of our policymakers and public agencies in promoting more walkable, healthy, and sustainable neighborhoods over the long term.

Keywords

neighborhood, public transport, town planning, urban studies, walkability

1. Introduction

The opening of the Doha Metro in 2019 highlighted a perceived lack of connection between several new public transport system stations and their surrounding neighborhoods. Such links are crucial for promoting walkability as an alternative mode of transport. The inability to walk or cycle to and around various Doha Metro stations reduces transport choices for citizens, residents, and visitors. It also unintentionally undercuts the potential socioeconomic and cultural benefits of constructing the transit system in the near and long term.

The research in this paper is a small part of a more extensive study, which reviews the current state of our knowledge in the field, compiling a comprehensive list of twenty-five (25) design criteria using best practices in the world (Jacobs, 1961; Gehl, 1971; Hess et al., 1999; Dijkstra & Timmermans, 2002; Clifton et al., 2007; Ewing & Handy, 2009; Berrigan et al., 2010; Gehl, 2010; Giles-Corti et al., 20110; Ozbil et al., 2011; Zhu & Timmermans, 2011; Speck, 2012, Gehl, 2013; Guo & Loo, 2013; Montgomery 2013; Alfonzo et al., 2014; Hass-Klau, 2015; Krogstad et al. 2015; Newman & Kenworthy, 2015; Arup, 2016; Su et al., 2017; Salaheldin, 2021). Based on this review, the ongoing study focuses on eleven (11) of these criteria to investigate built environment factors on walkability at three different Doha Metro stations – Al Ziziyah, Hamad Hospital, and West Bay – representing a variety of neighborhoods in the city: a suburban mixed-use area near Villaggio Mall, an urban medical-office center associated with Hamad Medical City, and a high-rise business district area in West Bay, respectively. The criteria include sidewalks availability and continuity, street hierarchy/character, functional mix, building heights, block sizes, street/segment length, connectedness, permeability, pedestrian network, and voids. However, this analysis becomes simplified since the last five criteria are primarily a function of the sixth. e.g., block sizes, which emphasizes morphological analysis in the study (Hillier, 1996; Major, 2015 and 2018).

This paper narrowly focuses on walkability, block sizes, and ground-level land uses within the pedestrian shed radius of 250 meters (m) from the station's entrances due to the harsh, hot climatic conditions in Doha. We then examine the characteristics of the contour catchment map within two changes of direction of the stations' entry/exit points using the space syntax model of Metropolitan Doha. The paper argues there appear to be significant problems for walkability in all three neighborhoods. Effectively resolving these issues in the Al Ziziyah and West Bay areas will require implementing structural development and planning solutions over the long term. In contrast, the Hamad Hospital area offers more opportunities for short-term design refinements and enhancements to promote walkability.

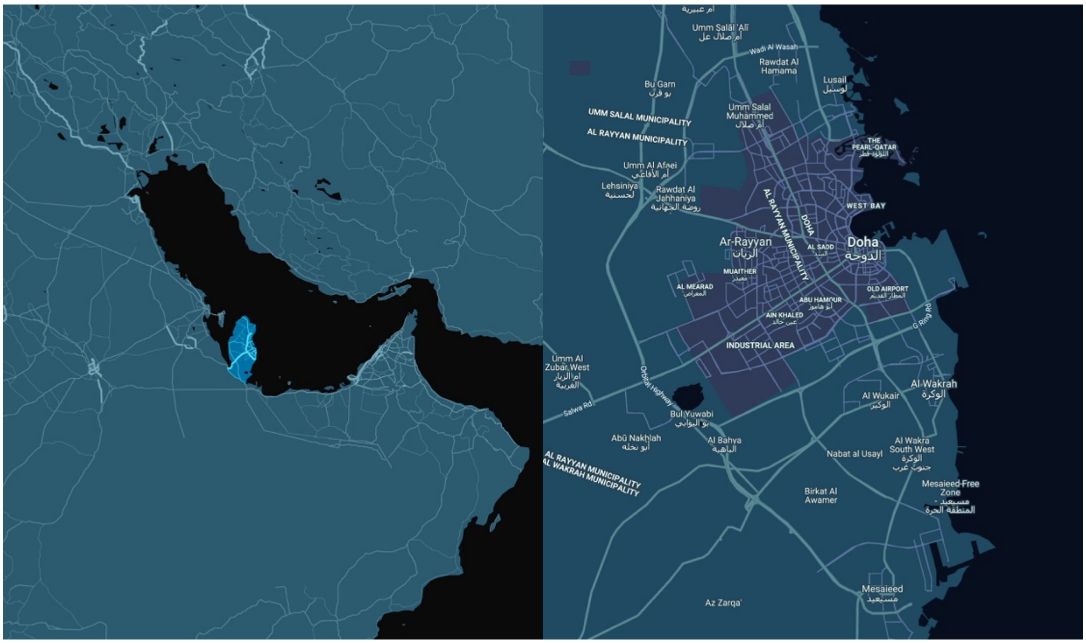

Figure 1: Map of the (left) State of Qatar (highlighted in light blue) on the Qatari Peninsula attached to the larger Arabian Peninsula within the Arabian/Persian Gulf region and (right) Metropolitan Doha region indicating the principal road system, the extent of the Doha Municipality (in purple) and other vital locations (Images: Authors/Google Maps). Source: Authors.

2. About Doha Metro

Since the mid-seventies, the State of Qatar has transformed from a small fishing and pearling economy into a modern, economically diverse, and rapidly urbanized society. It is due to a remarkable increase in national income through the natural gas and oil industry. Consequently, Doha, the capital of the State of Qatar and one of the oldest cities in the GCC, has grown economically and demographically (Furlan, 2015)

(Figure 1). The city has grown from a single core and expanded towards new urban districts. There was a major redevelopment of the transportation systems to accommodate the urban fabric expansion of the city. According to scholars, the Qatari government has plans to invest 100 billion USD in the next five years to develop new infrastructure projects and improve the conditions for the existing transportation systems (Shaaban & Radwan, 2014). Qatar's winning bid to host the 2022 FIFA World Cup tournament led to initiating a national investment strategy to construct new public transportation systems and infrastructure, the port, stadiums, and services facilities (Furlan & Alattar, 2017; Salama & Wiedman, 2013). The construction of a public rail system in Qatar will encompass ~100 metro stations distributed along four main lines. It will provide an opportunity to address a comprehensive strategy for the development and urban regeneration of Transit-Oriented Development (TODs) in the metropolitan region (Alsaeed & Furlan, 2019).

Doha Metro is a rapid transit system in Doha, Qatar's capital city, operational on 8 May 2019. The project is part of a more extensive railway network, which comprises five modern and flexible railway systems integrated across the Persian Gulf. The more extensive network includes the development of passenger and freight rail transport systems, along with fast rail links to the international airport, based on the Gulf Cooperation Council (GCC) feasibility study. There is a two-phase construction plan for the Doha Metro network.

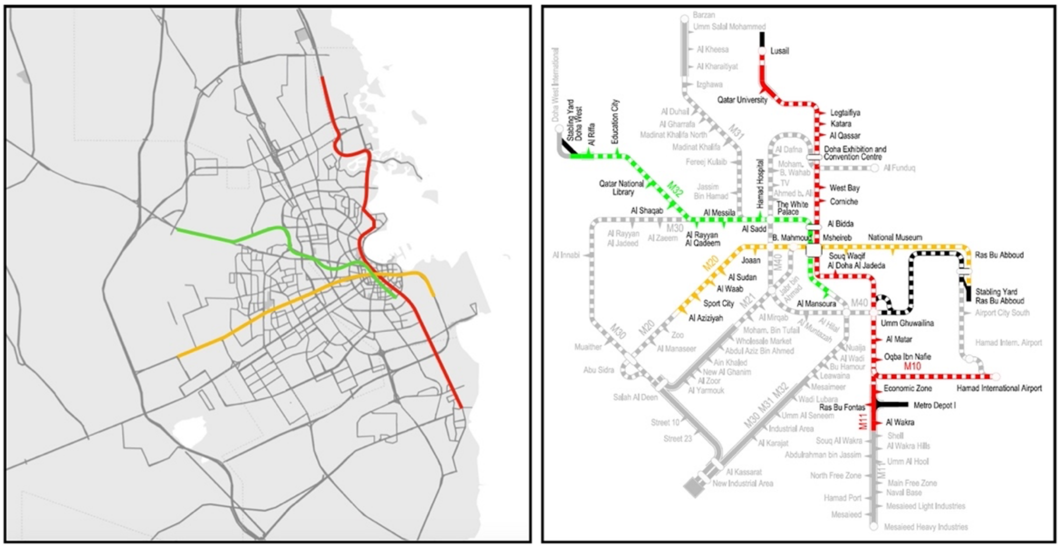

Figure 2: (left) The extent of the Doha Metro public rail network for the Red, Green, and Gold lines during Phase 1 and (right) wayfinding map indicating the Total number of Doha Metro stations in Phase 1 and Phase 2 (Images: Authors/Qatar Rail). Source: Authoers.

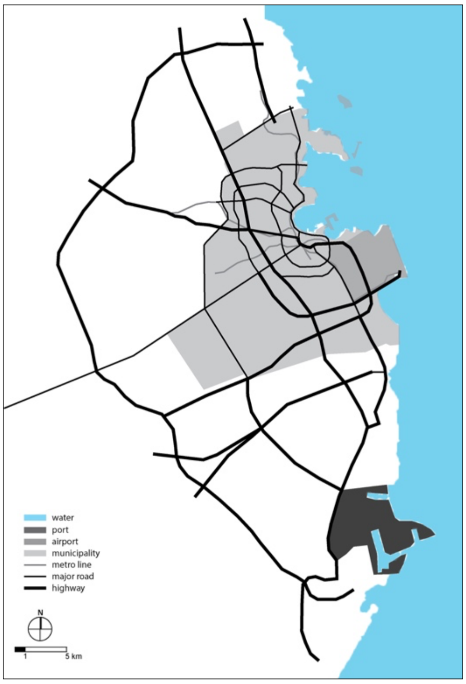

Figure 3: Diagrammatic representation of the key infrastructure comprising the transport pattern of Metropolitan Doha for air, water, rail and vehicular movement (Image: Authors).

Phase 1 is complete, and Phase 2 is due for completion by 2030. Phase 1 consists of three (3) lines; Red, Green, and Gold Lines. Red Line or the Coast Line consists of 18 stations and connects to the Hamad International Airport. Gold Line has 11 stations, and the Green Line with the same number of stations in the historical and educational lines. The first phase of the metro project was launched in 2019 by operating Red Line to decrease traffic congestion by 190,000 vehicles daily. This phase has three main lines, with 37 stations, 65 trains, and 76 k. There are 37 stations, including underground, at-grade, and elevated stations. All the stations interlink to the major terminal station at Msheireb (Figure 2). The lines and routes are:

- The Red Line, also called the Coast Line, runs from Al Wakra in the south to Lusail in the north via the Hamad International Airport. The 40 km line covers 18 stations, including the Legtaifiya Station, allowing passengers to transfer to Lusail Tram services.
- The Green Line or Education Line stretches 22 km and runs from Al Riffa to Al Mansoura. The line covers 11 stations, including Msheireb, Hamad Hospital, Qatar National Library, and Education City, with tram lines in Msheireb Downtown Doha and Education City.
- The Historic Line or Gold Line| connects Ras Bu Aboud and Al Aziziya. There are 11 stations along the 14 km route.
- The Blue Line or City Line will be a 17.5 km-long semi-circular line linking the West Bay and Airport City North areas along the main C-Ring Road and connecting four stations.

The unbuilt Blue Line is not part of this study. The public trail system incorporates ninety (90) stations/stops on the opened Red, Green, and Gold Line, including the three tram networks in Mshereib Downtown Doha, Education City, and Lusail City. The injection of the new public rail transit system into the expansive infrastructure for transportation, be it for pedestrians, vehicles, air travel, or the movement of goods, represents a significant evolution for investment in the transport pattern of Metropolitan Doha (Figure 3).

3. Background

Every trip begins and ends with walking. Everyone is a pedestrian for at least a part of most journeys. Walking is often the only way that people can access everyday activities. However, the streets and public spaces of many cities worldwide struggle with the degradation of 20th-century urban planning and design preferences for private vehicles, with social life effectively disappearing from most spaces of the public realm (Krambeck & Shah, 2006; Ghidini, 2011; Abley & Turner, 2011). Walking brings life to the street and contributes to safe urban environments, which Jacobs (1961) refers to as "eyes on the street." Evans (2009) argues that bringing back the benefits of walking to cities such as safety, accessibility, and social inclusion has become a specific challenge for the design of contemporary urban environments in the early 21st century. Over the last century, pedestrian access and use have declined steadily in many cities worldwide, especially Western cities (Forsyth & Southworth 2008).

Many scholars argue that walking is "the foundation of the sustainable city," providing many social, environmental, and economic benefits (Forsyth & Southworth 2008). Walking is the most equitable means of transportation as it is inexpensive, accessible for most (even most disabled people with reduced mobility), and requires only basic infrastructure. Lo (2009) argues that walkable environments are a characteristic of more democratic civil societies since pedestrian facilities provide benefits accessible to a more significant proportion of the community than road or rail infrastructure. Such benefits extend across social and economic classes, including senior citizens, children, and low-income groups, who do not own or operate automobiles (Forsyth & Southworth 2008).

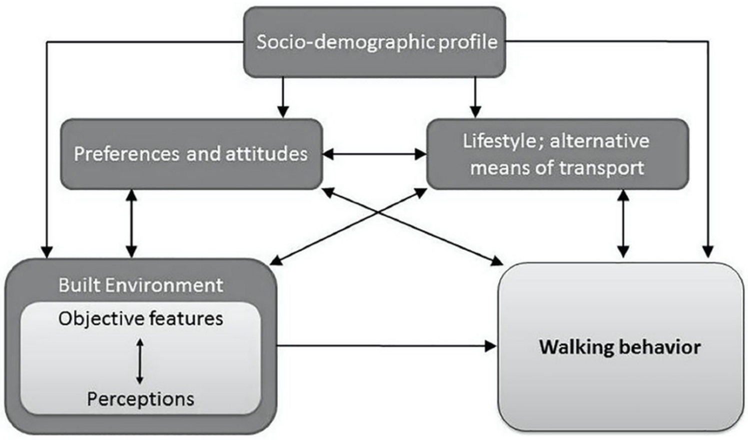

Figure 4: A conceptual framework showing the relation between walking and the built environment after Handy (2005) and Schmid (2006) (Image: Authors).

In terms of environmental benefits, walking is the 'green'-est mode of transport. It relies on human power for locomotion, with minimal environmental impact, i.e., air and noise pollution, energy, and resource consumption. In terms of economic benefit, there is little cost associated with walking as a means of transport and significant financial incentives in promoting local businesses, street shopping, tourism, and savings for public health at a macro scale over the long term. Studies demonstrate the benefits of walking as a moderately intense physical activity for promoting cardio-vascular fitness, reducing streets, and enhancing mental and physical health (Forsyth & Southworth 2008). Over the last thirty years, many public health organizations adopted guidelines to encourage walking (Bourdeaudhuij et al., 2005; Weil, 2009).

The factors influencing walking are socio-demographic factors, preferences and attitudes, lifestyle, availability of transport alternatives, and the built environment (Figure 4). Walking also plays a role in influencing lifestyle, preferences, and attitudes. For example, the attributes of a place that promote walking can affect an individual's choice to purchase or rent housing due to the alternative transportation choices such a place provides to people. Conversely, factors that discourage walking and limit alternative transportation choices can harm an individual's decision to live in such a place (Schmid 2006). Handy (2005) argues perceptions about the presence or absence of sidewalks and intensity of vehicular traffic can facilitate or constrain such choices. Social norms also play a role, especially in choosing alternatives to the automobile, such as walking, biking, or public transit (Handy 2005). Schmid (2006) argues people who enjoy walking tend to choose to live in more walkable neighborhoods and, thus, will choose to walk more. It is a lifestyle choice, meaning that certain types of people may choose to live and work in areas that suit their lifestyles and resources in the form of "self-selection" (Silva et al., 2018).

All of this serves as the background for developing the research design and methodology of the more extensive ongoing study about the walkability characteristics within the vicinity of the three Doha Metro Stations: Al Ziziyah, Hamad Hospital, and West Bay.

4. Research Design and Methodology

In this section, we outline the research methodology of the more extensive study before narrowly focusing on the findings for the four attributes evaluated in the paper. It includes walkability 'as the crow flies' in pedestrian sheds, block size and shape, ground-level land uses, and connectivity within the urban spatial network using space syntax. Space syntax is an international research program of academics and practitioners scientifically investigating spatial networks from the single building to entire metropolitan regions to understand better the role of built space in society (Hillier and Hanson, 1984; Hillier, 1996; Hanson, 1998; Major, 2018). Founded in the late 1970s and early 1980s by Bill Hillier, Julienne Hanson, John Peponis, Alan Penn, and many others in The Bartlett at University College London, space syntax has developed a set of techniques for the simple representation and mathematical measurement of architectural and urban space over the last 40 years (Benedikt, 1979; Hillier and Hanson, 1984; Hillier, 1989; Hillier et al., 1993; Penn et al., 1998; Turner et al., 2001). Today, the international space syntax community composes hundreds of researchers and practitioners in more than forty countries worldwide. A critical foundational concept for space syntax is our built environment is both a product of society and an influence on society (Tannous et al., 2021).

Representations in space syntax are usually plan-based using objective, easily understood constraints of the built environment for the most generic human uses such as movement, occupation, and visibility (Hillier, 1996; Major, 2018). For the space syntax analysis in this paper, the most important is the axis or line of sight and movement (also axial line) represents an idealization because a line is a set of points having a length but no width or depth. The matrix of longest and fewest (i.e., most strategic) lines of sight and access completely covering all spaces of a built environment as defined by its built surfaces (walls or facades) is the axial map (Hillier and Hanson, 1984). The axial map is the most common reference to a 'space syntax model' for forecasting (60%-80% accuracy) pedestrian and vehicular movement in the urban environment (Hillier et al., 1993; Penn et al., 1998). Movement tends to be linear because we are bipedal, forward-facing creatures bound by gravity (Tannous et al., 2021).

Walking means "to move at a regular pace by lifting and setting down each foot in turn, never having both feet off the ground at once" as a verb and "an act of traveling or an outing on foot as a noun. The word 'walk' derives from the Old English wealcan meaning 'roll, toss' and 'wander' of Germanic origin (Source: Oxford English Dictionary). For this paper and more extensive study, walking is for transport, exercise, recreation, and pleasure. However, we can further classify the first utilitarian walking and the latter three as recreational walking. The last means walking becomes the objective itself, whether walking for pleasure or recreation, be it for exercise or contemplation. The former is a means to reach a destination as a resource of activity or function such as going to school or work, shopping, meeting friends, and so on (Schmid, 2006; Leslie et al., 2007). Utilitarian walking is the focus of this paper and the more extensive study from which this paper derives.

There is a great deal of debate about the most critical factors for promoting walking in the built environment. “The physical features of the urban landscape (i.e., alterations to the natural landscape) that collectively define the public realm, which might be as modest as a sidewalk or an in- neighborhood retail shop or as large as a new town” (Cervero & Kockelman, 1997).

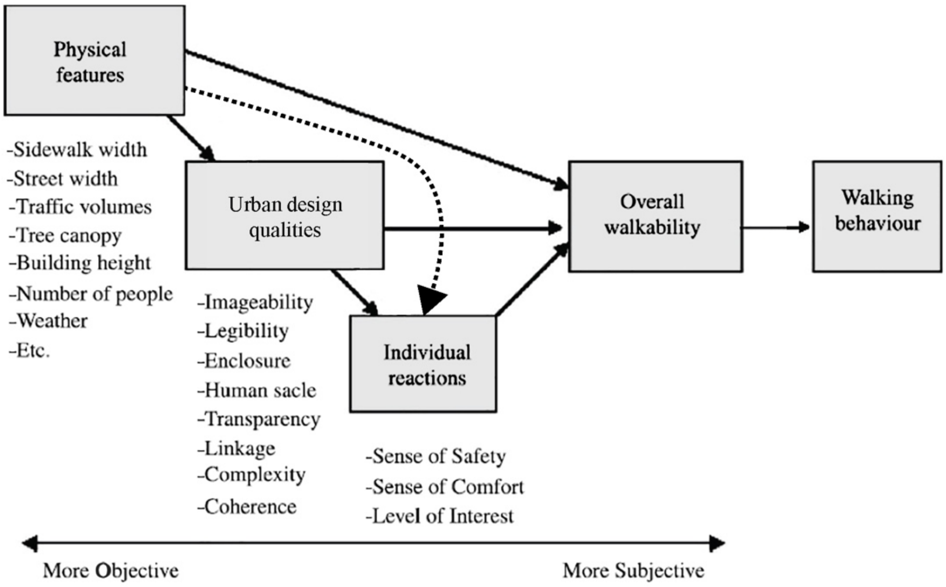

Figure 5: A conceptual framework classify the built environment into two evaluative dimensions on a range from the objective to the subjective or perceived (Image: Handy, 2005).

We can summarize and classify the current state of knowledge in the field for those built environment factors most relevant to urban planning and design as:

- Legibility or the ease that a spatial structure can be understood and navigated as a whole.
- Imageability or the quality of a place that makes it distinct, recognizable, and memorable.
- Enclosure is the visual definition of streets and other public spaces by buildings, trees, walls, and other elements.
- Human scale or the size, texture, and articulation of physical elements that match the size and proportions of people and, equally important, the speed at which humans walk.
- Transparency or the degree to which people can see or perceive what lies beyond the edge of a street or other public space.
- Linkage or physical and visual connections from building-to-street, building-to-building, street-to-street, and one side of the street to the other.
- Coherence or a sense of visual order.
- Complexity or the visual richness of a place.

Some scholars offer other measurable attributes such as traffic levels, slope, vegetation, barriers, parking, services, and amenities (Gehl, 1971; Appleyard, 1981; Handy, 2005) (Figure 5).

5. Morphological, Land Use, and Spatial Analysis

We examine the scale of the impact of the built environment on walkability within the selected area of investigation at two levels in this paper: the micro-neighborhood level and the macro spatial structure, including the rail network in the 2020 space syntax 'all-inclusive' model of Metropolitan Doha (Major et al., 2019). All-inclusive means including all pedestrian and vehicular routes represented as the most extended and fewest set of axial lines necessary to encompass the urban space of the entire metropolitan region in their simplest form, i.e., using a direct connection between all routes regardless of vehicular turning movements. The micro-scale analysis focuses on the immediate neighborhood level, including a comparison of spatial structure around the metro stations. It includes characterizations of urban typology and walkability using pedestrian sheds, and ground-level land uses surveys. The macro-scale analysis focuses on the size and shape of the configurational catchment area associated with each metro station based on two changes away from the station entrance, i.e., the route on which they locate and all changes in direction from that route up to two changes of direction. We then draw a catchment contour map to demonstrate the metric area and extent of the spatial structure within the context of Metropolitan Doha itself. Based on this analysis, the paper identifies some factors of the built environment that appear to be impacting the nature of walkability in the vicinity of these three Doha Metro Stations.

Pedestrian sheds and ground-level land-use surveys utilize figure-ground representations to illustrate the relationship between built and unbuilt space around the metro stations. Land coverage of buildings is visualized as solid mass (i.e., figure), while public spaces formed by streets, parks, and plazas are voids (i.e., ground). All are at the same scale for direct comparison. The pedestrian sheds encompass 250m, 400m, 600m, and 800m to illustrate what built forms are available within the defined distance from the metro station entrances. For stations with multiple entry/exit points, we set the center of the pedestrian shed at a location equally distant from all entry/exit points to simulate a standard distance for all of them. The ground-level land use survey focuses within the 250m radius distance from the metro station due to the harsh climatic conditions in Qatar during 7-8 months of the year, which can be a deterrent to walking. People are willing to – and do – walk during the hottest months of the year in Doha. However, the gross distances they walk decrease with increased heat. It suggests that promoting walkability in Doha should focus on intensifying opportunities within the immediate vicinity of the metro stations requiring only a short distance to walk, i.e., less than 250-300 meters.

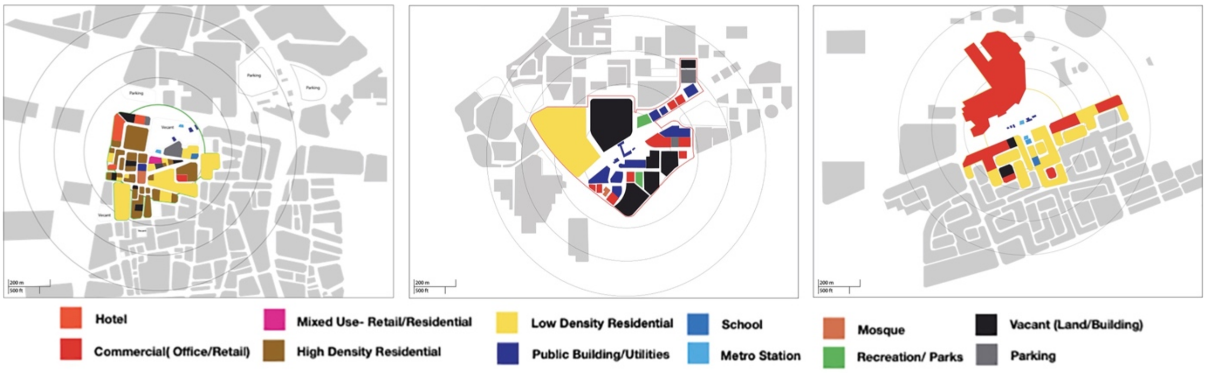

Figure 6: Pedestrian shed radii and 250m, 400m, 600m, and 800m and ground-level land use survey for all urban blocks within 250m of station entrances for (left) Hamad Hospital Station, (center) West Bay Station, and (right) Al Aziziah Station (Image: Authors).

Table 1: Number of urban blocks accessible within 250m or less of the metro station entry/exit point including and excluding structures associated the metro station itself (i.e., station and utility blocks) and the primary land use type available within a short distance (Image: Authors).

Metro Station	Blocks <250m	w/o Stations/Utility	Avg. Block Size (m2)	Primary Land Use Type
Hamad Hospital	28	23	8,741	Residential
West Bay QIC	20	17	11,341	Housing/Vacant
Al Aziziah	18	10	20,706	Retail/Residential

The location of the Hamad Hospital metro station is in the northern part of the Al Sadd area across the street (Al Rayyan Road) from Hamad Medical City. Al Rayyan Road is one of the most critical east-west arterial roads in Doha. It stretches east into the geometric center of Souq Waqif (the oldest remaining part of Doha), only about 400m from the coastline of Doha Bay and Al Corniche Road. To the west, it extends along a shifting alignment another 10km to the western edges of Metropolitan Doha to continue to Zekreet on the west coast of Qatar. There are twenty-eight (28) urban blocks available within 250m of the metro station (Figure 6, left and Table 1). However, five (5) of these urban blocks are the metro station and associated maintenance/utility blocks themselves for a total of twenty-three (23) urban blocks within the immediate vicinity. The average block size is 8,741 square meters (m2) within 250m of the metro station. All urban blocks and ground-level land uses available within 250 m of the metro station are only to the south due to the right-of-way width for Al Rayyan Road and surfacing parking lots in Hamad Medical City. These land uses are primarily a mixture of high-, medium- or mixed-, and low-density residential land uses.

The location of the West Bay QIC metro station is the southern portions of the West Bay business district on Majlis Al Taawon Street, running parallel to Al Corniche Road and the coastline of Doha Bay. The metro station is 330m northeast of Al Markhiya Street (running southeast-to-northwest in this part of Doha before re-aligning westward), a cross-street segment of the E-Ring Road. Al Markhiya Street connects to and terminates at Al Corniche Road on the coast only 425m further to the southeast. The pedestrian shed radii of 600m, and 800m are meaningless in this direction since they extend into the waters of Doha Bay. Twenty (20) urban blocks are available within 250m from the metro station entry/exit buildings, which a pedestrian bridge connects across Majlis Al Taawon Street (refer to Table 1).

There are two (2) other maintenance and utility urban blocks associated with the metro station. There are seventeen (17) urban blocks available within 250m or 35% less than the Hamad Hospital metro station. The average block size is 11,341 m2 within 250m of the metro station, meaning urban blocks are typically 30% larger in this part of West Bay than the northern Al Sadd neighborhood in the vicinity of the Hamad Hospital metro station. There is one large housing area to the immediate west of the station, of which about half lies within 250m of the station northern entry/exit point (refer to Figure 6, center). Other than this housing area, vacant skyscraper buildings and land parcels (or under construction) primarily characterize the urban blocks available within 250m of the West ay QIC metro station.

The location of Al Aziziah metro station is on Al Waab Street. It runs parallel to Salwa Road, about 2.25k to the south. Both are critical arterial roads from the center of Doha in a northeast to southwest direction. Salwa Road itself continues along a shifting alignment southwest to the Qatari border with Saudi Arabia. It continues northeast via Wadi Mshereib to define the southern perimeters of Mshereib Downtown Doha and Souq Waqif in Old Doha. Al Waab Street continues to the northeast another 5km until it shifts northward into Jawaan Street, which turns eastward until it terminates on the Al Corniche Road and Doha Bay coastline, forming part of Doha's ring road structure. Al Waab Street continues to the southwest for another 14km from the Al Aziziah metro station until terminating at the Doha's Orbital Highway on the city's western edges. Al Aziziah metro station is adjacent to the Villaggio Shopping Mall and Sports City, including Khalifa International Stadium, one of the stadia for the FIFA World Cup 2022. There are eighteen (18) urban blocks within 250m of the Al Aziziah metro station (refer to Table 1). However, eight (8) of these urban blocks are the station entry/exits and associated maintenance and utility free-standing buildings. It means there are only ten (10) urban blocks available within 250m of the station or 70% less than West Bay QIC and 130% less than Hamad Hospital metro stations. The average block size is 20,706 m2 within 250m of the metro station, meaning the typical block size is 83% larger than those near the immediate proximity of West Bay QIC and 137% larger than those near Hamad Hospital metro station.

Of course, the most important free-standing building available within 250m of the Al Aziziah metro station is the Villaggio Shopping Mall itself to the north (refer to Figure 6, right). However, only about 25% of the Villaggio building footprint is accessible within 250m, limited to its southern portions, and pedestrians must move through the mall's surface parking lots to access it. The owners of Villaggio have also made few accommodations for pedestrians accessing the shopping mall from the metro station. The building footprint of the Villaggio Shopping Mall is 140,000 m2, and the area of the land parcel is 350,000 m2, including surface parking lots representing 40% lot coverage. The primary ground-level land uses within 250m of the metro station are commercial retail/office and low-density residential compounds.

The most intriguing aspect of this micro-scale analysis is that the number of urban blocks – and, by definition, average block sizes – within a short distance of the three metro stations tends to follow the historical pattern of urban development in Doha. Due to urban growth and rapid urbanization, the sizes of urban blocks grew to increase in size over time. Urban blocks in the vicinity of Hamad Hospital, West Bay QIC, and Al Aziziah metro stations accurately reflect the chronological order of urban development. The areas around the first (Hamad Hospital) are the oldest, then those around West Bay QIC are the second oldest (1980s and 1990s). The neighborhoods surrounding Al Aziziah metro station (early 21st century) are the most contemporary (Figure 7).

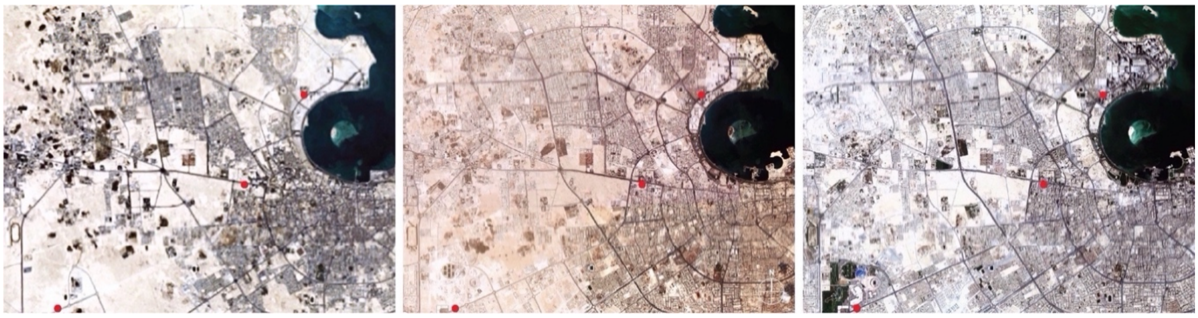

Figure 7: Satellite view of urban development in metropolitan Doha in (left) 1985, (center) 2005, and (left) 2010 with the future/current location of West Bay QIC (furthest northeast), Hamad Hospital (center east), and Al Aziziah (furthest southwest) metro stations indicated in red (Image: Authors/Google Earth/Maxar Technologies).

Researchers evaluated the accessibility of the three Doha Metro stations using the space syntax model of Metropolitan Doha in 2020 (Figure 8, left). The model incorporates the public rail network of the Doha Metro and the local tram systems in Mshereib Downtown Doha, Education City, and Lusail City. Using previous methodology, the public rail system connects into the urban spatial network like a separate floor in the urban environment with a direct link to public streets with station entries (Major et al., 2020). To examine accessibility characteristics in detail, researchers identified the two-deep system from each station and the Doha Metro public rail network itself. We ran step depth from the routes of which station entry/exits points and, in the case of the Doha Metro, all axial lines representing station-to-station connections within the public rail network. In the case of Al Ziziyah and West Bay, this means two cross-axis routes associated with the stations. Hamad Hospital represents three parallel routes, two of which are overlapping axial lines composing segments of Al Rayyan Road, a major arterial road connecting from Souq Waqif via Al Rayyan Road to Dukhan Highway. Eventually, Al Rayyan Road connects to the west coast of Qatar along alignments that marginally shift from east to west in the entire country.

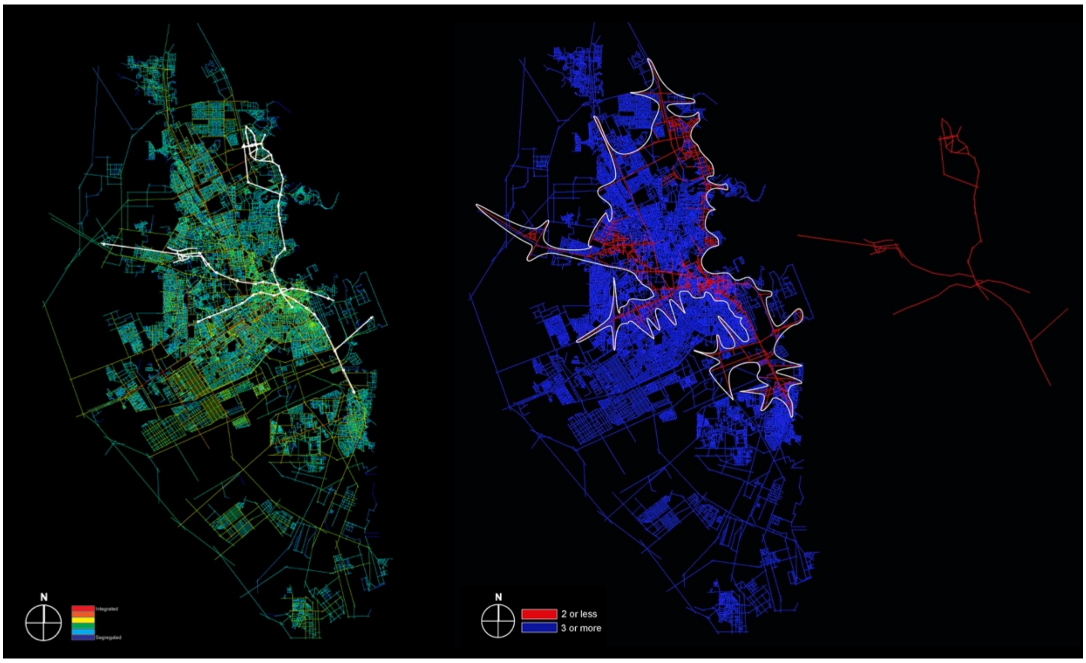

Figure 8: (left) Pattern of local integration (radius=3) in the space syntax model of Metropolitan Doha in 2020 with the Doha Metro public rail system and local tram networks in Mshereib Downtown Doha, Education City, and Lusail City indicated in white; and, (right) Catchment contour map of all routes within 2 changes of directions or less from the Doha Metro (to the right in red) rail network linked into the urban spatial network of Metropolitan Doha in 2020 (Images: Authors).

Color-coding of the space syntax model is binary, with red indicating all routes within two changes of direction or less and blue representing all routes with three changes of direction or more. Researchers then drew an irregular polygon connecting the farthest extent of the two-deep system to illustrate the catchment contour map of the stations and the Doha Metro (outlined in white in Figure 8, right, and Figure 9, below). Researchers brought the image overlay into Google Earth to measure the approximate metric area of each catchment contour map in square kilometers and derive the street density for each catchment area, i.e., the number of axial lines divided by metric area (Table 2).

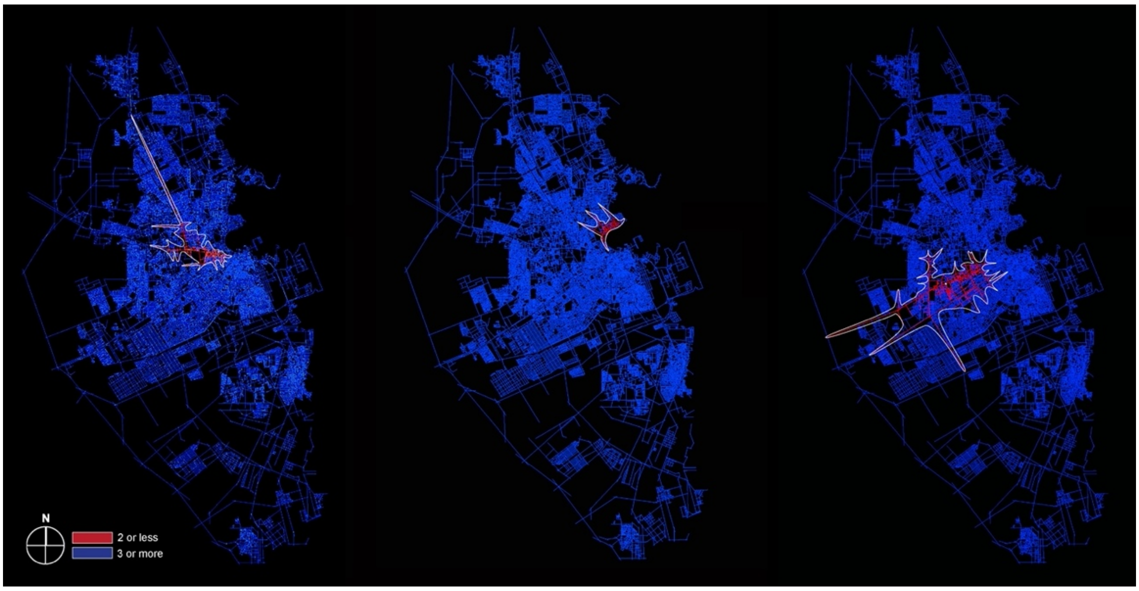

Figure 9: Catchment contour map of all routes within 2 changes of directions or less from the routes on which there are entry/exit points for (left) Hamad Hospital, (center) West Bay QIC, and (left) Al Aziziah metro stations within the spatial network of Metropolitan Doha in 2020 (Image: Authors).

Table 2. Mean metric values for the Catchment Area of the Doha Metro Stations within the space syntax model of Metropolitan Doha in 2020 for (left to right) Number of Streets, Street Length, Area ins square kilometers (km2), and Street Density (k/km2) compared to the mean values for the metric values in the spatial network of Metropolitan Doha and the Doha Metro itself in 2020.

Station Catchment (sd=2)	**Streets No.** (k)	**Length** (m)	**Area** (km^2)	**Street Density** (k/km^2)	**Routes/Stop**
Al Ziziyah Station (Villaggio)	1,179	205.85	66.50	17.73	N/A
Hamad Hospital Station	709	197.83	21.29	33.30	N/A
West Bay Station	180	237.18	6.68	26.95	N/A
Doha Metro (90 stations/stops)	2,879	221.13	219.91*	13.09	31.98
Metro Doha	24,396	119.93	1,328	18.37	N/A

*Total catchment area minus the metric area of the large interstitial gap (44.09 km^2) in northern Doha.

KEY: Streets No.(k)=total number of streets within 3 changes of direction of the Doha Metro Station or gross total in the space syntax model of Metropolitan Doha in 2020; Length(m)=average axial line length in the catchment area or spatial network in meters; Area(km^2)=metric area of the catchment area or spatial system in square kilometers; Street Density=number of streets divided by the Metric Area (km^2).

The two-deep catchment contour map for the Doha Metro rail network lines encompasses 264.0 km2 of the Metropolitan Doha urban fabric (refer back to Figure 8, right). The new rail system emphasizes the radial structure of the Doha along with the Red, Green, and Gold lines. It parallels significant routes such as Lusail Expressway (northward from Old Doha) and Al Wakrah Road (southward from Old Doha/Al Corniche), Al Rayyan Road/Dukhan Highway (northwesterly from Old Doha), and Al Waab Street (southwesterly from the C-Ring Road). The cumulative effect heavily skews the catchment area of the public rail transit toward northern Doha. However, there is a significant gap in service coverage of north Doha by the Red and Green lines measuring about 44 km2 in area. The large interstitial, primarily residential areas of north Doha within this gap is effectively served from its edges at the macro-scale, meaning the catchment area is 220 km2. The only notable penetration into this service area of north Doha occurs due to the Qatar University Station and routes crossing to the western edges of the campus itself. This catchment contour map derives mainly from the newness of public rail systems in Doha, as the system is not old nor expansive enough to fully service the metropolitan region. Of course, the focal point of the entire rail network is Old Doha itself. It is the central terminal station at Msheireb at the intersection of Wadi Musheirib Street, connecting the southern edge of Souq Waqif to Salwa Road and Abdullah Bin Thani Street, which defines the western perimeter of Msheireb Downtown Doha (Zone 3) and Mushaireb (Zone 4). If we examine the two-deep catchment contour maps and mean metric variables for Al Ziziyah, Hamad Hospital, and West Bay Stations, we can see more clearly how these three stations represent a contrasting but characteristic station type on the Doha Metro (Figure 9). The layout of the maps from left-to-right is consistent with the history of development in each area associated with the station (refer to Figure 7).

The catchment area of Hamad Hospital balances between the compact density of routes available in the vicinity of the station (especially to the south) and linear extension to the west due to Al Rayyan Road and north due to the Doha Expressway. Its two-deep catchment area encompasses 709 routes, a metric area of 21.29 km2 with a mean street length of 198 m. Hamad Hospital possesses the highest street density of the three stations with 33.3 streets/km2, 81% higher than the average for Metropolitan Doha (18.37 k/km2) and 154% higher than the Doha Metro (13.09) itself. However, routes per station/stop for the Doha Metro (90 in total, including tram stops) is a more reliable indicator than the routes/km2 parameter. In this case, Hamad Hospital station's routes/km2 availability in the catchment (+4%) is consistent compared to the Doha Metro.

The catchment area of West Bay station emphasizes the routes along the coastline and those within West Bay itself, with its only other linear extension occurring in a northwesterly fashion toward north Doha. Its two-deep catchment area encompasses the smallest number of routes (only 180), covering the smallest metric area (6.68 km2). Street density is still high (26.95) but 24% less than Hamad Hospital and 16% less than routes per station/stop compared to the entire public rail network. Mean street length in the West Bay catchment area (237 m) is the longest of the three stations, responsible for its high choice and connectivity values. However, mean integration at all radii is the lowest of the three stations, approximating the mean values for the entire public rail network. The West Bay catchment area has the highest mean depth (11.12), 3% deep than the public rail network. Collectively, this is compelling evidence for the planning of the West Bay area attempting to overcome its isolation on a small peninsula at the edge of the Doha urban spatial network. It also suggests that West Bay might most benefit from creating a local tram system, which introduces more public rail stops to the area.

The Al Ziziyah Station catchment area is expansive, encompassing 1,179 routes (6 /2 times that of West Bay) and measuring 66.5 k2 in area, or over three times larger than the next closest station (Hamad Hospital) in the sample. However, the mean street length associated with the Al Ziziyah Station catchment area is only 206 m. It is notable compared to the other stations in the sample (only a +4% and -15% difference with Hamad Hospital and West Bay stations, respectively) and the Doha Metro (+7%) catchment area itself. While the catchment area of Al Ziziyah Station is expansive in size, it is also shallow in terms of penetration into the intestinal area of the urban fabric and the density of accessible routes. The street density of the Al Ziziyah Station catchment area is 17.73 routes/km2, which is marginally less (-3.5%) than the mean street density in the entirety of Metropolitan Doha. It is 80% less than the number of routes available per stops in the public rail network and 88% less than the mean street density for the Hamad Hospital Station catchment area. The Al Ziziyah Station catchment area is effectively a transit corridor for both vehicle and public rail focused along Al Rayyan Road itself and its immediate connections in the urban spatial network. In combination with the much larger block sizes in the area (20,706 m2), it characterizes the area as an auto-dependent suburban area.

6. Conclusion

Many variables affect people's choices for using public rail transit. A lack of a cohesive and integrated relationship between the built environment and the transport system is one of the most significant factors. The paper argued that it was critical for policymakers and built environment professionals to understand better the design and planning factors that can promote or otherwise deter pedestrian use of the urban environment. The paper examined four (4) urban connectivity and walkability criteria in three different Doha neighborhoods associated with public rail transit stations: Al Ziziyah, Hamad Hospital, and West Bay. Criteria included pedestrian sheds, block sizes, ground-level land uses, and connectedness within the pedestrian network, representing a small part of a more extensive, ongoing study. The paper demonstrated that these three neighborhoods and metro stations are representatives of diverse neighborhood types in Doha: relatively compact but expansive for the Al Saad/Hamad Hospital Station area, metric and topologically restriction due to the poor planning and the peninsular location of the West Bay area, and expansive but shallow reliant on attraction for the transportation corridor associated with Al Waab Road, Sports City, and Al Ziziyah Station. The paper's analysis can help us better calibrate the design and planning strategies of our policymakers and public agencies in promoting more walkable, healthy, and sustainable neighborhoods over the long term.

7. Funding

Portions of the research in this paper involving the space syntax model of Metropolitan Doha was supported in part by internal grants of Qatar University (Grant IDs: QUSDCENG-2018/2019-4 and QUCG-CENG-20/21-1). The findings achieved herein are solely the responsibility of the authors.

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