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THE IMPACT OF BUILT ENVIRONMENT FACTORS ON WALKABILITY FOR THREE DOHA METRO STATIONS

BY

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ABSTRACT

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Title: The Impact of Built Environment Factors on Walkability for Three Doha Metro Stations

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The 2019 opening of the Doha Metro highlighted a perceived lack of connection between several new public transport system stations and their surrounding neighborhoods. Such connections are a crucial component 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 over the near- and long-term. Many factors contribute to people's decisions for using public rail transit in an urban network. However, a significant factor is the lack of a cohesive and integrated relationship between the built environment and the transport system. It is fundamental for architects, urban designers, town planners, and policymakers to understand the design and planning factors that promote and deter pedestrian behavior in the urban environment. The study assesses the relationships between pedestrian movement on streets and features of the urban environment, especially at the neighborhood and street scale near the metro stations.

The study will investigate built environment factors on walkability at three different Doha Metro stations – Hamad Hospital, West Bay and Al Aziziyah – representing a variety of neighborhoods in the city: an urban medical-office center

associated with Hamad Medical City, a high-rise business district area in West Bay, respectively, and a suburban mixed-use area near Villaggio Mall.

The analysis criteria will include ground-level land uses, block sizes, street/segment length, availability and continuity of sidewalks, connectivity, and traces of observed movement patterns within the pedestrian shed radius of 250 meters (m) from the station's entrances due to the harsh climatic conditions in Doha. The study argues there appear to be significant problems for walkability in all three neighborhoods. Effectively resolving these issues in the Al Aziziyah and West Bay areas will require implementing structural development and planning solutions over the long term for the next 10-20 years. In contrast, the issues in the Hamad Hospital area offer more opportunities for short-term design refinements and enhancements to promote walkability.

Keywords: built environment, catchment areas, metro station, sustainable urbanism, transit-oriented development, walkability

DEDICATION

This thesis is dedicated to the ones whom I know they will not read my thesis, but they have great faith on me with unlimited support and unconditional love for me: my beloved parents Amira and Tariq.

It is also dedicated to the ones who might one day will look up to me, my beloved siblings Mohammed and Heba.

Thank you.

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ABBREVIATIONS

GCC	GULF COOPERATION COUNCIL
MENA	MIDDLE EAST AND NORTH AFRICA
MME	MINISTRY AND MINISTRY OF ENVIRONMENT
QHDM	QATAR HIGHWAY DESIGN MANUAL
QNDF	QATAR NATIONAL DEVELOPMENT FRAMEWORK
QNMP	QATAR NATIONAL MASTER PLAN
QNV	QATAR NATIONAL VISION 2030
QPR	QATAR PUBLIC REALM
QR	QATAR RAIL
QSA	QATAR STATISTIC AUTHORITY
QUDC	QATAR URBAN DESIGN COMPENDIUM
TOD	TRANSIT-ORIENTED DEVELOPMENT

CHAPTER 1: INTRODUCTION

Accessing metro stations is an essential element in the success of any rail-based transportation system. It will play a prominent role in developing the future of any metro system, particularly in areas with high potential for travelers, such as dense housing, a substantial number of workplaces and attractions, and shopping and entertainment areas. Most travelers who are using public transit are residents coming from the neighborhood surrounding the station. These areas are known as catchment areas. A catchment area is defined as the area around the public transport station where most transfers arrive or depart (Shaaban et al., 2018). As a result, the surrounding built environment around the metro station must provide various modes of transportation, including buses, bikers, and pedestrians, according to varied principles for all users (Landex et al., 2006). This study will focus on the impact of the walkable built environment around the catchment areas of metro stations.

At its core, walking is the most basic mode of transportation for individuals to travel around and reach their destinations, integrate and live-in urban spaces, and engage in essential and beneficial physical activity. Walking has been connected to several advantages, including lower air pollution, transportation congestion, resource consumption, and the resolution of obesity and other health issues (Park, 2008). It is critical component for establishing livable communities, which improve neighborly interactions and make urban environments more enjoyable and secure to live in (Emery and Crump, 2003).

With so many advantages, it is important to address important topics about encouraging people to walk. It is a concern for urban planners to make more effort to promote walkability for people in the function of the built environment. The relation

between the built environment and walking behavior is intuitive from one point of view, but there has been minimal empirical evidence to support such a relationship in the past (Park, 2008). On the other hand, Handy's (2005) study had shown clear evidence of a relation between the built environment and walking and the need for additional attention to identify and measure the aspects of the built environment that contribute to a pedestrian-friendly environment.

Walkability is a concept to illustrate how pedestrian-friendly is an urban environment (Abley and Turner, 2011). Planners need to examine or measure the built environment efficiency for pedestrians, enabling evolution towards more attractive and connective cities, therefore more sustainable cities.

This chapter will introduce the aim of the thesis and the importance of studying walkability around metro stations. It will start by introducing the context of Qatar and Doha the development of the city, which lead to including the railway transport system. Then, it will continue introducing the Doha public rail system and its connections and development. The problem statement is also included in this section, explaining the importance of the thesis, followed by the research questions and significance.

1.1. Context of the Study Area

The State of Qatar is a small and narrow country facing the Persian Gulf and located between Saudi Arabia and Iran (Figure 1). It is one of the few countries in the world that has improved dramatically in global rankings for socio-economic and human development indicators in only a few decades. The country's economic rise began in the middle of the twentieth century. It was mostly attributable to the wealth generated by natural resource discoveries such as natural gas and oil. The urban settlement was based on an economy reliant on fishing and pearling until the 1940s and 1950s when

the discovery of first oil and then natural gas triggered unprecedented growth and rapid urbanization (Azzali, 2016).

Figure 1. The location of GCC region.

Consequently, the capital of Qatar, Doha, It has grown from a little town to a burgeoning international city with a population of over two million people (QSA, 2015) (Figure 2). The city has evolved from a single center to include the creation of new urban districts. The city's transportation infrastructure was redeveloped and enlarged by the state to facilitate the city's urban fabric development. As a result of Doha's rapid motorization in this setting of urbanization, sprawl, and dependence on private vehicles, environmental challenges, social inequalities, and physical fragmentation are the three main effects. To address these issues, the state government has set aside more than US$100 billion to improve and extend infrastructures such as air and road networks, as

well as to improve the city's transportation system's quality (Shaaban and Radwan, 2014). In response to the previous, implementation of a mass rapid transit scheme in Doha, consisting of four metro (underground railway) and one light-rail transit (LRT) lines, will help to mitigate the negative impacts of traffic and congestion (Azzali, 2016). As a result, the ongoing construction of Qatar's new public rail system (metro), which includes 100 stations will be distributed around the city along four main lines, can provide an opportunity for the development and urban regeneration of transit villages (TODs) as well as metropolitan premises to address comprehensive strategy built by the government (Al Saeed and Furlan, 2019).

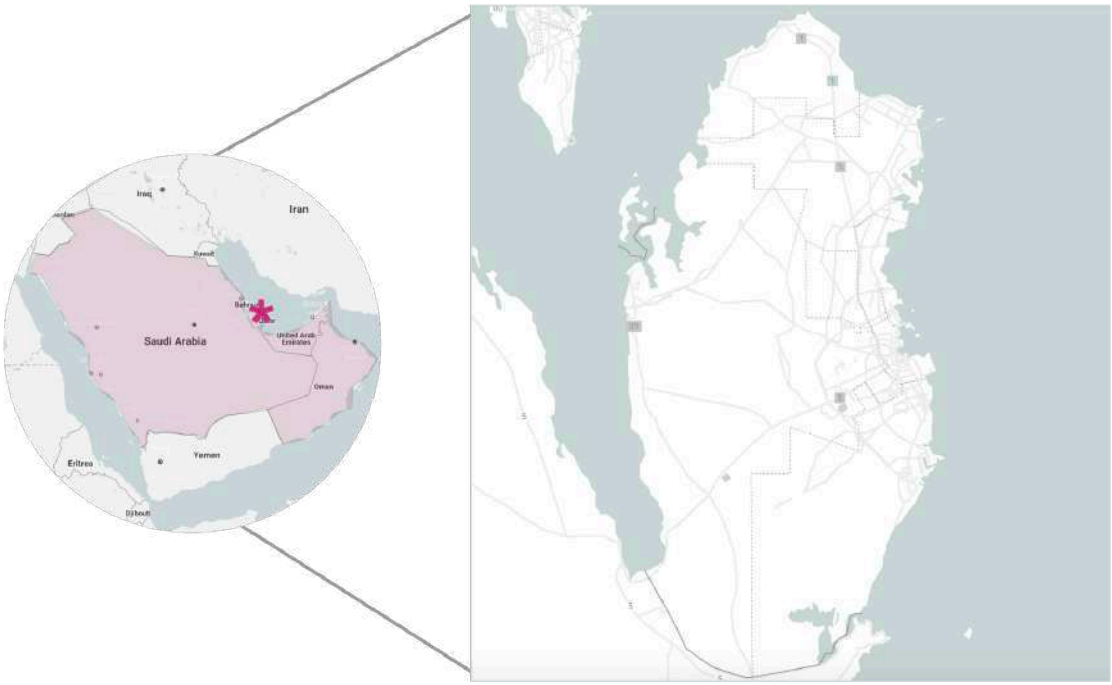


Figure 2. Location of State of Qatar within the GCC region.

1.2. Doha Metro Network

Qatar is a fast-growing Middle Eastern country confronted with difficulties in dealing

with rapid growth, constrained by high demand on the current road network and widespread use of private cars for transportation (Shabaan, 2018). To meet the rapidly increasing demand for transportation, the Qatari government invested in Doha's first public rail metro system. With four lines and 100 stations, design and planning of the metro network connects main town centers, important business hubs and residential regions, Olympic venues, villages, hotel districts, and the new Doha international airport with a total length of around 360 kilometers (km) (Shaaban and Hassan, 2014).

Construction of the Doha Metro network will occur in two phases. Phase 1 is complete and began operations in 2019. Phase 2 is in progress and is due to start operations by 2030. Phase 1 consists of the main three lines – Red, Green, and Gold – to connect and serve the major centers within Doha (Figure 3). In much of the functional aspect, each line generated a form to serve the national vision of Qatar along with the hierarchal distribution of cities. The first phase of the metro project was launched in 2019 by operating Red Line with the aim of decreasing traffic congestion by 190,000 vehicles daily. This phase had three main lines, with 37 stations, 65 trains, and a total distance of 76 km. The stations have different forms of placement, including underground, at-grade, and elevated stations. All the stations interlink to the central terminal station of Msheireb (Technology, 2020).

The Red Line, or coastal line, runs from Al Wakra in the south part of Qatar to Lusail City in the north and provides public rail access to the Hamad International Airport. The 40 km-long line covers 18 stations, including the stations related either to entertainment center points or business hubs. The Gold Line, or historic line, accesses the most historical site in Doha, Souq Waqif, and connects the Ras Bu Aboud area and Al Aziziyah area with 11 operating stations along the 14 km route. Finally, The Green Line, or Education Line, stretches 22 km and runs from Al Riffa to Al Mansoura. The

line covers 11 stations, including Msheireb Station at the heart of Doha, Hamad Hospital, Qatar National Library, and Education City. The line runs through the Education City, which has a diversity of well-known universities in the region, making it a significant contributor line to the entire system. 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.

Figure 3. The map is showing the metro tranist system in Doha with three operating lines, Red , Gold , and Green, and the location of the study metro stations.

However, few people in Qatar have used public transit to date (Shaaban and Kim, 2016a, 2016b). The metro must attract a considerable number of users, including

regular transit users and those who commute by automobile, to realize the benefits of the new metro service for lowering traffic congestion in Doha. The more individuals who move to public transportation, the better the city's mobility will be (Shabaan, 2018). Better access to the proposed metro stations is necessary to ensure the success of the new metro system. Most people who use public transportation come from adjacent areas or buildings surrounding the metro stations. The streets surrounding transit stations must accommodate a variety of modes to encourage walking and biking including buses, pedestrians, and bicycles.

1.2.1. West Bay Metro Station (West Bay District)

The station is in the primary business hub of the West Bay area in Doha, specifically in Zone 60 (Figure 4). West Bay is a recent development in Doha, i.e., the last thirty years (Al Saee and Furlan, 2019). The city paid a great deal of attention to developing the district due to the semi-circular shape of the coastline of Doha and invested significant funds arising from the oil and gas revenues of Qatar (Furlan, 2015). In addition, the district includes important transit stations, two of the 18 stations allocated within the Red Line pass through the West Bay District from south to north of Doha coastal lines (Furlan and Alfaraidy, 2017a, b) (Figure 5).

The station is a few minutes' walk from Doha's Al Corniche, provides access to vital areas in the city and the district between recreational and business areas. It is on the Red Line right after Al Corniche Metro Station and before DECC Metro Station. It lies on Majlis Al Taawon Street, next to the Qatar Petroleum District in the West Bay District. The station is on the north-south Red Line, which only recently resumed regular operations. Because of its location within Doha's CBD, this station should draw prominent ridership levels in the future, especially when other components of the city's

public transportation system are entirely connected with the Doha Metro (Alattar et al., 2021).

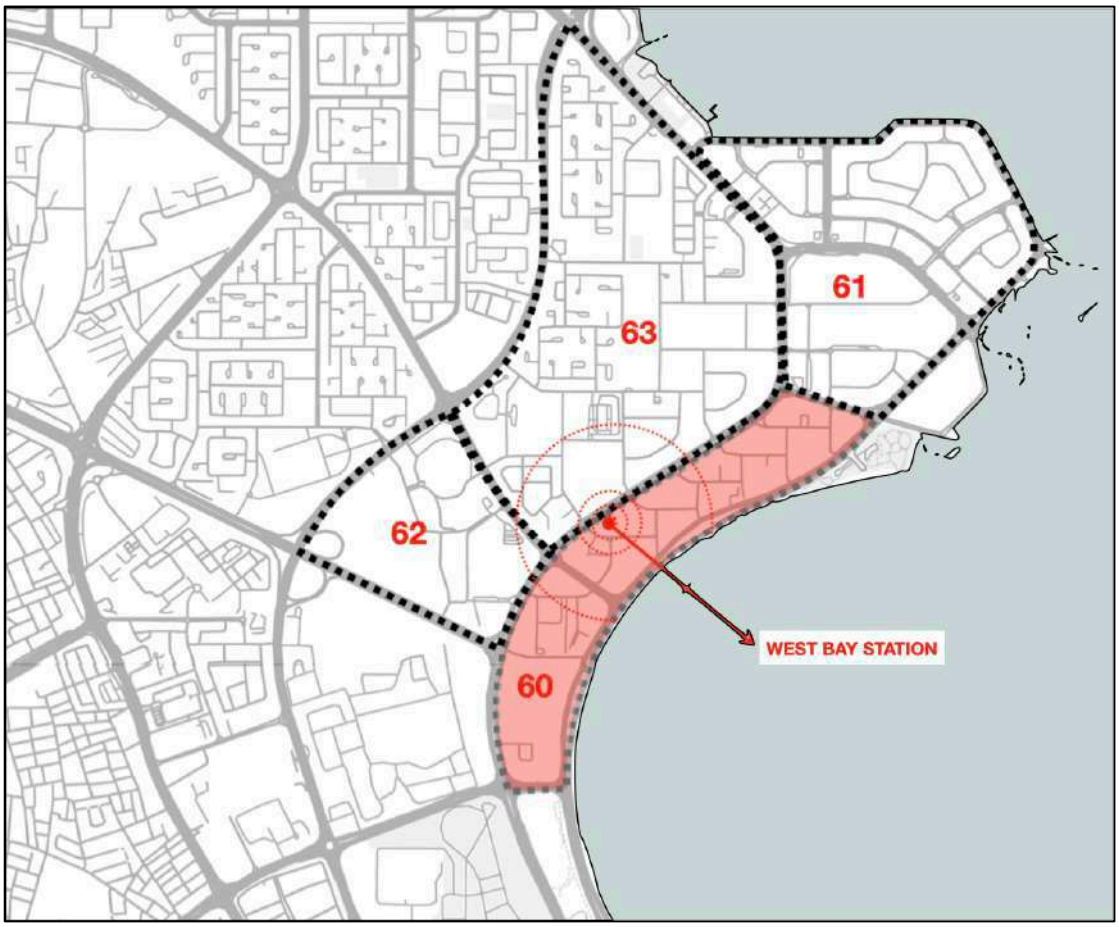


Figure 4. Location map of West Bay Station within Zone 60 of West Bay District.

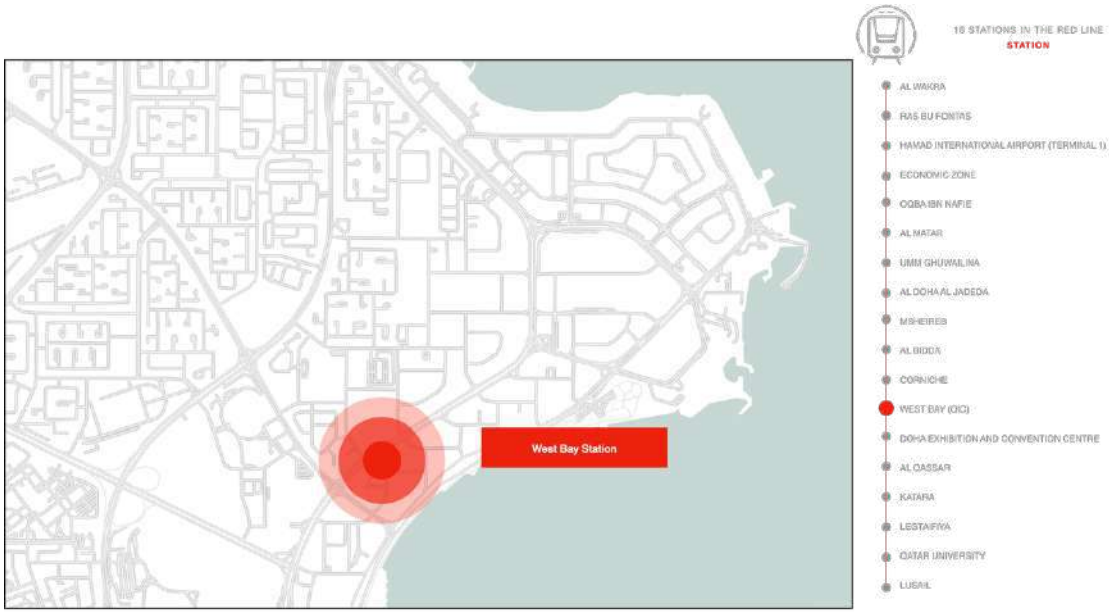


Figure 5. Map of West Bay Station location within West Bay District (left). The location of West Bay Station within the Red Line as it located number 18 station (right).

1.2.2. Hamad Hospital Metro Station (Al Sadd District)

Al Sadd neighborhood is part of the Doha Municipality, and it consists of residential blocks in the center and mixed-use complexes and institutional buildings on the outskirts. Significant development has resulted in an infusion of varied national workforces to support the expansion process over the years (Al Suwaidi and Furlan, 2018).

Hamad Hospital Station is within the Al Sadd area of Doha in Zone 38 (Figure 6). The station is next to Al Rayyan Road, between Mohammad Bin Thani Street and Ahmed Bin Ali Street to the west and east, respectively. This metro station, which serves the surrounding area, has its main entrance on Al Rayyan Road. Due to the dramatic increase in population in the Al Sadd area, which contains 17,820 people in Qatar's population (Planning and Statistics Authority, 2015). Major establishments surround the station and define the area, such as Hamad Medical City, Centre Point, Grand Regency Hotel, LuLu Centre, Royal Plaza, and the Sadd Plaza (Al Suwaidi and

Furlan, 2018).

According to the Qatar National Master Plan, Hamad Hospital Metro Station is a ‘node center station.’ One entry is located on the southern side of Al Rayyan Road and provides bicycle storage and bus waiting areas. A second station entrance is a corner doorway giving access to Al Balagh Street, a minor road, and a bicycle storage space. This position is more visible and accessible, so better suited to service the metro station’s area, including high-density residential zones (Nafi et al., 2021). Furthermore, a potential future station entry on Al Rabeia Road will allow access to a route that provides a north-south link from Al Rayyan Road to Al Sadd Street and the center part of the Al Sadd neighborhood (Al-Thawadi et al., 2021). It is the 5th station in the Green Line, which connects the city from the east to the city’s west side (Figure 7).

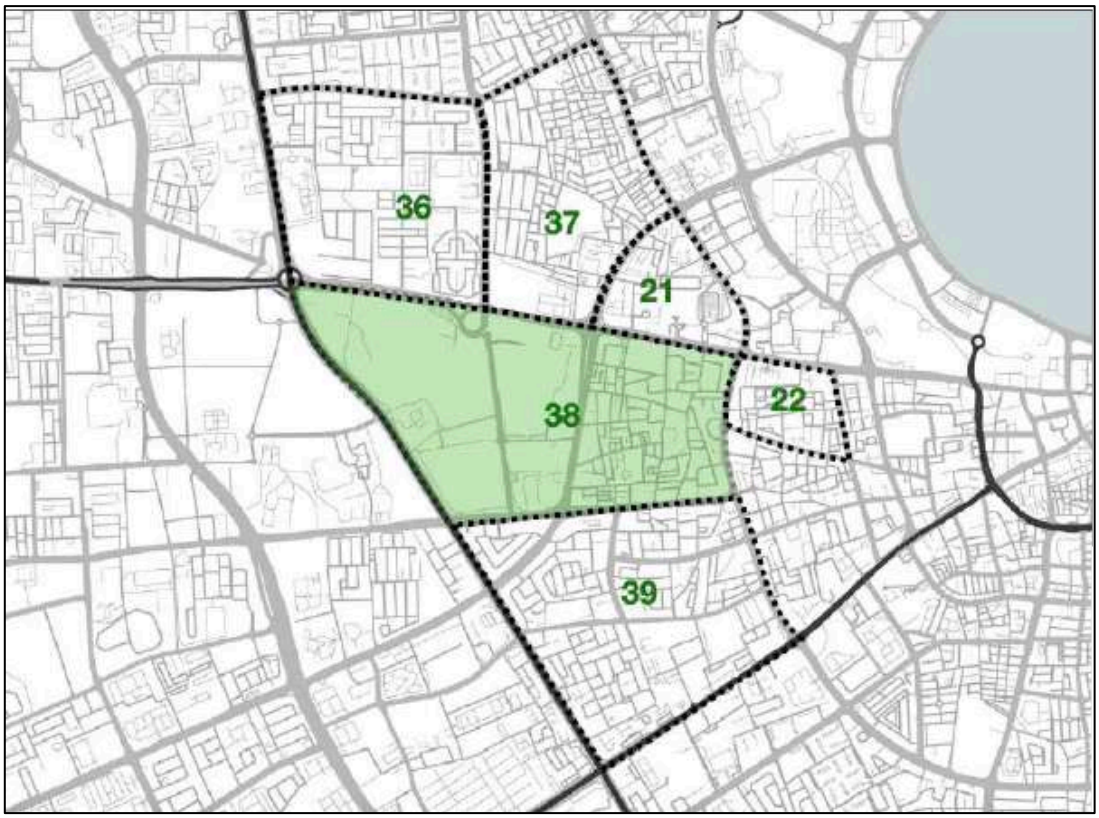


Figure 6. Location map of Hamad Hospital Station within Zone 38 of Al Sadd district.

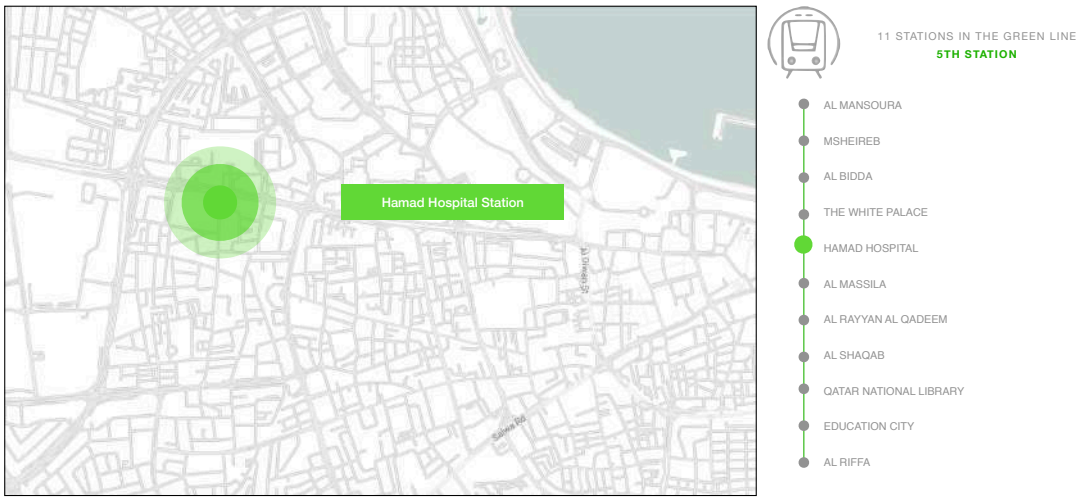


Figure 7. Map of Hamad Hospital Station within the Al Sadd District (Left). The location of Hamad Hospital Station on the Green Line as it is located number 5 station (right).

1.2.3. Al Aziziyah Metro Station (Al Aziziyah District)

Al Aziziyah Station extends the adjacent Sports City Station area within the Municipal Zones of 54 and 55 (Figure 8). The station falls under Al Aziziyah district on the south side and the Baya district on the north side of Al Rayyan Municipality. It encompasses parts of the international sporting complex and major shopping malls. The metro station area highlights a culmination of recreation, shopping, leisure, and culture serving.

Al Aziziyah Station sits along a suburban development area of Qatar. It strategically locates along Al Waab Street, forming part of the Gold Line network. Residential land uses and local serving shopping facilities surround the metro station. The station is next to Villaggio Shopping Mall, Hyatt Plaza Shopping Mall, and Aspire Park, all significant destinations for families. Al Aziziyah Station is the terminus station in Phase I, providing access in only one direction east-west towards Old Doha (Figure 9).

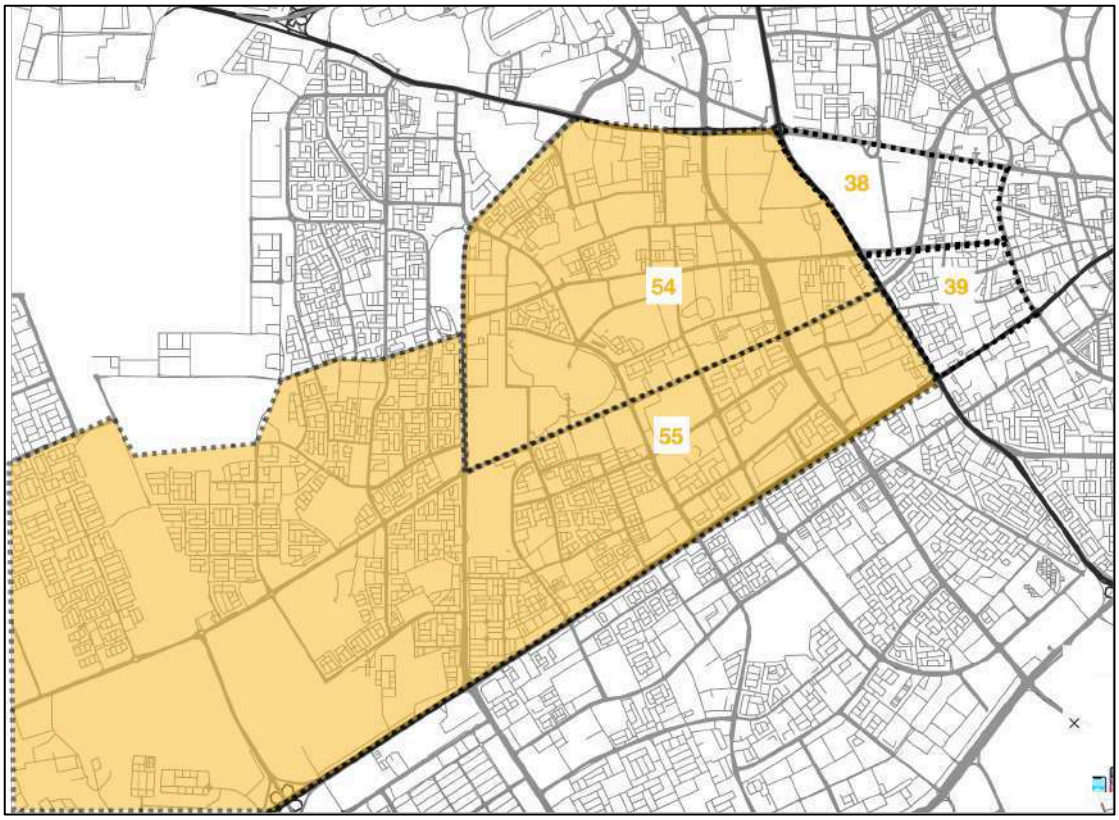


Figure 8. Location map of Al Aziziyah Station within zone 54 & 55 in Al Rayyan Municipality.

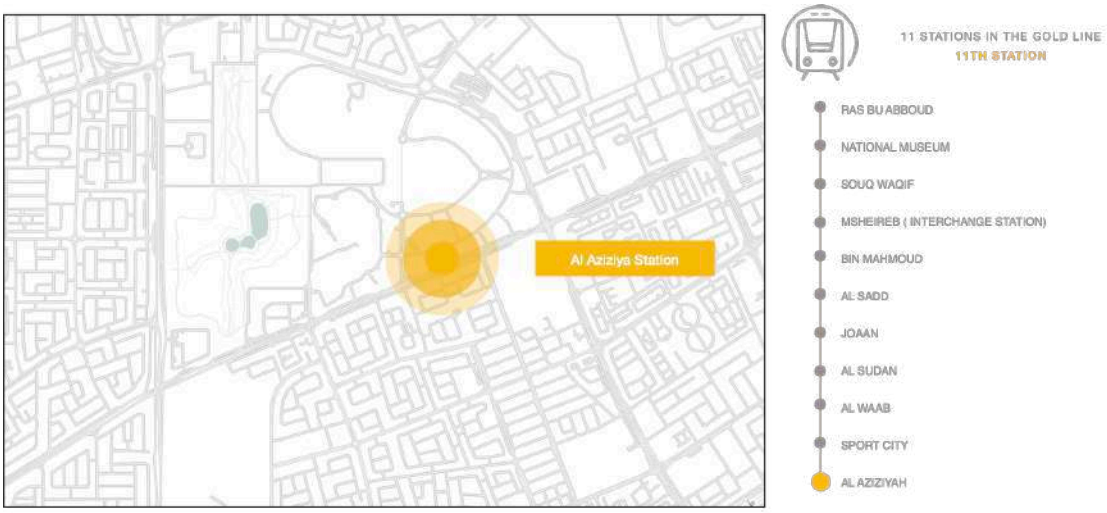


Figure 9. Map of Al Aziziyah Station within the Al Sadd District (Left). The location of Al Aziziyah Station on the Gold Line as it is located number 5 station (right).

1.3. Problem statement

After World War II, most urban planning theories and practices were affected by traffic-based development: transportation analysis rarely accounted for the quality of the environment and the user perceptions, as it focused on the motorized vehicle. Pedestrians were not a priority and even negatively considered because they did slow down the flow of vehicles at street crossings (Ramsey, 1990). The consequences for the urban environment and pedestrians have been enormous.

However, in the last two decades, attention to the pedestrian environment and walking activity has been increasing thanks to policies oriented to identify and develop the concept of walkability as the foundation for a sustainable city. Yet, as cities have been rapidly growing in recent decades, significant issues in the realm of transportation have developed. Doha, the study area, is a rapidly expanding city with a substantial increase in recent years. It began as an undersized village and grew into an urban city with numerous problems, particularly those related to land issues, which have led to constant conflicts.

In response, the Qatari government invested in rail and bus transit systems to reduce the urbanization issues and encourage the usage of a public rail transit system. However, the transport system tissue lacks connections between pedestrians and the transit system. It reduces the mode choice or ability to walk or cycle around metro stations. Several factors affect the decision to take the metro to transfer from one point to another. However, the lack of a cohesive structure between the built environment and transport system plays a vital role in making a metro network a mode choice for travel. Therefore, it is fundamental to focus on all those urban design features that influence pedestrians' walking choice and behavior and identify what promotes and discourages the walking activity from setting the design criteria of the urban

environment surrounding metro stations.

1.4. Developing Hypothesis, Research Questions and Objectives

Despite all the urban studies taking place in Doha, there is no emphasis on walkable urban streets around catchment areas. The hypothesis drives this thesis that creating a walkable infrastructure can help weave Doha's catchment areas fabric together. This research also develops hypotheses that draw on the research logic and understanding of the topic to articulate statements to drive the research questions and objectives (Figure 10).

- Doha's built environment around metro stations is not performing to the expectations of users.
- There is potential in creating pedestrian-friendly walkable environments around metro stations resulting in increased transit ridership.
- Enhancing the micro-scale level of the built environment around metro stations can increase transit ridership.

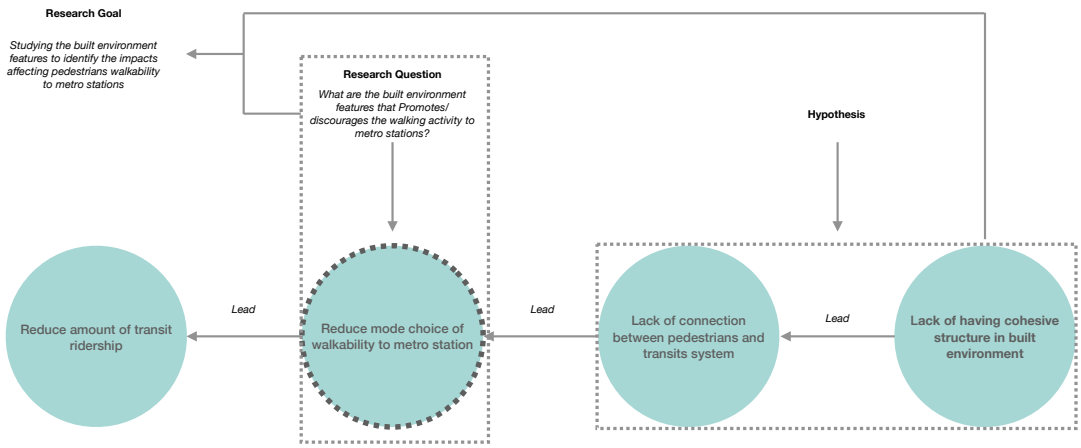


Figure 10. Development of research hypotheses and problem-definition for main questions and goal of the research.

1.4.1. Research Questions

This study aims to find answers to the following questions, which form the spine of the theoretical framework for this thesis.

The main research question is:

- What are the built environment features that promote or discourage walking activity to and from metro stations?

To answer this question, the thesis responds to the following sub-question:

- How are the three metro stations similar or different from each other within their urban context, specifically the impact of the built environment features within three selected case studies that covers different type of settings?

1.4.2. Research Objectives

Research main goal is to study the built environment features to identify the impacts affecting pedestrians' walkability to metro stations. These features are identified based on criteria arising from the current state of knowledge in the field in the literature review in Chapter 2. However, to achieve the purpose of this research, sub-objectives were generated, leading to the outcome of this research (Table 1).

Table 1. Research Questions and Objectives.

Research questions	Research objectives
• What are the built environment features that promote or discourage the walking activity to and from metro stations?	Identify the levels of the built environment around metro stations and the degree to which the urban environment plays a role in influencing walkability to and from metro stations.
• How are the three metro stations similar/different from each other	Investigate the urban environment context of the three metro stations. In this sense, this research's vital goal is to

Research questions	Research objectives
and fit/operate within their context at the macro and micro scale?	understand better how these metro stations and the built environment work.

1.5. Research Design

The research divides into chapters that drive the structure and arguments of this thesis (Figure 11).

Chapter 2, "Literature Review," explores the various definitions and the relevance of the subject. It will consist of three main sections: 1) introducing the sustainable urbanism and building relationship between the urban fabric and transportation implementing the Transit-Oriented Development (TOD) concept, 2) evaluating the relationship between walkability and the built environment in the frame of distinct characteristics shaping forming built environment and 3) presenting the background about urban development in the case study of Doha, Qatar.

Chapter 3, "Research Design," addresses the research methodology and approach of this thesis. It will introduce the selection procedure of metro stations based on their activities and importance. It includes the scope of research focusing on the different strategies used for in-depth analysis of the spatial structure and various methods for collecting data, including site visits, observations, space syntax analysis, photographs, maps, and plans.

Chapter 4, "Findings and Data Analysis," comprises several stages, defining its conceptual framework in the first stage. Then, it presents the process of analyzing the data for the built environment at two levels, i.e., macro scale and micro scale. It also offers a comparative analysis between the three stations based on the selected criteria of analysis.

Chapter 5, "Discussions and Conclusion," provide a brief overview of the

arguments of the thesis, discusses the main vital findings, answers the research questions of the thesis, and provides suggestions for future development. The thesis concludes by suggesting future research for the extension and expansion of the study.

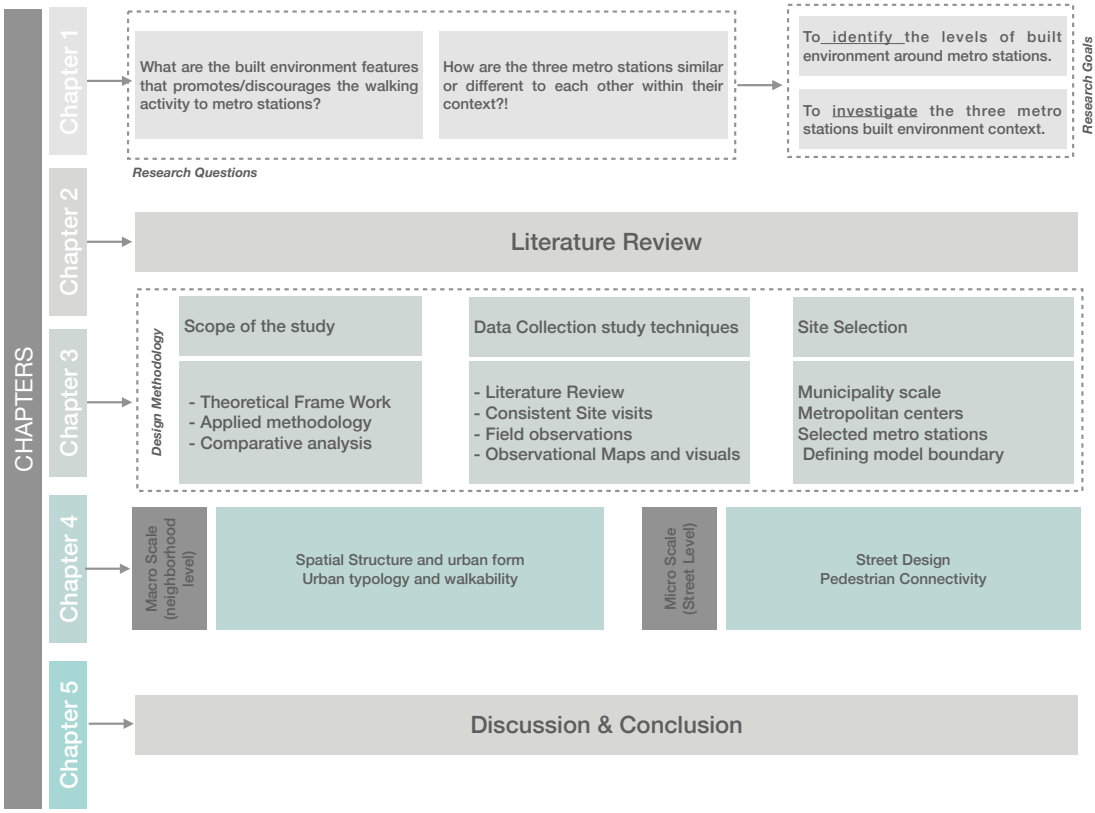


Figure 11. Summary of the organization of the thesis.

1.6. Significance of Study

Doha Metro began operating on 8th May 2019 with the Red Line including specific stations, followed by Gold Line on 21st November and Green Line on 10th December of the same year, leading to entire operation by the end of 2019. However, due to COVID 19 pandemic, the Doha public rail system had to stop operating during the lockdown in 2020 and began operations again on 1st June with a low percentage of transits due to capacity limits. It means that the new rail system operated for a few

months at total capacity, allowing limited time for research about its relation to the urban context in actual operation. Not much-published research occurred studying the Doha metro rail system after opening in 2019. However, Al-Thani (2021) did examine the central terminal station in Msheireb Downtown Doha. She explored several aspects such as travel behaviors, focusing on available parking and mobility, and the built environment elements of design quality of streets, urban fabric, pedestrian friendliness, and land use.

This study will focus on studying aspects of the built environment at micro and macro levels, including urban blocks, pedestrians' movement traces, pedestrian connectivity, and street design around metro stations allowing us to understand how the built environment affects walkability to metro stations. It will also provide more space to study additional aspects in future studies around metro stations. This study will also expand to different metro stations around the metropolitan of Doha by looking at other metro stations, which are representative stations for distinct types of areas.

1.7. Limitations of the Study

While perusing this master's research and drafting of this thesis, there were some factors contributing to limitations of the scope and expansion of the research, included but not limited to:

1) Time was a major factor in authoring this research, which affected other factors. Due to a full-time employment of the author, time was a challenge in balancing the research data collection or writing up of the research.

2) Covid-19, due to the recent events of the pandemic affecting all aspects of daily life routine during this research, collection of the data was challenge. Rail metro system was adjected according to the pandemic leading to either full closure of metro

systems and stations for serval months or operating at 30% during the collection of data phase for this thesis.

3) Provision of resources as some data resources were not easy to obtain due to the sensitivity of the information. Since the rail transport system is a national project, the resource information and maps are considered confidential, and sharing was not allowed by several agencies.

1.8. The Disciplinary Context

This study is multidisciplinary, incorporating urban studies, architecture, history, and other integrated social sciences. However, this research is specific in its disciplinary context with issues related to the built environment and walkability within the MENA region, especially metro stations in the Gulf Cooperation Council (GCC) countries.

Metro stations developed over a long time play an essential role in urban history, so the next chapter (Chapter 2: Literature Review) offers a brief historical review of the development and evolution of metro stations. It is also essential to understand and analyze the main characteristics of shaping the railway systems, in general, to assess the three-case study of metro stations in this research. This importance is due to the following:

1) There are many studies on the rail public transport system in European cities and older cities of the United States. However, public rail transit and urbanization in the GCC region are relatively new phenomena, lacking a comprehensive study.

2) There is a lack of study about the relationship of the built environment, pedestrian movement, and walkability associated with metro stations at a detailed level.

Understanding these built environment factors will allow for more in-depth knowledge and analysis of catchment areas, which can help establish urban design guidelines and successfully contribute to the long-term vitality of these metro stations-built environment contexts. It includes location, spatial structure, urban typology and walkability, street design characters, and pedestrian connectivity.

CHAPTER 2: LITERATURE REVIEW

The literature review of the thesis occurs in three sections in this chapter: (2.1) Sustainable Urbanism, (2.2) Walkability within the context of the built environment, and (2.3) Historical background of regional context and development of rail transit system.

Section 2.1 consists of four main parts. The first part provides a morphological analysis of the urban layouts and their relation to the transport system. The second part offers a general overview of the development and urbanism in the Arabian Peninsula and the Gulf region specific to the three main phases that manifest the overall urban growth of its cities. First, the pre-oil settlements as a product of a simpler economy and tribal traditions, then the current situation arising from the discovery and production of oil and natural gas, and, finally, future visions and frameworks that might characterize the post oil-city. The final part introduces the concept of the TOD and the vital influence of TOD on public rail transit systems. The last part focuses on urban planning and catchment areas in the public rail transit system.

Section 2.2 consists of three main parts. The first part introduces the concept of walking, illustrates the importance of walking and the motivational aspects that influence people to walk. The second part focus on highlighting the built environment factors affecting walkability. The third part continues to clarify the relationship between the built environment and walkability.

Section 2.3 consists of two parts, including introducing the context of Qatar and providing historical background of the urban context. Then, it focuses on creating the public rail transit system and provides a brief introduction to the Doha Metro.

2.1. Sustainable Urbanism

The MENA region is home to around 381 million people spread across 8.9 million square kilometers (km^2), accounting for 6% of the world's total population and land area (World Bank, 2014). It possesses ~57 percent of the world's petroleum reserves and 41 percent of its natural gas reserves, primarily concentrated in the Gulf States of the Arabian Peninsula (Source: US Department of Energy). As a result of increased urbanization and globalization over the previous half-century, the region has become a crucial source of global stability.

The Arabian Peninsula spans over 3.2 million km^2 for six countries: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE). It is bound to the west and southwest by the Red Sea, northwest by the Persian Gulf, north by the Levant, and southwest by the Indian Ocean. The Arabian Peninsula's landscape is made up of a big central plateau, a mix of desert, coastlands, and beaches, lush oasis, and mountain regions. The region is distinguished by geographical variation, spanning from the central plateau to the rocky desert in the north, sand dunes in the east, and coastlands with coral reefs in the Red Seas. With the discovery and exportation of oil and natural gas in the 1950s and 1960s, the Arabian Peninsula spent the last half-century transitioning from traditional economies and cultures to modern states of economic development and diversification (Tannous, 2020).

These states have had significant urban population expansion, demographic shifts, infrastructural development, and extensive alterations to the built environment. The newly constituted nation-state, land speculation, and political and economic competition for regional leadership were powerful motivators for dictating spectacular rapid urbanization (Benkari, 2017). This chapter aims to analyze the contextual

background of the urbanism in the Arabian Peninsula while focusing on the specific case study of Qatar.

Whilst the terms 'sustainability' and 'sustainable development' are relatively new to the profession, they have become a fundamental aspect to the urban development field. Development that meets current demands without jeopardizing future generations' ability to meet their own needs was the first definition of sustainability and sustainable development generated by the Brundtland Commission in 1987 (WCED, 1987). However, some scholars consider this definition to be vague at best (Jacobs, 1999). Al Thani explained the confusion of the definition as it is not clearly defining the types of development (e.g., environmental, economic, social, or other) nor how it will be sustainable for current generation demands without jeopardizing future generations' needs (Al Thani, 2021).

Sustainable urbanism cannot avoid examining the triple bottom line, regardless of one's concept of what sustainable and sustainable development are. Contemporary urban sustainability research generally focuses on environmental concerns by "exploring more efficient urban structures as well as technologies to reduce energy waste the sustainability of urban environments is highly dependent on economic growth and social equity" (Wiedmann et al., 2014; 1).

The triple bottom line concept of sustainability is recently introduced to the GCC Region. GCC countries growth had been revolving around creating Sustainable development. The outcome of leases on gas and oil resources is the social connection that links GCC governments to their citizens. Citizens expect to have certain privileges under the social compact. In this perspective, urban development is crucial since most citizens have moved to cities with jobs opportunities, especially governmental jobs, which many citizens and expatriates seek. One factor for fostering sustainable

development is the growing number of citizens in major cities.

Increased automotive traffic is one of the biggest challenges stemming from the mobilization of people to the GCC's major cities. It has led to pollution as well as decreased levels of livability and sustainability. " ...improving public transport, encouraging non- motorized modes, creating pedestrian zones, limiting the use of private cars..." are some activities that can help cities satisfy urban sustainability criteria (Pojani and Stead, 2015; 7785). This issue has been addressed in Dubai and Doha through extensive infrastructure overhauls to the transportation system.

The vision of the Qatar National Development Plan (QNV) 2030 is based on four pillars of sustainable development: the environment, economy, social, and health. Sustainability has also been incorporated into urban masterplan development activity. Sustainable development is more than just a goal to strive for; "... it is a process of uniting, formerly independent, social, economic and environmental policies into a systems approach" to make a space livable (Richer, 2014; 14).

The QNV 2030's sustainability vision centers on livability. To pursue greater livable environment, the government has established plans to build traffic-reducing infrastructure (e.g., highways) as well as railway system connecting the urban fabric of the country. TODs were incorporated into the government's plans as a holistic planning paradigm that assures that urban fabric development, mixed-use facilities, activity nodal areas, and public services are all centered around multimodal transportation terminals (Furlan et al., 2018). The Doha Metro and TODs would maximize the integration of transportation systems and land use by creating sustainable, lively, livable, compact, and mixed-use communities. (Furlan et al., 2020).

2.1.1. Urban planning and Transportation

The essential skeleton of the urban form is the road network (Schlossberg, 2006). Therefore, the structure of the city and the development of the urban perimeter are influenced by social, industrial, and economic developments. In fact, the evolution of street patterns has consequences for the quality and character of future urban areas (Southworth and Owens, 1993).

If transportation planning did not play an essential role in urban planning at the beginning of the last century due to a movement of people and goods based primarily on walking, horse-drawn cart, or carriage, in the 1930s, then attention began to split between two different branches: one focusing on the technical aspects of transportation planning and engineering and the other focusing on micro variables characterized by the use and form of local places and the building.

Southworth and Owen (1993) investigated the expanding metropolitan fringe, identifying the underlying concepts and spatial typologies and analyzing expansion, land use, and street layout trends during the last century. It is fascinating to see how urban planning has evolved as the volume of urbanization has increased. As previously said, street patterns are the first indications of settlement and serve to divide and connect various urban zones. They characterize and influence inhabitants' habits and jobs since they control where residents can go, how fast they can move, and what they can experience when traveling.

2.1.2. Station Catchment Area

The station catchment area is the spatial area where stations often have the largest impact on land use and development, as well as a major potential for transit ridership usage. (American Public Transportation Association, 2009). The concept of urban

planning and design as well as transportation was used to identify target locations where various TOD techniques should be implemented to maximize TOD's positive benefits. Station catchment areas of assorted sizes have been proposed. Guerra et al., (2012), for example, stated that in the United States, a half-mile (800 meters) became the standard measure for determining a transit station's catchment area. On the other hand, based on an analysis of walking trips to transit stations, Cervero (1997) proposed that the catchment area in suburban areas could be more significant due to low housing populations and large supplies of parking. However, based on actual evidence from Irish planning practices, Harrison (2012) concluded that 1 km was the most often recognized distance for a train station's walking catchment. Although the scale of a station' geographical region seems to vary reckoning on the regional context and mode of transit (O'Sullivan and Morrall, 1996; American Public Transportation Association, 2009 there is broad consensus that the catchment area of a train station must be defined in a way that that effectively covers the potential demand for transit passengers.

Pedestrians, cyclists, park-and-ride customers, and people who utilize other non-motorized modes of transportation are common transit users (Thompson et al., 2012). However, in the Seoul region, the majority of transportation users are pedestrians. As a result, a station's catchment area is determined by the distance that people are willing to go to take a transit ride (Kim and Nam, 2013).

2.1.3. Transit Oriented Development

As it offers an integrated approach to transportation and land use planning, the core concept incorporates all the theoretical considerations discussed above: transit-oriented development. TOD refers to residential and business centers that are intended to

maximize access by transit and non-motorized vehicles and include other characteristics that attract transit ridership (Litman, 2017). A typical TOD features a rail or bus station in the middle, surrounded by high-density development, with lower-density development spreading one-quarter outwards to one-half mile, representing pedestrian scale distances (Renne, 2009). This minimizes the distance required for automobile travels, allows for more trips by walking and cycling, and allows households to eliminate their car ownership, all of which can result in significant reductions in vehicle travel. It can do more than reduce car journeys; it can also improve accessibility and transportation options through land-use clustering and mix, as well as non-motorized transportation improvements.

TOD effectiveness is determined by numerous factors including higher-than-average density, land use mix, roadway connectivity and design, and building design. In contrast to Transit Adjacent Development, which is conventional, automobile-oriented development located near transit stations, Renne (2009) defines specific factors required for proper Transit-Oriented Development, in which residents own fewer cars, drive less, rely more on alternative modes, and a high level of local accessibility. Pollack, Gartsman, and Wood (2013) created the eTOD station area rating system, which analyzes individual rail stations based on transit service quality, rider orientation, and the connectedness of local development to the station.

Krizek's (2003) study examines the travel behavior of the same households across time in conjunction with extensive urban form measurements. The data imply that as households are exposed to different urban designs, their travel behavior changes.

People who live in locations with better neighborhood accessibility are more likely to walk and use public transportation than those who live in more traditional automobile-oriented surroundings.

The pedestrian access between transit stops and the adjacent surrounding neighborhood is an often unstated but critical component of TOD philosophy (Schlossberg, 2004). pedestrians' ability to navigate and access variety of land uses close to transport terminals is considered as a successful application of TOD. A significant component of TOD success is transit users' ability to access the transport stop, to begin with, or essential destinations after arriving at their destinations. As a result, because transit riders are pedestrians on at least one end of their transit travels, the pedestrian environment surrounding transit stops is critical to understanding TOD (City of Portland Office of Transportation).

2.2. Concept of Walking and Walkability

"Walking is the first thing an infant wants to do and the last thing an old person wants to give up. Walking is the exercise that does not need a gym. It is the prescription without medicine, the weight control without diet, and the cosmetic that can't be found in a chemist. It is the tranquillizer without a pill, the therapy without a psychoanalyst, and the holiday that does not cost a penny. What's more, it does not pollute, consumes few natural resources and is highly efficient. Walking is convenient, it needs no special equipment, is self-regulating and inherently safe. Walking is as natural as breathing." (Walk 21, 1999).

Many of the advantages of walking for individuals have been described in these phrases from the International Walking Charter. Because it exercises both the physical and mental bodies, walking is the most natural human means of transportation. Walking has even greater community benefits because it engages people both socially and geographically. Pedestrian has been relegated to second-class status on the street despite the growth in population and size of cities, thus, people have forgotten how and why to walk. It also plays an inevitable role in the debate over urban sustainability.

The section that follows explores walking importance in terms of urban sustainability, concentrating on its environmental, economic, and social benefits. It also provides a summary of the elements hypothesized to influence walking behavior, with a focus on the interaction between walking and the built environment. Following that, the concept of walkability is introduced, followed by a discussion of current walkability measuring approaches.

2.2.1. Importance of Walking

Every trip starts and ends with a walk, and everyone is a pedestrian for some portion of the journey (Cambra et al., 2012). Walking is often the only means for many people to get around on a daily basis; unfortunately, the streets and public areas that were once designed for walkers are being degraded and overrun by private vehicles, drawing social life apart from them (Ghidini, 2011, Krambeck and Shah, 2006, Abley and Turner, 2011). Since walking provides social, environmental, and economic benefits, it is " the foundation for the sustainable city." (Forsyth and Southworth, 2008; 1).

Walking is the most equitable means of transportation from a social standpoint because it is economical and requires only basic infrastructure. This is because pedestrian amentias can benefit a larger proportion of the community than highways

and railways improvements, walkable environments are associated with more democratic and ‘civilized cities’ (Lo, 2009). Forsyth and Southworth also extended these benefits to a range of populations, including the elderly, children, and low-income individuals who are unable to own or operate automobiles and not only in terms of population counts. Furthermore, walking provides life to streets and makes them more livable, leading to safer urban environments. Walking's importance in terms of community safety, accessibility, and social inclusion has become a focus of urban design (Evans, 2009), as pedestrian access in most cities has continually declined over the last century (Forsyth and Southworth, 2008).

In the perspective of the environment, walking is a ‘green’ mode of transportation since it has minimal impact on the environment and causes no pollution on air or noise. The provision of walkable environments and public transportation infrastructure could provide substitutes to driving a private vehicle, reducing traffic congestion, noise, and air pollution. Walking, as a moderate-intensity physical activity, has been demonstrated in numerous recent health studies to improve mental and physical health, including cardiovascular fitness and stress management (Forsyth and Southworth, 2008). In recent years, public health experts in several nations have adopted guidelines encouraging people to engage in at least 30 minutes of moderate physical exercise on most days of the week. However, it has been discovered that a considerable percentage of the population (30-60%) maintains a sedentary lifestyle (Bourdeaudhuij et al., 2005).

From an economic sense, walking is a low-cost activity for pedestrians when compared to other forms of transportation since it consumes less energy and resources in general. Additional economic advantages include the expansion of local businesses such as street retail and tourism, as well as large-scale public health savings.

2.2.2. What influence people to walk?

Because disabled people are also categorized as pedestrians with reduced mobility, walking is a vital means of transportation for everyone. Most people assume that their human body is all-terrain since it can endure slopes, stairs, uneven surfaces, and a wide range of weather conditions (Allan, 2001). These characteristics, however, have limitations. The most major constraint has been assumed to be stamina, as a person's fitness decreases with tiredness. This means that the person's starting speed will progressively drop, making long trips difficult to manage. For instance, a walker can sustain speed of 6 km/h for 20 minutes then start dropping to 5 km/h after 30 minutes to reaches 4 km/h after an hour (Allan, 2001).

Walking performance is further impeded by poor weather conditions. The principal practical (physical) limits of walking as a means of transportation are then tied to the distance required to walk, or, on the other hand, the time required to walk those distances (heat, rain, snow). Walking has long been acknowledged as one of the most appealing means of short-distance transportation. Data indicates that almost 80% of people are willing to walk up to half a mile (approximately 800m) to arrive at their destinations (Emery and Crump, 2003, Allan, 2001).

Many other issues have been identified in the urban context as limitations or restraints to walking (Handy, 2005). Stressors such as noise, congestion, traffic jams, community violence and crime, and physical elements that impair a sense of place are examples of such problems. The safety issue (as in dread of crime) has repeatedly been stated as the most significant restraint to walking by the most vulnerable populations and those who rely on walking the most (Evans, 2009). However, environmental elements that encourage walking have been found (as physical activity). Recreational activities, community cohesion, and physical qualities that increase imageability and

legibility are among these aspects (Handy, 2005).

Along with environmental factors, socioeconomic factors have been shown to impact travel behavior (Handy, 2005). Determining what motivates people to walk or what people value when deciding on a route choice was all proven using the Travel behavior theories.

According to Handy, in travel behavior theory, utility maximization mainly refers to lowering monetary costs and trip time. Generalized costs, which are quantified as a linear accumulation of attributes, each with a weight representing its importance, can be used instead of monetary costs. Elements such as 'comfort' and 'convenience' can be added as well. It has been suggested that when walking, considering total economic considerations such as comfort and convenience is likely more essential than simply calculating route time or distance. However, in the frame of travel, time and distance, perception becomes more crucial than actual time and cost (Handy, 2005). Furthermore, the utility-maximization model predicts that to maximize utility, travelers will reduce trip time, and walking would only be a feasible alternative if it could provide shorter travel times than other modes of transportation. Other benefits of walking (such as the pleasure of walking, social connections, or visual involvement) may considerably boost the utility of the decision to walk (Handy, 2005).

The conceptual understanding of walking alternatives has been enhanced with additional layers of complexity. The research of Kahneman and others (Kahneman, Wakker et al., 1997, quoted in Handy, 2005) shows that choice rationality is not always 'rational.' The term 'remembered utility' refers to a decision's retrospective evaluation that can influence a future decision. The remembered utility may lead to decisions that do not maximize value in the case of erroneous retrospective evaluations. Ratner and others' experiments (Ratner, Kahn et al., 1999 quoted in Handy, 2005) showed that

people are willing to sacrifice utility maximization for diversity. Meaning, rather than choosing the option that maximizes utility at the time, people may choose a less-preferred alternative to remember the series of choices more pleasurable.

The psychology field managed to feed the theories of planned behavior by providing additional essential insights in understanding and recognizing elements that influence behavior. The individual's thoughts – or perceptions – about the presence of such entities, rather than their real existence, are thought to explain behavior in this hypothesis. This indicates that, when walking, the presence or absence of sidewalks, as well as the presence or absence of traffic, can either help or hinder a behavior. Social standards are also important in this concept, especially when it comes to deciding whether to walk, bike, or take public transportation instead of driving (Handy, 2005).

A person's lifestyle indeed has an impact on longer-term decisions. That is, some people may choose to live and work in areas that best suit their lifestyles and resources, a process known as 'self-selection' (Silva et al., 2006). In this situation, people who enjoy walking will seek to live in more walkable neighborhoods. in different circumstances, the environment influence decisions, and people who live in walkable neighborhoods will prefer to walk more frequently in this situation (Schmid, 2006). (Figure 12).

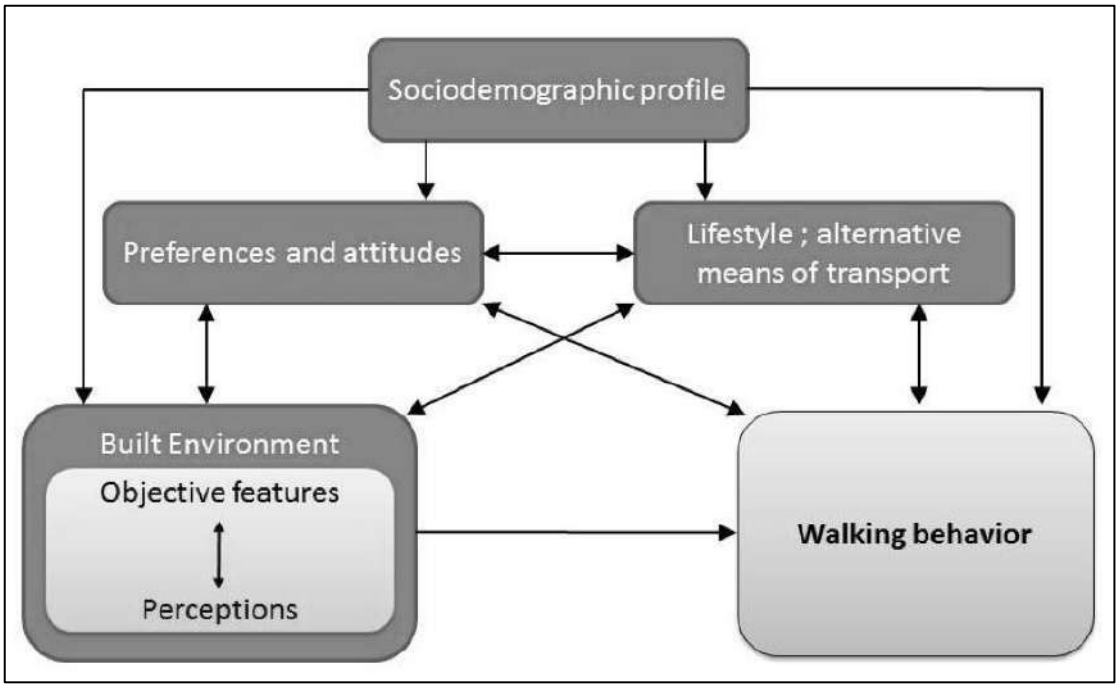


Figure 12. Conceptual framework factoers forming walking bahviour adapted from Handy (2005) and Schmid (2006).

Handy and Schmid's research, as illustrated in Figure 12, examined and summarized the conceptual links between walking and the environment. Sociodemographic variables, tastes and attitudes, lifestyle, the availability of alternative means of transportation, and the built environment are all factors that influence walking. Walking habits have been shown to influence lifestyle, preferences, and attitudes. The link between the built environment and walking behavior demonstrates how a location's qualities might influence a person's mode of transportation. This link demonstrates how the characteristics of a location can influence people's perceptions, attitudes, and lifestyles, thereby encouraging them to walk. It's easy to see how characteristics that prevent people from walking can change over time and under the influence of a pedestrian-friendly environment (Schmid, 2006). Within the scope of this study, only the interaction between the built environment and walking is investigated.

The built environment factors that have been associated to walking behavior are discussed in the following section.

2.2.3. Built Environment Factors Influencing Walking

At this stage, no differentiation has been drawn between distinctive styles of walking. Walking can be described broadly as walking for transportation, exercise, or pleasure/recreation (Cambra et al., 2012). Leslie et al. described the importance of distinction since the characteristics of the urban environment that influence walking behavior in terms of destination when it comes to walking for transportation versus walking for exercise and recreation are different. This means that walking for transportation or utilitarian purposes becomes a way of getting to a destination, whether it's a resource, activity, or function, like going to work or school, shopping, hanging out with friends, and so on. Walking for pleasure or recreation becomes a goal, with benefits such as exercise, relaxation, and contemplation. Although recreational walking is regarded to be more important in terms of physical exercise, transportation studies have always concentrated on utilitarian walking (Schmid, 2006).

The concept of the built environment has also not been introduced up to this point. There have been many numerous definitions of the term 'built environment,' and the lack of an agreed-upon definition has been a major contributor to the disparate approaches to defining and assessing built-environment parameters (Handy, 2005).

For this study, Cervero's definition of built environment has been utilized. It defines the physical aspects of the urban environment (i.e., surrounding landscape changes) that collectively form the public sphere, which might be as little as a sidewalk or a local retail shop or as huge as a new neighborhood. (Cervero and Kockelman, 1997).

Specific built-environment features are relevant at each spatial level, just as they

are for diverse types of walking, and the influence of the built environment on physical activity at one spatial level may be dependent on the influence of the built environment at another geographical scale (Handy, 2005).

The constructed environment is separated into two aspects, according to a conceptual framework (Figure 12): objective and perceived. Perception is defined as the process of being aware of and interpreting sensory input, according to urban planning literature. The result of what one perceives is the product of interactions between one's prior experiences, culture, and perception of what one senses. (Ewing and Handy, 2009). Then, it should be highlighted that physical, objective characteristics of the environment have an impact on the quality of the walking environment, either overtly or implicitly, on both individuals' perceptions and sensitivities. It is also worth noting that just a few components of urban design are objective and can be assessed objectively. According to Ewing and Handy, other attributes such as sense of comfort or level of comfort are largely perceptive, triggering varied responses in different people (Figure 13).

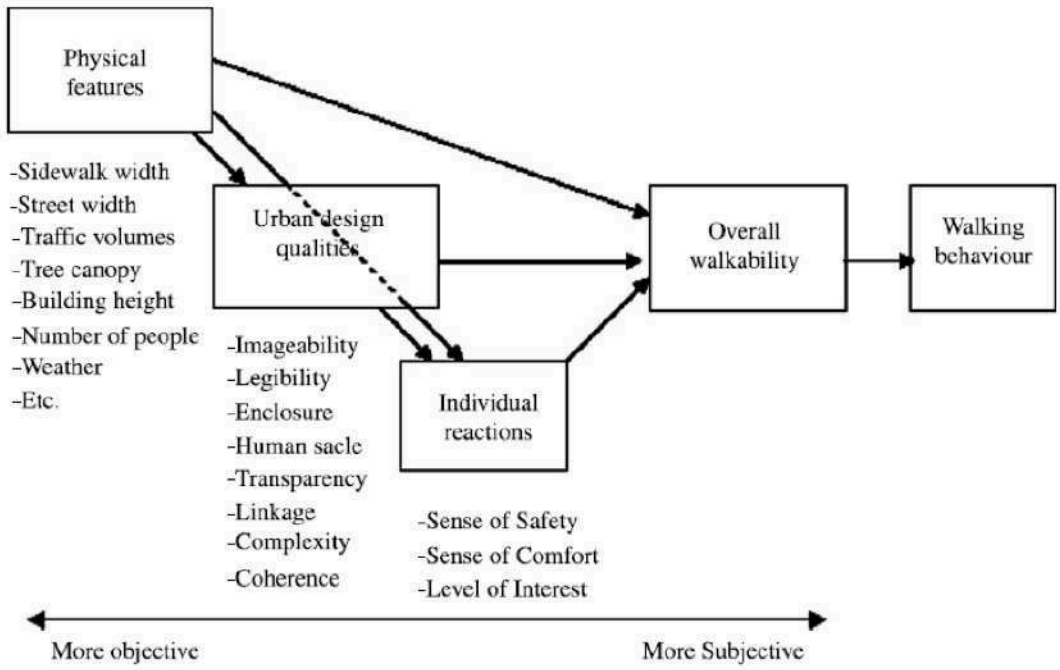


Figure 13. Conceptual framework adressing the role of preception between physcial features and walking behavior (Source: Ewing and Handy, 2009).

According to the urban planning and design literature (Handy, 2005), the following built environment elements are most critical to walking:

Imaginability

Imageability is defined by Kevin Lynch (1960) as a physical environment attribute that inspires a firm picture in an observer: "It is that shape, color, or arrangement which fosters the making of vividly identifiable, forcefully structured, beneficial mental representations of the environment" (9). A well-formed city has distinct components and is easily recognized by anyone who has visited or lived there. It has easily recognized pieces that are organized into an overall pattern. It taps into our natural ability to notice and remember patterns. Imageability is the quality of a place

that distinguishes it as distinct, recognized, and unforgettable. When specific physical elements and arrangement attract attention, inspire feelings, and leaves an impression, then a location has high imageability.

Enclosure

Vertical elements that obstruct viewers' lines of sight form and shape outdoor settings. A sensation of enclosure occurs when sight lines are so strongly barred that outdoor places appear room-like, as various urban design theorists have stated. According to Gordon Cullen (1961), "Enclosure, or the outdoor room, is, perhaps, the most powerful, the most obvious, of all the devices to instill a sense of position, of identity with the surroundings it embodies the idea of hereness" (29). Enclosure is eroded by breaks in the continuity of the street wall, that is, breaks in the vertical elements such as buildings or tree rows that line the street. The degree to which streets and other public places are visually delimited by buildings, walls, trees, and other vertical elements is called enclosure.

Human Scale

Human scale is defined differently by urban designers. According to Alexander et al. (1977), any building taller than four stories is out of human scale. Where significant buildings or wide roadways might be intimidating to pedestrians, a canopy of leaves and branches, according to Henry Arnold (1993), allows for a simultaneous perception of the smaller space within the larger volume. Human speed can also be used to define the human scale. According to Jane Holtz Kay (1997), far too many things nowadays are created to support the bulk and rapid speed of the automobile; we are designing for 80 km/hour.

In addition to these characteristics, the expert panel linked human scale to the complexity of paving patterns, the amount of street furniture, the depth of setbacks on tall structures, the presence of parked cars, building ornamentation, and window and door spacing. Interestingly, due to offsetting street-level components, both the high-rise Rockefeller Center and Times Square were viewed as human-scaled. Human scale refers to the size, texture, and articulation of physical elements that correspond to the size and proportions of humans, as well as the speed at which humans walk. Physical features that contribute to the human scale include building details, pavement texture, street trees, and street furniture.

Transparency

Transparency is a material condition permeable to light and/or air, an intrinsic quality of matter such as a glass wall. A classic example of transparency is a shopping strip with display windows that attract passers-by to look in and then come into the shop. Buildings with reflected glass and blank walls are famous examples of design components that reduce transparency. However, transparency can be more nuanced than this. What is beyond the street's edge can only be imagined, not seen. According to Allan Jacobs (1993), streets with multiple entryways contribute to the sense of human activity beyond the street, whereas those with blank walls and garages imply that people are far away. The degree to which people can see or perceive what lies beyond the edge of a street, particularly the degree to which people can see or sense human activity beyond the edge of a roadway, is referred to as transparency. Walls, windows, doors, fences, landscaping, and openings into mid-block spaces are all physical factors that influence transparency.

Complexity

Rapoport (1990) explained the essential properties of complexity in the built environment. The number of noticeable differences to which a viewer is exposed per unit time is proportional to complexity. Human beings want to receive information at usable speeds. Too little information causes sensory deprivation, whereas too much information causes sensory overload. The variety of building shapes, sizes, materials, colors, architecture, and ornamentation adds complexity. According to Jacobs and Appleyard (1987), narrow structures in various configurations increase complexity while vast buildings decrease it. The visual richness of a location is referred to as its complexity. The variety of a place's physical environment, precisely the number and types of buildings, architectural diversity and ornamentation, landscape components, street furniture, signage, and human activity, determines its complexity.

2.2.4. Relationship between Built Environment and Walking

Several meta-analysis studies conducted in-depth reviews of the relationship between the built environment and walking. Mixed-use development, street connectivity, and good design were suggestions provided by Handy et al. (2002) after providing an overview on urban planning studies which investigate the relationship between the built environment and physical activity (walking and bicycling). In a review of environmental and walking literature, Saelens et al. (2003) discovered that density, mixed land use and distance to non-residential destinations all showed a consistent positive relationship with walking. Kerr et al. (2012) analyzed a large number of studies on physical activity and the built environment to see if there was a link between the built environment and three distinct types of physical activity (transportation walking, recreation walking, and total physical activity). They asserted that ease of access to

destinations is critical in deciding whether the built environment favors transit movement, considering that safety, aesthetics, and parks are more significant than recreational walking destinations.

Density and diversified land use are crucial factors related to walking at the neighborhood level. One of the most important 'D' variables influencing transportation behavior is density (Cervero and Kockelman, 1997). Walking is linked to density because increasing density creates urban environments with compact land use and closer destinations, making walking more practicable and advantageous and eventually culminating in a critical mass of people (Forsyth et al., 2007; Sun et al., 2014). Several studies have presented the statistical significance of the relationship between walking and density using various density measures (Thomsen, 2011). Such as gross population and employment density (Frank and Pivo, 1994), development density (Lee et al., 2013; Sohn and Kim, 2010), population density (Saelens et al., 2003), and residential density (Saelens et al., 2003). In addition, multiple research studies have shown that mixed land use has a good impact on walking (Frank and Pivo, 1994; Lee and Sohn, 2012; Cervero and Kockelman, 1997). Proponents of mixed-use developments argue that putting origins and destinations closer and around each other encourages people to walk (Cervero and Kockelman, 1997).

In the study of walking habits, the effects of smaller scale of built-environment characteristics such as pedestrian amenities, sidewalk quality, public transportation availability, and the presence of retailers and enterprises were explored (Ferrer et al., 2015; Kim et al., 2013; Oakes et al., 2007; Sisiopiku and Akin, 2003). According to the findings of the study, more pedestrian activity on the street is associated to higher growth density, a greater mix of land uses, crossing aids, aesthetic value, and street conditions (e.g., slope, breadth, pavement) (Borst et al., 2008; Rodriguez et al., 2009;

Lee and Moudon, 2004; Cauwenberg et al., 2012; Park et al., 2013).

In conclusion, past research has found strong links between walking and the physical environment. At the neighborhood level, the most significant indicators of walking are density and land use diversity. Factors like as transportation accessibility, street connectivity, and land use density and diversity have been discovered to influence the desirability of walking on the street level (Kim, 2017). These findings provide a plethora of information for building urban design and planning strategies for Transit-Oriented Developments.

2.3. Measurement Attributes

This research aims to scientifically measure what appear to be subjective aspects of the walking environment. Although the framework has been defined by Ewing & Handy (2009) relating the physical features with urban qualities and individual reactions, the study of this thesis focuses on understanding the physical features at two levels of measurements considering the direct interaction with individuals (sidewalks, weather, building heights, greenery, etc.) and planning/neighborhood structure at a larger level of the study (block sizes, density, connectivity, etc.,). The findings will provide a physical framework for urban planners and designers to take future adjustments into consideration.

Table 2 illustrates the two levels of framework measurements followed by the indicators of street design to study the pedestrian environment, road design to study the vehicular environment near streets, and urban design to study the context of the area at a larger scale. The table summarizes possible factors and attributes of the built environment affecting the walkability to and from the metro stations. However, specific attributes were measured in this study, focusing on performing morphological analysis

and space syntax analysis.

Table 2. Factors and Attributes Used to Study the Built Environment (with highlighted criteria of this study in bold).

LEVEL	INDICATORS	FACTORS	ATTRIBUTES
Micro Scale (Direct Interaction)	Street Design	Street Geometry/Street Condition	**Sidewalks Width** **Street Segment/Length** **Continuity of sidewalks** **Street Shading/Provision of greenery** **Density of streetlamps** **Provision of crossing points and facilities** Signage and Wayfinding
	Road Design	Infrastructure and traffic	Street or road character Traffic volumes Speed levels Traffic safety Pollution and noise Public transport connectedness
Macro scale /Metropolitan scale (In-direct interaction)	Urban Design	Spatial pattern of the area and the urban context/ Urban Typology in relation to walkability/pedestrian connectivity	**Density/Diversity** **Buildings Height** **Block sizes** Permeability **Pedestrian network** **Building Frontages** Parking lots/ Voids

2.4. Space Syntax Analysis

Space syntax is a collection of theories and methodologies for modeling and evaluating cities that use built space as the city's primary generator. Bill Hillier and his colleagues developed space syntax theory in the 1970s and 1980s (Hillier and Hanson 1984; Hillier et al., 1987). They manage to represent society's logic through its appearance in spatial systems explaining the configuration of spaces. It relates to how people perceive spatial systems, move through them, and use them from small domestic spaces to large-scale urban regions. (Penn et al., 1998). The configuration-function link, often known as the space-society paradigm, directly impacts design and planning of the built environment. Analysis of spatial configuration is a valuable tool for creating, structuring, maintaining, and modifying urban functions since there is a clear relationship between spatial configuration and urban functions (Karimi, 2018).

Because of the nature of the elements utilized in computer modeling simulation, any analysis of spatial configuration using space syntax relates to how the urban system works. Simply said, this transforms a set of analytical spatial models into a functional approach for assessing how movement, activity, and behavior disperse across a spatial system (Karimi, 2012). These methods are simple, but they can become more complicated by integrating spatial arrangement with other spatial properties such as density, intensity, movement, land use, social interactions, and virtually any other property of the city positioned in space.

The model also provides a multi-layer investigation tool as researchers examine configuration in various situations and multi-disciplinary since the spatial qualities of the built environment are a fundamental factor in a variety of fields. The outcome is an

analytical tool that may better comprehend complicated spatial systems and design them using analytical evidence (Karimi, 2018). More details about space syntax representational and modeling techniques are available in Appendix E.

2.5. Qatar Urban Development

Ptolemy's (c. AD 90–168) map of the Arab Land has accounts of Qatar's little peninsula. In this record, the Roman/Egyptian geographer mentions a little peninsula known as "Katara" (Al Buainain, 1999). On the other hand, Qatar as a country is essentially the result of European colonization of the Persian Gulf. The Portuguese (in the 16th century) and the British (in the 19th century) attempted to establish port towns in the Persian Gulf region to enhance trading between Europe and India. The British consolidated their position in the Gulf against other regional powers such as Saudi Arabia and Iran, and international powers such as USA and France with the discovery of oil in Iran, Kuwait, and other Gulf Trucial States (today's UAE, Bahrain, and Qatar) at the turn of the twentieth century and the ultimate defeat of the Ottoman empire in 1918. A series of protection treaties between the small Arab Gulf monarchs and the United Kingdom secured British interests in the GCC region from the end of the nineteenth century until the mid-twentieth century (Rizzo, 2013).

In 1868, a British-led peace deal between Qatar and Bahrain recognized the principality of Qatar (Al Buainain, 1999). The treaty formally recognized the existence of an autonomous sheikdom in Qatar with the Al Thani family as the governor (Adham, 2008). Whilst technically a subject of the Ottoman Empire until 1918, Qatar's involvement in British’s Middle East strategy, especially with the discovery of oil in Dukhan to the west of the country in 1947 cannot be underestimated.

In the late 1930s, oil was discovered in Qatar. Economic use of the natural resource, on the other hand, would have to wait until after World War II. Qatar's population did not surpass 30,000 people prior to the discovery of oil. Only 12,000 people lived in Doha (also known as 'Ad Dawhah'), including the Ottoman soldiers based at Al Bidda Fort (Adham, 2008). The original Doha city districts (in Arabic fereej) grew near the shore to better advantage sea access for pearl fishing. However, the urban shape began to shift with the injection of oil profits, and the city began to grow to the country's interior towards the wilderness and desert (Adham, 2008). After Qatar acquired independence from The British protection in 1971, urban development in the region exploded to unprecedented levels. In fact, Doha has grown from a little port city to a bustling capital region with global ambitions, with a population that is more than 30 times larger than it was before independence. Today, metropolitan Doha is home to Approximately 90% of Qatar's overall population (2.4 million out of 2.7 million people). Between the two most recent general surveys (in 2004 and 2010), population increase was 128 percent at the national level and 93 percent in Doha. It means that Qatar's population has more than doubled in less than a half-decade (Rizzo, 2013). During the same period, the population of other Gulf cities and countries increased between 11%-16% in Abu Dhabi, Dubai, and the UAE.

Between 1949 until the early 1990s, Khaled Adham (2008) identified four major urban development stages in Doha following Pacione's (2005) and Elsheshtawy's (2004) assessments of Dubai. He characterizes the transitional period (1949–1955) as a pre-oil, colonial urban structure rooted in old vernacular principles, i.e., dense urban plots, small streets, and shared Majlis (Figure 14).

Figure 14. Doha historical settlement (Source: Al Buainain, 1999).

Between (1956-1971) it is called the ‘need’ period as it was the result of slow urban development rather than a quick response of urban growth associated with the high waves of expertise and workers moving in from South Asia and Iran. The 'modernization' era (1972–1984) witnessed substantial urban advances in the city, including the implementation of large-scale urban infrastructure projects in Doha (the New Town of Doha, which encompassed the regions of Al Corniche and Al Dafna) and other metropolitan expansions (Figure 15). Finally, the urbanity of stagnation (the mid-1980s to early 1990s) is the outcome of low rate of urban development due to decreasing oil production and prices in the 1980s.

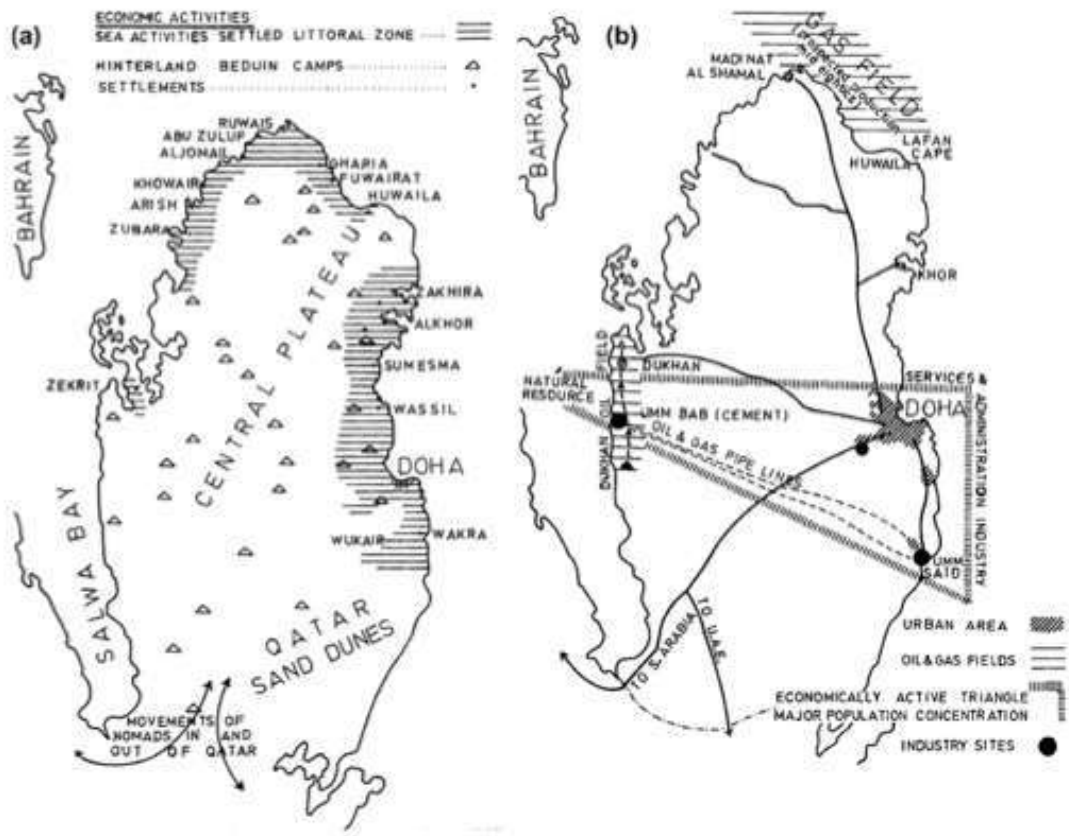


Figure 15. Significant ecological divisions before and after oil economy in Qatar (Source: Riad, 1981).

2.5.1. Development of Doha Metro

Today, metropolitan Doha comprise of nine cities spread throughout the municipalities of Doha, Al Wakra, Al Rayyan, Umm Salal, and Al Dayeen (Figure 16). With the help of new ring roads and major highways, low-rise, expansive urban development has progressively moved to the north of Doha. In Al Wakra, industrial and cargo activities are concentrated to the south, while in the West Bay area, a western-style Central Business District is being created. Education City and Qatar University are two places to the north and northwest of Doha that have research and higher education facilities.

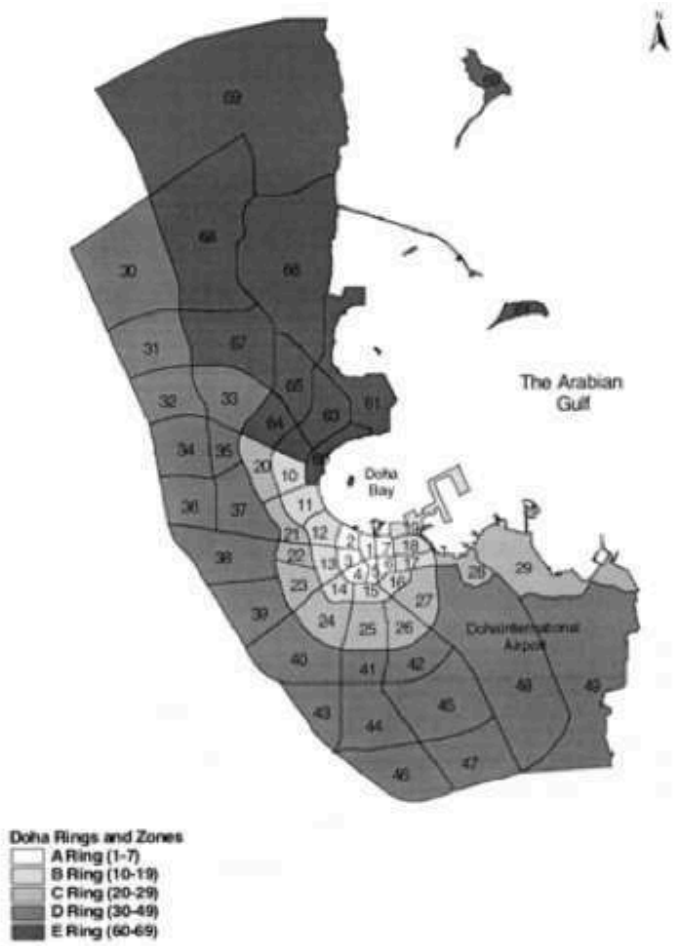


Figure 16. Doha Municiaplity zones (Source: Al Buainain, 1999).

A basic urban tissue of two-story detached dwellings with only a few important landmarks is peppered with private and public mega-projects (Rizzo, 2013). The road network is generous and orderly, as it is in other developing oil-driven economies — for example, Malaysia; (Rizzo and Glasson, 2011) – deterring people from using inadequate public transportation systems. Cycling and walking are further discouraged by the size and inaccessibility of main thoroughfares. The allocation of land for the road network (sometimes up to 30 m in width without crossing points) adds to the establishment of numerous barriers between neighborhoods. Because of all the reasons mentioned above, as well as the harsh climatic circumstances, people living in Doha rely extensively on private vehicles for working, meeting, and entertaining, which

contributes to Qatar possessing the highest carbon dioxide per capita ratio in the world (Energy Information Administration, 2006). Furthermore, the metropolitan area lacks appropriate green public spaces even while shopping complexes and mega malls sprout along major transportation corridors and further congest the road system.

The government has recently completed several projects in Doha that have provided modern urban facilities, including the New Doha International Airport (NDIA) to the south of the capital city, Mshereib Redevelopment in the city center, Aspire Zone to the west, Education City to the northwest, and the ongoing Lusail City development to the north (Figure 17). However, because to a lack of a cohesive development planning, these revolutionary new urban design initiatives contribute to further dividing the city by producing disparities in real estate value, which lead to the division of the have-nots in the neglected areas of the metropolitan region (Rizzo, 2013).

As a response, the Qatari government built the first railway system in Doha, adjusting to the nation's fast urbanization, which dramatically expanded the transportation network. The metro network's goal is to link the city utilizing 100 stations and four lines in a 360-kilometer system that includes stops at the new Doha International Airport, hotel areas, villages, stadiums, major residential and commercial zones, and adjacent cities and towns (Shaaban and Hassan, 2014). The first phase of the metro has been completed before the 2022 FIFA World Cup, with the final segments following four years later (2026).

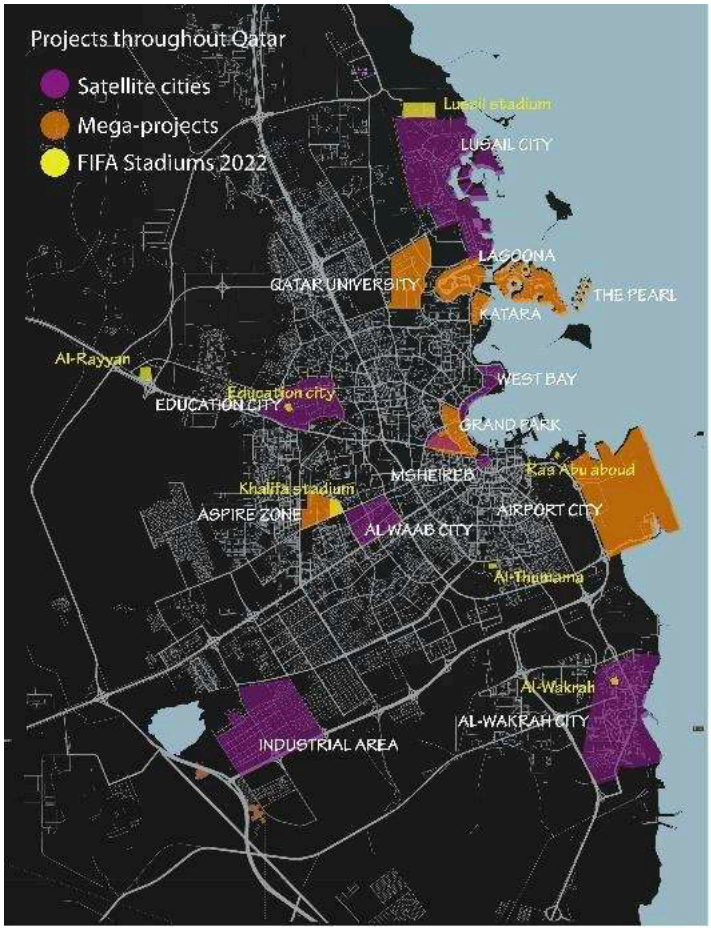


Figure 17. Location of Mega projects in Doha (Source: Tannous, 2020).

The Doha Metro project is a substantial Qatari government project with a ~$9 billion budget that intends to build an effective national railway system. The present phase consists of three metro lines (Red, Green, and Gold) distributed around Doha, with futuristic Blue Line meant to operate at a later stage (Figure 18). The metro line construction began in 2013 and is divided into two sections. Phase 1 entails the construction of three lines including a total of 37 stations. Phase 2 will see the start of the Blue Line (or the City Line), the extension of all present lines, and the inclusion of 60 new stations. All these expansions are scheduled to be finished by 2026 (Source: Qatar Rail).

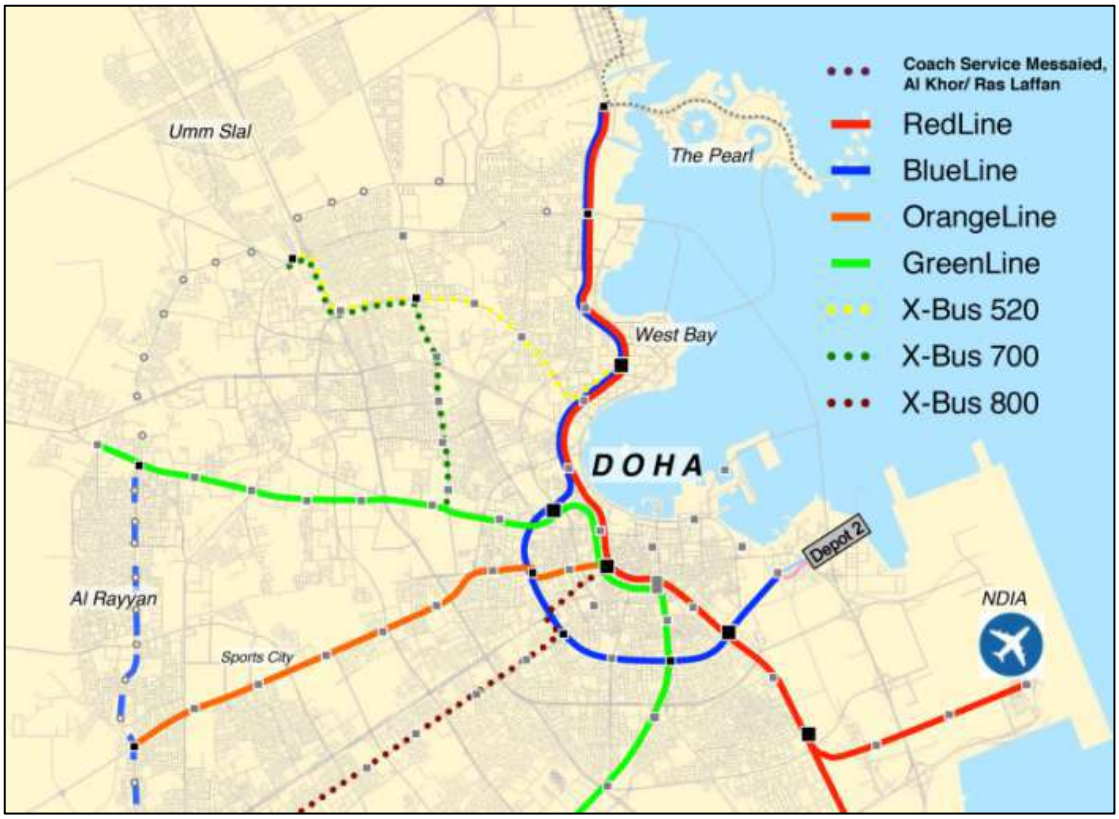


Figure 18. Diagram showing Doha mtero network including the four lines spreading around the city (Source: Furlan, 2015).

The network system links Qatar's key residential and industrial centers with a high-quality railway system with high-end amenities that moves riders at 350 km/h over short distances. The metro system will connect vital facilities around Qatar, including towns, World Cup venues, and hotels. The network will also be expanded to include connections between Hamad International Airport and Doha's port. The lines are run on an overhead railway and are tunneled. When it comes to generating, the majority of the Doha Metro lines are underground. For underground excavation, tunnel boring machines (TBM) have been employed (Al Thani, 2021).

The current functioning lines are as follows: the Red Line has 18 stops, while

the Green and Gold lines each have 11 stations. The Red Line extends from north to south for 40 km, the Green Line runs from east to west for 22 km, and the Gold Line runs from east to west for 14 km. The longest route, the Red Line, extends from Hamad Airport's coastline road to Lusail, West Bay, and Pearl, connecting to Education City. As it shows in Figure 19, the Gold Line goes east-west between Hamad Airport, the former airport, and industrial sectors, while the Green Line travels from the center of Doha to the western districts of Education City.

Figure 19. Diagram shows the mtero line routes in phase along with the mtro stations for the proposed Study.

CHAPTER 3: METHODOLOGY

The chapter outlines the methodology of this thesis. To assess Doha's current built environment on walkability in three different metro stations, the methodological study included both quantitative and qualitative data collection methodologies. It used a multi-layered framework to examine the current state of the studied locations and network of streets composing the built environment. The research methodology is a framework for evaluation based on several tools deployed in previous studies in the fields of urban morphology and environmental psychology. The first section of this chapter explains the thesis's methodological approach derived from previous studies. The data gathering process and study techniques are described in the second section. The third part will introduce the process of selecting the study areas based on the urban pattern of Doha. The last part will define a model boundary, explaining the context of the study area around each station.

3.1. Research Approach

The methodology of studying this thesis will focus on studying three aspects 1) the scope of the study, 2) site selection, and 3) data collection techniques. The data for the study was collected in a systematic manner. First, the scope of the study. Second, the selection of the areas will be mainly based on the land use and activities. Third, the data collection indicators which are based on previous literature reviews. The methodology for measuring the built environment and walkability is defined in three steps, and it covers the factors and attributes that are thought to be relevant to walkability (Figure 20).

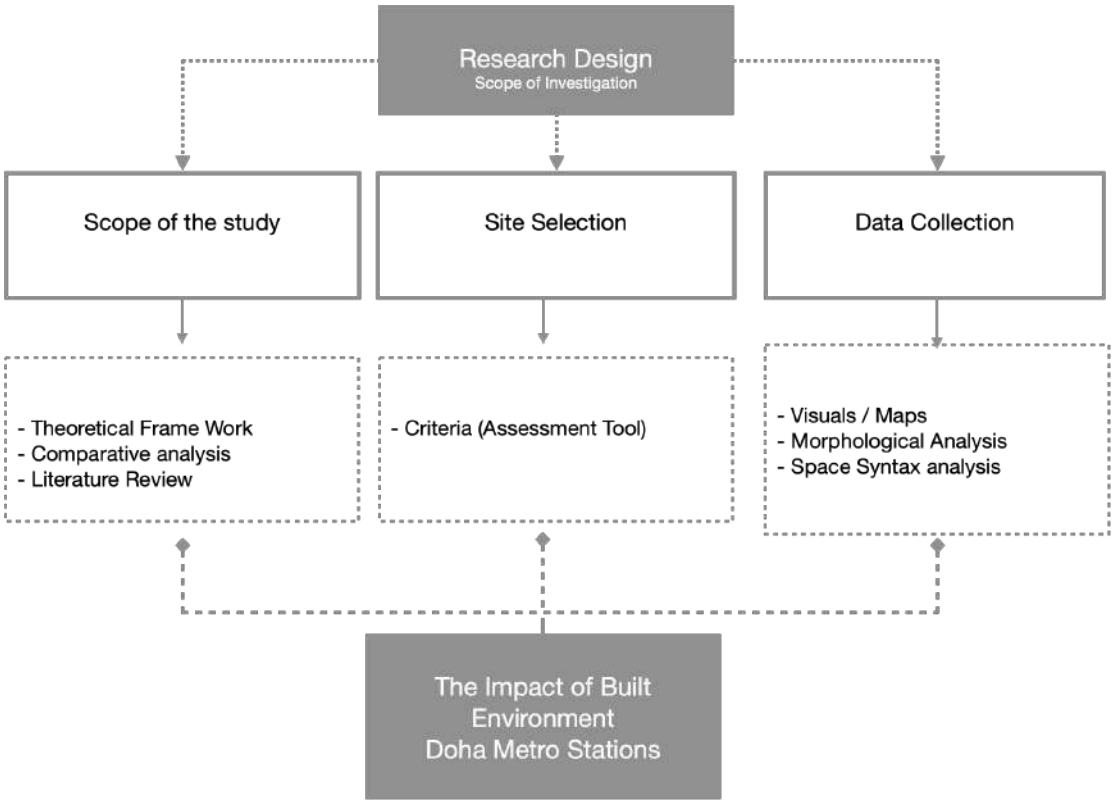


Figure 20. Summary of the research design of the thesis.

3.2. Scope of the Study

1. Theoretical framework

The theoretical framework includes an overview of walkability in gulf region focusing on the regional contexts of the capital city of Doha in Qatar, metro stations in urban context as well as a conceptual review of related concepts such as sustainable urbanism, TOD, walkability, and factors influencing built environment.

2. Comparative analysis

A comparative analysis is conducted between three metro stations. The study of the metro stations analyzes urban structure, urban spaces, street design, urbanity, surrounding and activities according to a set of common factors and attributes.

3.3. Data Collection Study Techniques

Researchers commonly utilize qualitative analysis to produce subjective measurements of a real-time situation to broadly illustrate attributes of the built environment and its use. The research in this thesis does the same, except many measurements are based on quantitative techniques common in the field of urban morphology, public transport, and space syntax (Whitehand, 2001). These measurements are conducted to obtain a better understanding of the built environment in each metro stations covering aspects of urban structure, urban spaces, street design, urbanity, surrounding activities and human behavior. These measurements also are helpful in fostering the study analysis results and determining their applicability because they make interpretations more realistic. In addition, they enable users to express complex points of view. Hence, the main techniques used to make these measurements were literature review, consistent site visits, field observations, observational mapping, and visuals. The thesis uses a few numerical measurements, especially in Chapter 4 "Findings," such as block size, streets segments and street width based on figure ground representations of the urban pattern, and street length and metric area based on the axial lines in the space syntax model (see Appendix E for a brief introduction to construction of the axial map).

Secondary data, such as online references, journal articles and books, were collected from the literature review. Consistent site visits and field observations were conducted in each study area to investigate user behavior such as use and activity patterns. Therefore, the observation checklist was formulated and filled by the researcher in the study areas.

3.3.1. Site Visits

The methodology includes a survey of existing physical conditions of the urban

fabric and streets (figure ground, street segments, traces of pedestrian movement patterns, block sizes and active/inactive frontages), observation to study and analyze the functions and human interaction within the built environment in each metro station. The multiple site visit to Hamad Hospital, West Bay and Al Aziziyah Stations occurred between January and July 2021.

3.3.2. Plans and Maps

Official maps of Qatar and Doha were collected from governmental online channels this includes Ministries and Municipalities of Doha, Qatar National Development Master Plan and Public Work Authority (Ashghal). For the outline set of Doha Metro lines maps reference was located based on Qatar Rail website. For the purposes of analyzing the current conditions for each metro station maps and help in understanding the impact of built environment the products of CGIS Qatar with different multi layered maps was used.

3.3.3. Observation, Photographing, and Test Walks

The aim of observation method was to allow the observer to list down all potential human behavior and traces of pedestrian movement patterns to and from the metro stations using different access points. This method managed to identify the traffic flow of users in the streets during the peak hours. Photographing was essential tool since it outlines the existing conditions of the areas along with the streets for visual aid and analytical purposes. Tests walks were elaborating in understanding the walkable distances from metro stations to destinations and the common size of street segments used by majority of people leaving the metro station.

The research will allocate the selected metro station in a general map of 1 km

distance. This map manages to create a direct reference between the metro station and understanding the correlation to the general context within the areas located at. Most of the data collection will be analyzed using block-based figure ground presentation within 200 m. The purpose of the figure-grounds is to illustrate urban form and space, scale comparisons, active and inactive frontages, street distances analysis, and the pedestrian shed.

3.4. Site Selection Methodology

In this section, it was important to set certain criteria to able to choose station for study which can fulfill the purpose of the thesis. This study had been divided into two sections, one, is narrow down the choices of the station by studying the urban structure for Doha metropolitan followed by Doha Municipality. Two, studying the existing built environment structure for the best fit to the study based on selected metro stations.

3.4.1. Municipality Scale and Metropolitan Centers

The QNDF (2016) designates a total of twenty-eight (28) Centers for seven (7) municipalities in a hierarchical order. With an aim to well-serve the communities, they work and operate complementing each other, from high order level down to local order level. The twenty-eight (28) centers comprise of three (3) Capital City Centers, three (3) Metropolitan Centers, eight (8) Town Centers and fourteen (14) District Centers (QNDF, 2016) (Figure 21).

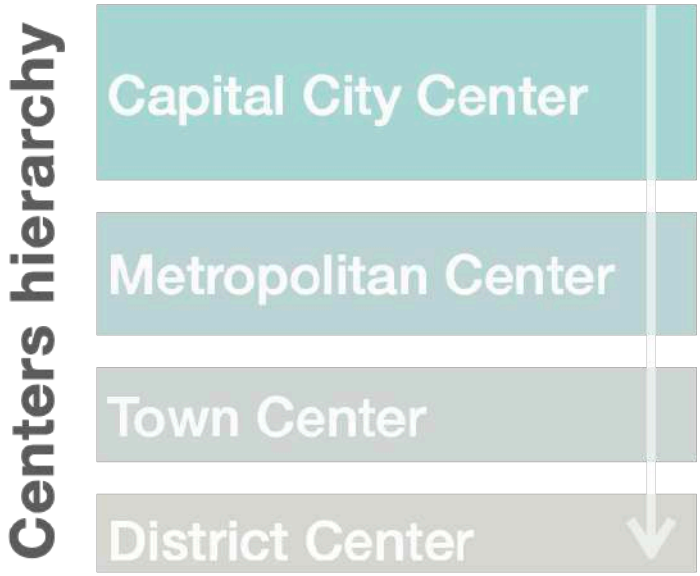


Figure 21. The urban hierarchy of Doha municiaplity.

The QNDF hierarchy of centers is the most important component of Doha Municipality's spatial structure. Employment activities, community services, commercial and retail activities, and transportation services all concentrate in centers. The hierarchy consists of a network of mixed-use and mixed-density centers, each serving a specific catchment of population with a specific role, function, and scale (QNDF, 2016). By looking at the spatial strategy for Metropolitan Doha Structure Plan, the hierarchy centers support the mixed-use areas, which cluster community and cultural activities, government services, leisure, office residential, retail, and leisure, land uses. The structural plan divides into two categories. One related into dividing the Doha metropolitan area into municipalities to manage existing and future growth. The second related to the hierarchy of centers within the metropolitan area.

Doha Municipality is the capital of Qatar, which makes it the busiest municipality in the country. This conveys importance in terms of providing a proper transportation system connecting the mixed-use areas within the municipality. It is Qatar’s largest city with about 50% of the nation’s population living in the municipality

in 2008 and the largest predicted population for 2032. The Municipality is made up of three distinctive separate physical places, all of which are part of the broader Metropolitan Doha. The municipality is centered around Doha's historic center, Old Doha, which includes a mix of older and newer residential districts as well as large-scale commercial areas including the West Bay tower complex and the Grand Hamad banking precinct (QNDF, 2016).

The municipality accommodates the three capital centers, four town centers and nine local centers (QNDF, 2016) (Figure 22). The variations of the centers are highly dependent upon the scale of land use serving its population. This is where the study manages to evaluate how each center is functioning by providing proper accessibility for public transportation and specifically for public rail metro stations.

Figure 22. Doha Municipality, capital centers and two centers.

After choosing Doha Municipality as the main study area, this reduces the

number of the stations from thirty-seven (37) operation stations to twenty-nine (29) stations in the three (3) operational lines. The study is focusing in relating the accessibility of the streets with the surrounding land use to the metro stations. In this is case, it will be more convenient to study two different center zones and understand how each center is providing proper walkable and accessible streets for pedestrians to metro stations.

The Capital City Centers serving national population catchments of 500,000+ people. It will be the location for international, national, and specialized knowledge-based business. West Bay Capital City Center, Downtown Doha Capital City Center and Airport City Capital City Centre are the main city centers for Doha Municipality. As the largest centers of employment and residential population, these centers generate and attract a high number of transport trips. However, to study street functionality, these centers will be more appropriate to study them during maximum capacity. This means, streets should be accessible and functional for maximum number of users during specific time of the day. Areas with high employment, business districts will accommodate a substantial number of users coming and leaving on the same time. Both Down Downtown Doha and Airport City Capital City Centre are areas consist of mixture of land uses such as hotel accommodation, commercial offices, high tech, retail, commercial, professional services, as well as cultural, tourism and entertainment facilities of national and international significance. This means their streets functionality to accommodate maximum number of users is not reachable since it is always dynamic and vibrant areas.

Since one of the main QNFD is promoting walkability and use of public transport rather than using private vehicles, it was important to study streets promoted for daily use to metro stations and public transports. Doha Municipality does not

include metropolitan centers which narrow it down to town centers. Town centers are the third level of the centers hierarchy and are designed to cater for the weekly and day-to-day needs of surrounding suburban residential catchments of 50,000-100,00 people.

Doha Municipality consist of four town centers: Al Gharrafa Town Center (shared with Al Rayyan Municipality), Al Sadd, Old Al Matar and Doha Industrial Area. Since the industrial area is not yet included in the current transit operating train system it will be excluded from the study. This applies also to Al Gharrafa Town Center since it is shared with Al Rayyan Municipality and no current transit system is feeding this area it will be excluded. This leaves two main town centers for the study, Al Sadd Town Center and Old Al Matar Town Center. The town centers managed to narrow down the scope of the study to the principal areas which both town centers fall under, Al Sadd area and Old Al Matar area. In between the two areas it was important to focus on the density of residential zones, walkable distances, and the centrality of the stations. Areas with high residential development was curial for the study as it indicates a high usage of the metro and high walking behavior to metro station. This means it will be important to study-built environment for area with high density. Residential (R5) is defined as High Density Residential Zone in zoning regulations, were the purpose of it is to create high density residential neighborhoods supported by district and town centers. By looking at the zoning plan for Doha Municipality, Al Sadd area has the highest residential area with R5 (see Appendix).

West Bay Capital Center and Al Sadd Town Center as the largest centers of employment and residential population, these centers generate and attract a high number of transport trips. After choosing the West Bay capital center as the study for maximum usage of metro and Al Sadd town center for daily usage of metro station, this reduces the number of metro stations into seven stations for the study.

On the other hand, there was major importance for studying an extra station to serve the comparative study of walkability for the built environment. Since Al Rayyan Municipality is the geographically the largest of the seven municipalities in Qatar and covers ~50% of the country (5,792 km^2) and Doha metro line is passing through many areas within it, hence it was important studying its centers and main location to allocate the suitable station for analysis in this study (Figure 23). The current Doha metro lines are covering and connecting both Al Rayyan North and South Metropolitan Center with ten metro stations. Unlike Al Rayyan North Metropolitan Center, the characteristics of Al Rayyan South Metropolitan Center aims to attract and sustain major employment activities makes a more convenient approach to the study in term of sustaining a daily consistent trip of employments from various places. This reduces the number of the stations within Al Rayyan South Metropolitan Center to four metro stations.

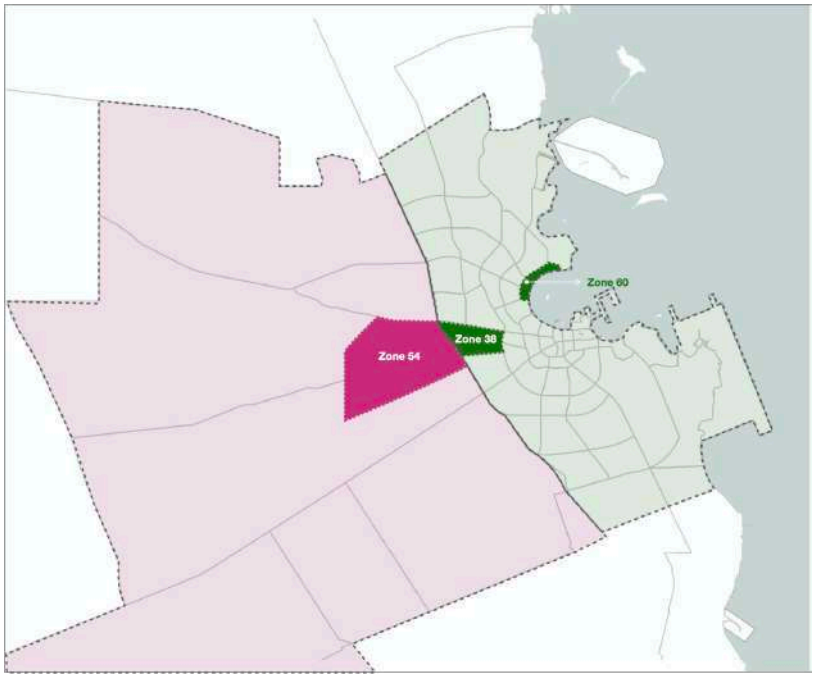


Figure 23. Zone numbers for slected areas of the studied metro stations within the context of Doha Municipality and Al Rayyan Municipality.

3.5. Three Areas in Doha

3.5.1. Al Sadd Area Stations

The Al Sadd area of Doha is extremely large, composed of multiple neighborhoods and two zones in Doha Municipality, with four stations. Al Messila, Hamad Hospital, Joaan and Al Sadd stations are all located within Al Sadd area. Because of its importance as an area, it is useful to study one of its stations to understand the characteristics of street functionality in Al Sadd. For this reason, Hamad Hospital Station was selected for this study because of its proximity to Hamad Medical City. By looking at surrounding land use for each station, the three stations were all serving diverse types of land uses such as, special development, mixed uses, special center zones and future sport zones (see Appendix). However, by looking at Hamad Hospital Station, it clearly serves the surrounding residential area with an extremely high percentage, which makes it suitable station for the study according to surrounding land use and surrounding streets leading to the station.

3.5.2. West Bay Area Stations

Choosing the West Bay capital center was based on studying the maximum capacity of users on walkable streets. Since West Bay is promoted as an area for business hub and financial district, it shall generate a high trip of employment coming from various parts of the city. The capital center narrowed down the study into the West Bay area with four different stations: Corniche Station, West Bay Station, Doha Exhibition and Convention Center (DECC) Station and Al Qassar Station. After studying and scanning the land use around each station, the most suitable station for the study would be the West Bay Station. It is considered as the only station to feed surrounding land uses in terms of employment flow and trips. The rest of other stations

are surrounded by major land uses serving other purposes such as entrainment and leisure which causes a constant movement and trips during weekdays and weekend without clear maximum capacity of users during specific time during the day.

3.5.3. Al Rayyan South Metropolitan Center Stations

Al Rayyan Municipality's urban division was generated using a different approach from Doha Municipality; thus, this study focused on studying Al Rayyan South Metropolitan Center without including more hierarchical center division. As it was stated earlier, Al Rayyan South Metropolitan Center has four metro stations distributed along Al Waab Street including Al Sudan, Al Waab, Sport City and Al Aziziyah metro stations. Both Al Sudan and Al Waab metro stations are clearly serving low to medium density residential zones while Sport City functions to serve the active recreation, which is usually highly used especially during games held in Al Khalifa Stadium. Al Aziziyah Station is the last station in the Gold Line serving both residential areas and commercial avenue. The importance of Al Aziziyah Station is covering most of the residential areas located after the last station which generate a behavior for many users to drive from the far west or far south of Al Rayyan Municipality to Al Aziziyah Station and park outside to use the metro either within Villaggio mall premises or from the other access of the station near the residential area in the southern part.

The three selected metro stations are Hamad Hospital Station within the Green Line, West Bay Station within the Red Line and Al Aziziyah Station within the Gold Line. All selected stations are covering Qatar Rail line systems which allows to investigate different urban structure and allow for comparative analysis reflected in the final outcome (Figure 24). All three stations are located within a context of high daily trip generation at specific time of peak hours. The peak hours are defined based on the

working hours in the country starting 07:30 a.m. until 05:00 p.m.

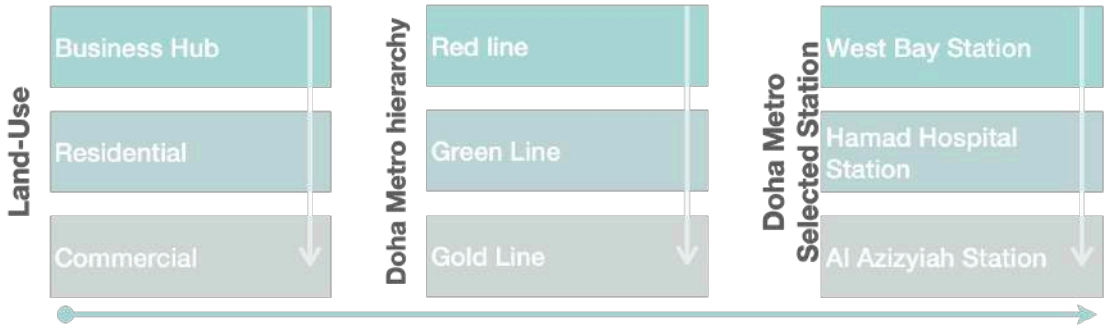


Figure 24. Selected metro stations corresponding to land-use and metro lines.

Hamad Hospital Station is located within high density residential area. It ensures capturing residents leaving to their work in the morning with high traffic flows through the streets to the stations and vice versa in the evening shifts. On the opposite side, West Bay ensures to capturing of incoming traffic flow for all employees to their work offices in the morning and capturing them at leaving time during the evening shift. Al Aziziyah is covering both concepts with different accesses: access A in the south area will cover all residents using metro station in the morning leaving to work, while access B will be used as departure point for all residents coming from surrounding land use and a destination for all users working in Villaggio Mall or nearby employment centers (Figure 25).

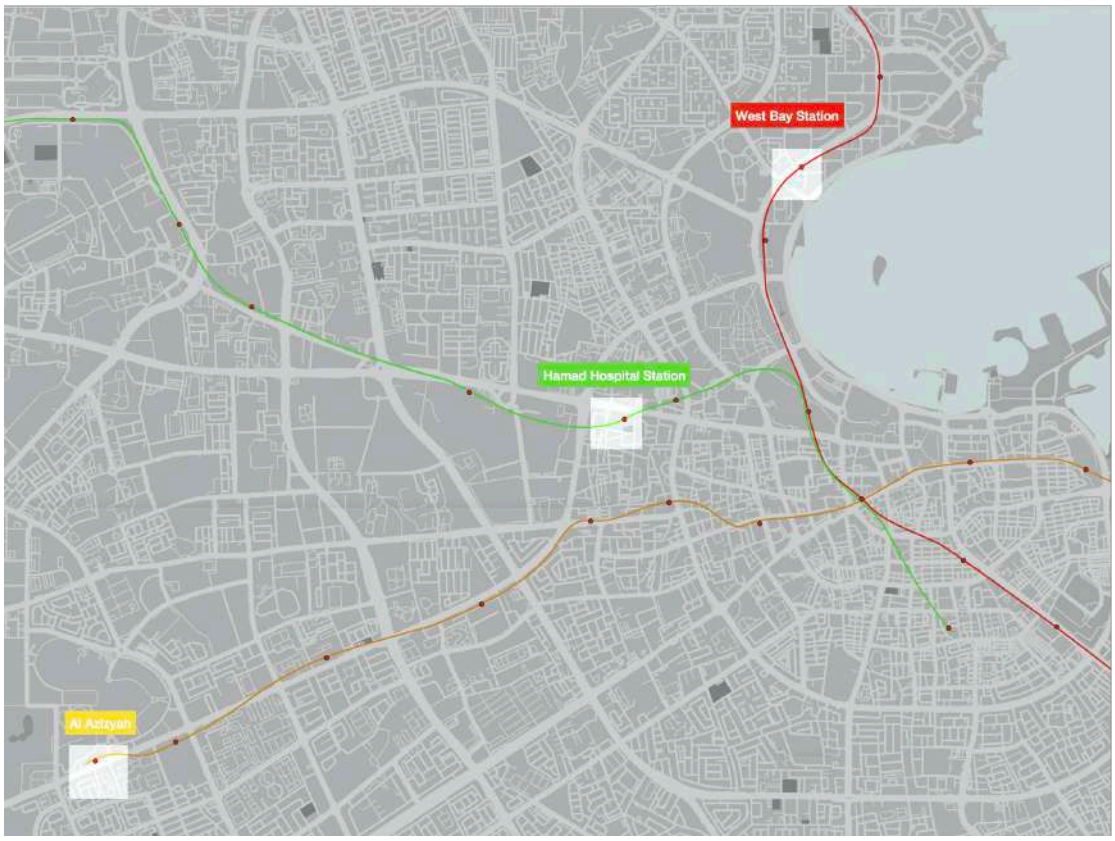


Figure 25. Map showing the location of the selected metro stations within Doha and Al Rayyan Municipality.

3.6. Defining Model Boundary

Defining the study model area within metro stations was essential element to narrow down the scope of investigation and study. This research employed the pedestrian shed which is applied to determine the approximate size of a neighborhood. A Standard Pedestrian Shed is 1/4-mile radius or 400 m, about the distance of a five-minute walk at a leisurely pace. However, this study investigated four levels of pedestrian sheds 800 m, 600 m, 400m and 250 m to understand the scale of the study and the maximum distance can be reached from metro stations based on previous studies (Figure 26).

A pedestrian shed is defined as a simple walkability tool that measures 'as the crow flies' following the metric distance system from the geometric center of an urban

area, which allows the usage of different specific radii based on different climatic conditions. Due to Qatar's harsh, hot climate in most months of the year, QU researchers often employ a pedestrian shed radius of 300-400 m or a 3-to-5-minute walk. However, in this study, a diverse set of a pedestrian shed metric systems were used for this study as it counts the least measurable distance for harsh climate in Doha, which was set at 250 m distance based on Qatar Urban Design Compendium (QUDC).

There are many factors affecting the choice of pedestrian shed as main reference for the study, but the main factor was the weather condition which plays a key role in walkability in hot regions. According to Qatar Urban Design Compendium a reasonable walkable distance fall between 250m (reasonable distance in local climate) and 400m (international best practice). Hence, all three metro stations covered a pedestrian shed of 250m around each station for examination and study.

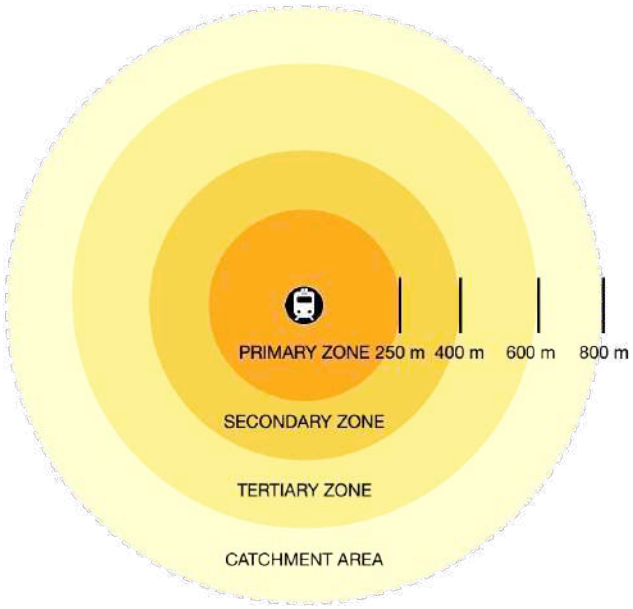


Figure 26. Diagram showing the scale of pedestrians shed for investigated urban area around metro station.

3.7. Limitations of the study

Some constraints and struggles occurred during the collection of the data caused mainly due to the COVID-19 pandemic. The site visits and site observations started at an earlier stage of this study but, due to the continues closure of public transportation and reducing the number of users inside the metro station, were paused until normal traffic flow returned. Also, during the pandemic, carrying a quantitative survey was difficult due to all safety measurements taken by Qatar Rail. However, a random sample survey was undertaken to generate an understanding of pedestrian movements within the metro station premises. The capacity of regular users dropped to 30% based on safety measures announced by the Qatari government, which affected the traces of pedestrian movement patterns compared to the previous year.

CHAPTER 4: FINDINGS

This chapter will go over the study's data collecting, analysis, and findings. The public rail transit system was used as the study setting, and data was collected based on this topic. Also, the chosen case studies methods were documented using data collection, illustrative representations, and photographic evidence, and the analysis of masterplans and sites.

This chapter will demonstrate the process of how data were collected on each metro station site explaining the details of existing conditions related to each studied attribute. It will also continue to analyze each collected attribute based on a given condition to illustrate the study's outcome. Lastly, it will present a comparative discussion for each attribute between the three metro stations, explaining if the current condition achieved a walkable environment for pedestrians.

The data analysis section examines the two-level scale of the built environment on walkability within the selected area of investigation neighborhood level and street level (Figure 27). The results and discussion section will identify the impact of the built environment on walkability based on previously discussed indicators.

Macro Scale Level

The macro-scale level will focus on studying the neighborhood level, with emphasis on the urban network around the metro stations. It will examine the spatial structure and urban form of the existing urban centers around each station and perform an analytical comparison. In addition, it will also study the relation of urban typology and walkability to metro stations and will also perform a comparison of the outcome of each station.

Micro Scale Level

The micro-scale level will investigate street-level aspects in terms of street design and pedestrian connectivity. This level will present the existing street design and analyze it in terms of street segments length and its effect on walking distances, street width, conditions, and characteristics. The street level will also study the pedestrians' connectivity to evaluate the accessibility of the three Doha Metro using space syntax.

Figure-ground diagram technique mapping is used in this study as a piece of visual information to illustrate the relationship between built and unbuilt space around the metro stations. Land coverage of buildings is visualized as solid mass, while public spaces formed by streets, parks, and plazas are represented as voids.

The boundary of the stations was defined based on studying the comfortable walking distance, which was defined by Qatar design compendium of 250 m around metro stations. The diagram also included the distances of 400 m, 600 m, and 800 m to illustrate a relationship between measured distances. After setting a proper distance for the study, a polygon will be generated around the walking distance to define the area and the blocks for the study within each station.

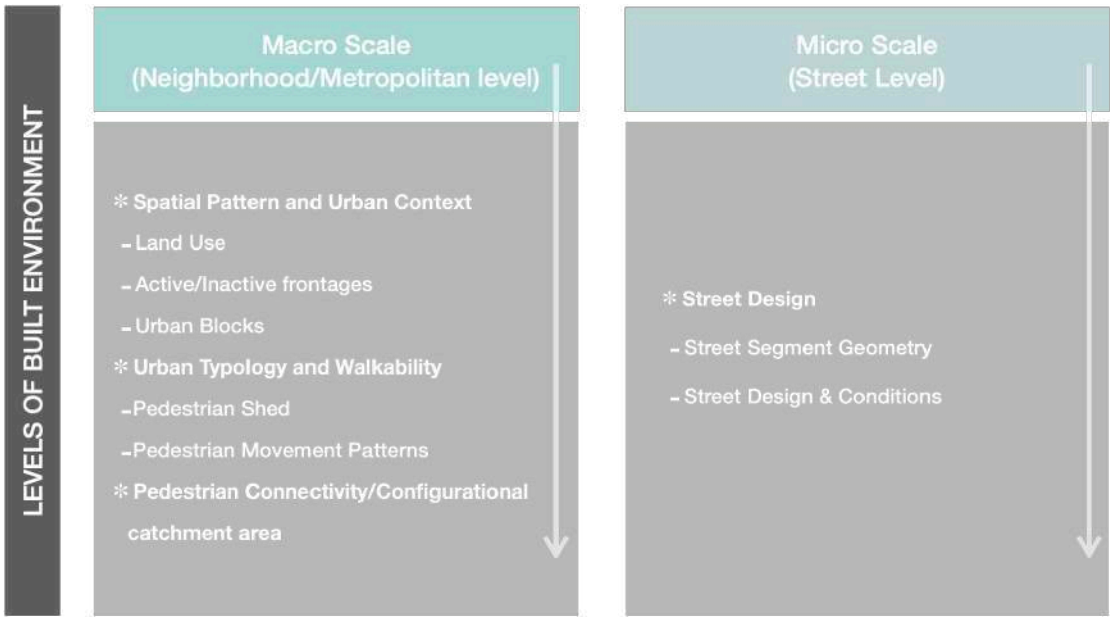


Figure 27. Diagram of indicators used for the study in macro scale level of neighborhood/ metropolitain and micro scale level of street.

4.1. Spatial Pattern and Urban Context

4.1.1. Land Use

In the Al Sadd area, the ground-level land use map was generated using a radius of 250 m (around the metro station access near the residential area towards the south part of the map. The area functions and colors are based on the existing land uses. Since the area is categorized as a high-rise residential area by MME, this was divided into high and low-density residential buildings (Figure 28). The high-rise residential is mainly apartment buildings with two floors above, accommodating more than one family. However, low-density residential buildings were categorized as accommodating single families with one to two floors and an outdoor fence around the house.

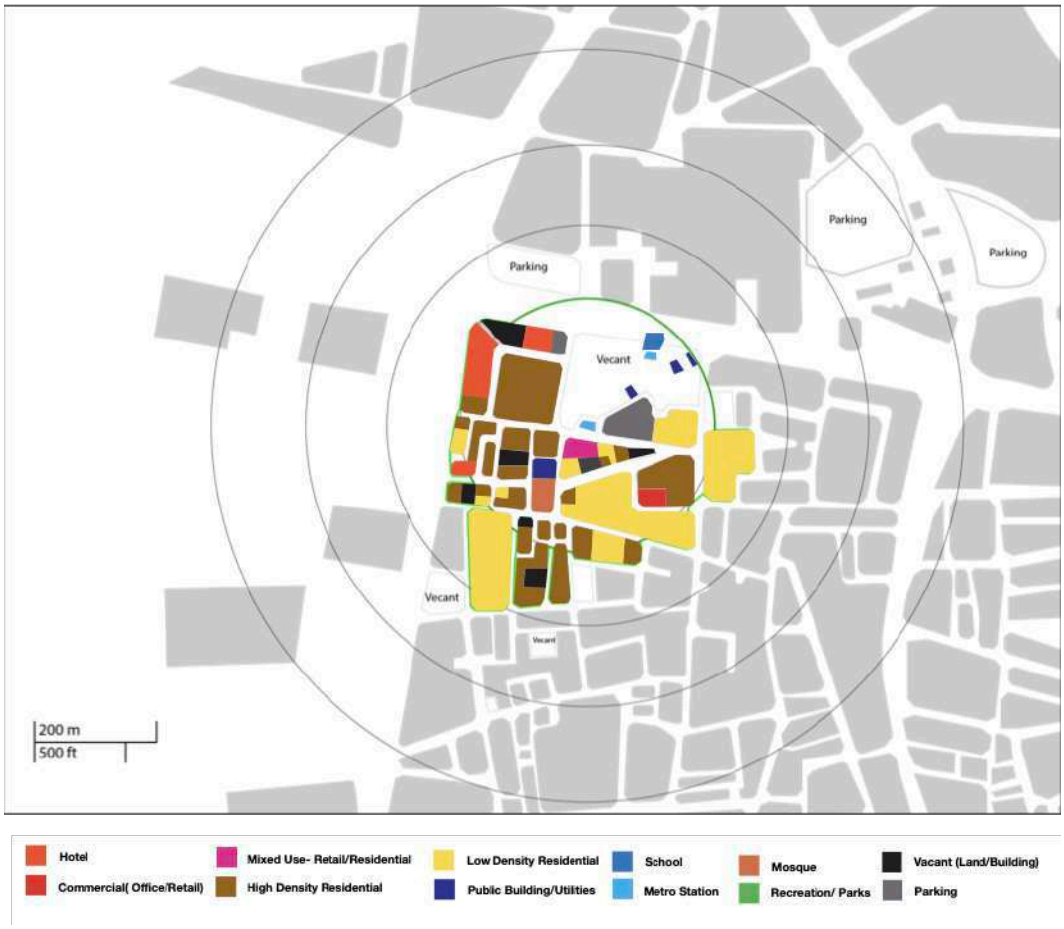


Figure 28. Land Use Plan/Functional territorial structure of Al Sadd area around Hamad Hospital Station with a radius of 250 m.

Public buildings and utilities include government-owned and operated buildings such as electrical stations, metro facilities stations, and governmental offices for public use. Parking areas cover both land parking with open spaces on ground level, i.e., surface parking and multi-story parking either owned by the government or private parking. Mixed-use areas were generated based on retail shops, including grocery shops and salons, on the ground level, while residential apartments were on the top level. Each of these functions has its access. Parking areas and parking buildings were defined based on the usage of open spaces near buildings; all parking areas covered private

parking related to hotels and gated parking and public parking available for all users.

West Bay area is the economic hub or center of the city. Most blocks serve public and private office towers. Covering the private offices includes towers either owned by individuals and rented for offices or big companies creating a whole tower for its employees like Qatar Petroleum. In both cases, towers with offices rented for different companies were grouped under the commercial/retail category. However, towers owned by the government and only providing offices for their employees were treated as public buildings visited by different users. It was treated as a low-density residential zone in the residential area since most houses are owned by one family and include two floors. The whole residential block is considered a gated community with a fence around it from outside (Figure 29).

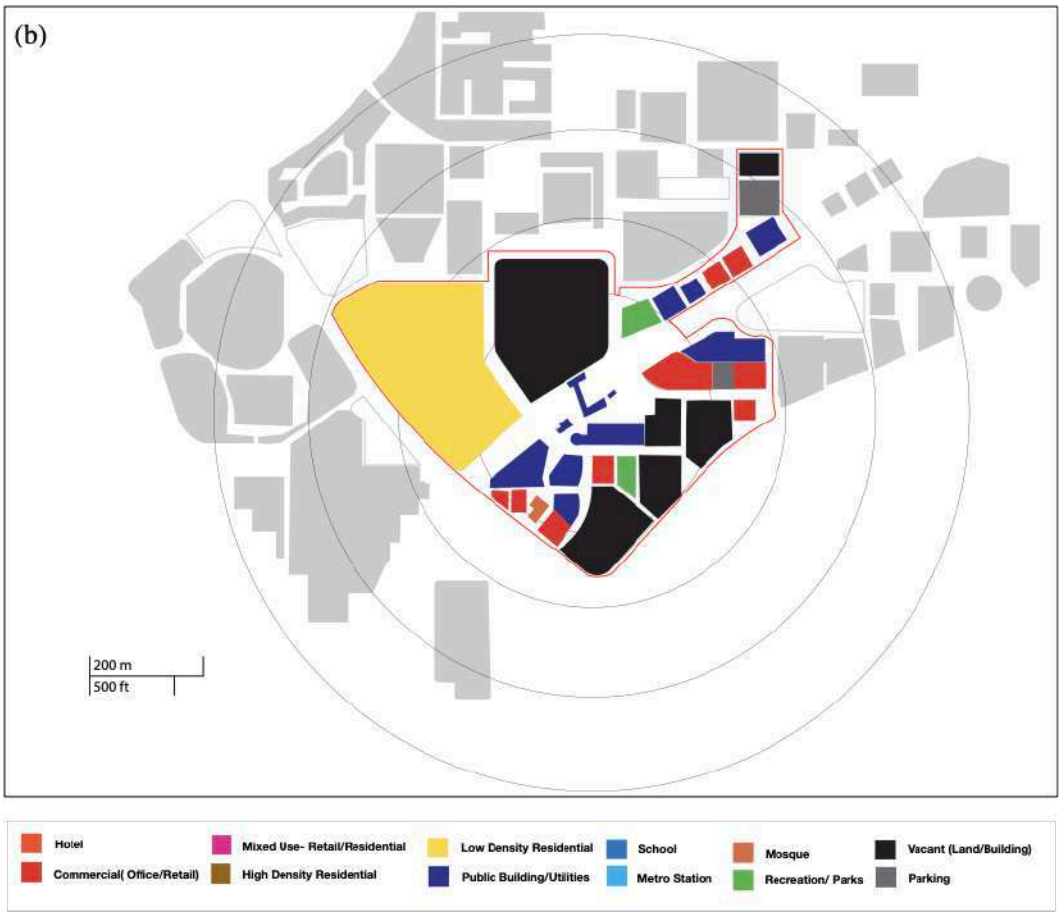


Figure 29. Land Use Plan/Functional territorial structure of West Bay area around West Bay Station with a radius of 250 m.

Al Aziziyah area was studied in covering one metro station with two access points. One access is within the premises of Villaggio Mall, and the other access is towards the southern residential area. The covered zone area is with a radius of 250 m from the middle of both stations when calculated (Figure 30). The covered area included a frontage of a commercial zone with different activities varying from selling retail items and providing services such as medical centers and salons. The area was treated as a low-density residential zone since it is covered chiefly with standalone villas having fences around the house with a maximum height of three floors.

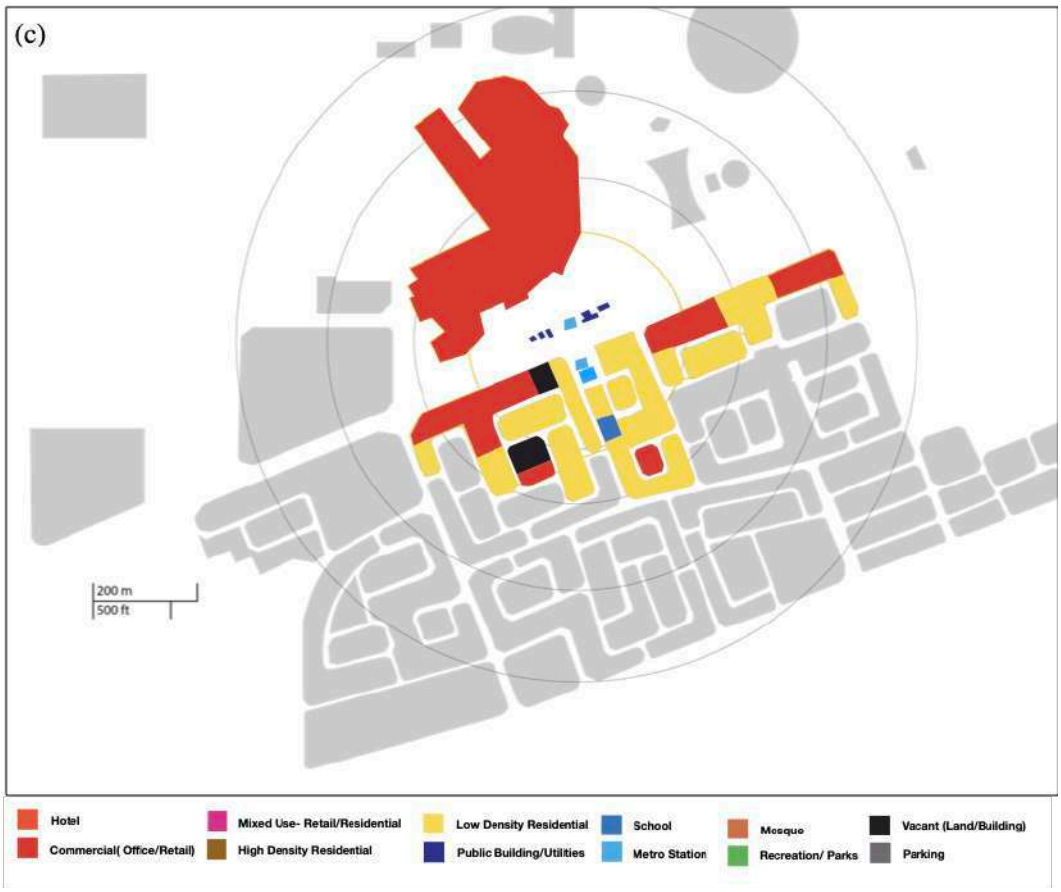


Figure 30. Land Use Plan/Functional territorial structure of Al Aziziyah area around Al Aziziyah Station with a radius of 250 m.

Around the Al Sadd Station, there is primarily residential, mixed-use with some offices, hotels, market shops, and other civic buildings. Residential and mixed-use units are in the study area and a public mosque and other amenities for residents, such as a private school. Small offices are also present in the area along minor roads. Around the station, the site does not enclose public buildings of national or historical significance.

Within the site, street parking is easily visible. Due to a lack of comprehensive city planning initiatives, various vacant lots, including undeveloped land and open parking spots, have been converted to parking lots. As a result, residents park their vehicles in available empty plots around residential and commercial buildings due to uncontrolled parking or a lack of parking regulations and specifically designated

parking areas, causing discomfort when walking along the existing non-continuous pedestrian sidewalk. Furthermore, streetscape components such as furniture and vegetation are missing from the wayside, and street pavements are damaged and discontinuous, making walking difficult.

The overall heights of the buildings in the neighborhood demonstrate no hierarchy, privacy, good views, or suitable setbacks (Figure 31). It appears due to a lack of forethought when it comes to height considerations. Moving outward the station, the area is characterized by a high to a low-density residential area, namely between six to seven-story apartment buildings with retail shops in some buildings surrounded by parking areas on the ground floor and standalone houses with either one or two floors.

Figure 31. No proper setback between buildings nor good view.

The public realm with parks, nodes, or town squares spaces where people congregate does not exist. In general, open spaces and vacant land areas characterize the area, which are utilized as public parking for residents from nearby residential

buildings.

The West Bay Station is within the West Bay district near the Qatar Petroleum facility. The current classification of the West Bay as a land use is special development, which means that high-rise buildings are permissible for governmental services. However, by focusing on the station surrounding the area at a radius of 250 m, the land's primary purpose is to house administrative and governmental buildings surrounding the West Bay Station and several specialized businesses (ministries and commercial companies). Nonetheless, this radius also includes residential functions surrounded by multi-public service areas such as a mosque, two parks, and numerous government towers. The dominating building style is high-rise towers occupied by government and commercial offices. Many coffee shops and small restaurants are within the premises of the high-rise buildings. There are various abandoned structures, vacant fields, and under-construction buildings or completed buildings. However, users are still unable to occupy these buildings due to financial considerations. The built environment surrounding West Bay Station does not fully embrace the notion of mixed-use development in which many amenities should be within walking distance, or the street network supports walkers by providing safe, well-connected pathways with shaded elements.

Around Al Aziziyah Station, the land use map generally indicates the area is primarily residential uses composed of single-family attached or detached villas located inside a compound and a small number of individual villas with commercial services located on Al Waab Main Street. In total, there is one gated development (residential compounds) of the same size, one school, one market, one mosque, many standalone villas, and many commercial and educational facilities. The area also contains a few ‘on hold’ vacant lands, which might have a potential land use to enhance the livability

of the study area.

The study area is characterized by low-rise (up to two-story and penthouse in some cases) villas, whether separate, free-standing, or inside the compound. Thus, it is considered a low-density residential area. The low-rise urban fabric provides a human-scaled environment but only for the internal spaces of the compound. People are limited by blank walls and wide streets outside the compound, unable to connect to the surrounding human infrastructure easily.

4.1.2. Active and Inactive Frontages

The active and inactive frontages map in the Al Sadd area was generated to demonstrate the direct interaction or lack thereof between the buildings and potential pedestrians. One included direct and transparent access or door from adjacent roads to the building, either paved or guiding bushes or tress to the entrance. Also, one way of defining the activity of roads was based on having ground-level windows or on street balconies. However, the Al Sadd area, with its residential context, has a twisted approach for the accessibility or the interaction between pedestrians and buildings, which only approached through ground-level parking. Most pedestrians must go through the parking area to get to the direct building access. Most cases were treated as active residential frontages. Most inactive frontages were either fenced access or blank walls with no interaction for pedestrians with the building at the street level. Also, the inactive frontages for the non-residential area included the vacant buildings or blank walls with no access at all. Finally, the active map is integrated with mixed-use frontages that generate some traffic flow of pedestrians along the road (Figure 32).

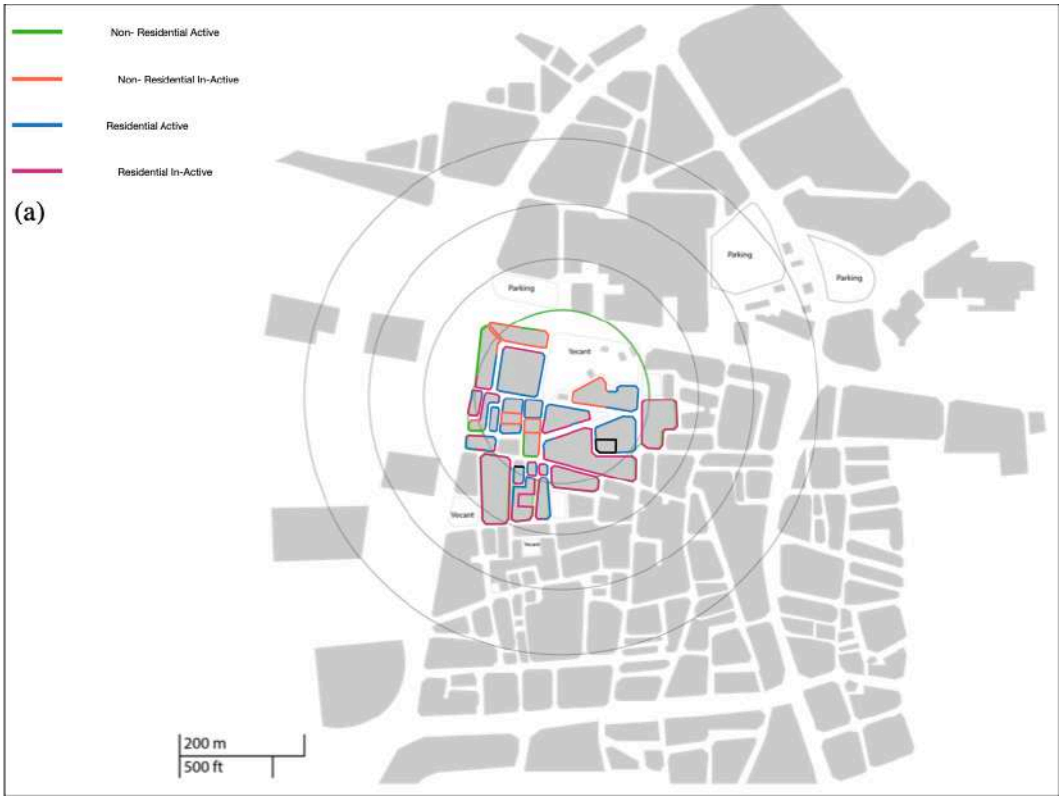


Figure 32. Active and inactive fronatge of Al Sadd area to illustrate the potential for interaction between pedestrians and building at the human scale. Al Sadd area has variety of active and inactive frontages responding to the typlogy of land-use.

Generally, the Al Sadd area demonstrates a high interaction between buildings and pedestrians in terms of many buildings with ground-level windows or common access of pedestrians and vehicles, as shown in Figure 33. In very few cases, there were fenced properties for tall residential buildings with 6-7 stories, unlike the standalone villas, which contained fenced large walls with no interaction at street level. The area has numerous variations of building front activeness with pedestrians at ground level.

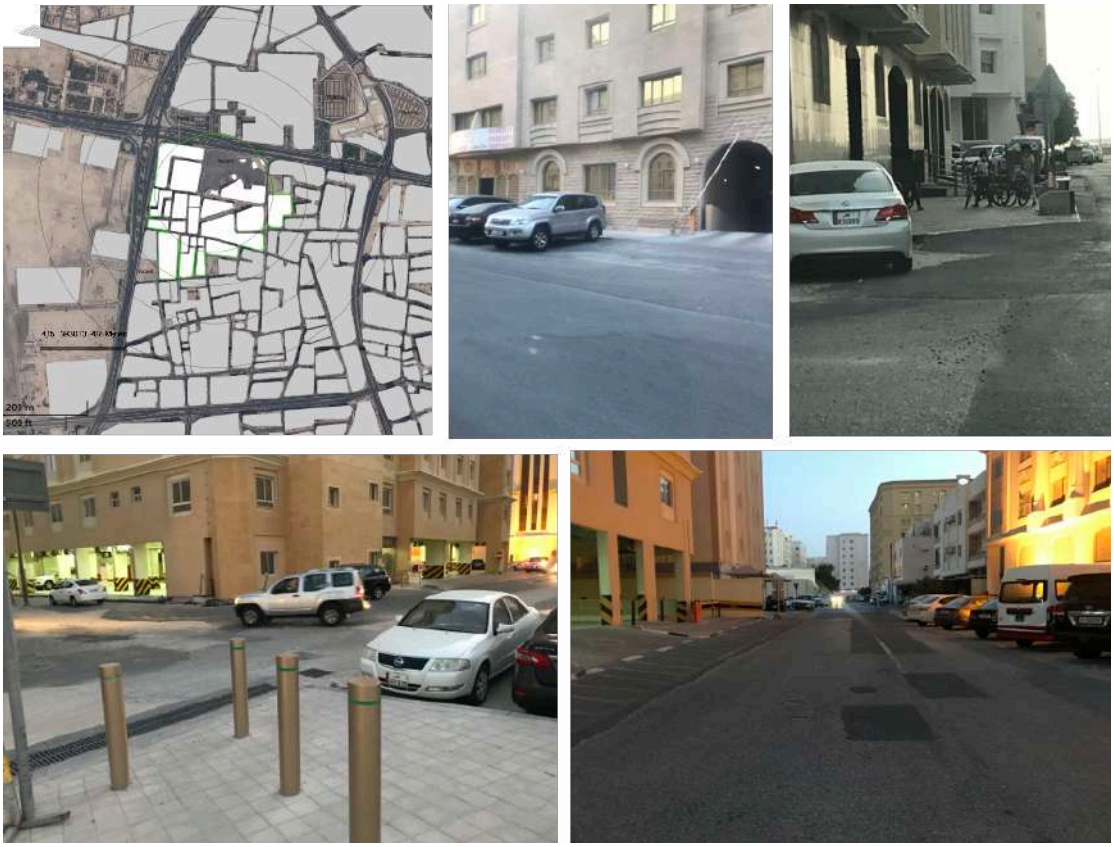


Figure 33. Al Sadd area has active frontages by introducing windows and direct access at the ground level.

The active frontages for most of the West Bay area are buildings with direct and transparent access for pedestrians from adjacent roads. In many cases, this included the same access is taken by cars leading to the parking area since most access is by both vehicles and pedestrians. The inactive frontages were due to the fenced building or areas and improper pedestrian access from nearby roads, such as being blocked by plant pots or raised areas. Some buildings were observed to have adjacent trees in large planters with limited pedestrian access, treated as inactive frontages. It was treated as inactive frontage for the residential area since all houses were included in one big compound and opening inward with a surrounding compound wall (Figure 34). West Bay Area mostly struggles to provide ground-level human-scale interaction since

stationary vehicles characterize most towers' ground-level areas. West Bay's high-rise buildings allow less interaction with pedestrians at ground level scale. In other cases, small buildings centralized in the middle of land surrounded by a large area for parking with a bulk fenced wall at the edge of the land are there (Figure 35).

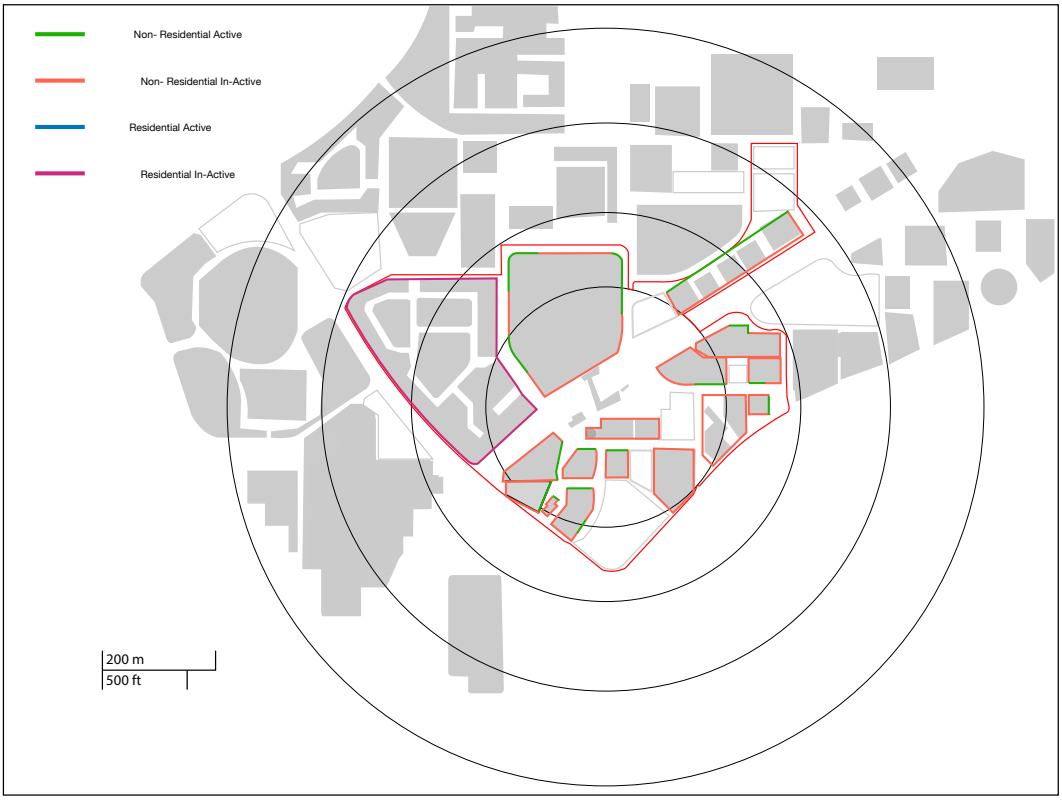


Figure 34. Active and inactive frontages within the vicinity of West Bay Station.

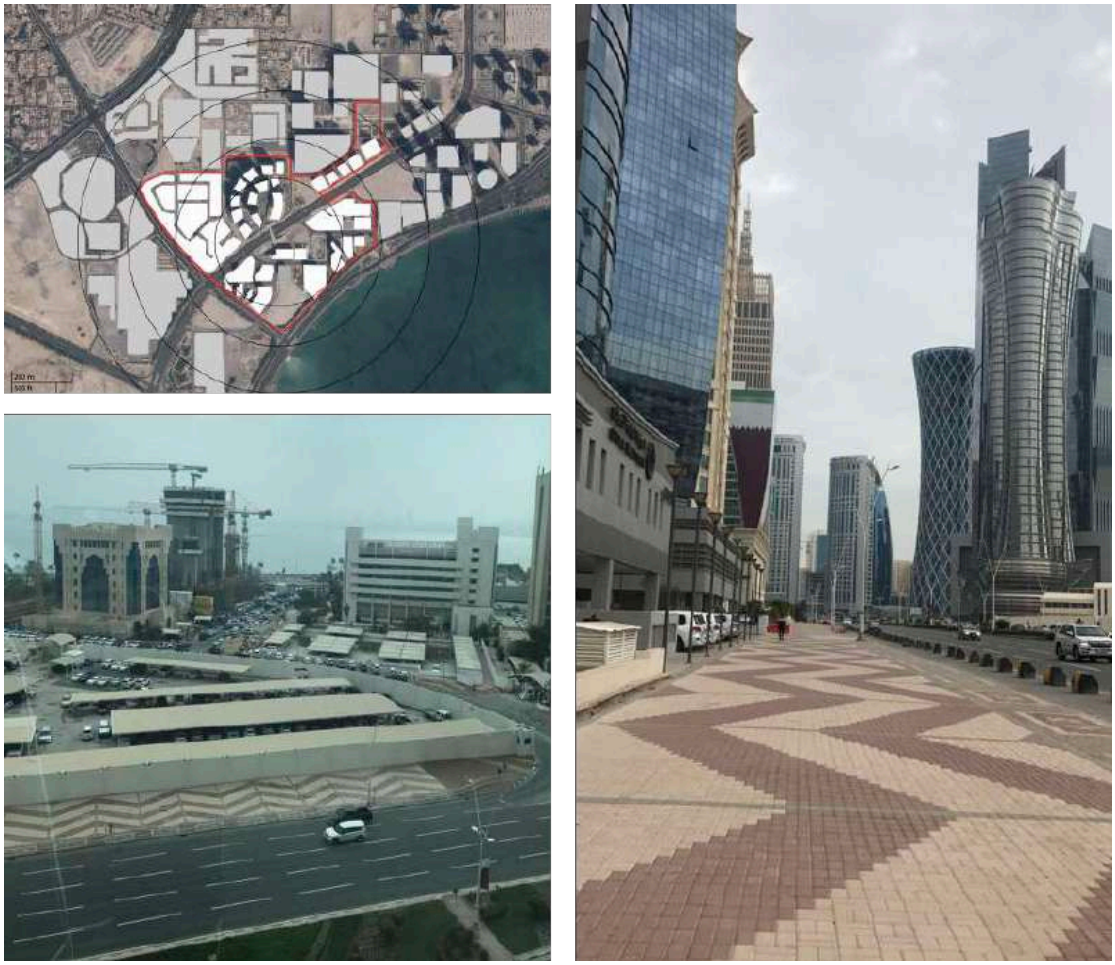


Figure 35. Adjacent streets either blocked by walls or access to surface parking lots.

Most active frontages in the Al Aziziyah area occur due to a door or window at ground level. As for the inactive frontages, any building surrounded by a fence or has a distance yard was classified as inactive frontage. The most active part is near the south access to the station, where many commercial and educational facilities are found (Figure 36). They provide clear door access for pedestrians as well as ground-level windows. Some frontages observed contain fenced walls with a small walking distance to the building. Away from the commercial zone, the rest of the study area premises are considered inactive, showing large walls with single-door access for pedestrians or car parking access (Figure 37). In very few cases, some buildings were Majlis (a detached building from the main house used as men sitting area) with a direct and transparent

glass window-opening at street level.

Figure 36. Al Aziziyah is dominant with inactive frontages around the residential houses and only active frontages along the commercial strip.

Figure 37. Photographs of Al Azizia area with fenced residential stand alone houses.

4.1.3. Urban Blocks

The basis of employing block size as a measure of the well-connected area is that the block is an impenetrable area; therefore, the larger the block, the greater its obstruction for walkability and movement through the environment. Thus, after setting up the study's premises to a walkable distance of 250 m, a polygon was generated following any block falling within the 250 m distance. This method managed to define the study area and the block sizes in the surrounding zones of each metro station.

For the three station areas, the polygon area was measured to quantify the metric area characteristics, then 20% was subtracted from the polygon area to eliminate the street area and have the actual block size within the polygon area. The total number of blocks from each metro station area was divided by the total block area within the polygon to estimate the area of the average block size.

Due to many free-standing buildings out of the block areas, both around Hamad

Hospital Station and Al Aziziyah Station, calculations of the average block sizes were tested with and without free-standing buildings. This approach was to evaluate the relationship between the number of blocks and average block size. Around Hamad Hospital Station, the center point was the station access with a radius of 250 m away from the main access. The radius covered the residential areas and an ample open space which was dedicated right above the station. However, the polygon around the metro station included any block that slightly covered within that radius.

Around Hamad Hospital Station, there are 27 blocks or buildings within 1 km^2 that is reachable in a radius of 250 m from the station building access. The variations of the block sizes are noticeable in comparison to each other (Figure 38). Most residential buildings are almost attached, or there is only wall separation between two buildings, creating a large block. In addition, since most standalone houses with large fences are old, they occupy a large-scale block size. The size of blocks reduces when introducing a street serving vehicles movement.

Figure 38. The premises of 250 m radius to calculate average block size around Hamad Hospital Station and the defined polygon.

Since the West Bay area is a special development zone, most buildings generate separate access and premises, calculating 34 blocks around West Bay Station (Figure 39). Towards the northern part of the station, the movement and accessibility between buildings are more reachable and accessible, unlike the southern part. The connection in the southern part is smaller, with wider streets between blocks resulting in difficulty of accessibility between different blocks. A crosswalk bridge located at the end of the road creates direct access between the two parts between the northern part of the station and the southern part of the significant Majalis Al Tawoon Street.

Figure 39. The premises of 250 m radius to calculate average block size around West Bay Station and the defined polygon.

Unlike the Hamad Hospital and West Bay Stations, the Al Aziziyah Station study area consistently shows the largest block size compared to the 17 blocks existing (Figure 40). The two reasons for this are 1) since the station has two access, including Villaggio Mall, which by itself has an approximate area of 150,000 m^2. All the residential buildings are adjacent to each other and separated by a shared wall or fence. The area's design was allocated to contain residential houses adjacent to each other and only separated by streets serving vehicles movement.

Figure 40. The premises of 250 m radius to calculate the average block size around Al Azizyah Station and the defined polygon.

Comparing the block sizes within the vicinity of the three stations, Hamad Hospital Station has the most diminutive block size of ~8,000 m^2, followed by West Bay Station with 11,000 m^2 and then Al Aziziyah Station with 20,000 m^2 (Table 3). It indicates that Hamad Hospital Station has many walkable streets compared to the other two stations, providing permeability for pedestrians to reach the station. Roads may have been constructed to service vehicles. However, it offered several options for movement. Blocks around Al Aziziyah Station have small, gated blocks which allow one way of accessibility and exist between blocks; as a result, it creates a less walkable environment for pedestrians. By looking at West Bay Station, despite the average size of the towers area, most of the block sizes are served to cover the parking plots within the building premises. It generates diverted movement and a long walk for pedestrians

to reach the station.

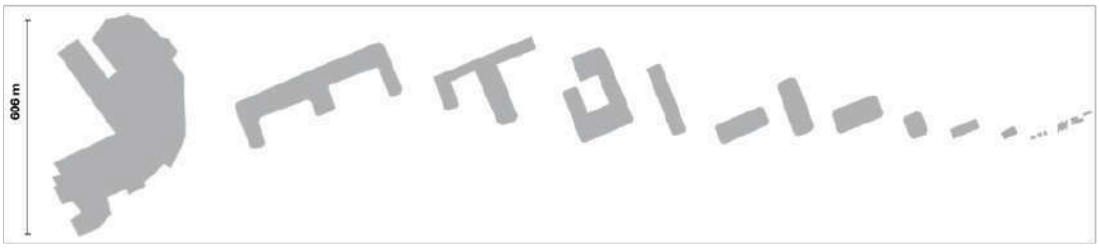
The blocks around Hamad Hospital Station tend to be smaller and less geometric in shape and size than the other stations. Al Aziziyah Station blocks have a more extensive scale size and more geometric shape, which share the same characteristics with West Bay Station but at a smaller scale (Figure 41).

Table 3. Number of urban blocks accessible within 250 m 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.

Station	Polygon area size (m sq)	-20% (subtracting streets)	No. of blocks (With free standing buildings)	AVG. Block Size (with Free standing buildings)	No. of blocks (Without free standing buildings)	AVG. Block Size (without Free standing buildings)
Hamad Station	294,893.00	235,914.40	27	8,740.74	22	10,727.27
West Bay Station	481,618.00	385,294.40	34	11,341.18	31	12,438.71
Al Aziziyah Station	437,402.00	349,921.60	17	20,705.88	10	35,200.00

Block within Hamad station area in descending order
27 Blocks within radius of 250m from the center of Hamad Station access including free standing buildings.

Block within West Bay station area in descending order
34 Blocks within radius of 250m from the center of West Bay Station access including free standing buildings.



Block within Al Aziziah station area in descending order
17 Blocks within radius of 250m from the center of middle street between two opposite access to the station including free standing buildings.

Figure 41. Blocks within the radius of 250 m in descending order (in terms of area from largest to smallest) for (top) Hamad Hospital Station, (middle) West Bay Station (bottom) Al Aziziyah Station set to the same scale.

4.2. Urban Typology and Walkability

4.2.1. Pedestrian shed

The pedestrian shed around Hamad Hospital Station shows four different metric distances for pedestrians from the metro station access near the residential area. The distance from 250 m to 400 m is based on recommended walkable distance from the Qatar Urban Design compendium, which took into consideration the weather condition of Qatar. The distances were measured by centralizing the metro station access closest to the residential plot in the Al Sadd area (Figure 42, top). The 250-meter distance covered most of the residential area in both the south and west parts of the study zone.

It also managed to cover most hotels located in the Al Sadd area on the northern side.

The same measure of the pedestrian shed was also utilized around the West Bay Station (Figure 42, middle). However, the centralization of accesses to measure the distance was from the southern access at the edge of Majalis Al Tawoon Street since this is the primary access of the metro station and the bridge is the access from the northside leading to direct access on the southside. Simultaneously, the 250-meter distance represented governmental entities as the primary land use and some residential buildings to the western side.

Since Al Aziziyah Station is serving two different land-use from the north and south of Al Waab Street, station walkable distance was measured from the geometric center of Al Waab Street. It was to ensure a consistent walkable distance for both access points (Figure 42, bottom). The 250 m distance from the northside managed to cover the commercial mall side and its parking large plot area, while the south serves the residential zone.

The pedestrian shed around Hamad Hospital Station shows that Al Sadd is very walkable, with every location being easily accessible within a radius of 250m from the geometric center. It provides straightforward access for all streets from various places in all directions. Near Hamad Hospital, from the northern side, it offers walkable access from the underground to allow safe and easy crossing from Al Rayyan Road. The 250-meter distance shows a semi-vertical spine for the covered area from Al Rayyan Road until Al Umma Street, a spine street for the area, especially for users coming from Jawaan Street. The exact distance succeeded to cover a horizontal spine which is Al Balagha Street from east to west. Despite the existence of many blocks yet, many

internal small streets were generated, creating walkable distances for users.

Figure 42. Pedestrian shed for a 5-minute walk (250-400 m) from (top left) Hamad Hospital Station, (top right) West Bay Station, and (bottom) Al Aziziyah Station.

4.2.2. Pedestrian Movement Patterns

Data collection and modeling occurred in phases during the lifetime of the research study. To be able to generate the traces of pedestrian movement patterns to and from

each metro station, every movement observation occurred in each station for 30 minutes. Every movement observation occurred for thirty minutes sample counts twice every visit (once in the early rush hour of the day and the other at the end of the day during also return rush hour) from 7:00 am to 7:30 am during the weekday mornings and from 5:00 pm to 5:30 pm in the evening. The fieldwork study was taken between March and June (Appendix F).

Hamad Hospital Station for observation key location was near the main access facing the southside of the station. The field observation tracked the path of a typical fifty (50) people during the 30 minutes observation period of their destination to the metro station in the morning peak (Figure 43). The total number of users is distributed into users entering the stations and users leaving the station. There were about 28 male users who entered the station with different street origins around the station. At the same time, there were about thirteen (13) females entering the station simultaneously using the exact street origins.

On the other hand, around three (3) users were leaving the station and entering a small office building near the station, which defines their destination. The evening peak hour showed a total of thirteen (13) users also either entering or leaving the station. The exact number of users were entering the station, and around ten users were leaving the station, stating that they were coming back.

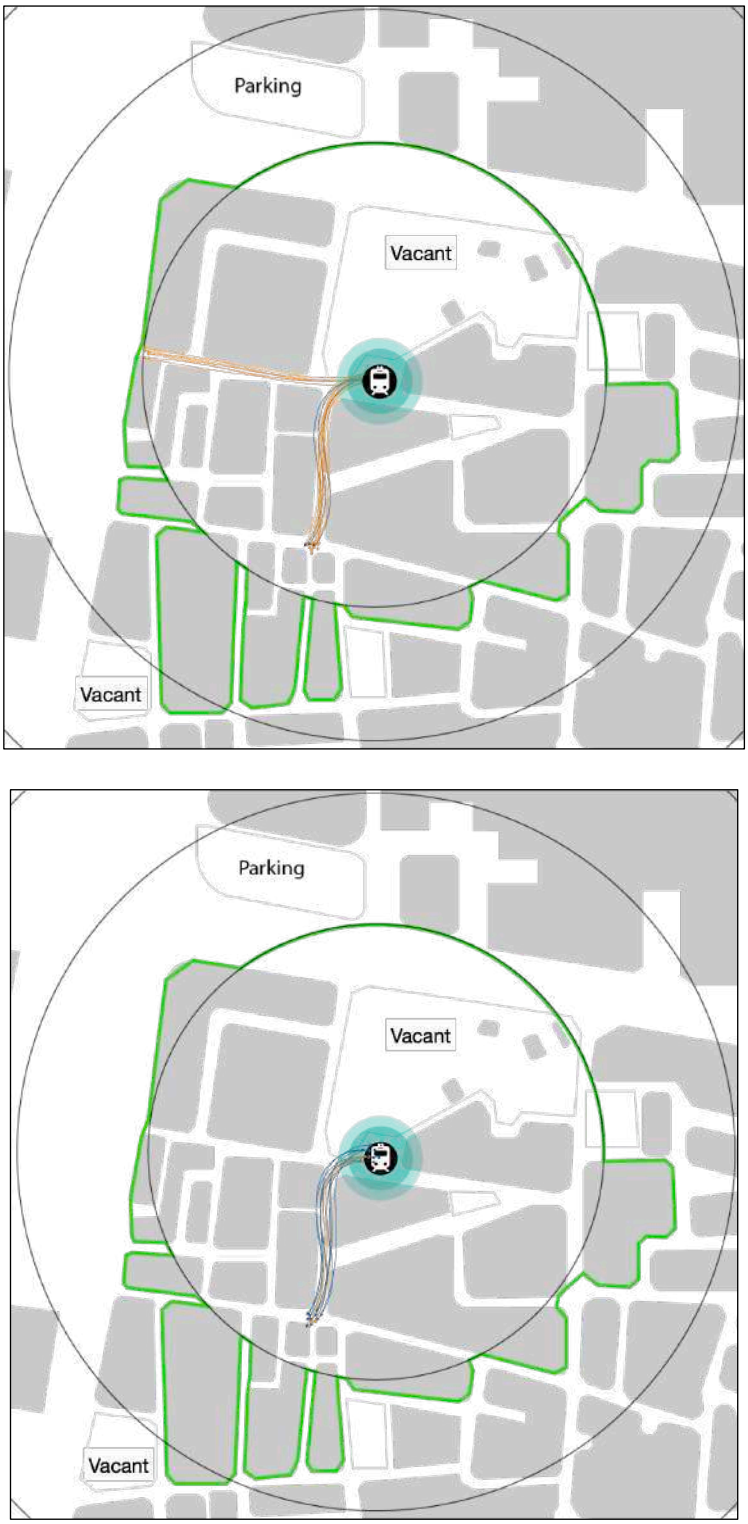


Figure 43. Movement patterns of users around Hamad Hospital Station (top) during the morning peak hour and (bottom) during evening peak hour.

On the other hand, collection of the West Bay Station movement traces occurred by choosing different spots to observe the accessibility of users from two entry/exit points on the northside of the station and the south access of the station (Figure 44). During the morning peak hour, the total number of users was one hundred and forty (140) during the thirty minutes observation. A total of one hundred twenty-three (123) users were male, and seventeen (17) were female. Since the station had two access, one through the bridge and the other through the station on the southside, the total numbers of users were merged after covering both accesses for observation. During the observation period, many routes were used based on the destination of users. However, a total of five routes were taken by users after leaving the station. Conversely, a total of eighteen (18) males came from two main routes of their origin to the station as their destination.

Figure 44. Movement patterns of users around West Bay Station (top) during the morning peak hour and (bottom) during evening peak hour.

Al Aziziyah Station has two access points, one near Villaggio Mall and the other near the residential area. This translated into the observation process for both morning and evening peaks. However, the station provides access to Villaggio Mall, so it generates a large number of pedestrians in movement outside the rush hour and not only the daily routine movement to and from work, based on observation and calculation of only the morning traces.

At first, the observation duration was divided between the two access points and then counted the number of users approaching and leaving the station. Throughout the morning rush hour, the observation period showed a total of thirty-one users (31) splitting between in and out of the station. Twenty-four of them were males, and only seven were female using both station accesses. The movement counts for evening peak hours exhibited a high movement pattern for the southside station access near the residential area. A total of sixty-one (61) males and eighteen (18) females were leaving the station using different routes seeking their destination. At the same time, eighty-one (81) males and sixteen (16) females were heading inside the station using multiple transportations to get to the station (Figure 45).

Figure 45. Movement patterns of users around Al Aziziyah Station (top) during the morning peak hour and (bottom) during evening peak hour.

Traces of pedestrian movement patterns enable us to have a more expansive view and focus on the busiest movement on streets near any station. The movement flow around Hamad Hospital Station is generated by two streets, making them the most used streets around the station, Ibn Idress Street, and Al Blagha Street. Both streets show a high density and flow of pedestrian movement patterns since both feed to smaller scale streets around them. Nevertheless, during the evening peak hour, more movement associates with Ibn Idress Street than the morning peak hour, which serves as a street spine for the area.

Most users who are approaching the station are observed coming either walking or, in rare cases, using the metro scooter. It is rarely seen any vehicles parked for pick up/drop off near the station. This indicates that most station users are walking to the station, and their destination is close by, which does not call for the use of any transportation form to leave or reach the station. This also illustrates that the station is located within a walkable distance for users.

The traces of pedestrian movement patterns around West Bay Station for both morning and evening peak hours are almost similar. They are similar in terms of the routes taken by users to leave or approach the station. There are around five main routes taken around the station. From the southern access, the main access for the station, most users are taking Neewat Lahdan Street, which leads to the governmental offices opposing Al Corniche Road. The second route is Majlis Al Tawon Street sidewalk, directed to the northeast side, including Governmental offices. Furthermore, the pedestrian movement patterns heavily flow towards Majlis Al Tawwon Street from the northside, leading through the bridge connecting the station access. Most users are headed northeast through Majlis Al Tawwon Street sidewalk or skew towards Al Kharais Street leading to internal roads to commercial office buildings within the areas.

Few movements were observed taken the southwest side routes leading to the residential area or Qatar Sports Club.

In addition, West Bay Station witnessed a variety of transport systems used by many pedestrians using the station. This includes scooters, metro link (public bus system only for metro), metro express Doha, and private 'on call' vehicles, such as Uber and Karwa. This reveals the tendency to use vehicles to transport to/from as the station does not have enough destinations with walking distance to/from the station, especially during the harsh weather.

Surprisingly, Al Aziziyah Station residential access shows a high number of users during the evening peak hour. Many pedestrians were noted to reach the station from two routes. The first is the busiest, which is Al Waab Street sidewalk. There were many users seen coming to the station or leaving it. This is due to the existence of many commercial buildings facing Al Waab Street, meaning there is a large workforce in that area. The second is Al Qatada Street, which leads to the residential area and works as a spine route leading to the station.

However, with many users for the station, others were using alternatives for their destination from the metro station or towards it. Many are seen using bicycles, scooters, private vehicles, and buses either for drop-off or pick up. Same as West Bay Station, this explains that pedestrians still face struggles reaching the station through a walking environment only.

The comparison between the three stations is significantly different, taking into consideration the context of each station. However, Hamad Hospital Station exhibits the least number of pedestrian movement traces reaching the station or leaving the station. There are many reasons that could lead to generating the least number of pedestrians. However, the generation of pedestrian movement patterns based on traces

occurs due to the typology of the context the station serves, unlike the West Bay, where there was the most pedestrian movement during both peak hours. This is due to the context of the station and the location of the business hub, which attracts all business-related elements, including employment—residents who are leaving to their work. Following the same steps of West Bay Station for the Al Aziziyah Station, southside access generates high levels of pedestrians in movement due to the existence of the commercial line laying on Al Waab Street, creating employment opportunities for daily users.

In addition, pedestrian movement at West Bay Station provided the highest number of routes for users to take compared to the other two stations, i.e., five routes. This means that the station provides a flexible approach to walking to the station. At the same time, Hamad Hospital Station and Al Aziziyah Station both had two routes creating route spine for the area.

4.3. Street Design

Understanding pedestrian preferences is crucial to creating user-friendly walking environments. As described in Saelens and Handy (2008), Ewing and Cervero (2010), McCormack and Shiell (2011), and Day (2012), there have been several research on the relationship between the built environment and user preferences at various spatial scales (2016). However, investigations assessing the nature and intensity of interactions at the micro-scale are still lacking.

Before introducing the microscale level of study for this part, it is essential to understand the relation between urban structure and street segment length, both affecting pedestrians' choice for walkability. The urban block typology and relation of the street segment will introduce how the hierarchy of street or road levels highly relates

with streets adjacent around each metro station.

According to QHDM, Qatar's road classification, road categories are based on the functionality and type of service roads. Functional classification refers to the actual or intended use of a road within the network as a whole and the degree of access or mobility that is to be provided to adjacent properties. Roads in the urban areas of Qatar fall into five main functional classifications, expressway, arterial, collector-distributor, collector, and local roads (Figure 46). The attention of the study depends on understanding people's movement within the street network. Thus, around each station, a spine road and local road were selected to illustrate the street segments from one crossing to the next crossing, and the total distance users travel to reach the station.

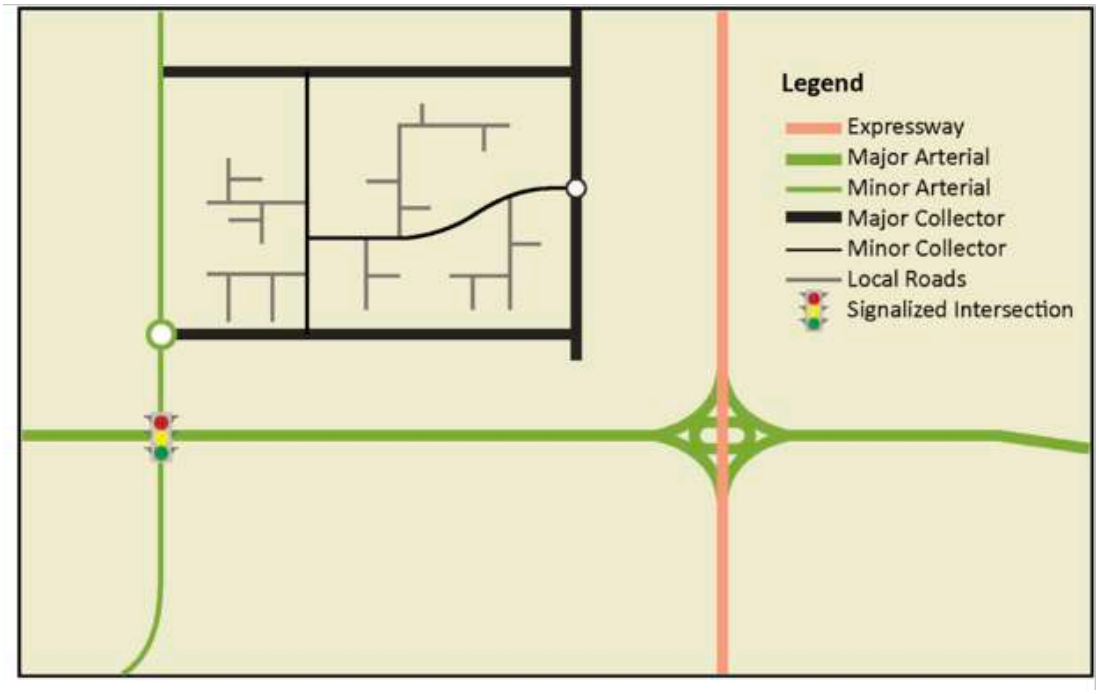


Figure 46. Classification of street hierarchy based on Qatar Highway Design Manual.

To narrow down the choice of case studies, each primary classification was chosen, either major or minor. It includes one arterial road, one collector road, and one

local road within the study area. Since the study focuses on the functionality of walkability and accessibility; therefore, it will be conducted on the streets adjacent to the metro station as much as possible for accuracy of pedestrian walkability to metro station experience. The major arterial roads had high to medium traffic volumes and were pedestrians' least used streets. At the same time, significant collectors will present medium to low vehicle traffic volume with the presence of pedestrians. The local roads will provide access for adjacent land use, which is more pedestrian-oriented. According to the MME, the following diagram shows the relationship between street classification, traffic volumes and land-use category (Figure 47).

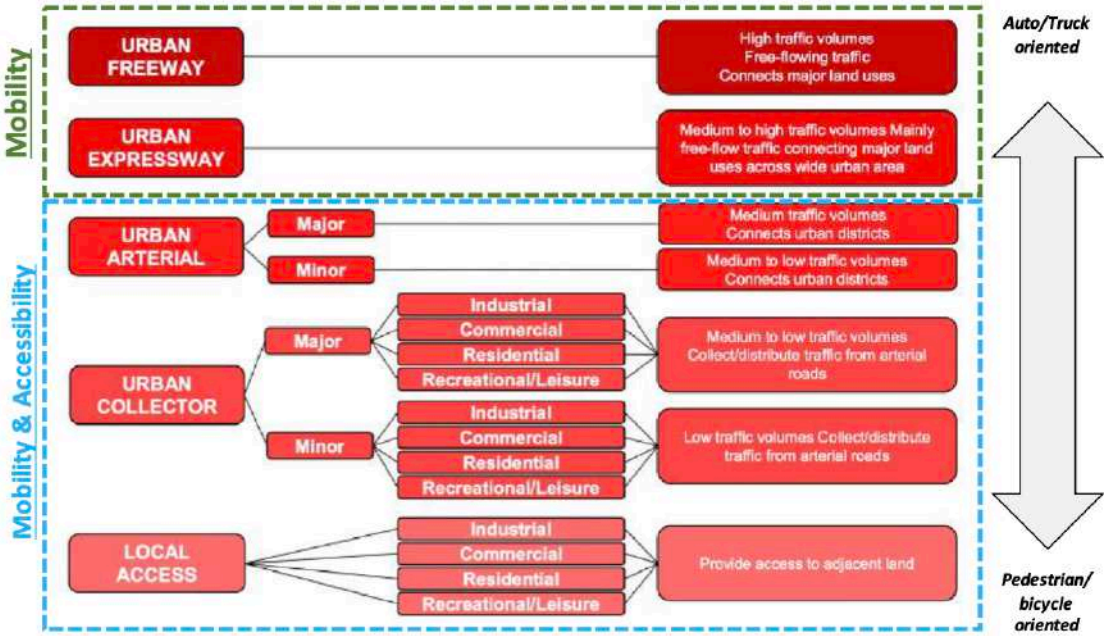


Figure 47. Road hierarchy (MME, 2015)

4.3.1. Street Segment Geometry

A road segment length from 100m to 200m is for street design around the metro stations. This section aims to help understand how the length of the street segment from one crossing to the next crossing affects human preferences in walking to metro

stations. Pedestrians' choice for street segment length from 100 m to 200 m suggests that pedestrians tend to avoid too many street crossings. Cyclists also prefer shorter road segments without significant performance (Liu et al., 2020).

The street geometry takes a random polygon shape when looking at the Al Sadd area street figure-ground around Hamad Hospital Station (Figure 48). The arterial routes defining the area are much more apparent within the figure-ground in four directions. However, since this is an old area, some street connections are connected at right angles, but many small streets connect in a non-geometrical manner. Most area blocks are polygons, and rarely find any perfectly geometrical blocks creating irregular polygons and irregular streets.

The major road crossing the area from the north of the station is Al Rayyan Road. This road is about 1 km from the crossing section between Al Rayyan Road and Jawaan Street and between Al Rayyan Road and the C-Ring Road. The route provides high service to vehicles, including comprehensive, clear lanes and one special traffic light built especially for ambulances near the hospital. The road does not show any pedestrian-oriented characteristics on both sides. There do not exist any bridges connecting the opposite sides of the road. However, the metro station underground tunnel introduces a crossing point between the hospital area and residential zone.

The collector road in Al Sadd is Al Rabbi Street, which is ~1.1 km street length. The street has the importance of feeding internal streets and works as a central spine for the area. It connects the north side of Al Sadd area from Al Rayyan Road to the south side of Al Sadd Street. It contains at least seven internal street connections, which creates small crossing areas for pedestrians. The average length of street segments with Al Rabbi Street is about 300 m within the walkable range. By looking at the local internal streets, they are created based on the existing buildings blocks or, in some

cases, based on building plots if it is a standalone house with a fence. Hence, this creates smaller street segments and much closer crossing points for pedestrians. Al Balagh Street, the nearest street to the metro station, is about a 500 m distance but contains many small streets ranging from about 60 m to 190 m.

Figure 48. Street geometery of Al Sadd area.

The shape of building blocks usually significantly shapes the geometry of street segments, the more significant the block sizes and the larger the street segments. The West Bay area is a relatively recent area adopting modern urban design, reflected in the street geometry (Figure 49). Major roads such as Majalis Al Tawoon Street, the arterial road, follow the curve line at the edge of the city, unlike the internal streets, which follow right-angle connections towards the south of Majalis Al Tawoon Street. The road does not include any crossing points except between two other arterial roads at the

edge of the street. The street has only one bridge crossing to serve the metro accessibility from the north side to the immediate access at the south side of the road. The street measures around 1.2 km with 300 m to the nearest crossing from the main street to the bridge.

The chosen collector road was Al Kharais Road for this study since many metro users take this road. The total distance of the street is about 400 m distance with only one section measuring 184 m. However, during this study, many users were crossing at any point along the street, allowing direct access to the road leading to the metro station with a short walking distance.

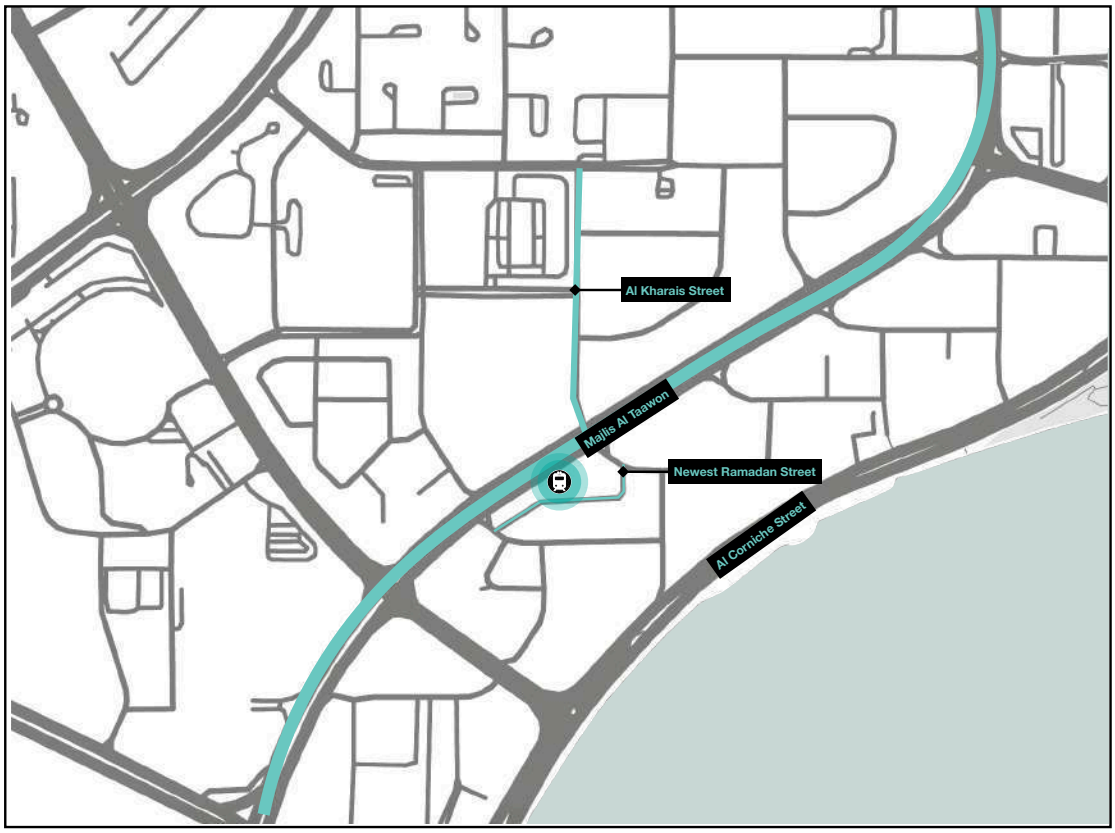


Figure 49. Street geometery of West Bay area.

According to the QHDM, the area has many internal collector roads, either major or minor, and does not have any local roads (Appendix B). Hence, the nearest

road to the station is an internal road with the least vehicle movement. The road is around 285 m and does not include any crossing except the ones at the road's edge. Newest Ramdan Street consists of the metro station to the north and a non-occupational building towards the south. It justifies the smooth transition for pedestrians and the safety of walking within this small street segment.

Al Aziziyah Station area has the same concept for street design s West Bay. The street segments follow a much geometrical shape. By looking at the station's south, east, and west sides, streets segments are connected at ninety-degree angles and follow smaller street segment patterns (Figure 50). Looking at Al Waab Street, the arterial road of the entire area measures around 1.5 km distance from the crossing of Al Numan Street and Sports City Street from west and eastside in order. Like the previously mentioned areas, the street does not include any middle crossing sections, which emphasize that the road serves vehicles movement only. The only possible crossing is underground using the metro station access from Villaggio mall in the north or the residential area in the southern part. The collector road, Al Qatada Street, works as the spine for the area, leading directly to the metro station at its edge. The street segment is 365 m from north to south and has only two crossing section points. Each of these points leads to an enclosed residential zone.

Figure 50. Street geometery of Al Azizyah area.

The internal collector roads serve areas that are in direct contact with residential houses accesses. The streets are small segments ranging from 40 m to 70 m, depending on block sizes. Leszhala Street, the internal local road, is in direct connection with the residential houses. It has one access and exit to one enclosed residential area.

The shape of street geometry between the three areas differs based on urban settlement and design timeline. In the Al Sadd area, streets are organized in non-geometrical shapes, and roads noticeably follow a shorter distance creating a more walkable street. The West Bay area has a combination of existing curve structure of city structure and implantation of organized streets with perpendicular street crossing. However, West Bay lacks short-distance roads due to large block sizes making it a challenging environment for a comfortable walking experience. The north part of the

Al Aziziyah area is relatively new urban planning, having organized street segments with sharp edges at the end of streets. The segmentation of roads managed in establishing the residential area distribution with smaller block sizes and smaller streets segments makes it a comfortable walking environment for pedestrians to metro stations compared to the West Bay area.

In between the three stations, Al Waab Street around Al Aziziyah Station shows the longest street, followed by Majalis Al Tawoon Street, then Al Rayyan Road in Al Sadd area (Table 4). Although Al Aziziyah Station previously showed the highest range of average block size, it showed the shortest streets segments between the collector roads or local roads. It suggests that streets around Al Aziziyah Station are more walkable in terms of streets distance than West Bay Station and Hamad Hospital Station. Nevertheless, streets surrounding Hamad Hospital Station are also considered walkable due to the short length of streets.

Table 4. Comparison of street segments length around each station

Station/Area	Arterial distance	Collector Road distance	Local Road distance
Hamad Hospital Station	1000 m	1100 m	60 - 190 m
West Bay Station	1200 km	400 m	285 m
Al Aziziyah Station	1500 km	365 m	40 -70 m

4.3.2. Street Design and Condition

There is much literature exploring macro-scale street design in different concepts with various attributes and variables. However, this section focuses on examining streets

leading to metro stations and utilized daily, considering the urban context. It means that streets should be functional, safe, and comfortable in terms of design and layout. The section included attributes associated with sidewalk width, the density of street lighting, the existence of crossing points, and the provision of walkway shadings or greenery. Since this research is studying streets leading to metro stations, the observation of the streets adopted a generic concept focusing on the internal streets rather than the main streets. It will offer insight into the design of the streets in each area and around each station.

In the case of the Al Sadd district, it is an essential and dynamic urban core in Doha's downtown zone. As a result, its streets are classified as having medium to high traffic levels during most of the day. The general context of the streets does not support the pedestrian's-built environment nor encourage walking behavior during the day. The current design of the streets mainly accommodates vehicles movement only with a massive absence of pedestrian supporting infrastructure. One of the essential elements for pedestrians in any street is the existence of the sidewalks allowing a safe and comfortable environment for walking. Most of the streets in the Al Sadd area have no sidewalks dedicated for pedestrians to walk through. The existing conditions of the streets with vehicles parking on the sides of the buildings and adjacent to the main street vehicles movement leaves no space for sidewalks. It generates a behavior of having an open street merging both vehicles and pedestrians in the same lane with a high chance of injuries. Figure 51 shows the conditions of some streets that have direct contact with buildings or parking areas placed in front of building apartments, leaving no space for sidewalks. On other occasions, it was witnessed that some building owners preserve their building premises by adding barriers from vehicles and pedestrians, causing a direct movement between cars and pedestrians.

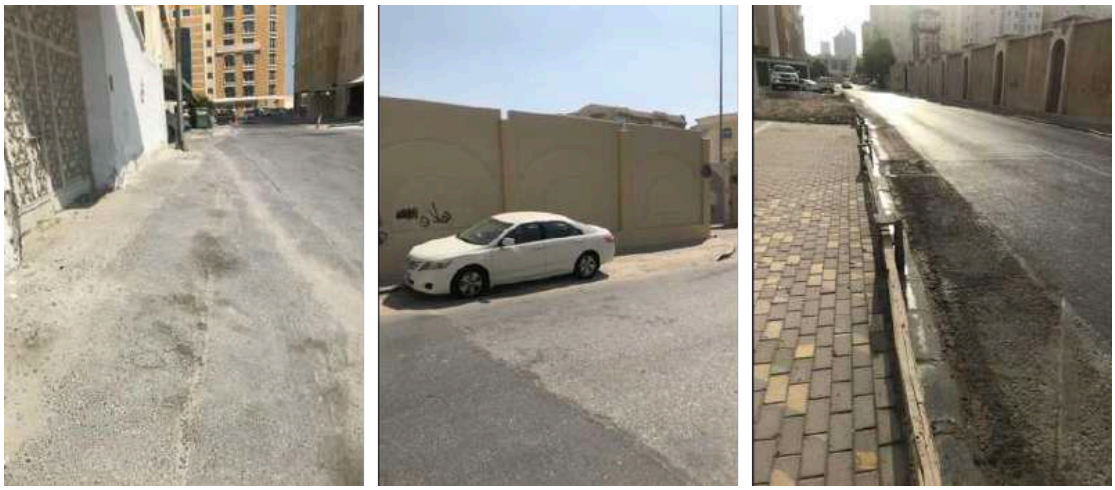


Figure 51. Al Sadd area streets lack the existence of sidewalks. (Left) streets are directly connected to building access (no paved streets for pedestrians), (middle) vehicles parked on sides of the streets, and (right) building properties make barriers for vehicles are pedestrians.

The area is categorized as a high-density residential area. It is reflected in the number of vehicles found to be parking in many spots around the streets. The lack of proper urban design and consideration of building design has many residents park on the sides of the streets since the buildings do not have enough parking spots or no designated parking at all. Such issue was translated on the number of vehicles parking on sides of streets and eliminating pedestrians from having safe walking environment. Instead, many users had seen walking side-by-side with moving vehicles or, in other cases moving in the middle of streets (Figure 52).

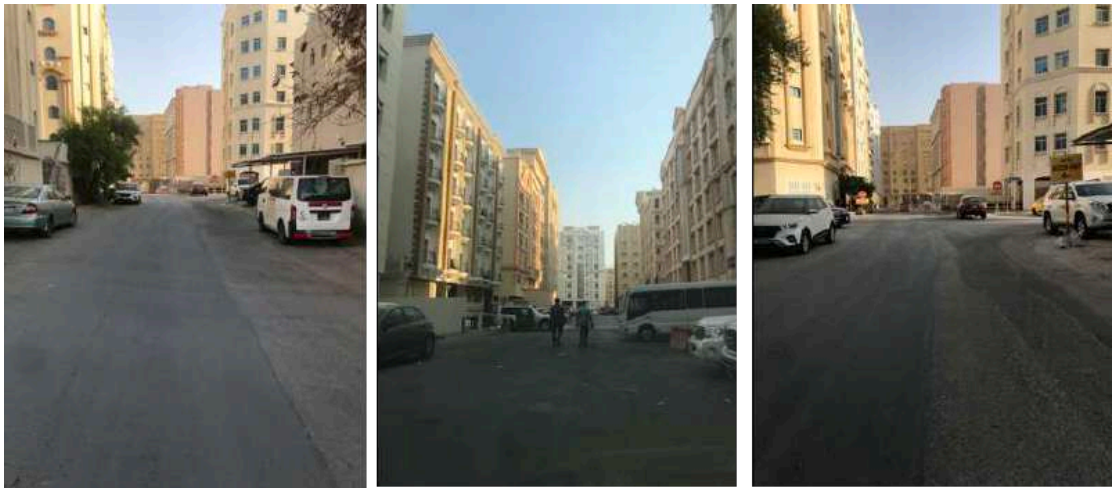


Figure 52. Vehicles are occupying all streets edges and provide no space for pedestrians to walk except near moving vehicles.

On the other hand, Hamad Hospital Station is a significant crossing section leading from Al Rayyan Road to smaller streets. The crossings are used by vehicles and pedestrians simultaneously, and they generate a high traffic of both during specific times of the day. The crossing section is creating an unsafe environment for pedestrians for two reasons. One, streets are not designed or paved properly either for vehicles or pedestrians and do not prioritize pedestrians to cross through clear crossing points. Two, the only light source comes from cars during the night, making it difficult to spot pedestrians or cyclists while traveling to the metro station (Figure 53).

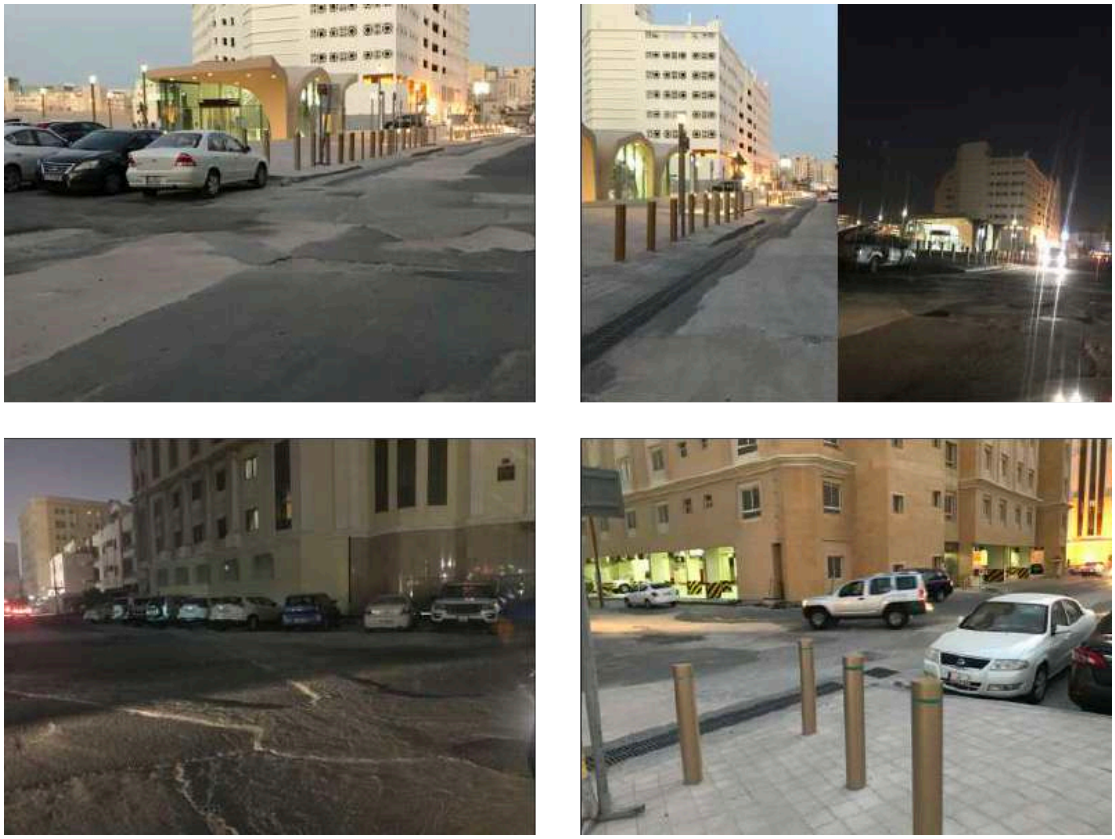


Figure 53. There are no crossing points around the station or between the internal roads. Also, streets light source is from surrounding buildings or vehicles.

One of the very notable missing aspects is streetlamps in the whole area with the internal streets. All inner streets depend on light from adjacent buildings as the primary source outside or depending on the light from the vehicles. Although Qatar is considered as one of the safest countries in the world yet, eliminating such an essential element from the area is creating an unsafe environment for pedestrians and may generate a crime environment in the future.

Despite the categorization for the West Bay as special development to create a business hub, there are many issues with the built environment at street level, making it difficult for pedestrians to walk around the area. The built environment lacks a

cohesive infrastructure integrating a pedestrians' network that can accommodate the large number of employees directed to the area from around Doha. As the case for many streets around Doha, West Bay streets service vehicular movements in large numbers during rush hours by creating wide roads and creating many parking spaces. Sidewalks are present in many internal and external streets. The approximate sidewalk width is 4 m between the edge of buildings and other barriers from the other side within the internal roads. However, a common problem is the discontinuity of the sidewalks, separated by providing a middle parking area on the sidewalk. It leaves a minimal sidewalk width to walk and does not provide enough space for supporting elements or amenities. Even having enough space for the sidewalk to encourage walking, it was occupied by vehicles parking illegally, leaving small space to dodge between parked cars (Figure 54). The width around the corners of the streets is about 8-9 m depending on the block size and building's edge. Still, these corners are also occupied by illegal parking during peak hours (Figure 55).

Figure 54. Vehicles parking illegally on the sidewalks of the streets leaving not enough space for pedestrians to walk.

Figure 55. Vehicles parking illegally on the sidewalks of the streets leaving not enough space for pedestrians to walk.

The urban context of the West Bay generates a high number of visitors daily. The urban context should serve many walking pedestrians and provide a simple, convenient built environment. The area lacks the provision of having shaded walkways or greenery shading that creates a comfortable walking experience. There are many

greenery trees planted within the premises of buildings or towers, which does not serve the purpose of having shaded walkways. There is some shade dropped from towers and in specific areas and during a specific time of the day, yet the walking experience during summer is difficult for pedestrians without shading.

On the other hand, the West Bay area streets lack a good crossing point between one area to another. There is no clear rule for creating crossing points as they appear on some streets and do not show on others. However, the only points with clear designated areas for crossing are on streets connected directly to the main Majlis Al Tawoon streets indicating crossings for pedestrians. Also, around the West Bay station, the streets are well designed, serving the station in terms of crossing points and creating a large, paved area for pedestrians. Unlike the Al Sadd area, the West Bay Area invested in creating a safe environment by adding a high density of streetlamps.

Al Azizyah as a suburban mixed-use area has witnessed remarkable growth, with the construction of various residential compounds for expatriates, villas, and commercial and healthcare facilities. The urban fabric was constructed to follow a regular grid system pattern that follows the land divisions set by the government. This was also translated in the structural leveling of streets design within the area as they are divided into two categories. The first category includes collectors' streets having a well-designed built environment for pedestrians. This includes the concept of the right way where the streets are divided to include wide sidewalks, proper parking lanes, vehicles streets, and a middle boundary between two-way streets. The approximate distance of the sidewalks is about 2 m from the fence of the compound or building edge to the parking lane. This provides enough space for pedestrians to walk, cycle and use scooters to reach the metro stations (Figure 56).

Figure 56. Providing walkable sidewalks and applying right of way concept.

The second category includes the local level streets, which lack all street amenities and sidewalks. The sidewalks do not exist since the adjacent side to buildings are occupied by vehicles parking near buildings. In other cases, some house owners define their properties by trees or shaded parking, making it difficult for pedestrians to have continuous sidewalks for walking (Figure 57).

Figure 57. Internal streets sidewalks occupied by parked vehicles.

Most of the streets around the metro station are shaded by the trees planted originally by house owners. However, since this personal effort by house owners, many areas within the street segments missing the shading element generated by trees which

can lead to an uncomfortable walking experience for pedestrians, especially during the summer season (Figure 58).

Figure 58. Street vision is provided by public street lamps.

The whole area is missing the crossing points between both collector streets and local streets. However, at the edge of turns, speed bumps were created initially to slow vehicular movements. It allows pedestrians to take advantage of these points for safe crossing.

On the other hand, Al Azizyah area streets provide an adequate number of streetlamps distributed appropriately along the roads. It gives a good vision during the night, especially for the roads leading to the metro station. Although the street is provided by one side of streetlamps, the vision is clear at night and does not depend on vehicles' headlights. It helps create a safe and comfortable walking environment for the area and around the station.

4.4. Pedestrian Connectivity

4.4.1. Space and Syntax Model

The evaluation of the accessibility of the three Doha Metro stations was employed through the space syntax model of Metropolitan Doha in 2020 (Figure 48, 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 as if a separate floor in the urban environment with a direct link to public streets with station entries (Major et al., 2020). This study measured accessibility using metric and spatial parameters in the model including choice, global and local integration, mean depth, street length, and integration (radius=7) based on mean depth from the most integrated street in Doha, which is the northern segment of the Doha Expressway intersecting with Salwa Road with a mean depth of 7.378 (see Appendix for foundational information about space syntax and configurational measures based on Major and Tannous, 2021). It means that it takes on average 7 ½ changes of direction to reach every location in Metropolitan Doha from this segment of Doha Expressway. The mean values in the urban network of Doha metropolitan region with the public rail network system, composed of 24,396 streets and station-to-station connections represented as axial lines, serve as the primary basis for comparison, i.e., how does the accessibility values for the stations compared to the metropolitan average. Tannous et al.'s (2020 and 2021) methodology for evaluating the metric and spatial parameters of parks (using perimeter streets) in Metropolitan Doha is the basis of deriving mean values for the Doha Metro stations by using all streets on which there are station entry/exit points. In the case of Al Aziziyah and West Bay, this represents two cross-axis routes associated with the stations. For Hamad Hospital, it represents three parallel routes, two of which are overlapping axial lines composing segments of Al Rayyan Road, which is a major

arterial road connecting from Souq Waqif via Al Rayyan Road to Dukhan Highway and, eventually, to the west coast of Qatar along alignments that marginally shift from east to west in the entire country. Finally, we also use the mean values of the entire Doha Metro rail and tram system within Metropolitan Doha (visible on its own to the right in Figure 59, right) to provide an additional layer of comparison of mean accessibility values in the urban spatial network, i.e., comparing the mean values of the stations against the entire public rail and tram network (Table 5).

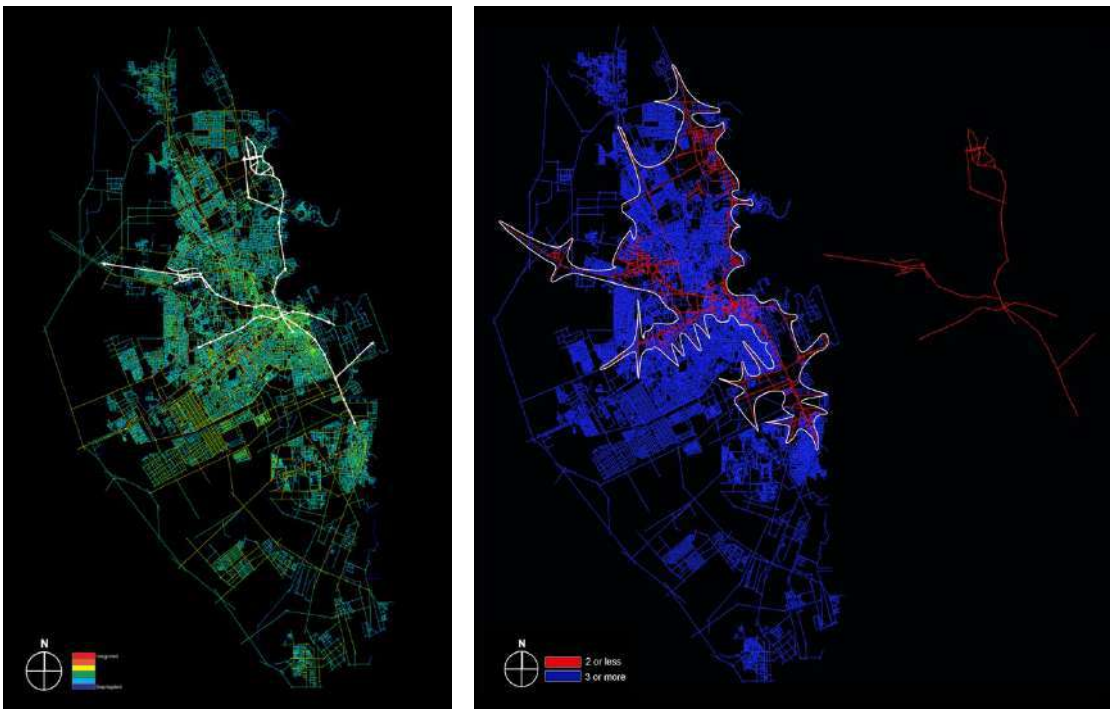


Figure 59. (left) Pattern of local integration (radius=3) in the space syntax model of Metropolitan Doha in 2020 with the Doha Metro public rail system and local tram networks in Mshereib Downtown Doha, Education City, and Lusail City indicated in white; and, (right) Catchment contour map of all routes 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.

Table 5. Mean spatial and metric values of the streets of Doha Metro Stations within the space syntax model of Metropolitan Doha for (left to right) Choice, Connectivity, Global Integration, Local Integration, Radius-radius Integration, Street Length, and Mean Depth compared to the mean values for the spatial network of Metropolitan Doha and the Doha Metro itself in 2020.

Station	Ref. No./Total (k)	Choice (Norm)	CN	Global (r=n)	Local (r=3)	Integ. (r=7)	Length (m)	Mean Depth
Al Aziziya (Villaggio)	3172/8932	0.0804600	40.00	1.64	4.14	2.34	1556.93	8.32
Hamad Hospital	3129/3459/3478	0.0344073	21.33	1.56	3.53	2.12	704.65	8.71
West Bay	3163/1201	0.0219007	9.00	1.31	2.70	1.80	317.56	10.16
Doha Metr	102	0.0076197	5.10	1.24	2.47	1.76	437.64	10.81
Metro Doha	24,396	0.0009402	3.53	1.08	1.76	1.47	119.93	12.47

KEY: Ref. No.(k)=reference number of the axial lines for the location of the Doha Metro Station in the space syntax model of Metropolitan Doha in 2020 or gross total number of the Doha Metro and Metropolitan Doha; Choice (Norm)=choice values normalized within a range from 1 (high choice) to 0 (low choice); CN=Connectivity; Global=global integration, radius=n; r=radius; n=infinity; Local=local integration, radius=3; Integration, radius=7 means the mean value for integration limited to mean depth from the most integrated street in Metropolitan Doha (7.378), which is the north-south section of Doha Expressway intersecting with Salwa Road; m=meters.

Al Aziziyah Station primarily lies on Al Waab Street, an arterial road parallel Salwa Road in an east-west direction to the Orbital Highway. Street length for the two routes on which Al Aziziyah Station locates is 3 ½ times longer than the mean length of connections from station-to-station in the Doha Metro rail and tram network and 13 times longer than mean street length in Metropolitan Doha. Station-to-station connections in the local tram networks of Mshereib Downtown Doha, Education City, and Lusail City have an effect of lowering the mean length of axial lines modeling the public rail networks. It would possess a higher value if we only modeled the Doha Metro rail network, exclusive of these tram networks. All percentage comparisons rounded off to the nearest whole number for ease of readability.

Because of this, Al Aziziyah Station possesses significantly higher values for choice, connectivity, global and local integration, radius-radius integration, and street length – and the lowest value for mean depth – of the three stations. Its mean values for choice are ten and ninety times higher than the mean for the Doha Metro and Metropolitan Doha, respectively. Mean connectivity for Al Aziziyah Station is eight to eleven times higher and integration values for Al Aziziyah Station range from 132% to 235% higher. Al Aziziyah Station entry/exit points are 130% to 150% shallower within the Doha Metro public rial network and urban spatial network of Metropolitan Doha, respectively. Collectively, it suggests that Al Aziziyah Station is very well served by large-scale vehicular routes as a 'park or drop and ride' option for public rail. The location of Al Aziziyah Station represents attractor-based planning as Aspire Park, Villaggio Mall, most Sports City facilities including Al Khalifa a Stadium are all within 1000 m or less 'as the crow flies' of the station entry/exit point on the north side of Al Waab Street. However, as we saw in the earlier morphological analysis, Al Aziziyah Station has characteristics that do not promote walkability such as exceptionally large

blocks sizes, especially to the south of the station.

Hamad Hospital Station lies, in part, on a segment of Al Rayyan Road across the street from Medical City in Doha. Its entry/exit points locate on routes with a mean street length over 1 ½ times and six times longer than the mean for the Doha Metro public rail system and urban spatial network of Metropolitan Doha, respectively. Because of this, Hamad Hospital Station possesses significantly higher values for choice (+300% and +2,300%), connectivity (+400% and +600%), global (+26% and +44%) and local integration (+43% and +200%), radius-radius integration (+33% and +50%) and lower values for mean depth (-21% and -43%) compared to the Doha Metro and Metropolitan Doha, respectively. Hamad Hospital is as integrated and shallow as Al Aziziyah Station while being half as connected into the larger urban spatial network. Collectively, this suggests that Hamad Hospital Station does more with less within the entire urban spatial network compared to Al Aziziyah Station. In large part, it appears a function of the station's proximity to Medical City, its relative centralized location, and a variety of alternative routes (pedestrian, vehicular, public rail) serving both the station and Medical City at the macro- and micro-scale of Metropolitan Doha. As we saw earlier, Hamad Hospital best promotes walkability for pedestrians based on its morphological characteristics, especially moving on foot to the southern residential areas. However, the entirety of Medical City lies within 700 m or less of the northern entry/exit point of Hamad Hospital Station on Al Rayyan Road, which only requires crossing the (admittedly high-speed, high-use vehicular) street.

Of the three stations, the mean values for West Bay Station are closest to the Doha Metro as a whole. West Bay Station's entry/exit points are on routes with a mean street length that is 27% less than that of the Doha Metro public rail network itself. It is a function of the West Bay itself lying on reclaimed peninsular land, which serves to

limit street lengths in the area to parallel the coastline. Because of the this, the mean depth of the West Bay Station is nearly the same as the entire Doha Metro public rail network, representing only a 6% difference. Choice (+298% and +2,400%) and connectivity (+76% and +269%) for the West Bay Station are significantly higher compared with the Doha Metro public rail network and urban spatial network of Metropolitan Doha. As we will see later, this appears due to skewing of the vehicular and public rail networks serving north Doha. The other spatial measures for West Bay Station are only marginally higher with integration at all radii ranging from only 2% to 53% higher than the Doha Metro and Metropolitan Doha, respectively. Based on the earlier morphological analysis, we noted several problems for walkability in the proximity of West Bay Station such as large block sizes and land use planning. These variation in values relative to the rail network and urban spatial network appear to arise from the peninsular shape of the West Bay area and poor planning in area in general.

To examine these accessibility characteristics in more detail, two-step system was identified 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. 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 that three changes of direction or more. Then an irregular polygon was drawn 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 59, right and Figure 60, below). We identified the same metric and spatial parameters as previously for only the two-deep systems, enabling further comparison of the station and Doha Metro catchment areas with each other as well as the urban spatial network of Metropolitan

Doha (Table 6). Finally, an image overlay was brought into Google Earth to measure the approximate metric area of each catchment contour map in square kilometers and derive the street density (i.e., number of axial lines divided by metric area) for each catchment area, again in comparison to the mean values for the same measures in the urban spatial network of Metropolitan Doha (Table 7).

The two-deep catchment contour map for the Doha Metro rail network lines at its farthest extent encompasses 264.0 km^2 of Metropolitan Doha urban fabric (refer back to Figure 59, right). The new rail system emphasizes the radial structure of the Doha along the Red, Green, and Gold lines by paralleling 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 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 km^2 in area. The large interstitial, mostly residential areas of north Doha within this gap is effectively served from its edges at the macro-scale, meaning of the catchment area is really 220 km^2. The only notable access into this service area of north Doha occurs due to the Qatar University Station and routes crossing to the western edges on the campus itself. In large part, this catchment contour map derives from the newness of public rail systems in Doha as the system is not old nor expansive enough yet to fully service the metropolitan region. Of course, the focal point of entire rail network is Old Doha itself with the main 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).

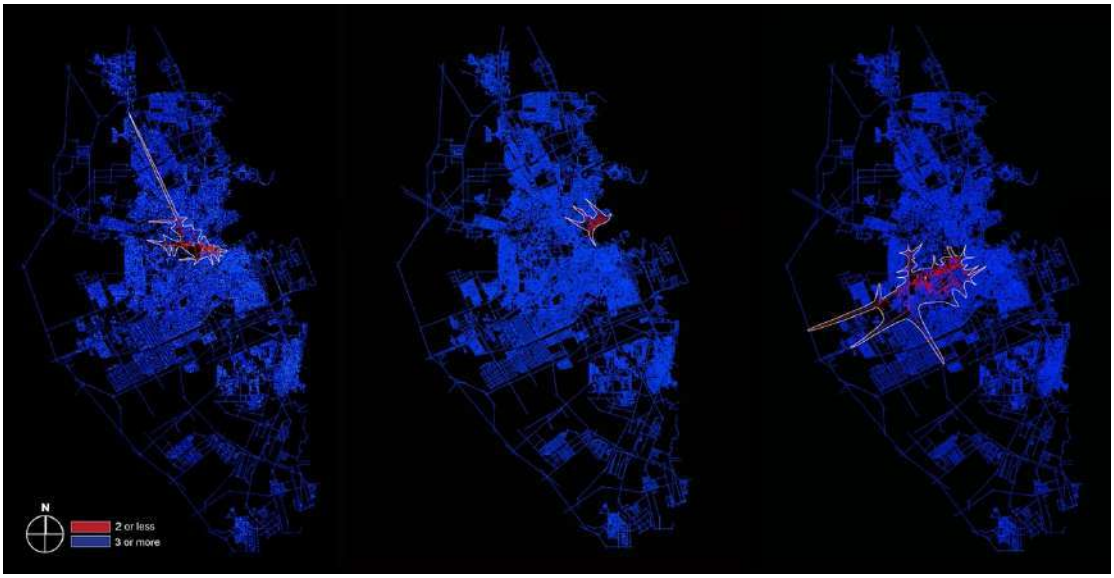


Figure 60. Catchment contour map of all routes within 2 changes of directions or less from the routes on which there are entry/exit points for (left) Hamad Hospital, (center) West Bay QIC, and (left) Al Aziziah metro stations within the spatial network of Metropolitan Doha in 2021.

If the two-deep was examined, catchment contour maps and mean metric/spatial variables for Al Aziziyah, Hamad Hospital, and West Bay Stations, can be seen more clearly how these three stations represent a contrasting but characteristic type of station on the Doha Metro (Figure 60). The layout of the maps from left-to-right is consistent with the history of development of each area associated with the station.

Table 6. Mean spatial values for the Catchment Area (sd=2) of the Doha Metro Stations within the space syntax model of Metropolitan Doha in 2020 for (left to right) Number of Streets, Choice, Connectivity, Global Integration, Local Integration, Radius-radius Integration, Street Length, Mean Depth, Mean Step-depth from the station, and metric area in km^2 compared to the mean values for the spatial network of Metropolitan Doha and the Doha Metro itself in 2020.

Station Catchment (sd=2)	Streets No. (k)	Choice (Norm)	CN	Global (r=n)	Local (r=3)	Integ. (r=7)	Mean Depth	Mean SD
Al Aziziyah Station (Villaggio Mall)	1,179	0.0055466	5.44	1.41	2.60	2.00	9.57	2.63
Hamad Hospital Station	709	0.0075247	6.25	1.39	2.59	1.90	9.66	2.63
West Bay Station	180	0.0072862	6.03	1.20	2.37	1.67	11.12	2.54
Doha Metro	2,879	0.0045007	5.66	1.25	2.49	1.80	10.76	2.58
Metro Doha	24,396	0.0009402	3.53	1.08	1.76	1.47	12.47	NA

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; Choice (Norm)=choice values normalized within a range from 1 (high choice) to 0 (low choice); CN=Connectivity; Global=global integration, radius=n; r=radius; n=infinity; Local=local integration, radius=3; Integration, radius=7 means the mean value for integration limited

to mean depth from the most integrated street in Metropolitan Doha (7.378), which is the north-south section of Doha Expressway intersecting with Salwa Road; SD=step depth.

Table 7. 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 (km^2), and Street Density (k/km^2) 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 Aziziyah Statior (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 (9(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 catchment area of Hamad Hospital balances between 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 km^2 with a mean street length of 198 m. Of the three stations, Hamad Hospital possess the highest street density with 33.3 streets/km^2, which is 81% higher than the average for Metropolitan Doha (18.37 k/km^2) and 154% higher than the Doha Metro (13.09) itself. However, routes available per station/stop for the Doha Metro (90 in total including tram stops) is a more reliable indicator than the routes/km^2 parameter. In this case, the routes/km^2 availability from Hamad Hospital Station in the catchment (+4%) is consistent compared to the Doha Metro. For Hamad Hospital, choice remains high (8x and 17x, respectively) relative to the means for the Doha Metro catchment area and Metropolitan Doha itself. Connectivity is only 10% and 77% higher, respectively. Integration values at all radii range from only +4% to +49% with the high and low end of the range being local integration.

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 km^2) of the three stations. Street density is still high (26.95) but 24% less than Hamad Hospital and 16% less than routes per station/stop compared of the entire public rail network. Mean street length in the West Bay catchment area (237 m) is the longest of the three stations, which is 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), which is 3% deep than the entire 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 the creation of a local tram system, which introduces more public rail stops to the area.

The Al Aziziyah Station catchment area is expansive, encompassing 1,179 routes (6 /2 times that of West Bay) and measuring 66.5 k^2 in area, or over three times larger than the next closest station (Hamad Hospital) in the sample. However, mean street length associated with the Al Aziziyah Station catchment area is only 206 m, which is notable compared to the other stations of the sample (only a +4% and -15% difference with Hamad Hospital and West Bay stations, respectively) and as well as the Doha Metro (+7%) catchment area itself. While the catchment area of Al Aziziyah 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 Aziziyah Station catchment area is 17.73 routes/km^2, which is marginally less (-3.5%) than 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. Because of this, choice is 34% less for the Al Aziziyah catchment area compared with Hamad Hospital and West Bay collectively. The Al Aziziyah mean values of integration at all radii represents a less than 5% difference with the means for Hamad Hospital despite its more expansive metric area. It is because the Al Aziziyah 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 urbans spatial network. In combination with the much larger block sizes in the area (20,706 m^2), it characterizes the area as an auto-dependent suburban area.

CHAPTER 5: DISCUSSION AND CONCLUSION

This chapter summarizes the thesis topic, study findings, and recommendations for measures that could be made to improve the design of catchment areas around metro stations that encourage people to walk. The chapter is divided into five sub-sections concluding the outcome of the thesis. First, it gives a brief of the main concepts that had been introduced in the thesis, then listing the main findings of the research, which will automatically answer the main questions raised through this thesis. It will continue providing potential recommendations that can enhance the catchment areas in both levels (Marco and microscale). Finally, the limitations of research are examined, as well as the implications for future research.

5.1. Summary of Main Concepts

Qatar's pre-independence urban shape has been substantially altered by the influx of petrodollars in the mid-20th century. Several megaprojects also changed Doha's landscape since the 1990s. In addition, the enormous influx of expats needed to power Qatar's oil/gas industry resulted in concentrated pollution, housing speculation, and urban segregation. Qatar has undergone a rapid economic boom in a brief time, causing sequential and significant issues related to the urban context. In response to the economic and population boom, the road network expanded dramatically to cover the sprawling city with little attention given to the different modes of transportation. However, through time, town planners and urban designers managed to increase awareness about the problem and began offering practical, sustainable solutions to stitch better the urban fabric together again. The Doha Metro rail project introduced a significant enhancement for urban development to connect urban centers.

However, reliance on private motorized cars causes traffic congestion, air pollution, and negative health impacts, all of which had a impact on a city's perceived livability and citizens' quality of life. Thus, it negatively affected the built environment, deterring residents from perform simple activities such as walking. Generating areas and streets that are well designed for vehicles and have the least attention for pedestrians affected the volume of pedestrians walking within any urban context. This suggests that neighborhoods need to develop more comprehensive strategy, as most individuals continue to have difficulty walking to metro stations from their homes. In the present study, an analysis around three metro stations in Doha helped to understand better how the built environment encourages or discourages users from selecting walking as a transport option.

This study has shed light on a cluster of parameters and assessed the interrelationships between them. It also focused on a quantitative approach related to physical characteristics and environmental variables, but not to non-physical characteristics such as user psychological adaptation. Data and information were collected from the three selected metro stations in three different districts and lines. It focused on studying diverse types of pedestrian context characteristics, according to diverse land use types. However, the focal point was studying stations based on daily traffic trips rather than occasional or instantaneous trips. This will allow us to explore the existing conditions of the built environment and its effect on daily users walking to and from the studied metro stations.

5.2. Key Findings

In general, it is challenging to define specific factors affecting walking behavior since many intakes are reflected in walking as behavior. However, the context of the metro

station has the most effect on walkability regardless of other factors that can contribute to it. This means that, even if the catchment areas around the metro station may not be prepared for pedestrians' walkability, the context plays a significant role in the flow of pedestrians. However, the context of it showed a high walkability behavior as indicated by pedestrian movement patterns. For example, West Bay Station and Al Aziziyah Station seem more walkable than Al Sadd station though Al Sadd station is placed in a high population district. Nevertheless, the nature of the first two stations is generated by the force of destination rather than origin. Both stations share the common land-use characteristics of employment hubs for different users from around the country.

Around Hamad Hospital Station, Al Sadd area shows a smaller block sizes and much shorter streets length, which normally encourage a larger number of people for walkability. Nonetheless, traces of pedestrian movement patterns had the least number of users compared to West Bay Station and Al Aziziyah Station, both of which have larger block sizes and longer streets. This indicates that the urban context plays a leading role in defining walkability to metro station as a form of destination rather than origin.

Distance indicated a substantial positive link with the walking level of the context, as expected and consistent with other studies' findings. People walk more frequently when the walking distance is less, and vice versa. The typical walking distance varies depending on the situation. Al Sadd has a more walkable distance in relation to the context it serves, as opposed to West Bay and Al Aziziyah, which have longer walked distances. The average distance walked is 138 m. This is smaller than the average distance walked in developed countries. In the United States, for example, the average walking distance to rail stations is half a mile (805 m) (Agrawal et al. 2008), while the distance to other destinations in San Francisco and other US cities ranges

from 548–600 m to 1100–1200 m in a few situations (Payadar et. al., 2020, Millward and Spinney, 2013).

The primacy in this city's transportation system has been given to private cars and street development, rather than pedestrian mobility. Private high-speed cars can be seen on several types of streets, including local alleys. As a result, little attention has been paid to improving pedestrian crossings in this city. Furthermore, traffic calming devices such as speed humps, pedestrian traffic lights, and crosswalks are few and only present at major intersections. Furthermore, bikers frequently use sidewalks to avoid traffic congestion.

5.3. Answering the Research Questions

- What are the built environment features that promotes/discourages the walking activity to metro stations?
  - There are many features affecting the walkability to metro station. However, the context of the metro station plays a key role in in promoting walkability to metro station as a source of destination.
  - Introducing a short distance which promote shorter walking distances around metro station encourage users to walk to metro stations. This can only be achieved by reducing the size of block sizes through urban designs.
  - Interaction at street level has important affect in promoting a sense and belonging for pedestrians. Interaction in Al Sadd area is high compared to Al Aziziyah and West Bay, just by promoting ground level accesses and windows to building design.
- How are the three metro stations similar or different to each other within their context?

- The three stations are different in terms of their context within the urban fabric. However, both West Bay and Al Aziziyah are relatively new districts, both are promoting the employment and business hub which are considered as destination stations.
- Since both West Bay and Aziziya are new districts, the blocks size and street segments are almost similar.
- Al Sadd has a very interactive context including variety of land use compared to the other districts. Al Aziziyah has front interaction rather than internal interaction. While West Bay has almost no ground level interaction with pedestrians.

5.4 Way Forward for Built Environment Around Catchment Areas

The recommendations for the enhancement of the built environment in the three-metro station aim to address the challenge in creating a walkable neighborhood. It can be divided into two phases:

The first phase consists of simple modifications that can be made immediately to the existing condition without the need for substantial implementations. The interventions are mostly focused on improving pedestrian connections and access through streets, suggesting public land uses for unused sites, and improving streetscape design by providing suitable walkways, planting, and shading components. Enhancing walkability on the ground levels of structures by introducing bicycle and pedestrian paths in the neighborhood.

The second phase entails major interventions that could be implemented later, when large-scale implantations is more feasible. A smaller land subdivision is advocated because the compact spatial grid enhances area through-movement potential,

increases permeability, and could efficiently direct developments toward a mixed-use and accessible urban form. Enhance land use diversity, density, design, and transport. Based on the analysis and the findings around each station, Table 7 describes a brief recommendation for each station based on the attributes presented previously to create a walkable environment for pedestrians using metro stations.

5.4.1 Spatial Pattern and Urban Context

Both the Al Sadd area and Al Azizyah area suffer from the exitance of many empty plots or provision of many empty spaces. This can be solved by transferring the empty plots to make them public nodes and greenery areas, especially in the Al Sadd area. This will fulfill the concept of complete urban structure that can be reflected in providing walkable urban areas (Figure 61). On the other hand, to accommodate many vehicles within the area, the Ministry of Transportation and Communication (MOTC) can cooperate with the MME to provide the minimum number of parking required per one apartment building according to the number of families and the average number of vehicles owned by families before providing permission to construct new buildings.

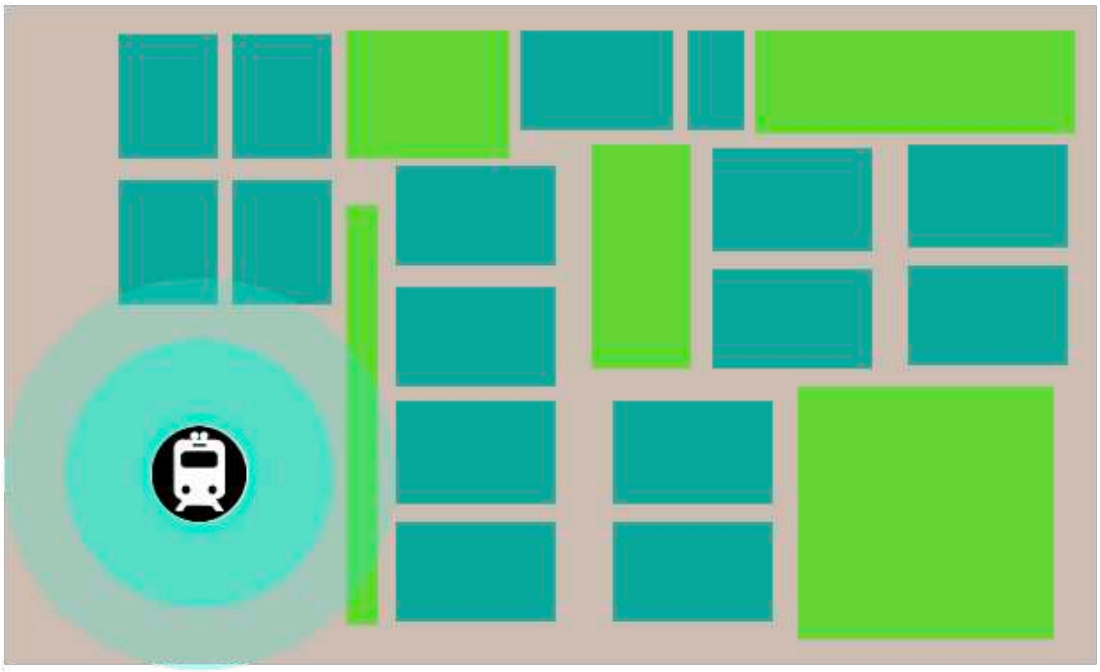


Figure 61. Transfering the parking/empty plots to public nodes or public parks.

Around the West Bay area exiting towers and new towers should provide a ground-level amenity, including groceries, cafes, restaurants, post offices, and transfer the vehicle's movement from ground levels to the basement or higher-level floors. This will provide an interaction between walking pedestrians and high towers in the area and will create human-scale balance (Figure 62). Around Al Azizyah station, it would be challenging to provide the pedestrians' interaction according to the cultural aspect of privacy generated in the existing context of villas and compounds. However, adopting the concept of open majlis street will create more interaction and provide a safe, walkable environment for pedestrians (Figure 63).

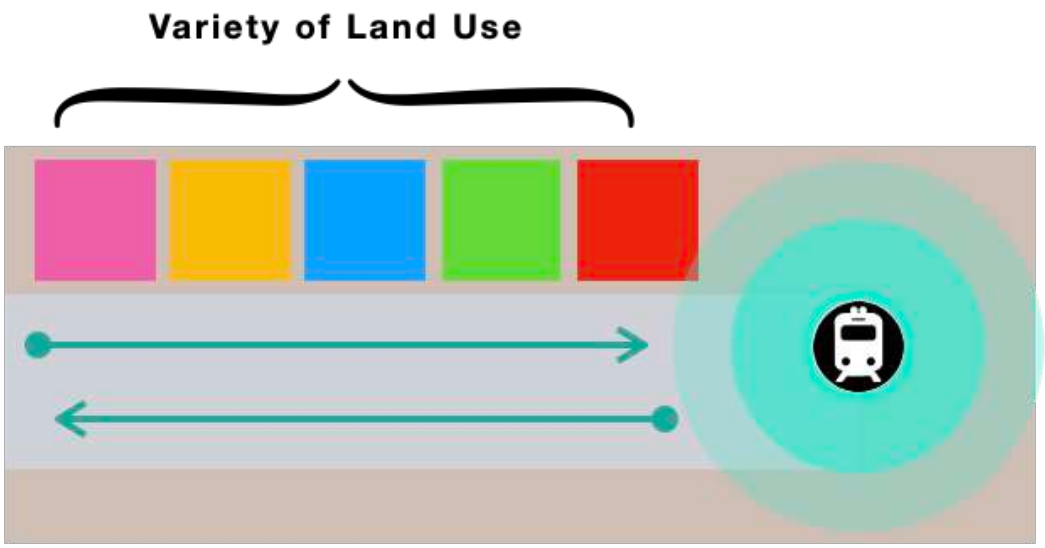


Figure 62. Providing different types of amenities at the ground level.

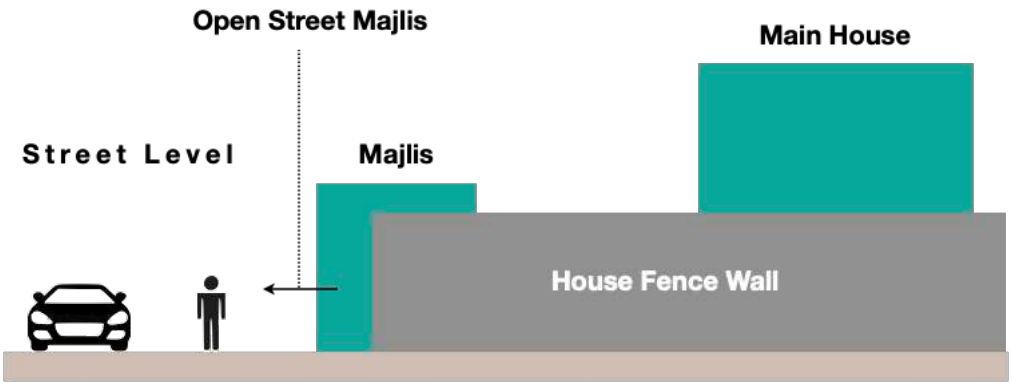


Figure 63. Introducing the Open Street Majlis for more interaction.

Furthermore, adopting the urban block size of the Al Sadd area and applying it to new future urban developments will enhance and encourage the walking behavior not only to metro stations but also to other surrounding amenities. The average block size of the Al Sadd area can be applied but enhancing the organic structure and providing organized urban segments, which will also provide a sense of place and increase the permeability.

5.4.2 Urban Typology and Walkability

Around the West Bay and Al Azizyah Station the government managed to equip the stations with bicycles parking and scooters distributed in different places, either within the stations premises or blocks near the stations (Figure 64). The same concept should be implanted within Hamad Hospital station as it will increase the number of pedestrians walking to the station. Also, providing a public transport system within the station can increase the number of users.

Figure 64. Scooters distributed within the Al Aziziyah area and West Bay Station.

5.4.3 Street Design

Generally, street segments and street width play a significant role in defining the walkable environment for pedestrians. However, the shorter street segments consider a more convenient approach for pedestrians when it comes to walking. The shape of building blocks usually significantly shapes the geometry and the length of street segments. Adopting an average block size will significantly affect the walking distances for pedestrians. Figure 65 provides a suggestion of creating a small gap between the blocks to allow pedestrians to take shortcuts while walking. Most of the blocks occupy the area of the plot allowing no setbacks between one building and the other. The same

concept can be applied around Al Azizyiah station for the compounds by making compounds accessible by the public and providing access from front and back of the compounds. Future houses can have fence set back to allow movement for pedestrians.

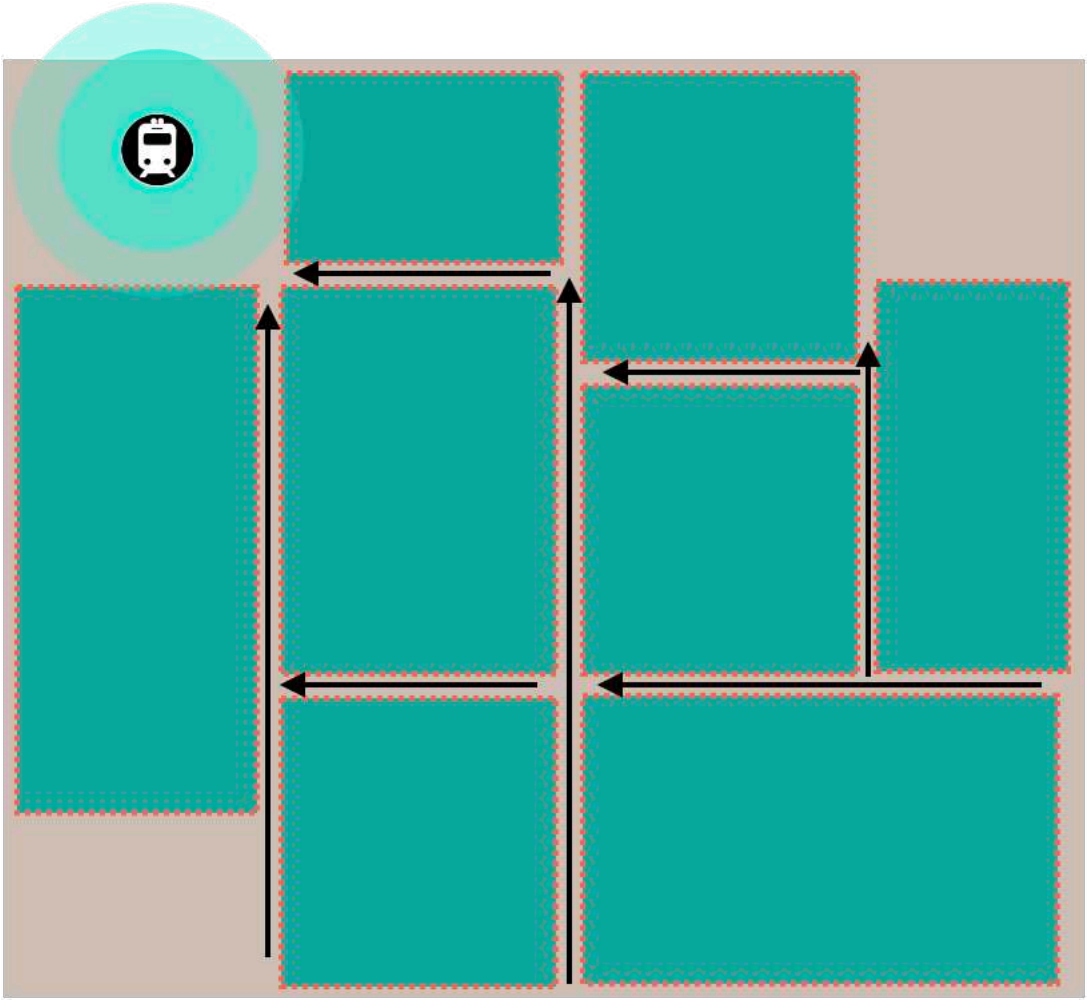


Figure 65. Providing proper setback between building only for pedestrians movement.

Regarding the street width and design there are many possible suggestions that can be implemented around each station to enhance the built environment. In support of the QNV and QNDF, Qatar Public Realm Streetscape was initiated to address the need to improve the quality, safety, and functions of the streets. It also outlines design strategies and approach to street design and layout which can be used to enhance the

streets leading to metro stations.

Around the three stations, it is important to provide much-needed crossing spots to connect to blocks across each other and provide safe between space. These crossings can take the shape of sub-terrain active retail corridors that serve as an extension of the main street store frontages while also providing shaded relief from the sun. Also, the streets can be designed to encourage more active interface through tree planting and provision of street furniture wherever necessary to provide shade and convenient environment for walkability.

Around Hamad Hospital Station, streets require a large amount of input to elevate the quality of the walking environment. Streets should be paved for both vehicles and pedestrians as it creates a hazard for both parties. It is suggested to construct a parking building that can accommodate a large number of vehicles and reconstruct the street design with time parking (Figure 66). Parking near the building this way will be eliminated and provide space only for pedestrians and vehicles movement. Establishing green walkways and providing alternatives of light transportation within the area will encourage people to walk and park away from their buildings.

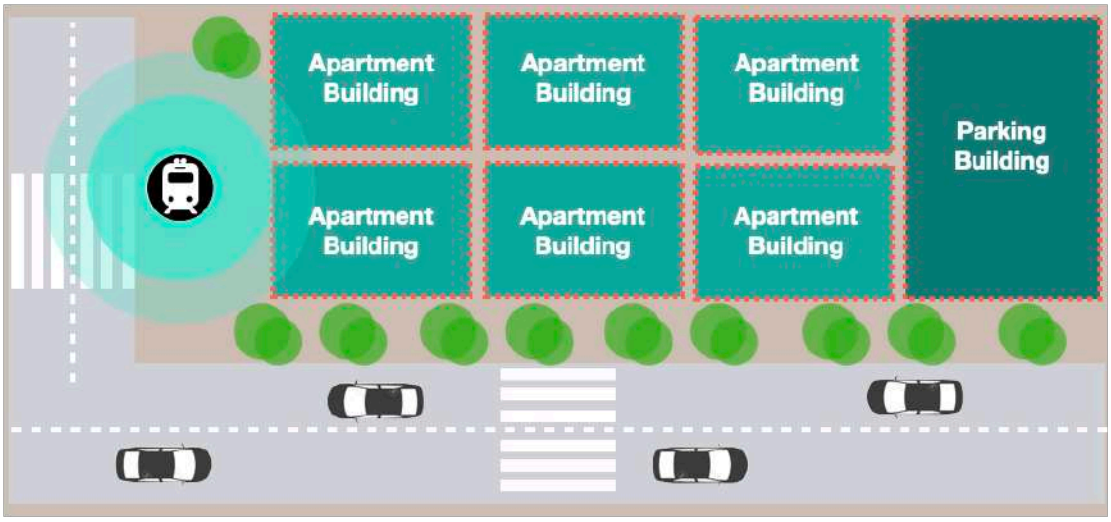


Figure 66. Suggested layout of street design within Hamad Hospital Station.

Within Al Azizyah area, it is essential to provide ample spaces for street parking and necessary green buffer between the streets and residential development and sidewalks for internal streets (Figure 67). Around West Bay Station, streets should be pedestrians oriented by creating crossing points between urban blocks and placing berries to stop illegal parking within the sidewalks. It is also essential to provide shaded walkways by adding trees and other plantings for a good view and comfortable walking experience (Figure 68).

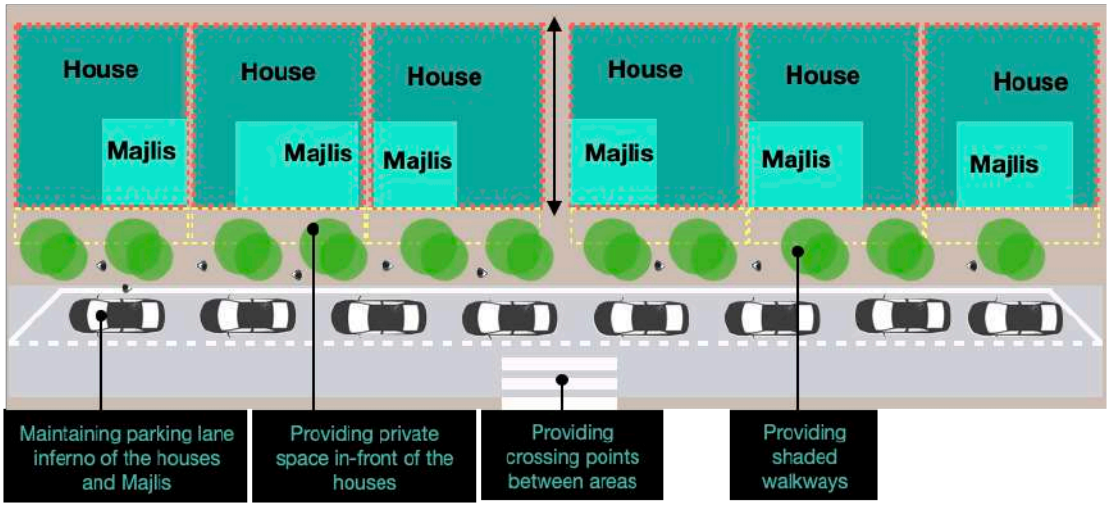


Figure 67. Suggested street layout within Al Azizyah Station.

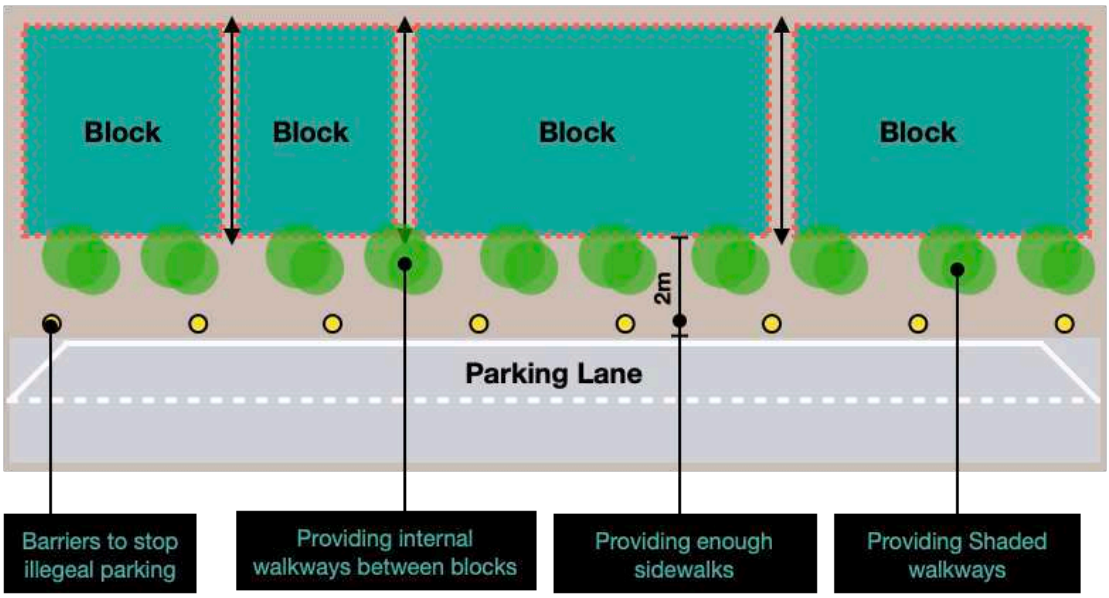


Figure 68. Suggested street layout within West Bay Station.

5.4.4 Pedestrian Connectivity

Based on the analysis of this thesis, West Bay would most benefit from the creation of a local tram system, which could introduce more public rail stops in the area. To the North side of the city, a metro line should be introduced to cover the residential area between Qatar university and Doha expressway. However, after reviewing the data of

the Qatar rail, the government is providing a safeguard for future development of metro line to cover this area (Figure 69).

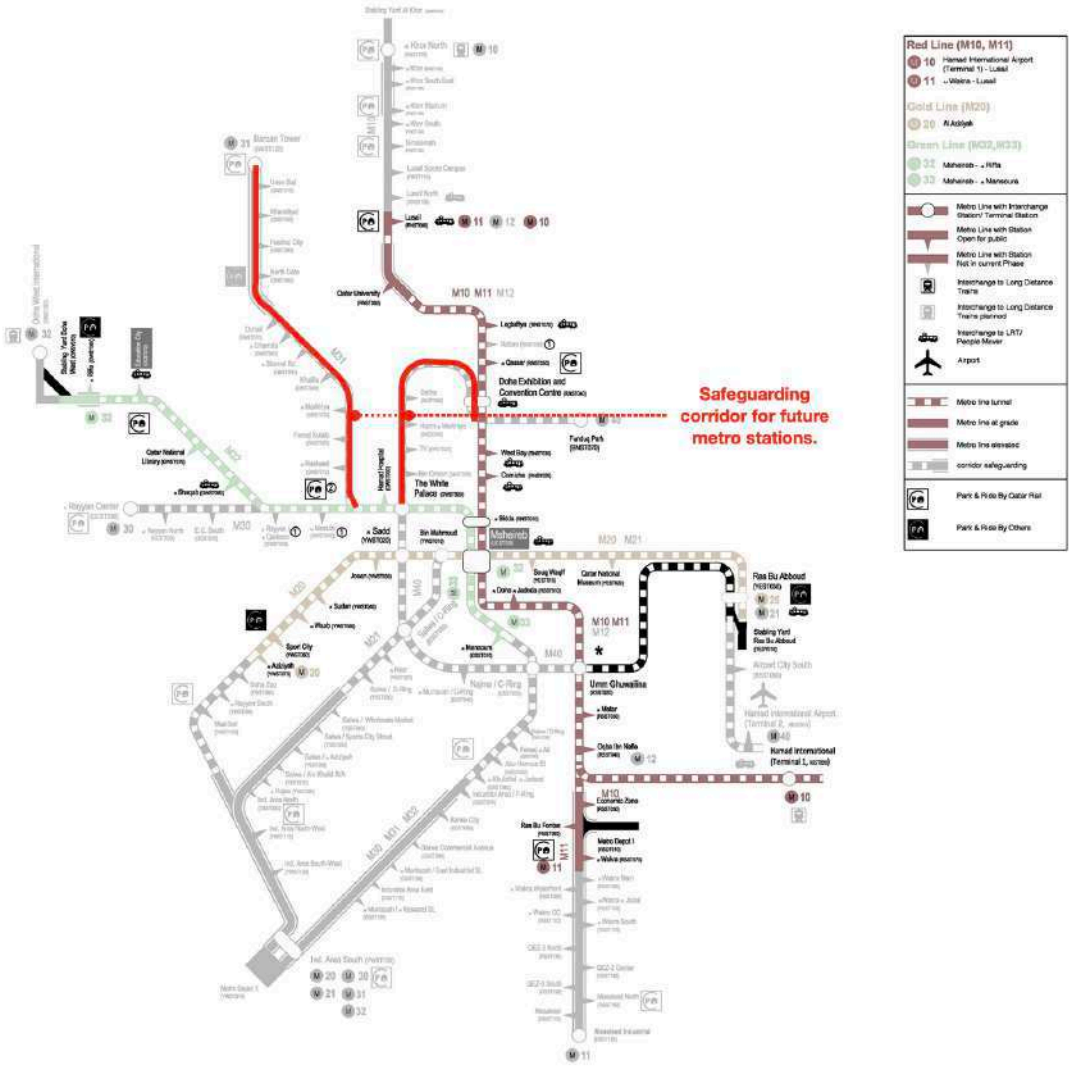


Figure 69. Doha metro lines including current operating lines and future lines.

5.5 Contribution to Knowledge

This study contributes to our knowledge of walkability around metro stations by expanding the investigation into the micro and macro-scale level of the Doha metropolitan area (Table 8). Existing studies of metro stations in Doha focus on understanding the microscale level of street design. However, this study allows another dimension of investigation by examining the neighborhood and metropolitan level

through morphological analysis and space syntax analysis. Improvements in new developments of Doha – as a still developing city – should focus on performing larger-scale analysis and studies as it will affect Qatar's urban planning and walkability around metro stations in the near- and long-term.

Table 8. Attributes and relation to contributions to our knowledge.

LEVEL	INDICATORS	FACTORS	ATTRIBUTES	CONTRIBUTION TO KNOWLEDGE
Micro Scale (Direct Interaction)	Street Design	Street Geometry/ Street Condition	**Sidewalks Width** **Street Segment/ Length** **Continuity of sidewalks** **Street Shading/ Provision of greenery** **Density of streetlamps** **Provision of Crossing points and facilities** Signage and Wayfinding	**Many studies had shown lack on providing simple street design elements that enhance walkability around metro stations. This study had shown incompetence at each station providing a room for modification.** -
	Road Design	Infrastructure and traffic	Street or road character Traffic volumes Speed levels Traffic safety Pollution and noise Public transport connectedness	-

LEVEL	INDICATORS	FACTORS	ATTRIBUTES	CONTRIBUTION TO KNOWLEDGE
Macro scale /Metropolitan scale (In-direct interaction)	Urban Design	Spatial pattern of the area and the urban context/ Urban Typology in relation to walkability/ pedestrian connectivity	**Density/Diversity**	**Walkability around metro station is majorly affected by the context of the area regardless the micro scale environment. Context if reflected on walkability behavior. (Morphological analysis)**
			Buildings Height	**-**
			Block sizes	**Walkability around metro station is affected by the block sizes which follows the historical development of the area and has a direct connection with density and diversity. (Morphological analysis)**
			Permeability	-
			Pedestrian network	**Station to Station level revealed the lack of connection in pedestrian network at metropolitan scale. (Space Syntax analysis)**

LEVEL	INDICATORS	FACTORS	ATTRIBUTES	CONTRIBUTION TO KNOWLEDGE
			Building Frontages	**Building frontage provide human interaction human scale level which is reflected at the environment of walkability to metro station. The connection between pedestrians/ street environment and building frontages can be studied at level of perceptual dimension. (Morphological analysis)**
			Parking lots/ Voids	-

5.6 Limitation and Future Research Implications

The findings revealed the complex nature of the metro station based on the context it is serving. By understanding the growth of the city in respect of the three stations, it highlighted the walkable environment in degrees of accessibility of these metro stations to their urban context. It was complemented by a focus on the current situation of the three stations in terms of spatial context and urban form, urban typology and context, street design, and pedestrians' connectivity.

This research can be used to expand the case studies to include more metro stations in other context forms, both in terms of the literature review and the analysis. Including more metro stations for the study in different lines and performing a

comparative analysis shall reveal the main aspects affecting walkability in the city of Doha, and it will allow implantation of significant adjustments around catchment areas. In addition, this study focused on interpreting and analyzing the existing conditions of the built environment in terms of physical parameters. This can be extended to allow a study for the social, behavioral, and perceptual aspects, which include interaction with the audience to understand the user's preference psychological adaptation when walking to the metro station, which clearly impacts user comfort and well-being. Hendy (2005) generated a complete study and precise definitions that will assist interested researchers to pursue social aspects to extend this study further.

The literature review revealed many aspects of built environment affecting walkability at three levels of the pedestrian environment, traffic environment, and urban environment. Due to time limitations and extension of the study, this research focused on studying only the pedestrian environment and urban environment, which allows for future study focusing on the traffic environment adjacent to the pedestrian environment and part of urban environment as well. Such an investigation will create an extended version of this study to full accommodate all the factors affecting walkability to metro stations.

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APPENDIX

Appendix A

The following reference relate to author publications:

Conference Papers (Published and Accepted for Publication):

Salaheldin, H., Major, M.D., Tannous, H.O. (2021) "Analysis of Built Environment Factors on Walkability at Three Doha Metro Stations," *Proceedings of the 57th ISOCARP Virtual World Planning Congress* (P. Lorens, H.H. Magidimisha, N. Balamiento Eds.), International Society of City and Regional Planners, 8-11 November 2021, Doha, Qatar, pp. 2419-2436, ISBN/EAN 978-90-75524-69-7, https://dryfta-assets.s3.eu-central-1.amazonaws.com/assets/doha2021/eventdocs/1639135625ProceedingsCompressed.pdf.

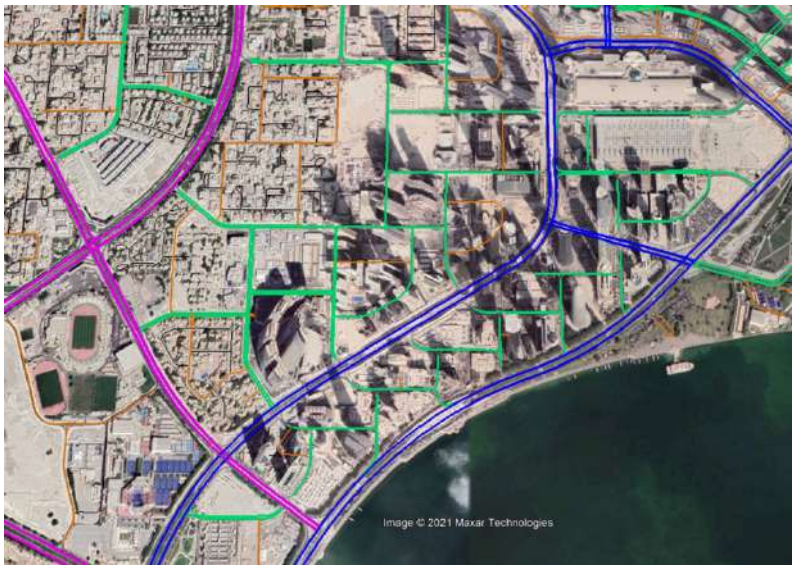
Major, M.D., Tannous, H.O., Al-Thani, S., Hasan, M., Khan, A., Salaheldin, H. (2020) "Macro- and Micro-scale Modeling of Multi-modal Transportation Spatial Networks in the City-State of Doha, Qatar," *56th ISOCARP Virtual World Planning Congress*, International Society of City and Regional Planners, November 2020-February 2021, Doha, Qatar, https://doha2020.isocarp.org/paper-platform/abstract/public/51/macro-and-micro-scale-modeling-of-multi-modal-transportation-spatial-networks-in-the-city-state-of-doha-qatar.

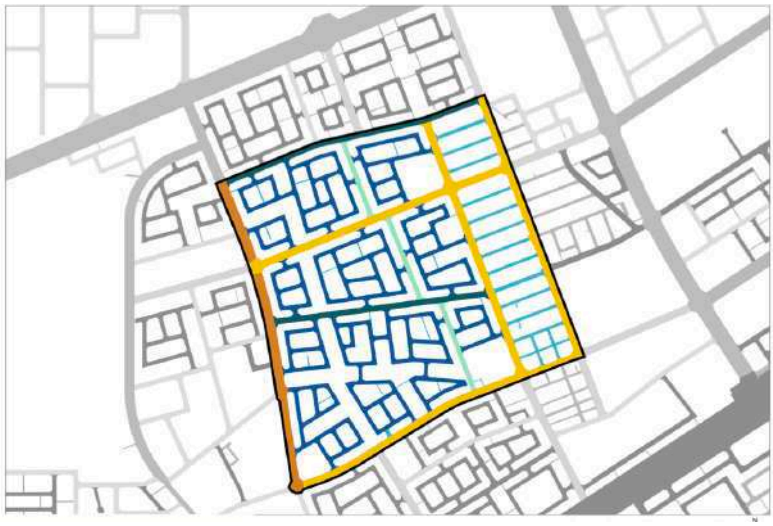
Journal Papers (Under Review):

Salaheldin, H., Major, M.D., Tannous, H.O. (forthcoming) "Analyzing Factors Affecting Walkability in the Neighborhoods of Three Doha Metro Stations," *Urban Design International.*

Appendix B

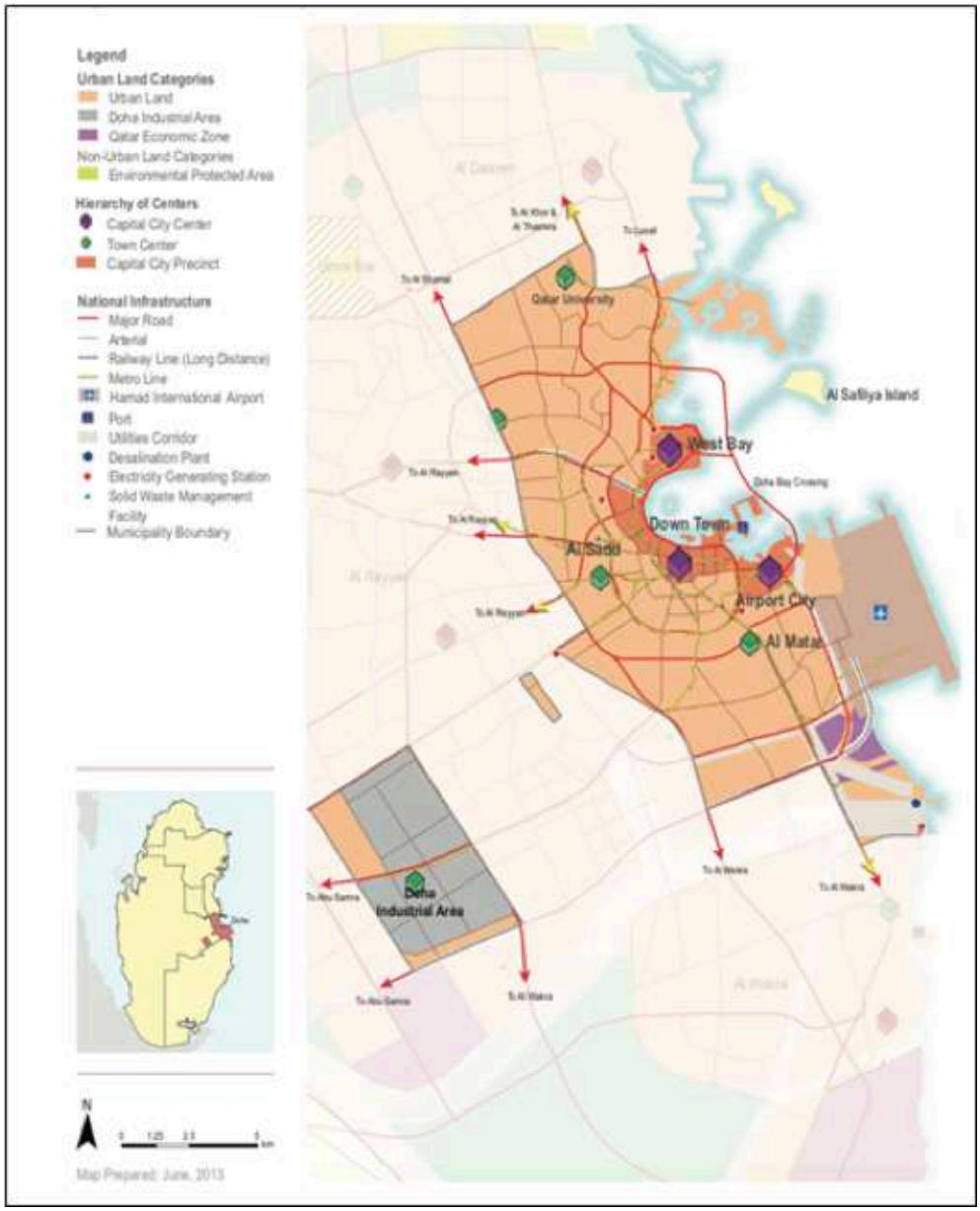
Map of street hierarchy within (top) Al Sadd area, (center) West Bay area, and (bottom) Al Aziziah area.



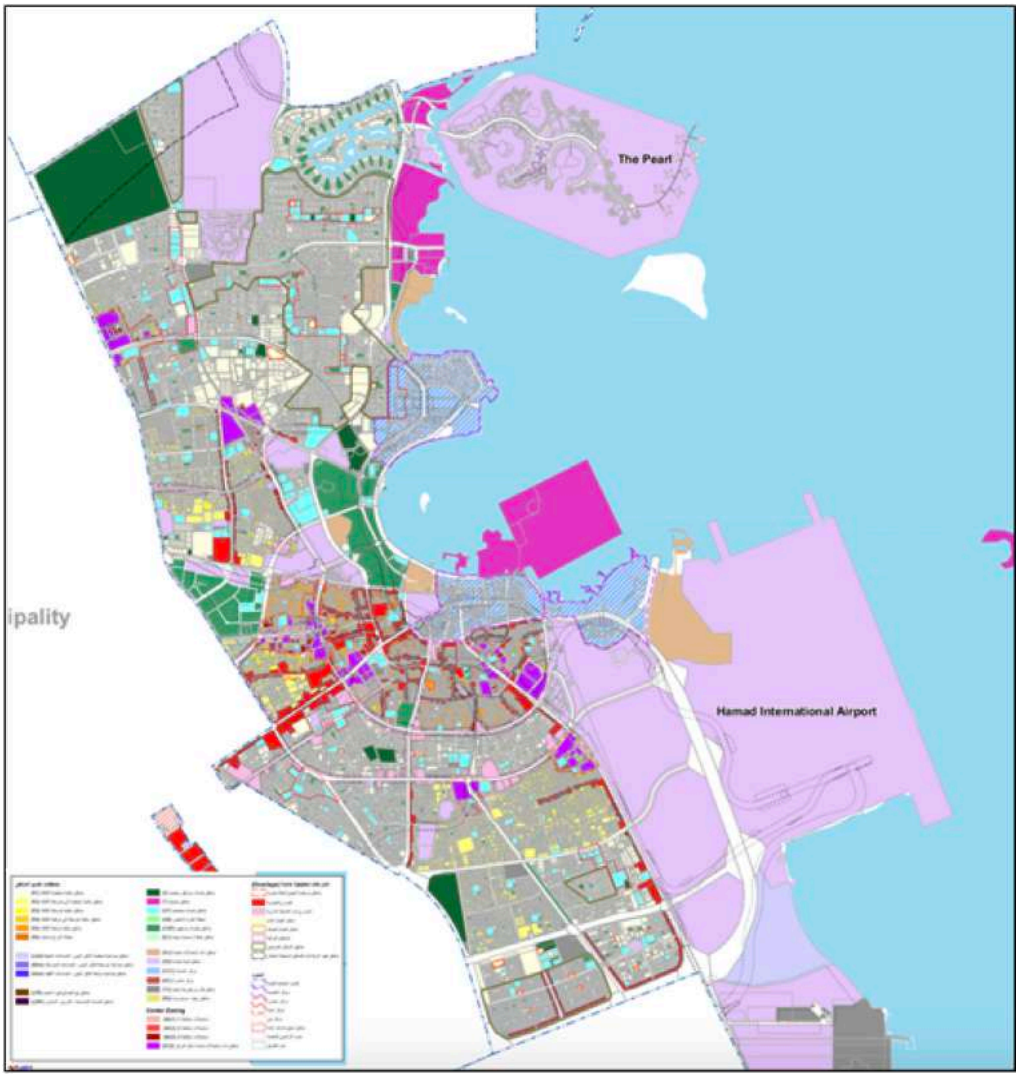


Road Network
Hierarchy
Freeway
Expressway
Arterial
Major Collector
Minor Collector
Local Street
Ramp/ Service Road
Roundabout
Turn Lane

Appendix C


Legend
Urban Land Categories
Urban Land
Doha Industrial Area
Qatar Economic Zone
Non-Urban Land Categories
Environmental Protected Area
Hierarchy of Centers
Capital City Center
Town Center
Capital City Precinct
National Infrastructure
Major Road
Arterial
Railway Line (Long Distance)
Metro Line
Hamad International Airport
Port
Utilities Corridor
Desalination Plant
Electricity Generating Station
Solid Waste Management Facility
Municipality Boundary
Qatar University
Al Safliya Island
West Bay
Down Town
Al Sadd
Airport City
Al Matar
Doha Industrial Area
N
Map Prepared: June, 2013

Appendix D



Appendix E: About Space Syntax

Excerpt from Tannous, Major, and Furlan (2021)

Our built environment is both a product of society and an influence on society. Space syntax is an international research program of academics and practitioners scientifically investigating spatial networks from the single building to entire metropolitan regions to better understand 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 around the world.

Figure A1. Representing (top, left to right) a point, line, and convexity ('the quality or state of being convex') in space syntax and (below, left to right) a visual field (in dark grey) from a point, line, and convex space (in light grey) in the plan of Souq Waqif in Doha, State of Qatar. NOTE: Plan elements in the large open plaza towards the lower left represents impediments to movement but not visibility, i.e., a normal human being can see over the top of these elements (Images: Mark David Major/Heba O. Tannous).

Representations in space syntax are usually plan-based using objective, easily understood constraints of the built environment for the most generic of human uses such as movement, occupation, and visibility because we are forward-facing, bipedal creatures normally bound by gravity (Hillier, 1996; Major, 2018) (Figure A1). A point in space is the simplest notion on which to build a geometry with no size, only position. The number of points in any space will be infinite without a resolution – defining the bounds of a space and 'size' for the points – such as the average standing area of a normal human being ($0.28m^2$) (Turner et. al, 2001). Movement tends to be linear because we are bipedal, forward-facing creatures bound by gravity. The axis or line of sight and movement (e.g., 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) of pedestrian and vehicular movement in the urban environment (Hillier et. al., 1993; Penn et. al, 1998). The occupation of space tends to be convex where everyone can see and be seen by everyone else such as a group of people gathered in a circle or a room. All points are visible to all other points in a convex space. The collection of all convex spaces composing a built environment is the convex map, which tend to be more useful for the analysis of buildings (Hillier et. al, 1987; Hillier, 1996; Hanson, 1998). The potential for seeing and moving is a visual field, which is all visible and accessible space from which we might see or move as defined from a point or set of points such as a line of sight and movement or convex space (Benedikt, 1979). The matrix of all visual fields from a gridded set of points to all others in a built environment is a visibility map (Turner et. al, 2001). Space syntax uses combinations of these simple descriptions — point, line, space, field — to create layered representations of the built environment. We can measure the matrices of these representations using topological graph theory to mathematically quantify the configurational relationship of all spaces — point, line, space, visual field — to all others or within a set range. Configuration is a relational system where any local change in a system can have global effects across that system to varying degrees dependent on the size of the system relative to the significance of the change itself within that system (Hillier, 1996) (Figure A2).

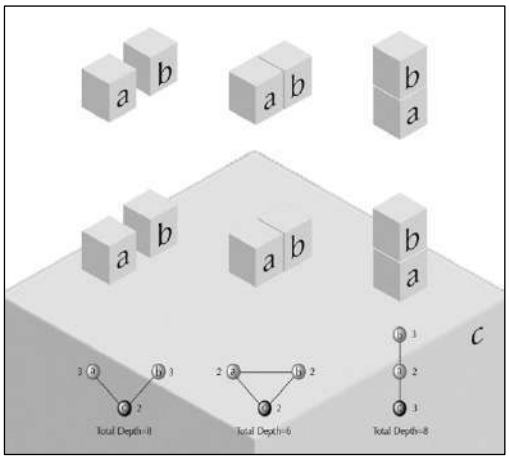


Figure A2: The basics of configurational measurements using topological graph theory where (top row) two objects labelled A and B are similarly related until (middle row) the introduction of a third object labelled C (such as the surface of the Earth). All three objects now have different configurational relationships based on connection or permeability, as represented (bottom row) in the justified graphs where the object is represented as a node and their relation as a line (Image: Major, 2018 after Hillier, 1996).

Configurational measures offer a scientific basis to implicate or dismiss the designed spatial network as a factor in social, functional, and/or cultural outputs. Space syntax software also incorporates metric parameters such as the length of streets/street segments and the plan area/perimeter surface area of visual fields. Over four decades, researchers have developed a diverse number of configurational and metric measures using space syntax. Some are more useful than others, and sometimes it can take years of testing to confirm or refute their usefulness. It can be overwhelming for those unfamiliar with space syntax. Generally, the most useful are:

- Connectivity is a simple measure of how many other spaces does a single space

immediately connect to within the network.

- Integration is the relativized mean depth of a space in relation to all other spaces in a network based on changes of direction using connectivity (see above). It represents how integrated/shallow or segregated/deep is a space within a spatial network. It demonstrates the pattern of 'to-movement' for those spaces most likely used for journeys from anywhere to everywhere else in the spatial network. Researchers can set the radii of integration measures based on specified parameters such as global integration (radius=n) and local integration (radius=3).
- Local integration is relativized mean depth of a space in relation to all other spaces in a network based on three changes of direction, which highlights the more immediate catchment area of a single space within the network. In effect, the justified topological graph underlying the measure is 'cut' off for every space more than three changes of anywhere from the origin space. Most usually, local integration is strongly related to connectivity (see above) because they measure the more immediate characteristics of space in the network. In the real world, the simplest way to understand local integration is if a person imagines themselves standing in the middle of an intersection of two or more spaces, looks down both spaces in all directions to see all other spaces immediately connected to those spaces defining the intersection, and then repeated that process for all the other intersections they can see from the first intersection. In larger spatial systems such as cities, it is often useful to limit the radius of integration based on relativised mean depth from the most globally integrated space in the spatial network because it reduces, though not necessarily eliminates completely, 'edge effect,' i.e., spaces at the edges of the spatial network tend towards segregation merely because of their location at the edge.

- Choice is a measurement of global 'through-movement' based on giving every space in the spatial network (however represented) a value of 1, then proportionally sharing that value amongst all its immediate connections. The shared values for every space are then added up to provide a measurement for the degree of importance of that street within the spatial network. Choice measures how likely a space it is to be passed through on all shortest routes from all spaces to all other spaces in the entire system or within a predetermined distance (radius) from each segment (Hillier et. al., 1987). Global choice tends to highlight the primary transportation routes within an urban spatial network and spaces facilitating some degree of social control in buildings. Finally, researchers can also set the radii of various configurational measurements based on metric parameters using the average distance to the center of each segment as defined by the midpoint between two separate connections such as 500 m, 1000m, or 5000m. Despite incorporating metric measures, researchers consistently find that the correlation with configurational measures tends to be more significant for understanding the 'social logic of space' than metric ones (Hillier and Vaughan, 2007).

Modeling Settlements

Urban analysis in space syntax primarily relies on drawing an axial map of the open space structure based on a plan of a settlement to describe and analyze its spatial configuration (Hillier and Hanson, 1984; Hillier, 1989) (Figure A3). For the best results, this usually requires a plan or plat that accurately depicts all building footprints in the settlement. We can also divide the open spaces into the fewest and fattest set of convex spaces as defined by built forms necessary to encompass the entire settlement, if we wish to double-check that one-dimensional mapping of longest and fewest strategic lines of sight and movement in the axial map connects all the two-dimensional

representations of space in the convex map. Most practitioners and researchers forgo this stage in urban analysis unless they are interested in researching the design or use of specific convex spaces in a settlement such as a public plaza or square. Instead, they tend to proceed to immediately drawing the longest and fewest lines of sight and movement in the settlement based on the plan/plat to create an axial map of the settlement. Best practice in space syntax usually suggests beginning with drawing the longest lines, then the shortest lines, and concluding with the lines of intermediate length that connect between the two extremes of length. The use of a figure-ground representation with all built forms in black often assists this process. The axial map represents the least set of longest and fewest lines of sight and movement necessary to pass through and encompass the open space structure of the entire settlement. Once the axial map is complete, then the map can be processed using computer software to analyze the system of relations between the lines. Hiller and Hanson (1984) argue the relation of all axial lines in the system are measured based on two basic properties, 'symmetry-asymmetry' and 'distributedness-nondistributedness,' which means is the degree to which space is composed of shallowness/rings of circulation or deepness/sequences that form trees in the underlying topological graph.

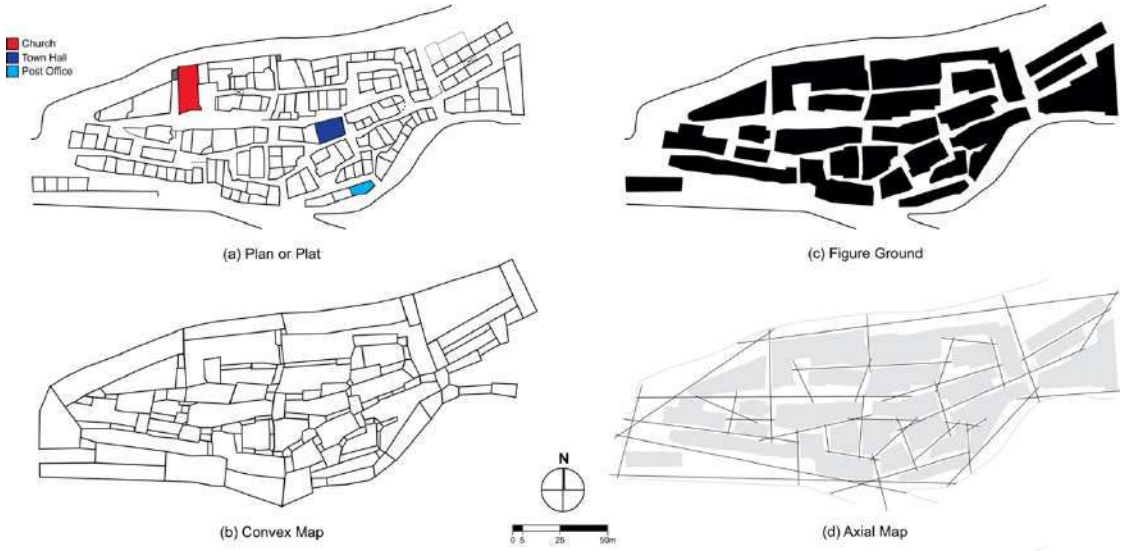


Figure A3. The procedure for modeling settlements based on the (a) plan/plat, (b) convex map, (c) figure-ground, and (d) axial map for the layout of Gassin in the Var region of France circa 1980 (Images: Major and Tannous, 2021 after Hillier and Hanson, 1984).

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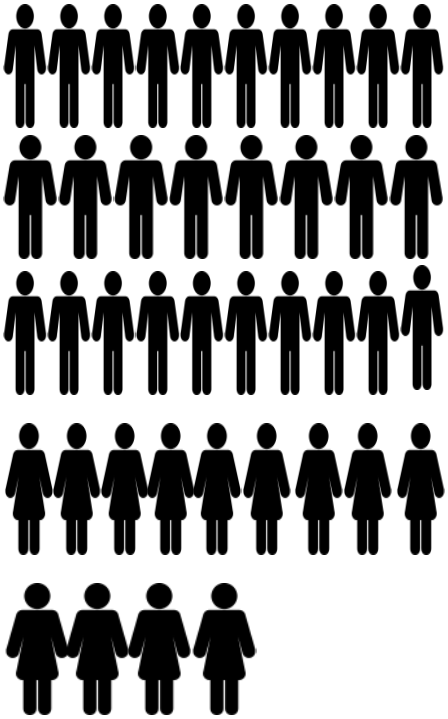
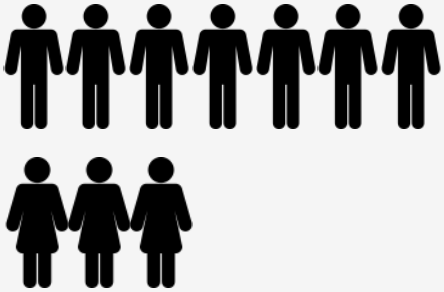
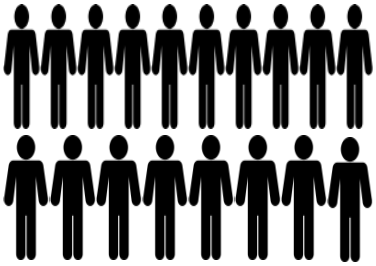
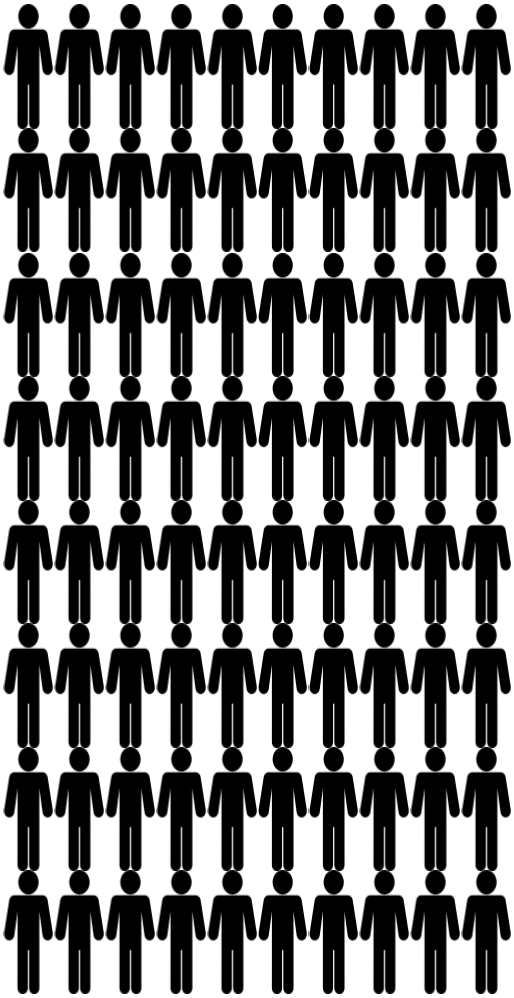
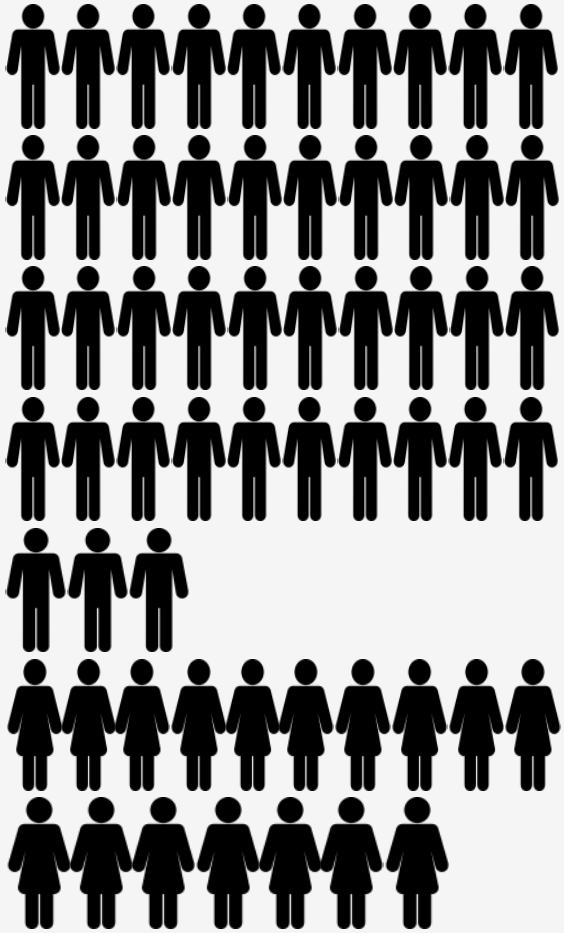
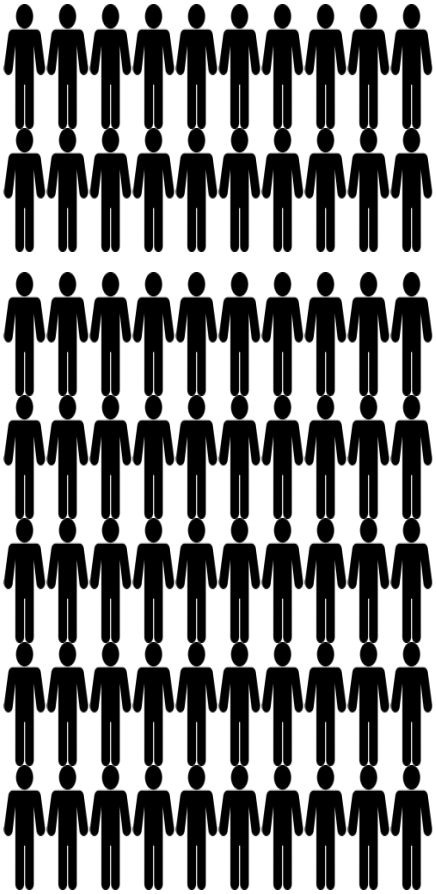
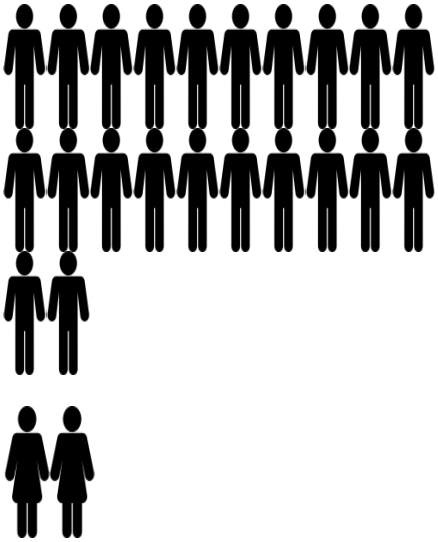
Appendix F

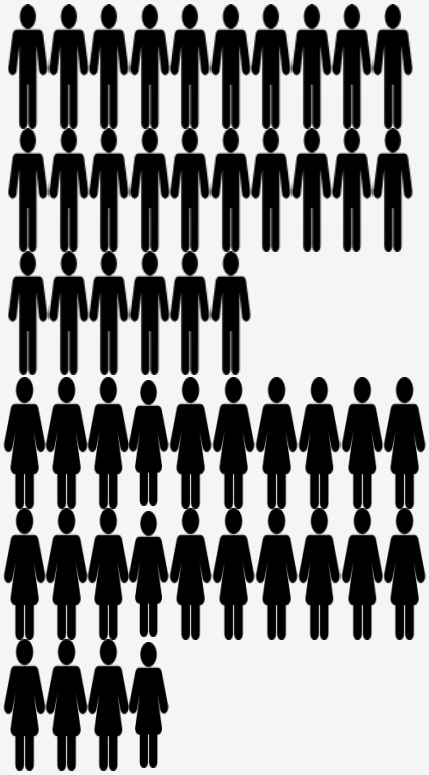
Station/Date/Time	In	Out
Al Sadd Station 01/April/2021 - Thursday (07:30 -08:00 AM)		

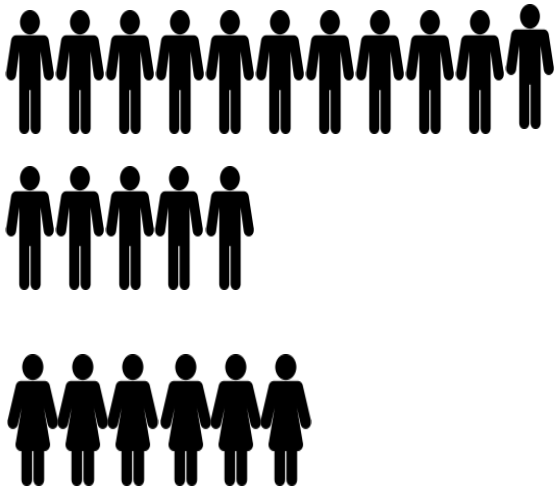
Station/Date/Time	In	Out
Al Sadd Station 31/03/2021 – Wednesday (05:00-05:30 PM)		

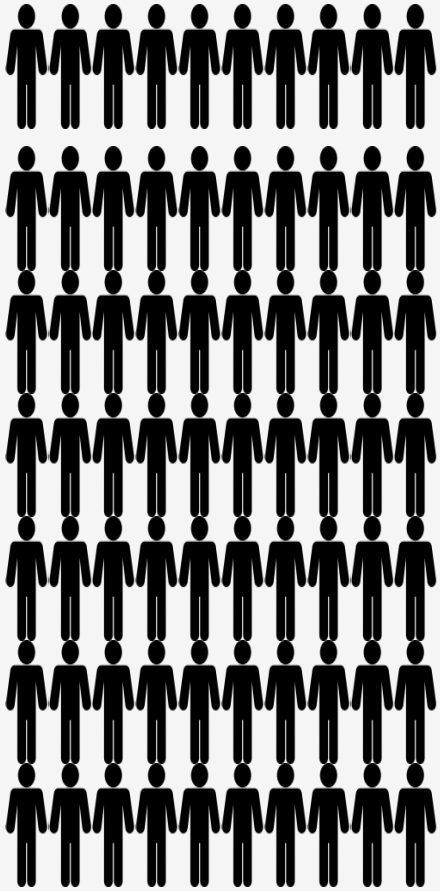
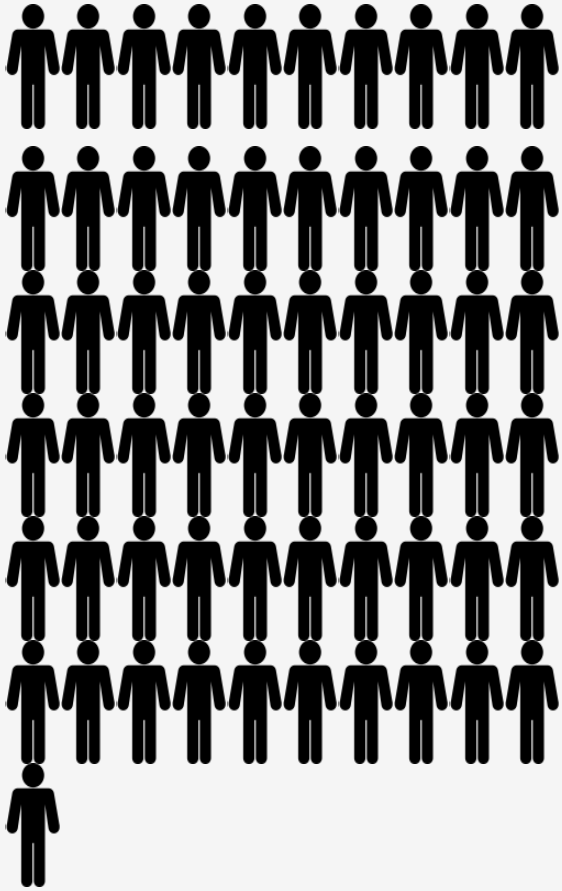
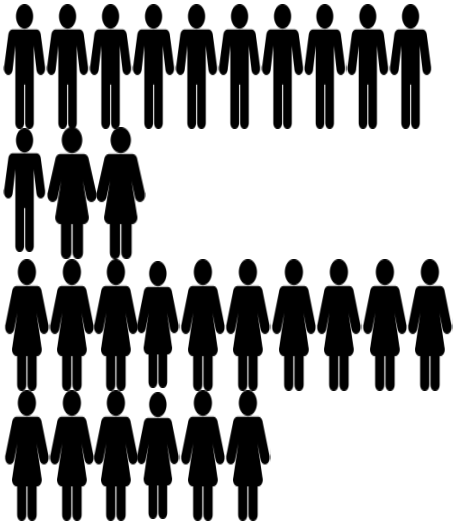
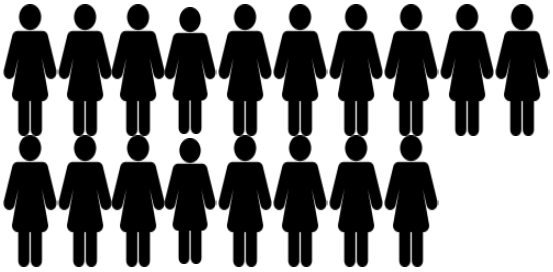
Station/Date/Time	In	Out
West Bay station 21/06/2021 - Monday (07:15 -07:45 AM)		

Station/Date/Time	In	Out
		

Station/Date/Time	In	Out
West Bay station 07/07/2021 – Wednesday (05:00–05:30 PM)		

Station/Date/Time	In	Out
		

Station/Date/Time	In	Out
Al Aziziyah station (North and South access merged) 25.05.2021 – Tuesday (07:00 -07:30 AM)		

Station/Date/Time	In	Out
Al Aziziyah station (North and South access merged) 10.10.2021 - Sunday (05:20 -05:40 PM)		

Station/Date/Time	In	Out