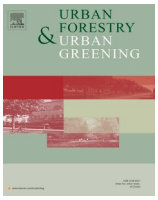
Urban Forestry & Urban Greening 58 (2021) 126892

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug



Accessibility of green spaces in a metropolitan network using space syntax to objectively evaluate the spatial locations of parks and promenades in Doha, State of Qatar

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ARTICLE INFO

Handling Editor: Wendy Chen

Keywords:
Accessibility
Green spaces
Network science
Planning
Policy
Urban

ABSTRACT

Accessibility indicates the ease of reaching many destinations from many origins in the urban network at various scales of space. It plays an important role in determining the location of public facilities to maximize usability for a large population or limit use to a smaller community. The absence of urban green spaces is a notable consequence of rapid urbanization in many cities around the world. Doha in the State of Qatar is no different, where rapid urban expansion and globalization has a significant impact on the quality and quantity of green spaces available. This paper analyzes the location and size of public parks, promenades, and other green spaces in Doha in terms of their accessibility. Do they follow a discernible spatial logic in terms of their size and accessibility linked to the design intent of public planning policies? The research shows there is spatial and social logic to the physical and spatial characteristics of open green spaces in Doha above a certain size. In contrast, those characteristics in smaller examples tend to be more random, mainly due to issues of land availability and amenity provision in private developments.

1. Introduction

Doha, the capital city of the State of Qatar, is currently constructing several megaprojects, including stadia and supporting facilities for hosting the FIFA World Cup in 2022, such as the Qatar Rail metropolitan public rail transit system and the Lusail City masterplan (Fig. 1). It represents a significant government effort to transform Doha physically and economically from its pre-oil, fishing and pearling origins to a modern diversified economy with global aspirations today. The prevailing urban planning strategy over the last 30 years has been simultaneous densification and land consumption. This strategy has obvious consequences for the provision of public parks and other green spaces in Doha. Also, inefficiencies in the municipal planning process further complicate the situation in the State of Qatar. Even the government recognizes that urban development is a major contributory factor for environmental deterioration in the country (Salama and Wiedmann, 2012).

In light of these issues, the State of Qatar developed the QNV 2030 plan to guide development strategies across all public and private sectors of the country. Based on this vision, the MPDS and MME developed a strategic policy document detailing a national master plan under the Qatar National Development Framework (Ministry of Municipality and Environment, 2016).One of the critical principles for guiding development was the adoption of urban design and planning strategies to ensure more sustainable growth, conservation of the natural environment, and preservation of land for public green spaces (Fig. 2).

Urban green spaces can provide a wide range of benefits for sustaining the natural and urban environment as well as creating and structuring the social systems that people utilize in such spaces. Many suggest there are additional benefits such as improving air quality and the general health of citizens as well as enhancing the urban settings of cities (Lee et al., 2015; Mitchell and Popham, 2007). They mean metric distance, but the topological distance in space syntax terms is also a potentially important, often overlooked factor for the locating of public green spaces (Koohsari et al., 2014).

Selecting inappropriate locations for public green spaces can make them less accessible to the populations they are supposed to serve,

Abbreviations: CNU, Congress for New Urbanism; FIFA, Fédération Internationale de Football Association; GCC, Gulf Cooperation Council; MIA, Museum of Islamic Art; MPDS, Ministry of Development Planning and Statistic and Environment; MME, Ministry of Municipality and Environment; QNDF, Qatar National Development Framework; QNV 2030, Qatar National Vision 2030.

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https://doi.org/10.1016/j.ufug.2020.126892
Received 28 February 2020; Received in revised form 8 October 2020; Accepted 17 October 2020
Available online 5 November 2020

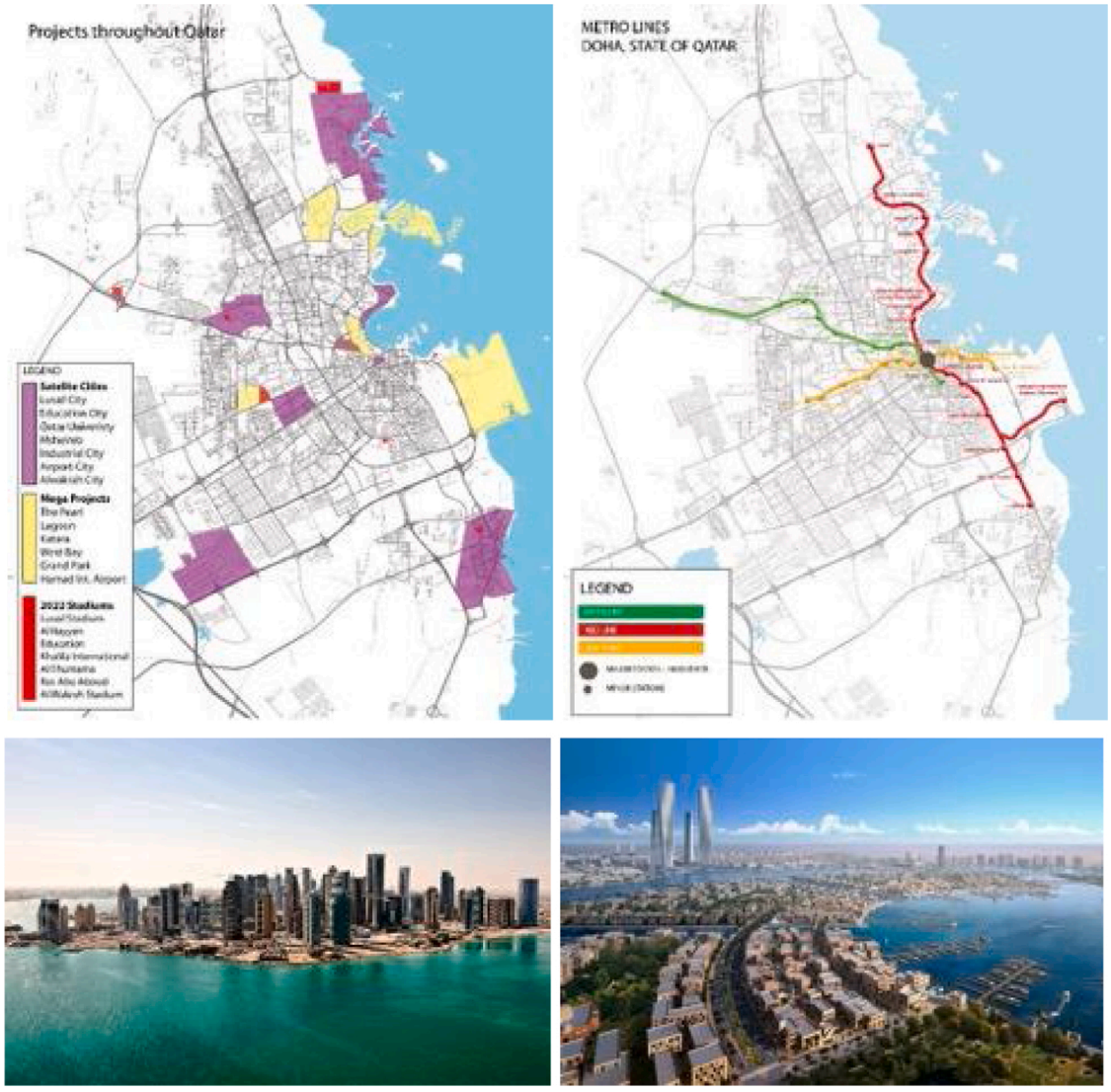


Fig. 1. (a) Megaprojects, FIFA 2022 stadiums, and satellite cities in Doha (Source: Authors); (b) Qatar Rail metro lines and stations (Source: Qatar Rail); (c) aerial view of City Center/West Bay in Doha (Source: Francisco Anzola/Wikipedia); and (d) render of proposed Lusail City masterplan (Source: Foster + Partners).

leading to underutilized or neglected spaces, and, in the worst-case scenario, abused space possibly exploited for illicit and criminal behavior (Hillier, 1996). In this sense, quantifying and understanding the accessibility of public green spaces based on the configurational measurements of space syntax using axial analysis, instead of mere location based on metric distance, might play an important role for promoting the physical and social functioning of pubic green spaces in a city. Refer to Appendix 1 for foundational information about space syntax representations and configurational measurements.

The research in this paper aims to examine the accessibility of public green spaces relative to metric size in the city of Doha. We review the current availability of green spaces using an MME index and analyze the characteristics for twenty-three (23) public parks, promenades, and green spaces in the urban spatial network of Metropolitan Doha using the axial analysis methodology of space syntax. We classify these 23 public parks, promenades, and green spaces based on metric area into six types: 1) mini-neighborhood; 2) neighborhood; 3) community; 4) promenade, 5) regional; and 6) metropolitan/national.[1] The underlying basis for quantifying the accessibility of public green spaces using space syntax is the *theory of natural movement*. It states that movement patterns in cities arise naturally from the way the street network organizes the simplest routes to and from all locations involving the fewest changes of direction in the network *before* accounting for the location of attractors or generators of that movement (Hillier et al., 1993; Penn et al., 1998). Based on the findings of this analysis, the paper argues there is spatial and social logic to the public green spaces of Doha, especially above a certain metric size. The paper concludes with some suggestions for the future design and planning of public green spaces in Doha.

2. About Green Urbanism and Space Syntax

Green urbanism is the multi- and interdisciplinary practice of urban design and planning that combines efforts in the fields of landscape architecture, transport planning, urban design, sociology, horticulture, and even agriculture, i.e., urban farming. Beatley (2000) elaborates cities that design spaces to function in ways analogous to that of the natural environment are those who best exemplify the goals of green urbanism. In this sense, public green spaces are more than a mode of decoration but a vital part of an ecosystem carrying out a wide range of physical/social functions and services on behalf of both citizens and the

[1] Promenades are not classified on the basis of metric area but their location adjacent to the coastline of the Arabian/Persian Gulf

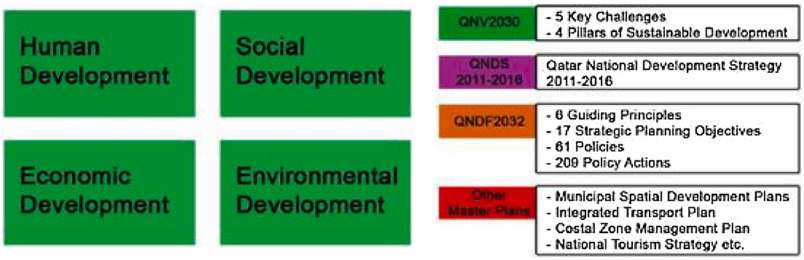


Fig. 2. Key Components of Qatar Vision 2030 and the Qatar National Development Framework (Source: (Ministry of Municipality and Environment, 2016).

natural environment. Parks can perform as areas of recreation, sporting activities, and relaxing pockets within the 'hustle and bustle' of city life. The efficient placement and use of green spaces can help to generate an enhanced level of social participation and collaboration between the users (Beatley, 2000). Other researchers tie the provision of public parks and green spaces to the long-term sustainability of cities and the planet in terms of zero-emission targets and current debates about climate change (Lehmann, 2010). Finally, some suggest the value of such spaces for cognitive restoration, though findings are hardly definitive (Ram et al., 2020). Green urbanism is also an important component in a somewhat recent update to the CNU and Talen's (2013) Charter for New Urbanism in the United States.

Because of this thinking, researchers have increasingly focused on the careful distribution and design of green spaces in urban settings over the last two decades. Such thinking often tends to focus on the quality of such spaces instead of mere quantity – allocation of land and provision of amenities – more characteristic of planning efforts during the early-to-mid 20th century.

Parks are one form of public green space in an urban setting. It is a long-held belief that the vegetation of parks and green spaces can help to improve the environment and air quality of dense urban developments (Parsons et al., 2015). Some research demonstrates that urban green areas can help to promote physical activity, improve the general public health, and enhance the psychological well-being of urban residents (Lee et al., 2015). In contrast, many consider the loss of natural landscape and green spaces due to rapid urbanization as detrimental to public health and natural ecosystems (Coutts et al., 2012). It seems to be true in Doha, which often neglected the efficient placement and use of public green spaces due to the pressing demands of rapid urbanization, economic diversification, and globalization over the last twenty years. It appears a more rigorous method for quantifying and assessing the provision of such spaces is necessary for public planning policy efforts to ensure better the efficient distribution of public green spaces in the city of Doha (Fig. 3).

In addition to user needs and the quality of green spaces, there is a large body of research focusing on the role of the built environment on human behavior in public open spaces over the last half-century (Jacobs, 1961; Whyte, 1980; Hillier, 1996; Campos, 1997 and 1999, Gehl, 2010 and 2011):

> *"The more successfully a city mingles everyday diversity of uses and users in its everyday streets, the more successfully, casually (and economically) its people thereby enliven and support well-located parks (authors' emphasis) that can thus give back grace and delight to their neighborhoods instead of vacuity"*

Previous research outside of the space syntax community to significant built components of the urban network such as parks, trails/bicycle lanes, or markets take an approach based on a predominantly location-based attraction modeling, statistical evaluation of demographics and design characteristic (nearby land uses, employment levels, facility provisions, etc.), or user surveys to understand some attribute of accessibility (Ottensmann and Lindsey, 2008; Strauss and Miranda-Moreno, 2013; Sahebgharani et al., 2019). Other recent research does not focus on the urban network effects of green spaces in terms of land use and accessibility but other localized issues such as human thermal comfort (Venhari et al., 2019) or impact of major road constructions on urban landscapes (Xie et al., 2016). Collectively, this suggests there is a lack of quantitative research on the topic, especially in the GCC region. However, space syntax provides quantitative measurements for various degrees of accessibility within the urban spatial network for this purpose where the more accessible (or integrated) spaces tend to obtain higher levels of movement and activities (and subsequently, land use attractors seek to capitalize on those movement levels, i.e., retail), and less accessible (or segregated) spaces tend to remain empty most of the time. In general, accessibility can have a broad meaning in both green urbanism and space syntax. However, for this research, accessibility refers to different ranges of integration from across the urban spatial network of Metropolitan Doha to the perimeter streets providing points of access to public green spaces. In this sense, accessibility might be one of the most important factors for consideration during the early stages of planning for such public amenities to influence better subsequent benefits for public health, urban lifestyle, and natural ecosystems. Mitchell and Popham (2007) argue that people who live near green spaces are healthier than people who live farther afield from such spaces. A strategic plan for public green spaces within their broader neighborhood, regional, and metropolitan context based on the network science approach of space syntax could better provide for public green spaces to service a diversity of socio-economic groups in Doha including Qatari citizens and a large expatriate (i.e., migrate worker) community from around the world.

Space syntax quantifies and studies the relationship between human behavior and the built environment from the single house and more complex building types to the neighborhood, settlements, and

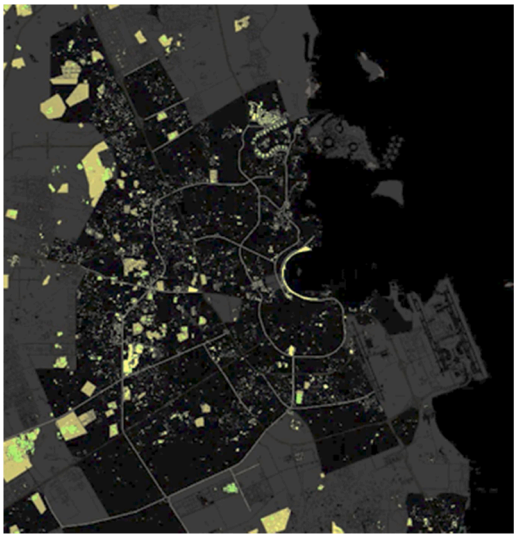


Fig. 3. All green spaces, including agricultural facilities in Metropolitan Doha in 2013 (Source: Authors/MME/Google Maps).

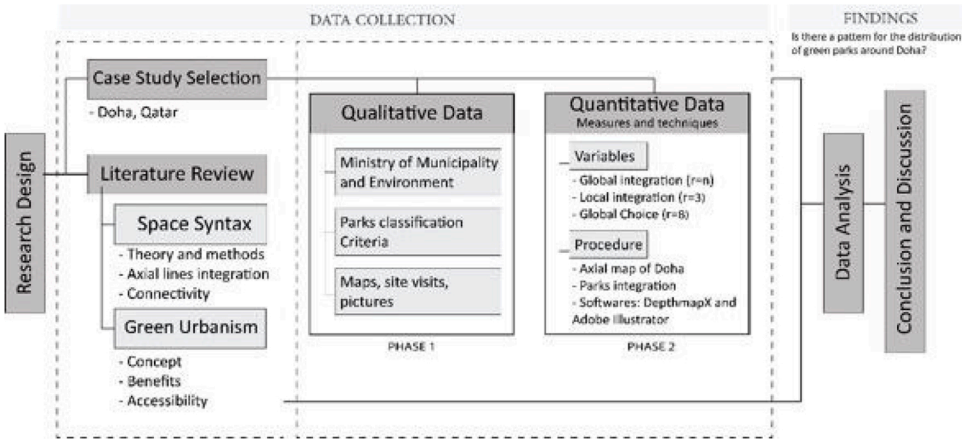


Fig. 4. Diagram of the research design (Source: Authors).

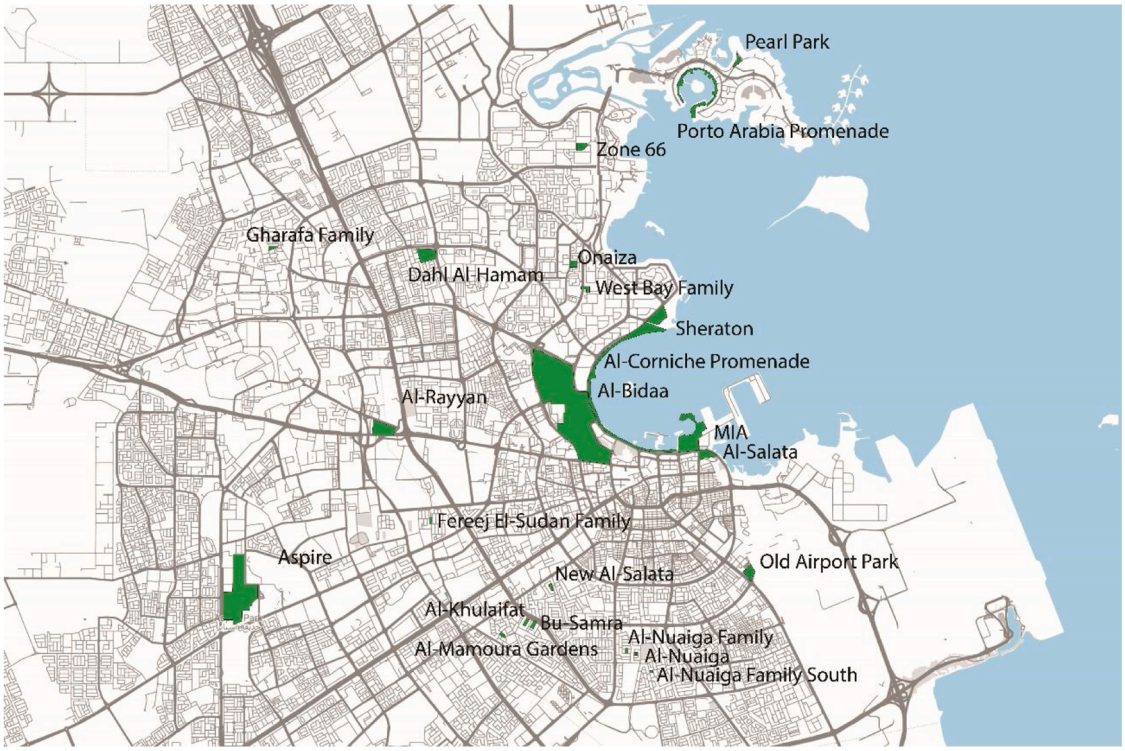


Fig. 5. The public parks, promenades, and green spaces of the study on a map of Doha (Source: Authors).

metropolitan regions (Hillier, 1996 and Major, 2018). It aims to investigate the relationship between the built environment and society using simple representations of space based on the most generic of human behavior, such as movement, occupation, and visibility (Major, 2018). For urban environments, the most important of these representations is the axis or axial line based on the fewest and most strategic lines of sight as defined by the facades of buildings and other physical impediments to visibility and movement because the movement is fundamentally linear in nature The matrix of these lines is the axial map or, more commonly, a space syntax model, which mathematically analyzes the impact of the urban network based on spatial configuration (Hillier and Hanson, 1984; Hillier, 1996; Hillier and Iida, 2005; Major, 2018). In its simplest formation, space syntax allows us to better identify and understand human behavior in the urban environment in terms of movement, occupation, and use. Space syntax researchers have found significant correlations between spatial configuration and empirical observations of pedestrian and vehicular movement levels (Hillier, 1996; Hillier et al., 1993; Penn et al., 1998). Major development projects around the world extensively applied space syntax as a design and planning tool over the last thirty years (Major, 2018).

Table 1
Initial categorization of public parks, promenades, and green spaces (Source: Authors).

Type	Number	Area	Service Radius
Mini-neighborhood	10	<4	1/4 miles radius
Neighborhood	4	4–10	1 miles radius
Community	2	20–50	2–5 miles radius
Regional	3	50–150	6+ miles
Metropolitan/ national	2	>150	service the entire metropolitan region and/or serve as an urban setting on a national basis
Promenade	2	N/A	N/A
TOTAL	23		

Table 2
The twenty-three (23) public parks, promenades, and green spaces from largest to smallest in the metric area showing (from left to right): name of the space; type of park or space; area of the city; the metric area in square meters and acres; and the average global integration, local integration, and integration (r=8) values of its perimeter/principal streets (Source: Authors).

	Park Name	Type	Region	Area m2	Area Acre	Global rad = n	Local rad = 3	Integration rad = 8
1	Bidaa Park	Metropolitan/national	East	991,181	244.9	1.223	2.442	1.596
2	Aspire Park	Metropolitan/national	South West	751,480	185.7	1.413	3.143	1.997
3	MIA Park	Regional	East	285,343	70.5	0.879	1.875	1.188
4	Al-Corniche promenade	Promenade	East	231,600	57.2	1.139	2.476	1.553
5	Al-Rayyan Park	Regional	West	97,960	24.2	1.433	2.987	1.877
6	Sheraton Park	Regional	East	92,505	22.9	0.978	1.433	1.433
7	Dahl Al-Hamam	Community	North	87,430	21.6	1.234	2.969	1.794
8	Porto Arabia promende	Promenade	North	81,450	20.1	0.534	1.474	0.956
9	Al-Salata	community	South East	21,400	5.3	1.171	2.987	1.631
10	Pearl Park	Neighborhood	North	19,248	4.8	0.524	1.736	1.088
11	Old Airport Park	Neighborhood	South	17,900	4.4	1.182	3.145	1.796
12	Zone 66	Neighborhood	North	17,000	4.2	0.903	2.214	1.344
13	West Bay Family Park	Neighborhood	North	16,000	4.0	1.029	2.249	1.524
14	Onaiza Park	Mini-neighborhood	North	9670	2.4	0.833	1.200	1.170
15	Bu Samra	Mini-neighborhood	South	9600	2.4	1.462	2.610	1.952
16	Al-Khulaifat	Mini-neighborhood	South	9290	2.3	1.065	0.887	1.290
17	New Al Salata	Mini-neighborhood	South	7220	1.8	1.079	1.295	1.405
18	Gharafa Family Park	Mini-neighborhood	North West	6890	1.7	1.000	2.528	1.385
19	Al-Mamoura Garden	Mini-neighborhood	South	6700	1.7	1.506	1.990	1.893
20	Al-Nuaiga family park	Mini-neighborhood	South	4100	1.0	0.998	1.489	1.366
21	Fereej Al Sudan Family park	Mini-neighborhood	South	4200	1.0	1.338	2.606	1.845
22	Al-Nuaiga family park (South)	Mini-neighborhood	South	3600	0.9	1.097	2.499	1.629
23	Al-Nuaiga park	Mini-neighborhood	South	3350	0.8	0.936	1.073	1.220
	TOTAL			**2,775,117**	**686**			
	AVERAGE			**120,657**	**30**	**1.085**	**2.144**	**1.519**

Accessibility based on visibility would seem especially important for the locating and designing of public green spaces. It could prove to be a valuable tool for enhancing people's appreciation and use of such spaces of the urban environment. Space syntax holds there is a fundamental relationship between space and society, as realized in the formal characteristics of the built environment based on two main concepts: the objectivity of space as a material and our intuitive engagement with it. The first is that space is not a background to human activity but an essential aspect of shaping *and* being shaped by human use of space. The second is spatial configuration consists not only of the characteristics of individual spaces but also the interrelation between all spaces that make up the entire urban network of the city. There is a social logic to space *and* spatial logic to society. This logic is important when it comes to the placement and design of public green spaces where the intent is to provide outdoor environments to accommodate the social activities and interactions of a specific population. Space syntax rejects the idea that space is merely a neutral background to such human activity, and we can read, understand, and interpret the 'content' of society independently of its spatial dimension.

3. Our Research Methodology

The research of this paper involves three stages: 1) a brief review of the literature about the multi-disciplinary context of green urbanism and space syntax in identifying key factors for the analysis of public parks/green spaces in Metropolitan Doha; 2) identifying the twenty-three (23) public parks and green spaces that constitute the case studies for the study; and 3) obtaining and analyzing the quantitative measurements of the metric area, global and local integration, and radius integration to all other axial lines based on all of the perimeter streets providing points of access to these public parks/green spaces in the urban network from a space syntax model of Metropolitan Doha (Fig. 4).[2]

[2] Radius for local integration based on three changes of direction up (radius=3). Radius for global integration is infinity (n) based on changes of direction since this is axial analysis, not segment analysis because we are seeking to understand public green spaces in terms of topological distance within the spatial structure of Doha, not metric distance or land use.

3.1. Study areas: public parks, promenades, and green spaces

The study area of this research paper is Metropolitan Doha. The city of Doha is the capital of the State of Qatar, encompassing an area of 132 km^2 with a metropolitan population of approximately 1.7 million people in 2016 (Source: Ministry of Development Planning and Statistics). The study identifies twenty-three (23) public parks, promenades, and green spaces in Doha for analysis of metric area and accessibility (Fig. 5).

For ease of organizing the data, each of these spaces has been initially categorized based on the following size parameters: mini-neighborhood (or pocket) parks ranging in size from 0 to 4 acres with a service radius of approximately a quarter (1/4) mile; neighborhood parks ranging in size from 4 to 10 acres with a service radius of about one (1) mile; community parks ranging in size from 20 to 50 acres with a service radius of approximately two-to-four (2–4) miles; regional parks ranging in size from 50 to 150 acres with a service radius of several miles; metropolitan/national parks are more than 150 acres in size designed to service the entire metropolitan region or serve as an urban setting for the siting of government buildings and sites of historical significance; and, promenades of varying size. These are linear parks associated with the Qatari coastline along Al Corniche in central Doha and Porto Arabia in The Pearl. Regional and Metropolitan/National Parks are government-owned and managed green spaces (Table 1).

The basis for constructing the space syntax model of Metropolitan Doha is a 2013 MME map showing building footprints at a scale of 1:400 and verified against high-resolution 2013 Google Earth satellite imagery. It comprises nearly 23,000 streets covering a metric area of +/-650 square kilometers (+/-250 square miles) stretching from Al Khor in the north to Sealine Beach in the south and from the Arabian/Persian Gulf in the east to the Salwa Truck Route and (under construction at the time) F-Ring Road to the west. An internal grant from Qatar University funded the development of this model by researchers in the Department of Architecture and Urban Planning in the College of Engineering.

3.2. Some space syntax terminology and methodology

Global integration is the relativized mean depth of space in relation to all other spaces in a network based on changes of direction. It

represents how integrated/shallow or segregated/deep is a space within the urban spatial network. In this sense, global integration represents where you are in relation to everywhere else in that network. According to the theory of natural movement, spaces with higher levels of integration tend to carry higher levels of movement and, hence, a greater potential to access different varieties of land use (Hillier et al., 1993; Hillier, 1996). Globally integrated spaces tend to play a much larger role in the urbanity of a city. These spaces are not only more frequently visited as destinations but also more intelligible for carrying through movement where people are daily on their way from somewhere to somewhere else in the city. The measure of relativized mean depth is based on simple connectivity, which is the number of spaces directly connected to a single space. "If you can move or see from one location, space, or street to another without accessing an intermediary one, they are connected" (Major, 2018). Local integration measures relativized mean depth to three (3) changes of direction away from an origin space. It is a more immediate measure of the local catchment area of a single space. The simplest way to understand local integration is if you imagine yourself standing in the middle of an intersection of two or more spaces, look down the streets in all directions to see all other streets immediately connected to those streets defining that intersection, and then repeat this process for all intersections you can see from the initial one. In this sense, local integration is a measure of locality like connectivity. Finally, radius integration measures the relativized mean depth of a space based on the mean depth from the most globally integrated street in the urban spatial network. In the case of Doha, this is the longest section of Salwa Road, with a mean depth of 8.3 in the 2013 metropolitan network. On average, this means that it takes a little over eight changes of direction from this section of Salwa Road to reach everywhere else in Doha. Radius integration is a useful measure because it reduces – though not necessarily eliminates completely - the 'edge effect' of global integration, i.e., spaces at the edges of the urban spatial network tend towards segregation because of their location on edge.

Finally, we set the average of these measures for the perimeter streets accessing and defining the edge of each public park, green space, and promenade to a ratio based on the approximate metric area of that individual green space. We are primarily interested in how accessible or inaccessible a public park, promenade, or green space is, rising above or falling below the mean for the entire sample when controlling for their varying sizes. Some are long and linear, whereas others are small pocket parks, and a few are very large for overall length and width. This ratio is necessary because they range in size from less than 1 acre (+/-3500 m^2) to nearly 250 acres (+/-900,000 m^2). Larger parks tend to be more accessible in the network by merely being bigger than smaller ones.

Nonetheless, the metric area is still a strong determinant when controlling for size in this manner. Using this ratio, it is spaces that do not strictly follow the pattern from smallest to largest that are the most interesting because it might indicate that a park, promenade, or green space is too large or small for its degree of accessibility within the urban spatial network. It might prove useful for design and planning purposes; for example, identifying parks that might represent ideal candidates for future expansion. As we will see, using space syntax methods for representing and measuring accessibility in the urban spatial network seems useful for identifying key distinctions between different types of parks, promenades, and green spaces in Doha.

3.3. Limitations of the study

There are some limitations to this study. First, researchers in the Department of Architecture and Urban Planning, College of Engineering at Qatar University were in the process of updating the baseline 2013 space syntax model of Metropolitan Doha at the time of this study. Because this process was incomplete when completing the study, we had to limit our investigation of public parks, promenades, and green spaces to their status – both in terms of size and accessibility - as of 2013. Space syntax uses abstracted representations of space in the built environment and a series of quantitative measures using topological graph theory founded on 40 years of research, which first began at University College London in the 1970s and 1980s (see Appendix 2 for more foundational information about space syntax). All axes/lines maps are plan-based without any link to population density, land use, or the three-dimensional nature of the built environment. More detailed studies of specific urban areas can and often do include such variables. However, part of the strength of space syntax lies in the fact that its topological graph-based measurements of space provide a very realistic picture of urban functioning even before the inclusion of such variables in any analysis. Finally, this paper only presents some of the key findings of this analysis. There is much more information available in the dataset about the characteristics of accessibility and size for individual public parks, promenades, and green spaces in Metropolitan Doha – and the comparison between them – than presented here.

4. Size does matter but so does where you are

For the study, we plotted the location of the 23 public parks, promenades, and green spaces on a map of Metropolitan Doha. The basis for the selection of these spaces for the study was two sources: 1) State of Qatar MME listings; and, 2) Google Earth/Maps with an emphasis on

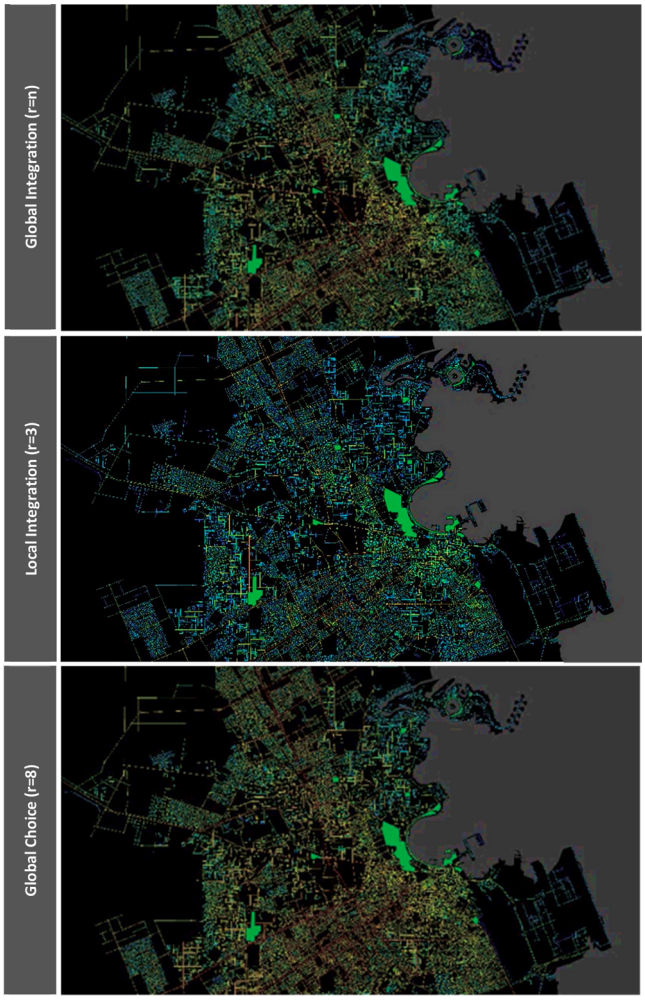


Fig. 6. Space syntax model showing the pattern of accessibility of the 23 parks, promenades, and green spaces indicated (in lighter green) in the urban spatial network of Metropolitan Doha with streets colored in a range from red (most shallow/integrated) through orange, yellow, green to blue and purple (most deep/segregated) for (top) global integration (radius = n), (middle) local integration (radius = 3), and (bottom) integration (radius = 8) (Source: Authors).

Fig. 7. View of (left) MIA Park with the Museum of Islamic Art and Doha Bay in the background and (right) the Porto Arabia promenade in The Pearl-Qatar at night (Source: Authors).

well-defined, easily-identified named public parks, promenades, and green spaces. The total area of these spaces is approximately 688 acres or about 1 acre for every 2325 residents in Metropolitan Doha. It includes ten (10) mini-neighborhood (usually family-associated pocket) parks, four (4) neighborhood parks, two (2) community parks, three (3) regional parks, two (2) metropolitan/national parks, and two (2) promenades (refer to Table 1). Several of these parks/promenades are immediately associated with – or parallel nearly adjacent to – the Persian/Arabian Gulf coastline in Doha, such as the Al Bidda Park, MIA Park, Al Corniche, Sheraton Park, and the Porto Arabia promenade. Others consist of smaller parks serving only the immediate neighborhood.

The space syntax model of Metropolitan Doha covers encompasses 22,000 axial lines over an approximate metric area of 650 km^2. A well-defined ortho-radial grid characterizes the spatial structure of the metropolitan region based on long radial routes or sequences of radial routes from old Doha near the coast of Doha Bay, such Salwa Road to the southwest, Al Rayyan Road to the west, and Al Wakrah Road to the south. A series of progressive larger ring roads (A–F) radiate outward from old Doha to the Orbital Highway; under construction at the time of this study but recently completed in 2020. A few papers elaborate about the well-defined spatial logic of Doha at the macro- and micro-scale of its metropolitan region using space syntax (Mirincheva, 2015; Major et al., 2019; Tannous and Major, 2020).

Public parks, promenades, and green spaces are more than their physical characteristics or amenities from the perspective of users but also about their accessibility to the local neighborhood and, depending on size, broader regional/metropolitan context. Improving access to such spaces for the urban community requires more than high-quality lighting, footpaths, and sporting facilities, no matter how vital these aspects might be for the individual user experience of that space. Accessibility can influence the decision-making process about even choosing to utilize that park in the first place, i.e., it must be convenient to get there before you can use it. The study identified the perimeter or principal spaces defining these public parks, promenades, and green spaces by locating them in the space syntax model of Metropolitan Doha, then collating and averaging the accessibility measures of these spaces as a representative measurement for each green space within its local and broader metropolitan context (Table 2 and Fig. 6).

First, there is a noticeable lack of community parks between 5 and 20 acres in size. Only two spaces marginally fit this range: Al-Salata Park in southeast Doha and the Porto Arabia promenade in The Pearl. It seems a consequence of private development provision of green spaces less than 5 acres in size and governmental emphasis on large-scale megaprojects for urban park development. Second, all non-neighborhood parks/promenades globally integrate above (within a -10 % margin of error, i.e., 0.9765 and above) the mean for the sample except for MIA Park and the Porto Arabia promenade (Fig. 7).[3]

Initially, this appears to be an artifact of their location on the coast at the edge of the metropolitan network. If we examine integration (r=8) to partially mediate for the 'edge effect' of global integration, MIA Park and the Porto Arabia promenade remain significantly less accessible than other spaces in comparison to the mean (within a -10 % margin, i.e., 1.3671 and above) for the whole sample. The global integration mean for non-neighborhood parks is 1.11, local integration is 2.42, and the integration (r=8) is 1.39. Crucially, Al-Corniche promenade is at the edge of the urban spatial network like MIA Park and Porto Arabia. However, it is more accessible than the mean of all measures for these types of parks and the entire sample. It demonstrates being on edge is not a deterrent to accessibility. MIA Park is less accessible in a 'descending' range (-21 % to -51 %) for all measures. Descending, in this sense, means accessibility decreases in relation to the mean for these types of parks, from global integration to local integration to integration (r=8). MIA Park is more globally accessible to the entire metropolitan network than its local/regional context, probably due to its nearness to Al Corniche Road. The differences in local integration and integration (r=8) for MIA Park might reflect its under-construction status (not only in 2013 but today as well) in long-term planning for a larger park. For local integration, MIA Park functions much closer (only -12.5 %) to the mean for the entire sample (2.144). Over the last five years, MIA Parks has been a (more or less) peninsular park with a single indirect access point about 375 m from a segment of Al Corniche Road. Future expansion of MIA Park will increase its metric area and provide additional points of access further south along Al Corniche Road. It should increase its overall accessibility in the urban spatial network. Further modeling of the proposed MIA park plans and its surroundings would be necessary to offer a more definitive answer.

For the Porto Arabia promenade, it is less accessible in an 'ascending' range from -32 % to -52 %. Ascending, in this sense, means the accessibility of Porto Arabia increases from global integration to local integration to integration (r=8) in comparison to the mean for non-neighborhood parks and promenades. Porto Arabia is still less accessible compared to these types of spaces and the entire sample, but this suggests the urban catchment area of Porto Arabia is more attune to north Doha than the metropolitan region. While individual towers in The Pearl are completing construction today and several retail units remain unlet, the Porto Arabia promenade itself has been basically complete since 2012. Its degree of accessibility is significantly lower than other large parks and promenades. It is almost certainly the result of the segregated location of The Pearl as reclaimed land, island development on the edge of the metropolitan region – connected via only a single road – to the northeast and the exclusive nature of The Pearl residential area itself in the Doha housing market.

The distribution and degree of accessibility for all other neighborhood/mini-neighborhood parks (i.e., less than 20 acres) tend towards randomness. It is not surprising. The provision of such parks depends on land availability in the case of the government-owned/managed parks and amenity provisions of individual private

[3] The authors selected +/-10% within the mean of the entire sample as an easy-to-understand, shorthand margin of error in the comparison.

Table 3
Rank order of public parks, promenades, and green spaces set to a ratio based on metric area for (left) global integration, (center) local integration, and (right) integration (r=8) where green indicates the highest (extremely accessible for its size), orange indicates the lowest (very large for its accessibility) and the thick black line indicates the mean for the sample (Source: Authors).

Park Name	Area (Acres)	Global rad = n	Global/Area Acres
Fereej Al Sudan Family park	1.0	1.338	1.2891
Al-Nuaiga family park (South)	0.9	1.097	1.2337
Al-Nuaiga park	0.8	0.936	1.1303
Al-Nuaiga family park	1.0	0.998	0.9846
Al-Mamoura Garden	1.7	1.506	0.9098
Bu Samra	2.4	1.462	0.6162
New Al Salata	1.8	1.079	0.6050
Gharafa Family Park	1.7	1.000	0.5875
Al-Khulaifat	2.3	1.065	0.4639
Onaiza Park	2.4	0.833	0.3487
Old Airport Park	4.4	1.182	0.2673
West Bay Family Park	4.0	1.029	0.2603
Al-Salata	5.3	1.171	0.2215
Zone 66	4.2	0.903	0.2151
Pearl Park	4.8	0.524	0.1102
Al-Rayyan Park	24.2	1.433	0.0592
Dahl Al-Hamam	21.6	1.234	0.0571
Sheraton Park	22.9	0.978	0.0428
Porto Arabia promende	20.1	0.534	0.0265
Al-Corniche promenade	57.2	1.139	0.0199
MIA Park	70.5	0.879	0.0125
Aspire Park	185.7	1.413	0.0076
Bidaa Park	244.9	1.223	0.0050
AVERAGE		1.085	0.412
Park Name	Area (Acres)	Local rad = 3	Local/Area Acres
Al-Nuaiga family park (South)	0.9	2.499	2.8091
Fereej Al Sudan Family park	1.0	2.606	2.5111
Gharafa Family Park	1.7	2.528	1.4850
Al-Nuaiga family park	1.0	1.489	1.4697
Al-Nuaiga park	0.8	1.073	1.2962
Al-Mamoura Garden	1.7	1.990	1.2021
Bu Samra	2.4	2.610	1.1001
New Al Salata	1.8	1.295	0.7258
Old Airport Park	4.4	3.145	0.7110
West Bay Family Park	4.0	2.249	0.5688
Al-Salata	5.3	2.987	0.5648
Zone 66	4.2	2.214	0.5271
Onaiza Park	2.4	1.200	0.5020
Al-Khulaifat	2.3	0.887	0.3865
Pearl Park	4.8	1.736	0.3649
Dahl Al-Hamam	21.6	2.969	0.1374
Al-Rayyan Park	24.2	2.987	0.1234
Porto Arabia promende	20.1	1.474	0.0733
Sheraton Park	22.9	1.433	0.0627
Al-Corniche promenade	57.2	2.476	0.0433
MIA Park	70.5	1.875	0.0266
Aspire Park	185.7	3.143	0.0169
Bidaa Park	244.9	2.442	0.0100
AVERAGE		2.144	0.727
Park Name	Area (Acres)	Integration rad = 8	Integration/Area Acres
Al-Nuaiga family park (South)	0.9	1.629	1.8314
Fereej Al Sudan Family park	1.0	1.845	1.7775
Al-Nuaiga park	0.8	1.220	1.4734
Al-Nuaiga family park	1.0	1.366	1.3484
Al-Mamoura Garden	1.7	1.893	1.1434
Bu Samra	2.4	1.952	0.8227
Gharafa Family Park	1.7	1.385	0.8134
New Al Salata	1.8	1.405	0.7874
Al-Khulaifat	2.3	1.290	0.5617
Onaiza Park	2.4	1.170	0.4897
Old Airport Park	4.4	1.796	0.4061
West Bay Family Park	4.0	1.524	0.3856
Zone 66	4.2	1.344	0.3200
Al-Salata	5.3	1.631	0.3084
Pearl Park	4.8	1.088	0.2287
Dahl Al-Hamam	21.6	1.794	0.0830
Al-Rayyan Park	24.2	1.877	0.0775
Sheraton Park	22.9	1.433	0.0627
Porto Arabia promende	20.1	0.956	0.0475
Al-Corniche promenade	57.2	1.553	0.0271
MIA Park	70.5	1.188	0.0168
Aspire Park	185.7	1.997	0.0108
Bidaa Park	244.9	1.596	0.0065
AVERAGE		1.519	0.567

developments where economic motives (i.e., profit) are more significant than social ones in the decision-making process. Sheraton Park clearly functions (only -5.7 %) within the -10 % margin of error for global choice (1.3671 and above) but appears to significantly underperform (-33.2 %) in terms of accessibility to its immediate context for local integration. It suggests improving the connectivity of Sheraton Park in all available directions might enhance its neighborhood catchment area, bringing added benefits for everyday use instead of relying on attracting users via special events, which tends to be the case for this park. The two mini-neighborhood (pocket) parks of Al-Khulaifat and Busamra Park in south Doha are also fascinating. Even though they are practically the same size (2.3 and 2.4 acres, respectively) and only two blocks from each other (less than 150 m), there is a significant difference in global integration due to buildings isolating the northern edge of Al-Khulaifat Park from the D-Ring Road. No such structures exist at the northern edge of Busamra Park to 'shield' this space (in terms of impeding movement or visibility) from one of the busiest thoroughfares in the city. Further observational research might prove useful for better understanding how these different settings positively or negatively impact the actual use of these mini-neighborhood parks despite their strong similarities in all other regards (i.e., size, design, and location), if at all.

When accessibility measures are relativized for the metric area of each public park, promenade, and green space, some interesting distinctions emerge in the data (Table 3). Controlling for size in this ratio allows us to determine if there is underlying spatial logic to the locating of public parks, promenades, and green spaces regardless of their size. Nonetheless, the metric area remains a strong indicator of the distribution. For most spaces (15) in the sample under 20 acres in size, the variations are small enough to mostly attribute to land availability and amenity provision in private developments. There are some interesting variations between some of these smaller parks that might warrant closer examination, including the potential small-scale expansion of some family parks such as Al-Nuaiga (South) Park, where land is still available.

5. Discussion of findings and possible implications

Researchers have extensively used space syntax to research public spaces with an emphasis on squares and plazas, usually concerning Hillier's (1996) concept of the movement economy (Campos, 1997, 1999; Koohsari et al., 2014; Major et al., 2019). However, space syntax has not been utilized before using the methodology developed in this paper to assess the size and location of public parks, promenades, and other green spaces within a metropolitan region like Doha. In this sense, the methodology developed for this paper has the merits of being both original and straightforward. Researchers in other cities worldwide can similarly apply this methodology to assess public parks' accessibility and size in their region. In the future, this can help to foster cross-cultural comparisons for the allocation of such public facilities in different parts of the world. Taking such a systematic approach to public park

Fig. 8. 2018 Satellite view of Al Rayyan Park in west Doha (Source: Google Earth).

facilities can help contribute to Jacobs (1961) and Gehl (2010 & 2011) vision of more humane cities for people.

Parks, promenades, and green spaces where there appears to be a lack of correspondence between accessibility and metric area are Al Rayyan Park and the Porto Arabia promenade. Al Rayyan Park seems too small for its strong degree of accessibility from the large-scale to the neighborhood level in the urban spatial network. Fortunately, there remains a significant amount of land available near Al Rayyan Park today. The MME Al Rayyan Municipality Spatial Development Plan for the Al Rayyan Municipality Vision and QNDF is unclear about the what precisely are the plans for Al Rayyan Park beyond the mention of a green corridor system linking the municipality parks together with the metropolitan/national Aspire Park to the southwest (Ministry OF Municipality and Environment, 2016). Our analysis suggests Al Rayyan Park warrants special due care in the design and planning for any future expansion because of its strategic location in the local and metropolitan networks. The surrounding roads already play a traffic management role for large-scale vehicular movements associated with the Doha Expressway/D-Ring Road to the east, Al Rayyan Road to the south, Al Rayyan Al Ateek Street to the north, and Bu Erayyen Street to the west (Fig. 8). Such traffic management measures are notorious for serving as impediments to pedestrian movement (Jacobs, 1961; Gehl, 2010). It is the very thing that makes Al Rayyan Park such an attractive candidate for future expansion (i.e., accessibility). Still, it might serve to isolate its edges further and deter expected levels of use in such a strategically-located park, if the design proves insensitive at the micro-scale neighborhood level.

Finally, the Porto Arabia promenade is simply oversized for its degree of accessibility at the macro- and micro-scale of the urban spatial network even when controlling for size. As the most public area of The Pearl development, this makes sense because its purpose as a promenade is more regional. Its design must overcompensate for the isolated, exclusive nature of The Pearl as an island residential development connected to the mainland via only a single road. The design of the Porto Arabia promenade accomplishes this by making its metric size an attractor – in combination with an intensity of retail/restaurant land uses along its edge and nearby walkable locations such as Medina Centrale – so non-residents of The Pearl will visit the area, especially from northern Doha.

5.1. Avenues for future research

Researchers and public agencies can utilize the methodology and findings of this paper for the future advancement of knowledge and evaluation of the viability of public parks and other greens spaces. It includes tailoring an appropriate size for the degree of accessibility in the design and planning process. Space syntax provides a powerful tool to better understand the current conditions of the urban spatial network. It helps to identify the optimal implementation of design enhancements and interventions for the benefit of all citizens. This study also made it clear – though only briefly noted – that several neighborhoods of Doha almost entirely lack access to any parks and recreational areas. It requires citizens to travel some distance via vehicle to access regional and metropolitan/national parks such as Aspire Park or MIA Park. Further research in this area should consider the population density of neighborhoods, travel distances (on foot and by car), and the presence of other public/semi-public facilities such as schools, shopping malls, and other institutions that might benefit from such spaces.

Furthermore, this study could also expand into a more ambitious research project supported by and correlated to the actual usage of the public parks, promenades, and green spaces. Such a research project could provide a comprehensive dataset about the volume and patterns of use in such spaces for quantitative analysis using space syntax, supplemented with user surveys of perception and experience of such civic spaces in Doha. It would bring greater methodological richness to the study of public parks and green spaces and could elevate this initial study to another level, perhaps in collaboration with Qatari government ministries such as the MDPS, MME, Ashghal (public works ministry), and the Supreme Committee for Delivery & Legacy.

5.2. Conclusion

Green parks and public spaces are essential for improving the aesthetic values of a society, enhancing social interactions, and improving the general health of users and citizens. In an environment with a hot and arid climate like Doha, outdoor public parks and green spaces offer relief to users and serve as temperature moderators for the urban environment. The paper applied space syntax for the morphological analysis of the accessibility and size of public parks, promenades, and green spaces in Metropolitan Doha. The paper demonstrated that space syntax can be a useful tool to assist public entities and private developers. It can be a valuable tool to objectively select the most optimal location and appropriate size of such public park facilities and infrastructure for their degree of accessibility in the urban spatial network. Such an objective, scientific approach to parks can help bring the greatest benefit to most citizens. Based on the paper's findings, such benefits include concerns about the morphological design outcome and the planning process itself. First, some public parks and green spaces perform better for their size and degree of accessibility than others

within their local, regional, and national contexts. Second, parks and green spaces do not have to be a binary choice where urbanists stand against environmentalists engaged in a dense vs. green debate. The analytical assessment process outlined in the paper demonstrates that land-use efficiency and open space distribution are not mutually exclusive concepts. We can tailor both factors to provide more effectively for urban life and vitality based on the quality of design instead of mere quantity allocation. Finally, the analysis indicated there appears to be a lack of neighborhood/community parks between the size of 5–20 acres in Doha, and Al Rayyan Park, in particular, warrants special care in its design and planning for any future expansion. All of this could prove vital for the well-being of Doha's urban community over the long term.

CRediT authorship contribution statement

Heba O. Tannous: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - review & editing, Supervision, Funding acquisition. **Mark David Major:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing - review & editing, Supervision, Funding acquisition. **Raffaello Furlan:** Conceptualization, Investigation, Resources, Supervision, Software.

Declaration of Competing Interest

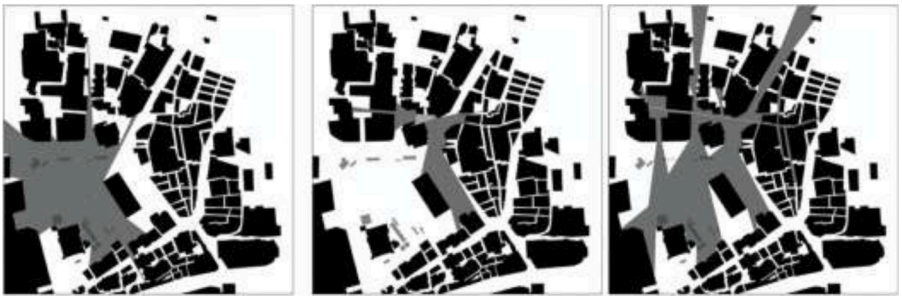
The authors report no declarations of interest.

Acknowledgments

Portions of this research related to the construction of the space syntax model of Metropolitan Doha were supported by an internal grant of Qatar University (Grant ID: QUSD-CENG-2018/2019-4). Open Access funding provided by the Qatar National Library.

Appendix A. A: about space syntax

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 et al., 1987a and b; 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.



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) (Fig. 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 (0.28 m^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

Fig. 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).

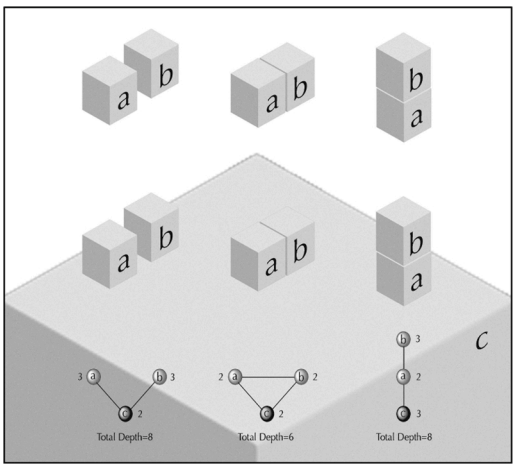


Fig. A2. The basics of configurational measurements using topological graph theory where (top row) two objects labelled A and B are similarly-related until (middle row) the introduction of a third object labelled C (such as the surface of the Earth). All three objects now have different configurational 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).

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. xe "configuration:explained"xe "configuration"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) (Fig. A2).

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.

Global choice is a measurement of '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 (m), 1000 m, or 5000 m. 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).

A.1 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) (Fig. 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

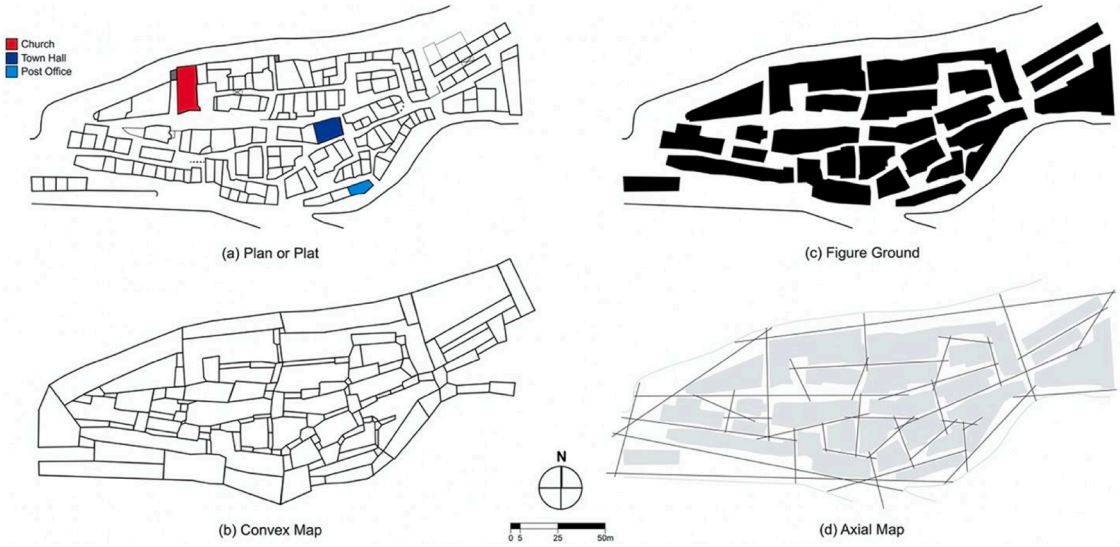


Fig. A3. The procedure for modeling settlements based on the (a) plan/plat, (b) convex map, (c) figure-ground, and (d) axial map for the layout of Gassin in the Var region of France circa 1980 (Images: Mark David Major after Hillier and Hanson, 1984).

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-non-distributedness,' 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.

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