Journal of Urban Design

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cjud20

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To cite this article: Khaled Alawadi, Asim Khanal & Sara Al Hinai (2021): Rethinking suburban design: streets v/s alleys in improving network connectivity, Journal of Urban Design, DOI: 10.1080/13574809.2021.1921570

To link to this article: https://doi.org/10.1080/13574809.2021.1921570

Published online: 01 Jun 2021.

JOURNAL OF URBAN DESIGN
https://doi.org/10.1080/13574809.2021.1921570

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Rethinking suburban design: streets v/s alleys in improving network connectivity

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ABSTRACT

The notion of an urban-suburban dichotomy is deep-rooted in the literature, which regularly denigrates suburbs and nostalgically g lorifies urban centres. Meanwhile, suburbs have continued to dominate the urbanization process in many regions. This paper does not reject suburbs as an undesirable phenomenon but instead investigates how suburbs can be improved. Taking Abu Dhabi and Dubai as case studies, the article studies the connectivity efficiency of 32 suburban samples. Results reveal that not all suburbs have inefficient connectivity, but there is a room for improvement. Reclaiming alleys could enhance connectivity by 31% in some areas.

Introduction

It would not be an overstatement to say that suburbs are omnipresent in today's world. Suburbs exist globally and have started to dominate the built landscape in the developed countries of North America (Berger and Kotkin 2018; De Vidovich 2019) and Europe (Batty, Besussi, and Chin 2003) and the rising economies of Asia, Africa, and South America (Kotkin 2005). The GCC (Gulf Cooperation Council) region, and the UAE in particular, are not aberrations from this trend: suburbs occupy significant portions of the built landscape in this region and make up more than 50% of Abu Dhabi's urbanized land and 38% of Dubai's urban area. Suburbanization began as an alternative lifestyle for relatively well-off people who aimed to escape the vices of the city centre, such as crime, pollution, and congestion (Andrews 1995). Unlike in the West, suburbs in the UAE were not developed as an antithesis to city living. Instead suburban lands were granted for free to all citizens as a means to distribute wealth in a non-democratic region.

Suburbs have been described as secondary to urban areas (McNeur 2014). Mumford (1975) called suburbs 'anti-city', and Batty, Besussi, and Chin (2003) compared suburbs with cancer to describe their uncontrollable growth. Debates over suburbanization have focused on vilifying suburbs and the spectacularization of downtown revival, barring few exceptions. For instance, Fava (1975) introduced the notion of an urban-suburban dichotomy for the first time and noted that 'megalopolis' is the new reality that accommodates all areas, urban or suburban. However, voices that opposed the creation or any reinterpretation of suburbs were much more prominent and had support from movements such

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as the Compact City agenda and New Urbanism in the 1990s (Ellis 2002) and Smart Growth in the 2000s (Bruegmann 2006). Other scholars have claimed that suburbs lack communal life and regarded it as a site of isolation (Vaughan et al. 2010). Nonetheless, suburbs have continued to exist and therefore cannot be blatantly ignored without giving due consideration to the possibility of revamping them. On the other hand, interest in city living has been increasing, particularly among the millennial generation (Gallagher 2014). However, outlying suburbs are still more affordable for many residents (Ehrenhalt 2013), as the prices of downtown real estate have risen dramatically over the years. For example, in Denver's CBD, property values increased from 20 USD/sq. ft. in 1990 to 50-70 USD/sq. in 1999 (Moulton 1999).

In the UAE, public housing programs are the main contributors to suburban growth. As in North America and the rest of the world, neighbourhood typologies changed from compact forms to dispersed suburbs. Starting in the 1980s, close-knit homes and dense urban fabrics were replaced by the unstoppable growth of big suburbs. Dense urban blocks were replaced by superblocks. Diversity in land use was swapped for a monotonous utilization of land. The interconnected street system became fragmented and curvilinear. More specifically, the street typology of suburbs became dominated by looping, disjointed, and fragmented networks with loops and cul-de-sacs similar to their North American counterparts. These physical attributes of the neighbourhoods affect the daily lives of residents. Street layouts play a crucial role in making communities more connected and walkable, one of the principal qualities of sustainable urban forms (Porta and Renne 2005). For example, interconnected street systems are known for the creation of vibrant public realms (Whyte 1988). Street design determines whether the street in a neighbourhood is a thriving thoroughfare or a mere service road (Forsyth and Southworth 2008).

Suburbs are very diverse in form. To understand what more efficient suburban design might look like, it is necessary to study a variety of suburban typologies, including their urban form elements (e.g., streets, land parcels, and urban blocks), their public transportation systems and provisions, and their pedestrian connectivity. This research focuses on one element of urban form in suburbs: the street. In particular, streets are a critical urban form element that strongly influences the choice to walk, bike, or use transit (Marshall 2015). Planners and designers acknowledge that long-established physical conditions of streets constrain the potential to retrofit existing neighbourhoods with new standards of connectivity. This article studies the connectivity efficiency of diverse suburban street typologies to provide design actions and guidelines for future suburban street design. It is unwarranted to discard any suburban typology simply because it does not mimic a pre-modern dense fabric. It is commonly accepted that good street networks can come in several different configurations (Marshall 2005, 2015). Thus, the paper analyses a total of sixteen neighbourhoods, eight each from Dubai and Abu Dhabi, that represent different suburban street typologies from the birth of suburbs in these cities (early 1970s) to present. Thirty-two samples have been taken from these sixteen neighbourhoods for analysis. Efficient street typologies are identified by measuring connectivity efficiency. Connectivity efficiency is quantified for all neighbourhood samples through the use of *pedestrian route directness* (PRD). PRD is a metric that calculates the network's ability to provide direct routes between origins and destinations (Stangl and Guinn 2011). It is the ratio of the network distance between an origin and a destination to the virtual straight-line distance joining these two points.

The study utilizes a mathematical spatial analysis to explore new ways of redesigning/ retrofitting suburban street networks. This investigation is relevant for urban planning and design scholarship as it contributes to the evolving literature that depicts suburbs as a potent ground for innovation instead of demonizing them. This paper asks three questions: 1) How connected are the suburbs of Dubai and Abu Dhabi for pedestrian movement? 2) How are those suburbs similar and different in terms of connectivity efficiency? 3) What kinds of urban design strategies would improve the connectivity efficiency of suburbs for pedestrians?

Literature review

Global suburbanization

Suburbanization has shaped cities throughout the world, and it has been defined by various scholars in different ways (Orenstein, Frenkel, and Jahshan 2014). Suburbs were first defined as communities within an overarching metropolitan area from which the central city can be reached conveniently (Douglass 1925). In general terms, suburbs are characterized by low-density housing, single-use zoning, and high automobile dependency (Ewing 1997), although there is no consensus on the operational definition of a suburb (Airgood-Obrycki 2019).

Today, suburbs exist globally, including in China, Thailand, Argentina (Bruegmann 2006), Germany (Haag 2002), and North America (Razin and Rosentraub 2000); however, their manifestations differ. In North America, suburbs are characterized by low density, automobile dependency (Moos and Mendez 2015), newness in urban form, peripheral location (Harris 2010), and single-use, private buildings (Dunham-Jones and Williamson 2008). In Europe, suburbs emerged differently: they acted as new nodes that had active relationships with existing city centres (Batty 2009). Thus, European suburbs are generally more compact than their North American counterparts and are not characterized by the same level of isolation. Existing studies identify suburbs primarily based on residential land density or population density. However, it is difficult to set an exact density standard to distinguish between urban, suburban, and rural areas.

Theories of sustainable urban forms, such as the ‘compact city’, became popular in academic and policy-making circles in the 1990s (Neuman 2005). The agenda focused prominently on inner urban areas and vilified suburban areas (Breheny 1996) and depicted suburbs as undesirable and wasteful places (Williams, Joynt, and Hopkins 2010) and as cradles of many of the social and environmental problems faced by cities (Williams, Burton, and Jenks 2000). Scholars have suggested that the intensification of suburbs, including redesigning them as ‘sub-cities’ with their own mixed-use, transit-oriented urban villages, will offer a degree of self-containment from the larger city area (Calthorpe 1993). These discourses on suburbs have primarily been applied to new greenfield developments and the redevelopment of brownfield sites. However, ways to modify the existing suburban fabric have been only explored by few scholars, including Dunham-Jones and Williamson (2008) in *Retrofitting Suburbia* and Berger and Kotkin (2018) in *Infinite Suburbia*.

The debate over sustainable urban forms should not continue to denigrate suburbs but instead should recognize the possibility of improving upon their inefficient forms. No matter how much criticism suburbs receive, the truth of the matter is that suburbs are here to stay (Kotkin 2005). Thus, this study focuses on a major physical component of suburbs: their street patterns. Street network design, density, and diversity have been widely identified as key ideals in planning sustainable neighbourhoods (Condon 2012). Thus, this paper investigates the connectivity efficiency of the existing suburbs of Dubai and Abu Dhabi in order to propose a more efficient layout for suburban design.

The narrative of suburbs being a highly undesirable urban form (Mumford 1975) often glamourizes the revival of downtowns and rules out suburban forms altogether, which is problematic. The literature on suburbs tends to link them with increased energy consumption and climate change (Ewing, Pendall, and Chen 2002). There is a dearth of research that reinterprets suburban growth, in contrast to the ample attention given to the compact development of inner urban areas (Breheny 1996). Although suburban development began, following World War II, as the antithesis of compact, dense, and mixed-use neighbourhoods, the suburb can still be a 'site of major change' (Williams, Joynt, and Hopkins 2010, p. 109). For example, this study will argue that the super-grids in North American suburbs and the resulting restriction of pedestrian accessibility (Filion 2018) can be addressed by retrofitting designs to increase connectivity efficiency. Suburbs are places where status-quo planning practice could change. This research begins from the understanding that suburbanization is a common fact. For that reason, the paper focuses on a major component of suburban fabrics, their streets, to provide pathways for designing better and more connected suburbs.

Suburban development in Dubai and Abu Dhabi

The urbanization of Abu Dhabi began in 1966, when Sheikh Zayed became its ruler. In those initial years, the urban fabric was dominated by a superblock design that promoted dense, self-sufficient neighbourhoods. The neighbourhoods were compact and dense with interconnected streets. In 1975, suburban growth began to proliferate, and the form of these superblocks started to change from smaller plots and connected streets with legible layouts to large plots with looping and fragmented streets. In 2007, planning in Abu Dhabi began to shift towards nostalgic urbanism. This phenomenon started in North America with movements such as New Urbanism (Ellis 2002) that once again promoted traditional, compact, and connected street patterns instead of hierarchical and sparse street networks (Marshall 2015). Plot sizes were reduced, and while street patterns stayed mostly fragmented as in previous years, in some cases a radial system inspired by 'garden suburbs' was adopted (Hashim and Bani 2018).

In Dubai, modern planning ideals were introduced in 1956 through John R. Harris's modernist street network plan, which featured orthogonal streets (Elsheshtawy 2004). Nonetheless, because automobile ownership was scant, development patterns were relatively compact and featured well-connected and pedestrian-oriented street networks. When suburban growth started in 1971, propelling urban expansion, the city ceased to grow in a tightly knit fashion (Alawadi, Alameri, and Scoppa, 2020). New development resembled post-World War II North American suburbs and featured large land divisions with interrupted parallel, looping, curving, and fragmented street layouts.

Measuring network connectivity

Pedestrian connectivity has been studied by various scholars, but there is no consensus on how to measure it. The classical approach uses proxy measures of connectivity such as links/nodes ratio, intersection density, and block length, all of which are rendered inaccurate (Stangl and Guinn 2011) because these density metrics cannot comprehend the complex geometry of the network and thus calculate connectivity inaccurately. Alternatively, network analysis measures such as multiple centrality assessment (MCA), and pedestrian route directness (PRD) have been used to assess pedestrian connectivity. These measures are considered more accurate due to their inclusion of topology and distance. PRD is the ratio of the network distance to the Euclidean distance between two points known as an origin and a destination. Hess (1994) first introduced PRD when he evaluated pedestrian environments in Washington. Likewise, Randall and Baetz (2001) used PRD to evaluate pedestrian connectivity and sustainability in suburbs. They showed that retrofitting suburbs to make them more walkable and connected to daily destinations and public transit can reduce energy consumption from automobile usage and thereby achieve sustainability goals.

This study uses PRD metric for several reasons. It is suitable for studying variations in connectivity between different designs, and provides better insights about the design of individual street segments (Dill 2004). It corresponds directly to walkability because it calculates the availability of short, direct routes between origins and destinations, which affect the decision to walk (Saelens et al. 2003). PRD is also easy to calculate; however, compared with other methods, proper interpretation of the results obtained from PRD may require greater experience (Ratti 2004).

Methodology

Selection of neighbourhoods

Connectivity efficiency is computed for different neighbourhoods in Abu Dhabi and Dubai by using pedestrian route directness (PRD) metric. Abu Dhabi, which has been strongly influenced by the concept of Neighbourhood Planning Units (NPUs), developed large, consistent, and monotonous neighbourhoods. By contrast, Dubai, with no evident NPU, built irregular subdivisions on a smaller neighbourhood scale. The street patterns of Abu Dhabi's neighbourhoods are rigid and integrated into a grid, while Dubai's streets have no evident systematic form. Dubai's neighbourhoods are characterized by large subdivisions with no consistent planning unit. Abu Dhabi is composed of an island and a segment of the mainland. Abu Dhabi Island is dense and compact; a superblock often represents a neighbourhood. The mainland, by contrast, is characterized by leapfrog development and neighbourhoods made up of multiple superblocks.

This article studies sixteen neighbourhoods in Abu Dhabi and Dubai developed from the beginning of suburbanization process (1970) to the present. The selected neighbourhoods represent a variety of street typologies corresponding to the two cities' different growth phases (See Table 1). These neighbourhoods are mainly residential, are located at different distances from the urban core, and feature different plot sizes, land use systems, physical forms and attributes, and layouts.

Table 1. Morphological attributes of sample areas. (Sample areas are arranged in chronological order).

S.N.	City	Neighbourhood name	No. of plots	Area (acre)	Street length (km)	Street density (km/acre)	No. of inter-sections	Intersection density (no./acre)	Average plot size (sq. m.)	Plot density (plots/acre)
1	**Abu Dhabi**	Al Manhal	1105	640	84.35	0.13	645	1.01	958	1.73
2		Al Mushrif	778	640	62.61	0.10	388	0.61	1253	1.22
3		Baniyas 1	760	575	53.18	0.09	370	0.64	1209	1.32
4		Baniyas 2	871	640	56.95	0.09	410	0.64	1303	1.36
5		Shahama 1	128	168	18.11	0.11	89	0.53	1962	0.76
6		Shahama 2	514	283	33.71	0.12	286	1.01	932	1.82
7		Al Bahya East 1	340	308	32.67	0.11	222	0.72	2794	1.10
8		Al Bahya East 2	264	311	28.67	0.09	219	0.70	2771	0.85
9		Al Bahya West 1	392	555	28.31	0.05	53	0.10	2319	0.71
10		Al Bahya West 2	230	326	27.49	0.08	24	0.07	2558	0.71
11		Khalifa 1	663	640	34.04	0.05	168	0.26	2481	1.04
12		Khalifa 2	492	640	34.70	0.05	191	0.30	3329	0.77
13		MBZ 1	533	640	45.57	0.07	113	0.18	2678	0.83
14		MBZ 2	494	640	46.62	0.07	148	0.23	2769	0.77
15		Al Falah 1	1330	640	48.93	0.08	216	0.34	1243	2.08
16		Al Falah 2	1339	640	44.35	0.07	160	0.25	1409	2.09
17	**Dubai**	Al Badaa East	718	136	21.18	0.16	280	2.06	540	5.28
18		Al Badaa (West)	181	122	15.25	0.13	126	1.03	2254	1.48
19		Al Rashidiya 1	1326	640	55.39	0.09	412	0.64	1041	2.07
20		Al Rashidiya 2	1491	640	59.20	0.09	525	0.82	838	2.33
21		Al Quoz North	691	320	28.31	0.09	130	0.41	1073	2.16
22		Al Quoz South	836	320	36.06	0.11	152	0.47	1083	2.61
23		Nadd Al Hamar 1	1115	640	52.71	0.08	232	0.36	1505	1.74
24		Nadd Al Hamar 2	1027	640	49.72	0.08	220	0.34	1460	1.60
25		Al Barsha 1	1216	640	60.85	0.10	404	0.63	1434	1.90
26		Al Barsha 2	1217	640	50.24	0.08	230	0.36	1481	1.90
27		Al Warqa 1	1381	640	41.89	0.07	146	0.23	1194	2.16
28		Al Warqa 2	1512	640	37.03	0.06	162	0.25	1124	2.36
29		Al Barsha South 1	1693	640	57.72	0.09	199	0.31	896	2.65
30		Al Barsha South 2	1288	640	40.71	0.06	156	0.24	1197	2.01
31		Nadd Al Sheba 1	946	640	47.29	0.07	154	0.24	2021	1.48
32		Nadd Al Sheba 2	844	640	45.23	0.07	128	0.20	2025	1.32

Network analysis: PRD

Built landscapes are studied to understand the different neighbourhood typologies performance characteristics and environmental behaviour (Wheeler 2015). Built-landscape assessment enables researchers to analyse the interaction of neighbourhoods' physical features to ultimately understand proximity, compactness, land-use diversity, connectivity, and the implications of each of these urban form attributes on regional planning (Moudon 1997). This article quantifies the street connectivity and suggests retrofit designs to enhance inefficient streets. Connectivity, in particular, is linked to the directness of links and the density of connections in road networks. A highly connected network allows for more direct travel between destinations through increased directness and route options. The extent to which different origins and destinations of a neighbourhood are linked to one another determines the level of street connectivity. This study utilizes pedestrian route directness (PRD) as the best method for assessing and comparing connectivity between different network designs.

The results from the PRD test always produce values greater than or equal to one. Greater connectivity is indicated when the score is lower; at the lowest possible score of 1.0, the actual distance is equal to straight-line distance 'as the crow flies' (Dill 2004). The

PRD test requires the researcher to set a threshold such that all plots in the study either pass or fail based on the obtained PRD values. For this study, a threshold of 1.5 was selected for the PRD test. In this test, plots with values below 1.5 are considered to have efficient access to their surroundings, while plots with values above this threshold are not. With a threshold of 1.5, routes up to 50% longer than the straight-line distance would pass the PRD test. Previous studies in the U.S. have noted that PRD values around 1.6 and higher are characteristic of suburban developments and neighbourhoods with poorly connected streets. By contrast, an average PRD value between 1.3 and 1.4 is associated with connected, gridiron street systems (Hess 1997; Randall and Baetz 2001). Studies of street connectivity in suburban developments have adopted both 1.5 (Clapp 2009) and 1.6 (Hess et al. 1999; Zhou and Xu 2020) as PRD threshold values. The article used the stricter value of 1.5 because of the UAE's hot and humid climate and because the analysis involved neighbourhoods whose street layouts and designs vary widely and include gridiron, fragmented parallels, looping, and cul-de-sac layouts. A threshold value of 1.5 is used not only in the scholarly literature, but also by Abu Dhabi's Department of Municipalities and Transport (DMT) in its assessments of street network efficiency (Scoppa, Bawazir, and Alawadi 2019). Abu Dhabi's DMT is guided by Estidama ('sustainability' in Arabic), the Middle East's first rating and guiding system for sustainability. Estidama ranks construction and planning projects using a Community Rating System, which is designed to guide sustainable urban development across its life cycle, from design to construction to operation.

Computation of network connectivity

The sixteen neighbourhoods selected for the study represent different eras and characterize the city's morphological diversity. An area-wide assessment is applied to samples from each neighbourhood. The sizes of the neighbourhoods vary considerably, from 1.93 sq. km. to 15.87 sq. km. in Dubai and from 5.69 sq. km. to 44.80 sq. km. in Abu Dhabi. In addition, the PRD value is sensitive to distance: the greater the distance, the less accurate the PRD calculation is (Stangl 2012). For this reason, samples are selected from case study neighbourhoods to facilitate a realistic comparison.

A total of thirty-two areas in Abu Dhabi and Dubai are analysed in this study: sixteen in Abu Dhabi and sixteen in Dubai (Figures 1 & 2). Two square-shaped areas are selected from all chosen neighbourhoods to enable a comprehensive analysis. The selection of two areas in each neighbourhood enables better evaluation of the connectivity of the different network designs within neighbourhoods. Sample selection has considered a reasonable morphological variety; each area in the sample represents a unique neighbourhood pattern. Table 1 shows the morphological attributes of the samples.

Various studies have previously used square-shaped samples to: (1) analyse urban form and make comparisons across different cities (Jacobs 1995; Southworth and Owens 1993), (2) correlate pedestrian volumes with site design (Moudon et al. 1997), (3) compare urban evolution of cities (Wheeler 2003), and (4) compare built landscapes of multiple metropolitan regions (Wheeler 2008). This study uses areas of one square-mile for analysis (Figure 3). A neighbourhood scale area that falls between 1 km^2 and 2 km^2 is deemed appropriate for analysis. This size is large enough to understand the effects of morphological attributes on residents' lives, behaviour, and movement patterns (Wheeler 2015).

1) Al Manhal, 2) Al Mushrif, 3) Baniyas East -1, 4) Baniyas East -2, 5) Shahama-1, 6) Shahama-2, 7) Al Bahya East-1, 8) Al Bahya East- 2, 9) Al Bahya West- 1, 10) Al Bahya West- 2, 11) Khalifa City- 1, 12) Khalifa City-2, 13) MBZ-1, 14) MBZ-2, 15) Al Falah-1, 16) Al Falah-2.

Figure 1. Sixteen sample areas from Abu Dhabi.

Moudon and Hess (2000) studied urban form within this range (1–2 km^2). They used areas of one square mile to analyse and compare the progression and change of suburban landscapes. Likewise, Cardillo et al. (2006) used areas of one square mile to compare the structural properties of urban street patterns in different cities around the world.

Inside each square-mile area, the study measures PRD values within a 400 m search radius. The PRD measure's bias for long distances is eliminated by applying a limiting radius of 400 metres for all areas in the sample (Dill 2004; Stangl 2012). A quarter mile is often used as a benchmark distance for network planning and walkability assessments (Southworth 1997). To obtain accurate results, this area is extended to include a buffer of 0.25 mile (roughly equivalent to 400 metres) in each direction (Figure 3). Street networks are continuous in reality, and when analyses are carried out within an artificially bounded study area, network elements and events that occur beyond the boundary are ignored (Gil 2017). This ignorance results in a bias, known as *edge effect*, because the analytic

1) Al Badaa East, 2) Al Badaa West, 3) Rashidiya-1, 4) Rashidiya-2, 5) Al Quoz North, 6) Al Quoz South, 7) Nadd Al Sheba-1, 8) Nadd Al Sheba-2, 9) Nadd Al Hamar-1, 10) Nadd Al Hamar-2, 11) Al Barsha-1, 12) Al Barsha-2, 13) Al Warqa-1, 14) Al Warqa-2, 15) Al Barsha South-1, & 16) Al Barsha South-2.

Figure 2. Sixteen sample areas from Dubai.

algorithms are fundamentally relational. Edge effect affects not only the nodes on or adjacent to the study area's boundary, but also all other nodes in the network (Barthélemy 2011). The reliability of any network analysis results is deemed questionable if the edge effect is not considered (Ratti 2004). Several approaches to addressing the edge effect have been proposed over the years. The most effective is to extend the network with a buffer around the study area (Hillier et al. 1993). Thus, to combat edge effect, this study extends each area beyond its boundary by approximately 0.25 mile in each direction.

PRD indicates the level of connectivity of a neighbourhood plot in relation to the street network. In this study, the centroids of the existing plots are selected as the origins and destinations. This approach to urban network analysis is termed 'all plots to all plots'. The street network and the plot centroids are the base input used to calculate the network's efficiency, measured by PRD. Calculations are performed using an 'all plots to all plots' rationale because this approach assesses the ability of different network designs to

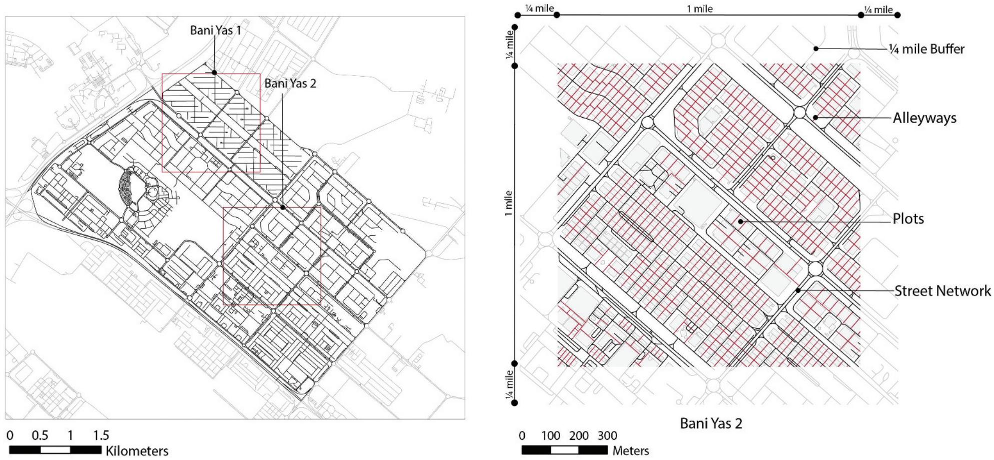


Figure 3. To the left, Baniyas neighbourhood. To the right, morphological structure of the sample area (1 X 1 mile).

provide efficient access throughout the selected study areas in any direction (Stangl 2012). This procedure also resolves the biases that might occur if the analysis were carried out by only measuring PRD to particular destinations, such as transit stops, retail outlets, or schools (Dill 2004).

Results

Abu Dhabi neighbourhoods

In Abu Dhabi, ten of the sixteen samples pass the PRD threshold of 1.5, which are located in neighbourhoods such as Al Bahya West, MBZ, Khalifa City, Al Falah, Al Bahya East, and Shahama (see Table 2 and Figure 4). Al Bahya West 2 has the most efficient connectivity: its PRD value is 1.11 and 98% of its plots pass the PRD test. This result is due to the efficiency of orthogonal grids in providing direct routes. MBZ 2 is the second most efficient area in the Abu Dhabi sample, with a 90% passing percentage and a PRD value of 1.27. This is because the MBZ neighbourhood has a semi-grid system nested in a loop that serves the entire area. It is worth noting that none of the samples taken from the early suburbs pass the PRD threshold of 1.5. Four out of the six failing samples are located in early suburbs which were established during the start of the suburbanization process in the late 1960s–early 1980s.

Baniyas 1, built in the late 1970s, has the highest PRD value at 1.66, and only 37% of its plots pass the PRD test. This is due to the combination of different street patterns and block sizes prevalent in this neighbourhood. For instance, the northern part of the area has smaller blocks, while the southern part has longer blocks with more irregular orientation and shapes. The West Island areas – Al Manhal and Al Mushrif – have PRD values of 1.65 and 1.57, respectively. Al Manhal follows Baniyas 1 with the second poorest connectivity efficiency. It has a PRD value of 1.65 and a passing percentage of 34%. All five early suburban areas – Al Manhal, Al Mushrif, Baniyas 1, Baniyas 2, and Shahama 1 (Old Shahama) – have lower PRD values and much lower passing percentages compared with

Table 2. The percentage of plots passing the PRD test, and average PRD values for the sample areas. (Sample areas are arranged in chronological order).

Abu Dhabi						Dubai					
S. N	Neighbourhood name	Estd. year	Category	PRD	Passing %	S. N	Neighbourhood name	Estd. year	Category	PRD	Passing %
1	Al Manhal	1968–1974	Early suburbs	1.65	34.00	1	Al Badaa East	1968–1975	Early suburbs	1.50	55.00
2	Al Mushrif			1.57	42.00	2	Al Badaa West			1.44	73.00
3	Baniyas 1	1978–1984		1.66	37.00	3	Al Rashidiya 1	1969–1977		1.49	62.00
4	Baniyas 2			1.53	49.00	4	Al Rashidiya 2			1.49	60.00
5	Shahama 1	1980		1.45	73.00	5	Al Quoz North	1976–1977		1.62	38.00
6	Shahama 2			1.55	51.00	6	Al Quoz South			1.61	40.00
7	Al Bahya East 1	1996	Newer suburbs	1.42	72.00	7	Nadd Al Hamar 1	1992–1994	Newer suburbs	1.45	63.00
8	Al Bahya East 2			1.45	66.00	8	Nadd Al Hamar 2			1.42	67.00
9	Al Bahya West 1	2003		1.33	77.00	9	Al Barsha 1	1992–1994		1.46	70.00
10	Al Bahya West 2			1.11	98.00	10	Al Barsha 2			1.43	74.00
11	Khalifa City 1	1997–2002		1.34	79.00	11	Al Warqa 1	2001–2006		1.49	55.00
12	Khalifa City 2			1.33	81.00	12	Al Warqa 2			1.43	66.00
13	MBZ 1	2003		1.33	80.00	13	Al Barsha South 1	2009–2010		1.49	54.00
14	MBZ 2			1.27	90.00	14	Al Barsha South 2			1.43	62.00
15	Al Falah 1	2001–2008		1.54	47.00	15	Nadd Al Sheba 1	2010		1.41	72.00
16	Al Falah 2			1.42	70.00	16	Nadd Al Sheba 2			1.39	72.00

newer suburban areas such as Al Bahya West 2, MBZ 2, and Khalifa City 2. Al Manhal, Al Mushrif, and Old Shahama have highly inconsistent urban forms composed of various street patterns (e.g., cul-de-sacs, semi-grid, orthogonal) and larger and smaller blocks built incrementally during different urban growth periods.

Dubai neighbourhoods

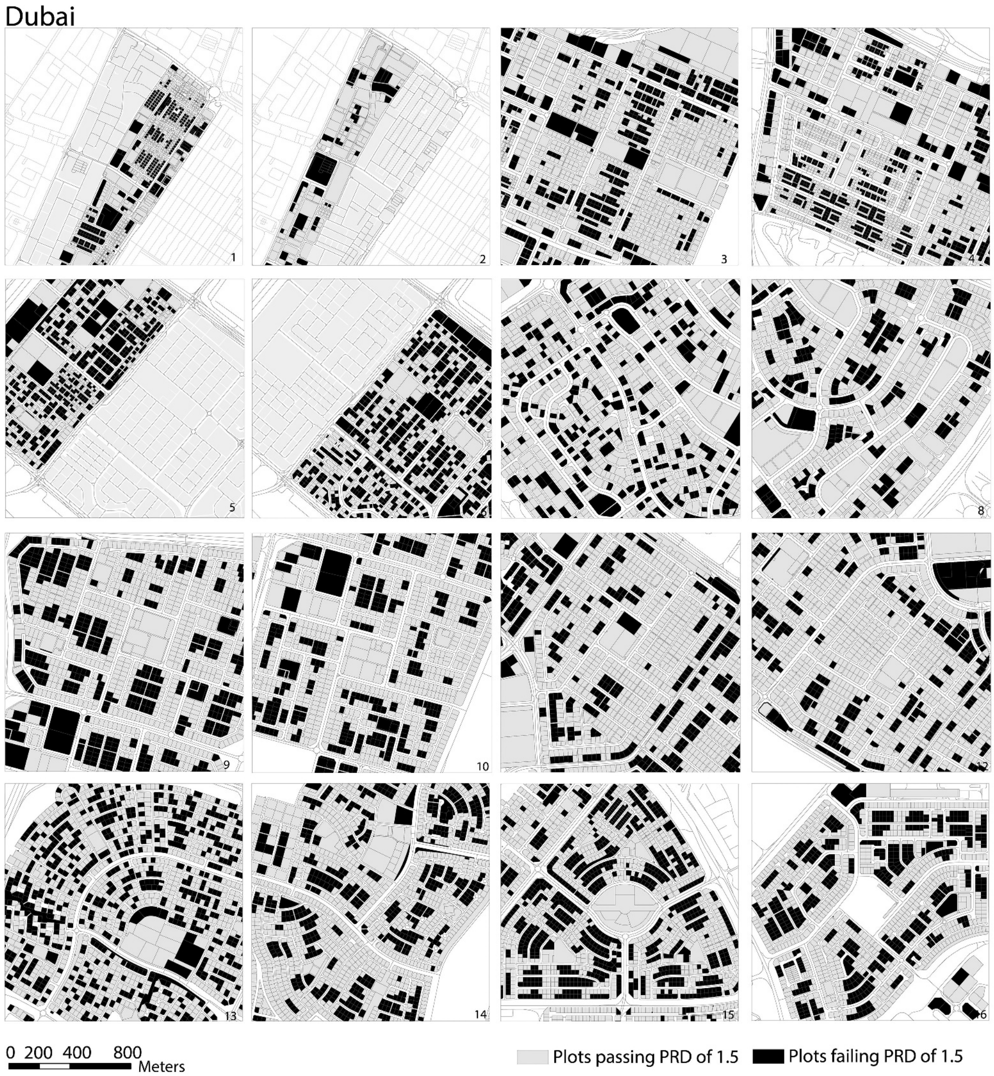
In Dubai, fourteen of the sixteen samples pass the PRD threshold of 1.5; these areas are located in neighbourhoods such as Nadd Al Sheba, Nadd Al Hamar, Al Warqa, Al Barsha South, Al Barsha, Al Badaa, and Al Rashidiya (see Table 2 and Figure 5). Of these fourteen, five – Al Barsha South 1, Al Warqa 1, Al Rashidiya 1, Al Rashidiya 2, and Al Badaa East – have values that fall near the threshold; these areas pass the test with PRD values of 1.49, 1.49, 1.49, 1.49 and 1.50 respectively. Only two samples in Al Quoz, an early suburban neighbourhood, fail the test; these two areas together have an average PRD value of 1.61 and an average passing percentage of 39%. The presence of different street patterns (e.g., looping, curving, fragmented, and long blocks) built during different suburbanization periods is responsible for these areas' low connectivity efficiency.

The samples from the Nadd Al Sheba neighbourhood perform better than other Dubai areas studied in terms of connectivity efficiency. Nadd Al Sheba 2 has a passing percentage of 72% and a PRD value of 1.39. Another area from the same neighbourhood, Nadd Al Sheba 1, also has passing percentage of 72%, with a PRD value of 1.41. This is attributable to the consistent and continuous looping streets that serve the neighbourhood. The older suburbs of Dubai, including Al Badaa, Al Quoz, and the relatively older neighbourhood of Rashidiya, are outperformed by newer suburbs of Nadd Al Sheba, Nadd Al Hamar, Al Warqa, Al Barsha South, and Al Barsha.

Figure 4. PRD results, passing/failing plots for sample areas in Abu Dhabi.

Synthesis: Abu Dhabi and Dubai

The early suburbs of both Abu Dhabi and Dubai have high PRD values (indicating that they are less efficient) compared with their newer suburbs. The average PRD values for the early suburbs of Abu Dhabi and Dubai are 1.59 and 1.53, respectively, and thus fail to pass the PRD threshold of 1.5. In Abu Dhabi, the early suburban areas of Baniyas 1 and Al Manhal have poor connectivity scores, with PRD values of 1.66 and 1.65, respectively. Results improve slightly for Al Mushrif and Shahama 1 (Old Shahama), whose PRD values reach 1.57 and 1.55, respectively. Among the early suburbs of Abu Dhabi, Baniyas 2 approaches the threshold with a PRD value of 1.53. In Dubai, the early suburban areas



1) Al Badaa East, 2) Al Badaa West, 3) Rashidiya-1, 4) Rashidiya-2, 5) Al Quoz North, 6) Al Quoz South, 7) Nadd Al Sheba-1, 8) Nadd Al Sheba-2, 9) Nadd Al Hamar-1, 10) Nadd Al Hamar-2, 11) Al Barsha-1, 12) Al Barsha-2, 13) Al Warqa-1, 14) Al Warqa-2, 15) Al Barsha South-1, & 16) Al Barsha South-2.

Figure 5. PRD results, passing/failing plots for sample areas in Dubai.

of Al Quoz North and Al Quoz South perform poorly in the PRD test, with values of 1.62 and 1.61, respectively. The PRD values of Al Rashidiya 1, Al Rashidiya 2, and Al Badaa East lie near the threshold at 1.49, 1.49, and 1.50, respectively. One of Dubai's early suburban samples, Al Badaa West, passes the PRD test with a value of 1.44. Average PRD values for newer suburban areas are 1.36 for Abu Dhabi and 1.44 for Dubai, both of which pass the PRD threshold of 1.5. All the samples in newer suburbs pass the PRD test, except for one in Abu Dhabi: Al Falah 1, whose PRD value is 1.54.

Abu Dhabi's PRD values vary much more widely than Dubai's, from 1.11 in Al Bahya West 2 to 1.66 in Baniyas 1. In Dubai, PRD value varies from 1.39 in Nadd Al Sheba 2 to 1.62

in Al Quoz North. It can be noted that when areas that include a variety of street patterns (i.e., a combination of semi-grid, orthogonal, and fragmented) generate higher PRD values. By contrast, areas with consistent urban form (a repetitive street pattern and similar block sizes throughout the sample) have better PRD values. These findings call into question the conventional labelling of suburbs as inefficient and poorly connected urban environments.

Discussion

Urban research conceptualizations and measurements of suburban sprawl have indicated its detrimental impact on cities' environmental and social fabrics. Planners and designers have 'overwhelmingly vilified suburbia' (Berger and Kotkin 2018, p. 10) because of its negative and interacting social, aesthetic, and environmental consequences. The narrative that suburbs are characterized by wasteful land divisions, fragmentation, and automobile dependency is well established in the literature. However, some scholars have emphasized the potential of rethinking suburban design (Fava 1975; Bourne 1996; Danielsen, Lang, and Fulton 1999; Bruegmann 2006; Kotkin 2010). Suburbs have become pervasive around the world; they have become the urban model that dominates cities of today. For that reason, this article does not reject suburban development, the most persistent trend in urbanism in the past 80 years. Design and planning practice in Abu Dhabi, Dubai, and similar places need an overhaul, including an improved ideology of urban design. So, how can the current problems of suburban design be mitigated, such as connectivity efficiency, which is one of the main problems indicated by the planning and urban design literature?

Research findings indicate that connectivity in the suburbs of Abu Dhabi and Dubai is not extremely inefficient but could be improved. The obtained results for the selected suburban areas indicate better connectivity efficiency in newer suburbs than in early suburbs. Areas with a consistent urban form (i.e., uniformity in street layout, block length, plot size, etc.) performed better in the PRD test. Most of the older suburban neighbourhoods, including Al Manhal, Al Mushrif, and Baniyas in Abu Dhabi and Al Badda, Al Quoz, and Al Rashidiya in Dubai, have a combination of different street layouts, block lengths, and plot densities, the latter of which range from 0.40 to 2.65 plots per acre. The newer suburbs, including Al Bahya West, Khalifa City, and MBZ City in Abu Dhabi and Nadd Al Sheba and Nadd Al Hamar in Dubai, have very uniform urban form throughout each neighbourhood and plot densities ranging from 0.71 to 1.74 plots per acre. Thus, the PRD values of the samples in newer suburbs are more desirable than those in early suburbs.

This study provides evidence that most early suburban layouts are inefficient for pedestrian movement. The newer suburban layouts, in most cases, pass the PRD threshold of 1.5; however, they may still be practically inefficient. In other words, the 1.5 PRD threshold, which represents pathways that are 50% longer than the corresponding straight-line distances, may not represent convenient pathways for walking in hot, arid cities such as Abu Dhabi and Dubai. Therefore, in order to make walking viable, connectivity efficiency in the suburbs needs to increase so pedestrians can access their destinations more quickly.

Connectivity efficiency can be improved significantly by retrofitting existing network systems. However, in most situations, retrofitting streets is infeasible. Considering the difficulties involved in altering street networks once built, an understanding of alternative network systems such as alleys and their contribution to connectivity is critical. The process of modifying streets involves acquisition of public and private plots, compensation, displacement of some residents, diversion of utility lines, and interruption of the daily lives of residents during construction. An alternative to retrofitting existing street networks is to incorporate, utilize, and promote a secondary network of alleyways for pedestrian movement. Alleyways are critical but often forgotten components of urban form (Alawadi et al. 2021). For that reason, this article argues for reclaiming alleyways as a critical infrastructure element. Incorporating pedestrian-friendly alleyways can make for a more connective network and lead to measurably improved conditions for pedestrians.

In studied neighbourhoods, alleys are regular and uniform; they form straight lines of constant width, which varies between 2 and 3 m and rarely exceeds this latter dimension. Alleys can provide pedestrians with route efficiency comparable to neighbourhoods that feature regular orthogonal grids, such as Al Bahya, where the average PRD value is 1.22, corresponding to a mere 22% longer network distance. Alleys can convert many inefficient street layouts into more efficient ones. The study analyzes the additions of the alleys to the street network of the 10 areas whose street networks have the least efficient PRD values (Figure 6). Results indicate a considerable improvement for areas such as Al Quoz North and Al Quoz South, where PRD value improves by 0.31 (see Table 3). In other words, the trip lengths (i.e., pedestrian paths) that are 60% longer than straight-line distances when only streets are considered, become only 30% longer than the straight-line distance when both streets and alleys are considered. Likewise, significant changes in PRD values are observed in areas such as Shahama 1, Baniyas 1, and Al Rashidiya 1. For instance, in Shahama 1, the PRD value decreases from 1.55 to 1.30, which indicates that trip lengths are only 30% longer than straight-line distances when alleyways are considered, as opposed to 55% longer when alleyways are excluded.

The total network length and the intersection density increase dramatically when alleyways are added. For instance, in Baniyas 2, Al Quoz South, and Baniyas 1, alleyways add 50.23, 39.17, and 36.18 kilometres to the network, respectively. Similarly, in Al Badaa East, Al Quoz South, and Al Quoz North, the intersection densities increase significantly, from 2.06 to 4.97, from 0.47 to 3.25, and from 0.41 to 2.94 intersections/acre, respectively.[1] These findings highlight the importance of alleyways in improving pedestrian connectivity. Alleys have been a characteristic feature of Abu Dhabi's and Dubai's neighbourhoods since their inception. This is evident in their extensive and massive alleyway systems which added to the total network length approximately 50.23 km in Baniyas 2, 39.7 km in Al Quoz South, and 36.18 km in Baniyas 1.

The common presence of alleys in both cities' neighbourhoods indicate their importance in network design. Thus, the current trend of neglecting alleys needs to be replaced by a practice that integrates these narrow thoroughfares into the neighbourhood design and retrofitting efforts. This study contributes to urban planning scholarship and practice. In case of the former, the study of suburban street layouts with alley systems clarifies their ability to facilitate connectivity, adding to the discussion of the design of suburban network systems. In case of the latter, this study could assist current practice and policy making, particularly in regard to the provision, management, and improvement of alleys in suburban development.

1) Al Manhal- West AD), 2) Al Mushrif- West AD, 3) Baniyas East -1, 4) Baniyas East -2, 5) Shahama-1, 6) Shahama-2, 7) Al Badaa East, 8) Rashidiya-1, 9) Al Quoz North, 10) Al Quoz South, 11) Al Warqa-1.
1-6 are located in Abu Dhabi, and 7-11 are located in Dubai.

Figure 6. Addition of alleyways and the consequent improvement in PRD in results of selected sample areas.

Table 3. Improvement in PRD, network density, intersection density after the addition of alleyways to the network.

		PRD							Intersection Density (no./acre)		Intersection count per sq. mile	
S. N.	Neighbourhood	Streets only	With alleys	Improvement in PRD value	Street length (km)	Street density (km /acre)	Alleys length (km)	Alley density (km/ acre)	Without alleys	with alleys	Without alleys	with alleys
1	Al Quoz North	1.62	1.31	0.31	28.31	0.09	28.37	0.09	0.41	2.94	260	1880
2	Al Quoz South	1.61	1.30	0.31	36.06	0.11	39.17	0.12	0.47	3.25	304	2082
3	Baniyas 1	1.66	1.35	0.31	53.18	0.08	36.18	0.06	0.64	1.47	412	940
4	Shahama 2	1.55	1.30	0.25	33.71	0.11	25.89	0.09	1.01	2.90	647	1859
5	Al Manhal	1.65	1.44	0.21	84.35	0.13	44.45	0.07	1.01	3.01	645	1928
6	Al Rashidiya 1	1.49	1.29	0.20	55.39	0.09	8.85	0.09	0.64	0.95	412	605
7	Al Mushrif	1.57	1.38	0.19	62.61	0.10	32.86	0.05	0.61	1.66	388	1064
8	Al Badaa East	1.50	1.33	0.17	21.18	0.07	15.40	0.11	2.06	4.97	1318	3181
9	Baniyas 2	1.53	1.38	0.15	56.95	0.09	50.23	0.08	0.64	1.77	410	1134
10	Shahama 1	1.45	1.32	0.13	18.11	0.06	9.27	0.06	0.53	1.62	339	1039
11	Al Warqa 1	1.49	1.36	0.13	41.89	0.07	8.83	0.01	0.23	0.46	146	297

Nevertheless, travel behaviour and movement are not determined solely by urban networks' physical characteristics. People do not always follow the dictates of urban form; movement through urban space is also predicated on numerous other factors, such as the location advantage of attractions, the condition of the pedestrian infrastructure, the presence of activities and diverse land uses, cultural nuances, climate circumstances, and other aspects of behaviour (Hillier et al. 1993). Considering this complexity, the understanding of pedestrian travel would certainly benefit from mixed-methods studies of the relationship between network connectivity and actual pedestrian movement in these same neighbourhoods – or any other sample.

Such studies would need to begin with a quantitative analysis of networks that includes additional Urban Network Analysis (UNA) metrics such as Betweenness and Gravity (Sevtsuk and Mekonnen 2012). In principle, gravity measures the appeal of travelling to a destination by taking into account both the destination's overall attractiveness and the difficulty of getting to it. The longer the distance from an origin to a destination, the higher the 'friction,' which reduces the appeal of walking to the destination. Betweenness, on the other hand, identifies movements on streets (Freeman 1977) and is defined as the number of trips that cross a node or a street segment in a street network. Betweenness is also used to assess path selections. The higher the number of trips on a certain path, the greater the attraction of the facilities on that path (Bielik et al. 2018). Betweenness provides information about critical places (streets and nodes) that have location advantages within the network.

Future studies should further include qualitative analyses that explore the conditions of pedestrian infrastructure, presence of activities, attractiveness of destinations, and residents' movement rates, patterns, and behaviour. Follow-up qualitative studies would be necessary to understand the real situation on the ground and how these streets shape residents' actual daily lives. This type of qualitative study would be able to answer questions that quantitative studies cannot address. For example, why do residents walk, for what purposes, and at what rate or frequency? How often do residents walk? How do they interact with the built environment and each other? Why do they prioritize certain routes over others? And how could their walking experience be improved and enhanced?

Conclusion

Suburbs have been labelled as inferior to urban centres. Many planners, designers, and scholars have either overlooked suburbs or written them off as an undesirable spatial expression of capitalism and consumerism. In this narrative, suburbs are comparable to wastelands and are sites of isolation. Fava (1975) started the debate on the potential of redesigning suburbs instead of ridiculing them constantly, but this debate only became prominent in the 2000s with the work of Berger and Kotkin and other scholars. This article builds upon this later work of exploring how suburbs can be improved and turned into better places. In particular, this study measured suburbs' street connectivity, which is essential for effective pedestrian movement.

This paper analysed thirty-two one-square-mile suburban areas in Abu Dhabi and Dubai as case studies to quantify their connectivity efficiency. PRD measured the connectivity efficiency of each sample. The physical design aspect of the suburban samples that has been quantified by the PRD metric reveals that a consistent urban form (comprising street layout, block size, plot size, intersection density, etc.) results in better connectivity. Conversely, connectivity is lower for a neighbourhood sample with a combination of different urban typologies. Results show that the early suburbs are inefficient compared with the newer suburbs in terms of providing quick and direct access to destinations (i.e., connectivity) when an established PRD threshold of 1.5 is considered. However, this paper argues that better connectivity is required for practicality in hot arid regions. Therefore, the study explored how the forgotten and neglected system of alleyways could be reclaimed to improve connectivity efficiency. It is evident that the utilization of alleys boosts pedestrian connectivity in suburbs by as much as 31% for some areas.

This paper studied the physical design and attributes of network systems, thus its findings about connectivity efficiency may not coincide with the actual situation on the ground. In other words, the actual pedestrian flow in the study sites depends on various other parameters related to human behaviour, demographics, weather conditions, land uses, and availability and condition of infrastructure. On-the-ground realities such as the presence of sidewalks and other pedestrian infrastructure, thermal comfort, and pedestrian preferences are not incorporated into this study's analysis. Future studies can focus on micro urban design elements, human behavioural aspects, demographics, and other physical design and microclimate aspects to determine what factors encourage walking. One important future research question worthy of exploration is: Are newer suburbs less desirable for walking compared with early suburbs even when, as this research showed, some physical design attributes favour the former?

Note

1. For 9 out of 11 samples areas (shown in Table 3), the number of intersections (streets only) is more than 300/sq.mile, which is considered fairly high. The LEED-ND 'Street Network' credit gives one point for 300–400 intersections/sq.mile and 2 points for more than 400 intersections/sq.mile. UN-Habitat recommends about 100 intersections/sq.km, which is 259 intersections/sq.mile. Similarly, Canada's Ministry of Transport recommends 0.6 intersections/hectare, which is about 155 intersections/sq.mile. After adding alleyways, the number of intersections became more than 600/sq.mile for all except two samples.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Khalifa University of Science & Technology – Competitive Internal Research Award, CIRA-2019-053 [Project number: 8474000184].

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