Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 11, No. 06, June, 2025

Street Networks and Urban Sustainability by Quantifying Connectivity, Accessibility, and Walkability for Resilient Cities

Haider J. E. Al-Saaidy [1*], Dhirgham Alobaydi [2], Sally F. K. Abdullah [2]

[1] *Department of Architectural Engineering, University of Technology- Iraq, Baghdad, Iraq.*

[2] *Department of Architecture Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.*

Received 26 January 2025; Revised 19 May 2025; Accepted 24 May 2025; Published 01 June 2025

Abstract

Street networks are crucial in shaping the quality of urban life. Through their impact on mobility and social interaction, they play a critical role in shaping how people move around the city and determine the connectivity, accessibility, safety, and convenience of different areas. Thus, it is essential to develop a systematic understanding of street networks to create livable, sustainable, accessible, and equitable cities. The aim of this study is to analyze and develop the role of street networks in shaping urban mobility, connectivity, and accessibility, and thereby enhance sustainable urban living by creating people-centric cities. Quantitative techniques and measures are employed to examine urban structure metrics to understand both physical and spatial characteristics at micro and macro scales. Three primary parameters for the configuration of street patterns - grid pattern ratio (GPR), pedestrian route directness factor (PRD/PRF), and ped-shed (PS) and effective walking area (EWA) - are selected to compute the formational attributes of selected streets in Baghdad, Iraq. The evaluation employs different arithmetic methods linked with a Geographical Information System (GIS) to quantify and compare two examined areas, and the results reveal a contradiction in the spatial configuration of the sample street patterns. From these findings, the paper offers specific recommendations and urban design guidelines to improve the quality of similar urban areas. The paper concludes that in-depth knowledge of a street's role in its urban context helps to optimize spatial configuration processes in the built environment.

Keywords: Street Network; Accessibility; Connectivity; Walkability; Walking Area; Baghdad.

1. Introduction

Over recent decades, morphological studies of urban form have become an essential approach to evaluate and understand the configuration of the built environment. These studies use a range of quantitative and qualitative methods to analyze the physical form and structure of urban areas, including buildings, streets, public spaces, and natural elements [1-6]. Morphological studies can provide insights into the spatial organization and function of urban areas and how they shape social and cultural practices, economic activity, and environmental sustainability. By analyzing the form and structure of cities, researchers can identify patterns and relationships that inform urban design and planning decisions [7-14]. Street network characteristics play a key role in measuring connectivity and accessibility, enabling people to move from one place to another. Increasing walkability and social interaction throughout the street while understanding its fine scale and adjacent buildings can offer a better comprehension of pedestrian movement [15-18].

The quality of surrounding urban areas plays a significant role in enhancing the liveability of streets, and creating a pedestrian-oriented urban environment increases the potential to form a walkable climate [19]. Conversely, a deficient

* Corresponding author: haider.j.essa@uotechnology.edu.iq

http://dx.doi.org/10.28991/CEJ-2025-011-06-015

neighborhood can easily impact the liveability of inhabitants; therefore, walkability is considered a key criterion of urban design. It is applied to places to determine the support for physical activity and whether it is enhanced or impeded by the environment [20-22]. Thus, the primary concern for many urbanists is to create a walkable environment that meets various people's needs [23]. One of the most important street characteristics is accessibility, which is often employed to measure walkability in the built environment. Accessibility refers to the ability of the street network to offer good opportunities for users to access different destinations across the network and move easily from one space to another.

Measures of connectivity and accessibility, which influence the street pattern, nodes, and length, are systematically considered. The movement of pedestrians and how they use the street edge constitute the main concern for many urban and sociological studies [24-28]. The network system has been evaluated in several ways by considering its spatial-physical elements, streets, and intersections. Moreover, intersection density has been examined by many researchers [29-35], while others have focused on street density [34, 36-39]. At global and local levels, accessibility measures have been employed in human geography to illustrate the growth of towns, the location of facilities and functions, and the juxtaposition of land use. Thus, the fine scale of street characteristics at both micro and macro levels must also be acknowledged and understood. This represents one of the key conditions for improving street life, helping people benefit from the surrounding setting, and prompting interesting negotiations, whether with the adjacent street edge or other pedestrians. In addition, land use and urban development, besides different growth patterns, are affected by the accessibility of existing street networks and potential accessibility [40, 41].

Street characteristics represent another aspect of walkability and connectedness by describing how people connect. For example, connectivity governs the interrelationship between two primary components of a street pattern - link (street) and node (intersection) - which, alongside other urban structural elements, constitute the entire urban fabric. Moreover, connectivity needs to be understood and considered on both a micro and macro scale when formulating the built environment, particularly how it controls people's movements. Furthermore, improving a network’s connectivity helps to increase urban liveability and street life at the street edge on both a micro and macro scale. The block’s properties are the first consideration when determining a street pattern's characteristics from its spatial geometrical dimensions. Afterwards, the street's features are examined, particularly the adjacent edge parameters, to consider evidence of a symbiotic relationship between the block and street pattern. Moreover, this association can be seen when comparing the fine grain of the historic urban block and modern patterns, which is especially relevant to this study. In this regard, the plot pattern implies fewer influences on connectivity at the local level of the neighborhood. For example, in their research on street network, density, superblocks (such as Neighborhood Planning Units), and street connectivity in Abu Dhabi, Alawadi et al. [42] concluded that plot density does not influence efficiency. Instead, an effective network pattern generates maximum efficiency regardless of its plot density.

The characteristics of street networks can have a significant impact on the quality of urban form. The following are some of the key objectives through which different street network patterns can be explored to improve existing urban forms or adopt new urban design and planning models:

- Develop spatial connectivity and accessibility to promote walkability and reduce traffic congestion by relying on well-connected street networks. These networks can facilitate social interactions and provide many destinations within easy reach.
- Create a sense of enclosure by including denser streets and buildings within urban spaces to form a spatial configuration of sociability and public safety.
- Improve the quality of the urban environment by ensuring well-oriented streets. These streets can take advantage of solar exposure and prevailing winds, creating more comfortable and livable urban spaces.

Studying the characteristics of street networks by calculating their grid pattern ratio (GPR), pedestrian route directness factor (PRD/PRF), ped-shed (PS), and effective walking area (EWA) can help to create more connected and accessible urban areas that better suit the needs of residents. Firstly, GPR can facilitate movement and connectivity within an urban area since the presence of intersecting streets makes it easy for people to travel between different parts of the city. It can enhance walkability by creating a pedestrian-friendly environment. The regularity of the blocks and the presence of sidewalks make it easy and safe for people to walk from place to place. Secondly, PRD/PRF measures the efficiency of pedestrian routes in terms of distance and time. A better understanding of this factor can help urban planners design more direct and convenient routes for pedestrians, which can make a city more accessible and encourage people to walk rather than drive. Moreover, by creating more accessible pedestrian routes, the city can be improved for people with disabilities who may have difficulty navigating longer, less direct routes. Finally, PS and EWA measure the extent of pedestrian access to different destinations within a given radius. With this information, urban planners can design more walkable and accessible cities with a greater range of amenities and services within walking distance. By understanding the ped-shed and effective walking area, it is also possible to identify areas that may be poorly served by pedestrian infrastructure or public transport. This can inform decisions about where to prioritize investment in infrastructure and services to improve accessibility for all residents. These street network characteristics can help to create more walkable, accessible, safe, and healthy cities that are better suited to the needs of their residents and visitors.

This paper has four sections: First, the paper introduces the main topic, problem, main objectives, and structure of the study. Second, the analysis includes a description of the case study areas, selected streets, and main analytic street parameters employed in the analyses. Third, the paper quantifies and compares processes among the outcomes of the examined streets, although it is essential to note that these areas were also designated to capture other urban characteristics. Finally, the conclusions, recommendations, and future research directions are outlined.

2. The Literature Review

Many studies have focused on the importance of street networks in creating urban life. According to Wang et al. [43], density relates to the degree of connectivity and accessibility of the network. It links a dense location to other places in a city or urban area. Hence, priority is given to street centrality and its role in defining the validity of a place's intensity. Porta et al. [44] referred to street centrality indices as indicators to formulate the urban structure. A street provides a distinction between spatial privacy and spatial publicity in a historic urban area; moreover, the degree of permeability, transparency, accessibility, and connectivity is closely controlled and restricted [45]. Connectivity and accessibility are configurational properties that define the extent to which various spatial routes connect in a network. For example, Thwaites et al. [46] defined permeability as the capacity for connection to other realms through spatial-physical interaction. According to Marshall [3], permeability is a compositional property that refers to the extent to which accessible space permeates a two-dimensional plan area. Carmona [47] recommended that permeability, as a sustainable feature, should be involved in the design of urban spaces, whether at the urban core or periphery. They stated that the sustainable dimension in urban design requires development patterns that accommodate permeability and accessibility within the network system and enable effective social interaction.

Khder et al. [48] referred to seven fundamental principles that define a walkable street: Connectivity, safety, accessibility, comfort, convenience, engagement, and vibrancy. Every principle has an active role in shaping the street to meet people's needs and desires. Moreover, Massingue & Oviedo [49] state that the notion of walkability is based on three concepts - connectivity, accessibility, and permeability. These concepts depend on the spatial configuration of the street pattern. The fine ingredients of the urban form and the shaping of the street's adjacent edge play key roles in optimizing street life and can be identified at various levels of urban analysis, such as through micro, macro, local, and global measures. Urban quality and the right-to-use open spaces are key concerns when considering street life and social interaction, as they provide the infrastructure for the range of activities undertaken [49]. For example, Shields et al. [50] denote that "walkability has emerged as not only a set of indexes and metrics but also a normative discourse. This review of walkability studies draws on English, Spanish, and Portuguese literature, as well as case studies evaluating pedestrian walking in cities".

Al-Hasani [51] pointed out that historic urban spaces are classified into two typologies, which relate to associability and privacy. These topologies are historic-surviving spaces and modern-emerging spaces, the latter of which are divided into hybrid urban spaces and entirely modern urban spaces. According to Alobaydi & Rashid [52] and Alsaffar & Alobaydi [53], the city’s space is organized with a distinct sense of hierarchy, starting with private to semi-private places and then semi-public to public spaces. Furthermore, Rashid & Alobaydi [54] stated that these spatial hierarchies are employed as tactics or practices, even in hard times or during conflict.

Although previous studies show that many urban topics and elements have been addressed, the characteristics of the street network (such as geometric properties that influence the quality of the built environment) remain relatively little understood. This signified a research gap, as it is essential to develop a systematic understanding of street networks to create livable, sustainable, accessible, and equitable cities. Thus, this study addresses this gap by examining the characteristics and quality of the street network through its geometric properties. For this study, a set of street parameters is adopted to examine the degrees of connectivity and accessibility in two selected neighborhoods. Three sets of statistics are used: grid pattern ratio (GPR), pedestrian route directness factor (PRD/PRF), ped-shed, and effective walking area (PS and EWA). The selected areas include the historic regions of Baghdad, Iraq, which have organic street network patterns. The other selected areas are located outside the historic zone and were developed according to modern urban planning principles.

3. Methods and Definitions of the Case Study

To examine the parameters of the street network in the two urban areas of Baghdad, we analyze the physical characteristics of the street layout in each area. The following offers a brief overview of each area and some potential parameters for study:

A) Organic area in Al-Russafa Historical Center: A hybrid area with an organic street layout that has tended to develop over time without a strict plan, resulting in irregularly shaped blocks and winding, narrow streets.

B) Hybrid area in Al-Karkh historical center: A hybrid area combining organic and planned development, resulting in a more structured street layout with some irregularities.

Figure 1 shows the research flowchart for the study.

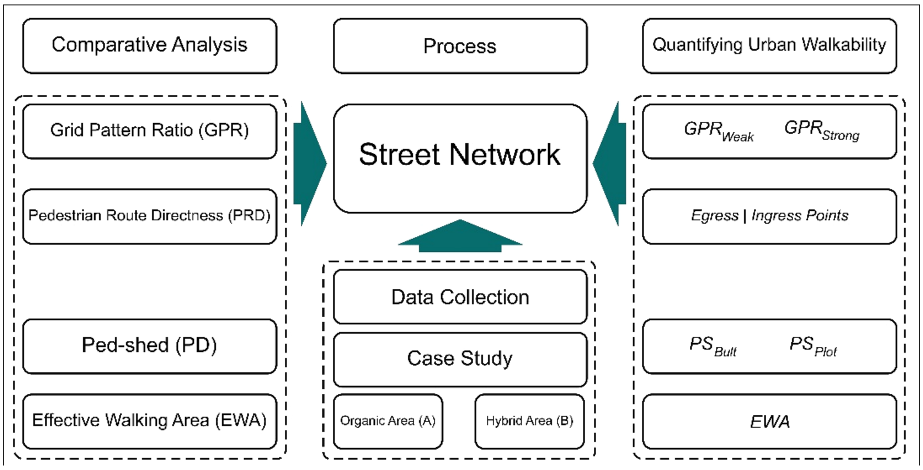

Figure 1. Research flowchart

The two examined urban areas are described in accordance with recognized patterns: (A) organic area and (B) hybrid area. This study seeks to examine the parameters of the street network based on its physical characteristics and spatial qualities, which have formed accumulatively and include organic growth and/or planned development. The two selected areas are important crossroads and typologically different because they provide a point of intersection between different streets, creating opportunities for connectivity and accessibility. They facilitate the movement of people, goods, and vehicles across different areas of the City of Baghdad. They also serve as nodes for social interaction, economic activity, and public space, providing opportunities for people to gather, socialize, and exchange ideas. In urban areas, crossroads often play a critical role in shaping the character and identity of different neighborhoods or districts, influencing the built environment and residents' quality of life.

A set of techniques and measures are combined to analyze and evaluate the two selected samples of the urban areas. These techniques and measures are employed to quantify the different characteristics and features of the street networks from their geometric and typological properties. This integrated research model enables greater accuracy, particularly when data are derived from multiple case studies. Since the spatial configuration and physical characteristics of the street patterns are considered significant to the street properties, while the analysis relies on the following three main variables: A grid pattern ratio (GPR), the pedestrian route directness factor (PRD/PRF), and the ped-shed and effective walking area (PS and EWA).

According to Sommer & Sommer [55], a case study method is an in-depth search that analyzes a phenomenon by applying multiple methods and techniques. Moreover, Yin [56] stated that samples enable the examination of a contemporary phenomenon within a marked boundary between the event and its context. For this study, an 800-meter diameter circle defines the boundaries of the four case studies, which were based on a commonly acknowledged, advisable walking distance indicating the range of a five-minute walk [26, 34, 39, 57, 58]. A case study method such as this enables an environmentally based, detailed contextual analysis of a given phenomenon. Therefore, adopting a contextual parameter for a limited number of objects, events, and activities helps to understand and analyze a complex problem to determine reliable findings [59].

The paper highlights Baghdad's historical and historic urban area by associating it with other selected neighborhoods. The main basis for selecting these areas is their location in two different Baghdad regions, including the concurrently linked network. Figure 2 refers to the boundary of the two circles, which have a 400-meter radius and represent the two cases: (A) a hybrid pattern with more organic influences and (B) a hybrid pattern with more planned influences. To track and draw the street network, the author employed georeferencing maps using two software programs, AutoCAD Map 3D 2021 and Geographical Information Systems (GIS). For Baghdad's historical and traditional zone, a key consideration is the complicated network in which convoluted, waved streets, compacted residential clusters, irregular street lines, and a high number of cul-de-sacs are located [60, 61]. Before illustrating the street's variables, it is necessary to explain the three parameters for the spatial configuration of these street patterns.

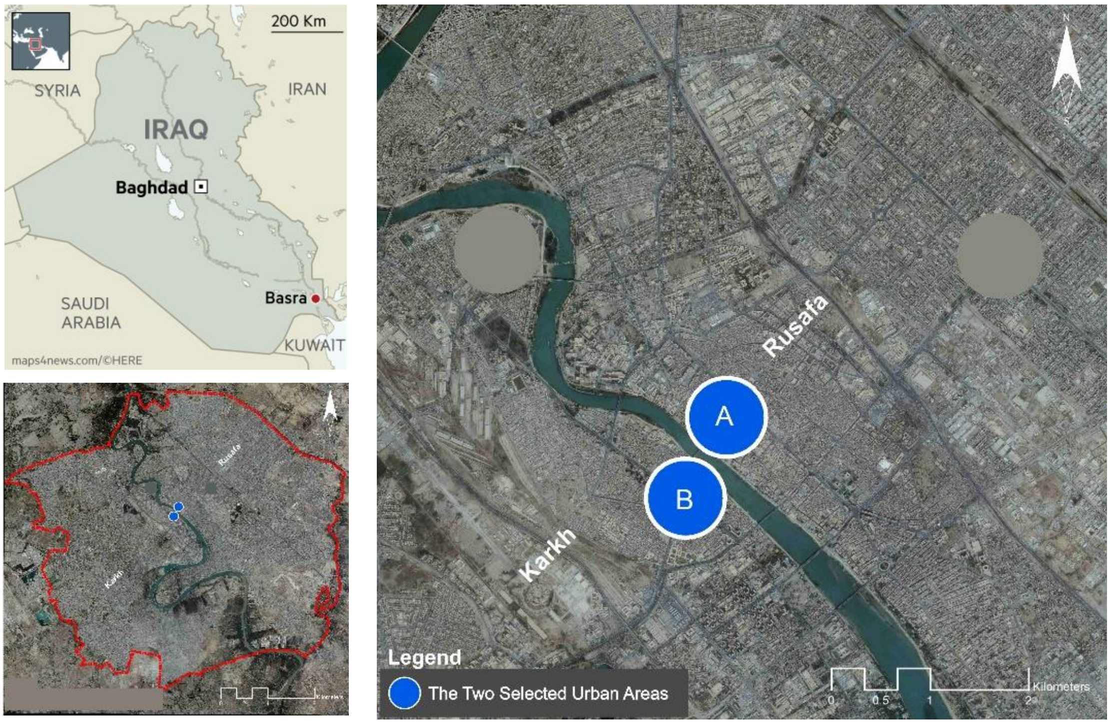

Figure 2. (Left) Georeferencing Satellite Imagery of Baghdad shows the border of the study area; (Right) The two chosen urban samples (radius 400 m)

4. Street Parameters

The street variables include four main factors: Grid Pattern Ratio (GPR), Pedestrian Route Directness (PRD), Ped-Shed (PS), and Effective Walking Area (EWA).

4.1. Grid Pattern Ratio (GPR)

This indicator measures the extent to which the street network is 'griddy', which spatially defines all urban blocks in the selected area that converge into 4-way intersections at the block corners. For clarification, if a block consists of a 4-way intersection at each corner, it is defined as 'strongly griddy'. In comparison, if a 4-way intersection defines the block at only three corners and one is 3-way or less, the block is described as a 'weakly griddy'. The indicator integrates with variables, such as block size and intersection density. In their study, Boarnet & Crane [62] referred to the street pattern as an indicator to determine travel behavior and its influence on land use and classified the network into three patterns - grid, cul-de-sac, and mixed. Greenwald & Boarnet [63] examined the role of the built environment in walking behavior in Portland, Oregon, and studied three variables - street crossings, sidewalk continuity, and street connectivity - to analyze walking behavior. Moreover, Porta & Romice [64] employed GPR to study several neighborhoods in Glasgow, UK, which was applied with other built environment indicators of street life [65]. The formula for Grid Pattern Ratio (GRR) is Equations 1 and 2:

$$GPR_{stong} = A_{strong}/A_{total} \tag{1}$$

$$GPR_{weak} = A_{weak}/A_{total} \tag{2}$$

where A_{strong} is the total area of blocks defined by all 4-way intersections, A_{weak} is the total area of blocks defined by all 4-way crossings except one 3-way crossing, and A_{total} is the total area of the sample. By applying *GPR* to the two areas, the result varied in terms of the level of griddy pattern. Case study A had a higher amount of A_{weak} at about 407960.6334 m^2, and its GPR_{weak} was 0.81. Hybrid area B had a lower amount of A_{weak} and GPR_{weak} at 320279.89 m^2 and 0.64 respectively. Furthermore, sample A had a lower value of both A_{strong} and GPR_{strong} at about 36797.35 m^2 and 0.07 respectively, while sample B had a greater amount at 84509.11 m^2 and 0.17, (see Table 1 for the full range of results).

Table 1. The data of the Grid Pattern Ratio for the two selected areas: Open areas are excluded (riverbanks, green spaces, parking, squares, and undeveloped land)

Case study ID	Case area	Total number of blocks	Number of blocks with 4-way crossing	Strong area	Weak area	GPR strong	GPR weak
Case A	502654.82	138	7	36797.35	407960.63	0.07	0.81
Case B	502654.82	125	16	84509.11	320279.89	0.17	0.64

4.2. Pedestrian Route Directness (PRD)

The Pedestrian Route Directness factor defines the ratio of the route distance to the straight-line distance between two selected points. The lowest value, equal to 1.00, confirms that the route has the same length as the direct line between these two points. The indicator measures the most direct pedestrian route to the center of the selected area and is compared to the distance between these origins and the center, measured as the bird flies [25, 66] (an example of the PRD is shown in Figure 3).

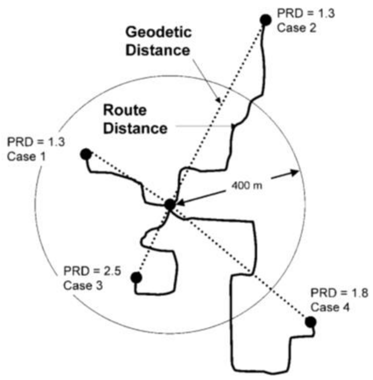

Figure 3. An example of the Pedestrian Route Directness PRD to illustrate the two types of distance - route distance and geodetic distance [26]

Pedestrian walkability is more likely affected by the route length and walk purpose than trip time [67]. Randall & Baetz [26] referred to the PRD as measuring pedestrian connectivity and stated it is an indicator of the walking accessibility of a neighborhood by its residents. The Pedestrian Route Directness (PRD) ratio assesses pedestrian connectivity and denotes the ratio between the route distance and the geodetic (or straight-line) distance, as given by Equation 3:

$$PRD = D_{route}/D_{geodetic} \tag{3}$$

where *PRD* is the Pedestrian Route Directness, D_{route} is the formal route distance along existing sidewalks, footpaths, or trails, where informal routes are those on streets without sidewalks, and $D_{geodetic}$ is the straight line linking the ends of the same direction.

The PRD was applied by Hess [25] when examining two neighborhoods, Wallingford and Crossroads, in Seattle. Furthermore, Randall & Baetz [26] used the measure to evaluate pedestrian connectivity in the Berrisfield neighborhood in Hamilton, Ontario, Canada, aiming to generate and evaluate potential retrofitting alternatives for pedestrian movement. Dill [31] applied the PRD to compute the network connectivity for cycling and walking in the Portland, Oregon region, while Kim [32] used it to compare five new urbanism areas to test network connectivity in the Metropolitan Atlanta region. The term PRD is known as the "Circuity Factor" and is a multiplier to coordinate calculated or straight-line distances to estimated real travel distances. As travel distances cannot be shorter than a straight line, the circuity factor must be one or larger [68-70] (as shown in Figure 4). It is calculated as follows (Equation 4):

$$CF_{ij} = \frac{D_{ij}^{n}}{D_{ij}^{e}} \tag{4}$$

where C_{ij} is the circuity factor between the origin *i* and the destination *j*, D_{ij}^{n} denotes the short distance between *i* and *j*, and D_{ij}^{e} represents the Euclidean distance between *i* (origin) and *j* (destination). Like the *PRD*, the hypothetical minimal value of circuity is 1 when the shortest network distance equals the Euclidean distance.

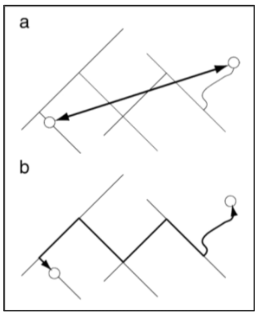

Figure 4. A diagram displaying the difference between (a) the Euclidean distance and (b) the network distance [69]

In this study, the PRD and CF are reformulated to achieve the research purpose. Each case has a 400-meter radius boundary that intersects with the street network at the External Point Connectivity (EPC) and represents the ingress/egress points along the borderline. The EPC is mapped and labelled to generate and define the destination points, and the center of the sample represents the origin. The aim is to identify the disparity and quantity between these two types of distance for each case; furthermore, a comparison of values is conducted between the selected samples. In this respect, the PRD as a PRF is computed as follows (Equation 5):

$$PRF = \frac{D_{c\,|\,epc}}{R} \quad (5)$$

where PRF is the Pedestrian Route Factor, $D_{c\,|\,epc}$ denotes the shortest distance between the center point of the selected area and the External Point Connectivity (EPC) (Egress/Ingress), and R is the radius of the sample (in this research, 400 meters). The shortest distance is computed using GIS, ArcMap 10.2.2 through the network analyst to track the shortest link between the external point (ingress/egress points) and the center of the case study. Also, in this research, the D_{mean} is calculated to discover the mean value of the total shortest distance, which is characterized by the routes that link the external nodes and the center of each selected area. The D_{mean} is formulated as Equation 6:

$$D_{mean} = \frac{\sum D_{c\,|\,epc}}{N_{route}} \quad (6)$$

where D_{mean} is the mean value of the route's (network) distance per selected area, $D_{c\,|\,epc}$ is the shortest distance between the center point of the selected area and the external point connectivity (EPC) (egress/ingress), while N_{route} is the total number of routes, excluding the egress/ingress points that do not reach the center of the sample. If the D_{mean} value is closer to the radius of the selected area, the routes offer the shortest distance between the border and center of the sample.

In sample A, there are 42 EPCs (ingress/egress points) which are located along the boundary of the hybrid organic and planned area A; they denote the destination points reaching the center (origin) of the case study (Figure 5). Most external points (42) reach the center of the sample, with the exception of five: EI4, RDID4; EI5, RDID5; EI6, RDID6; EI11, RDID11, and EI39, RDID39. After applying the PRF formula, the ratio of the two distances indicates a difference among the 42 routes.

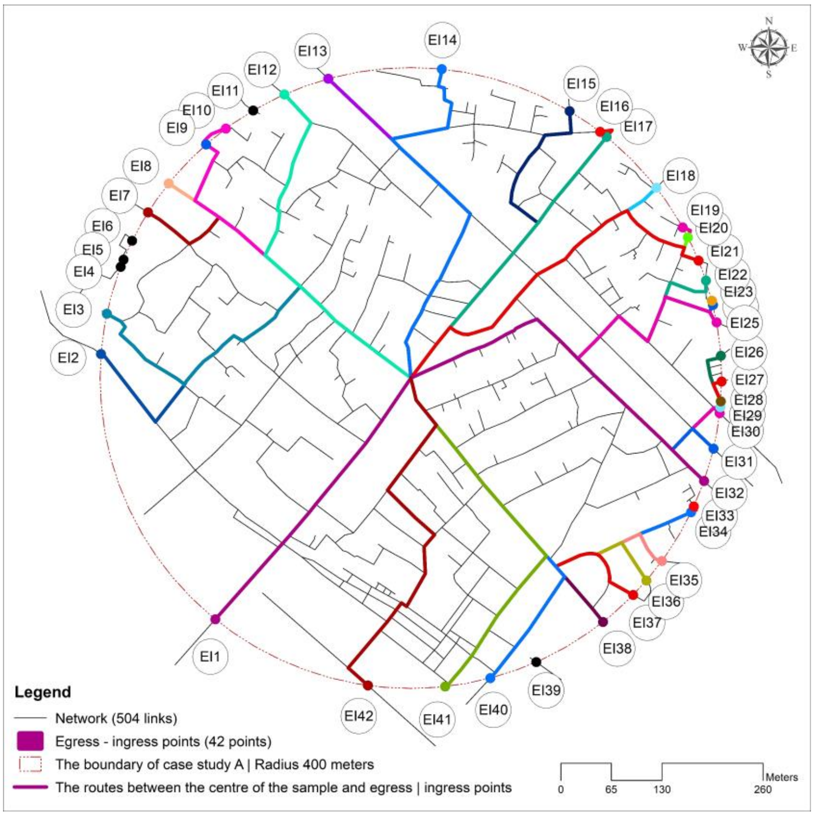

Figure 5. The route of the shortest (network) distance between the center of sample A and the external (egress/ingress) points

The shortest distance is equal to the radius of the 400-meter sample, and the PRF is labelled RDID01, RDID08, and RDID17 (the value zero means the external point does not reach the sample's center). The longest distance is 592.16 meters for RDID26, with a PRF of about 1.48. The median value of the PRF is 1.22, and the ratio average is 1.07; these correspond to 486.283 meters and 428.24 meters as medians and averages of the route distances (network distances), respectively (Figure 6). The value of D_{mean} in area A is about 486.11 meters for 37 routes, which correspond to the shortest distance between the external point (egress/ingress) and the center. The D_{mean} is closer to the radius of the selected areas (400 meters), meaning that the routes of the case study give the shortest distance for movement between its boundary and the center of the sample.

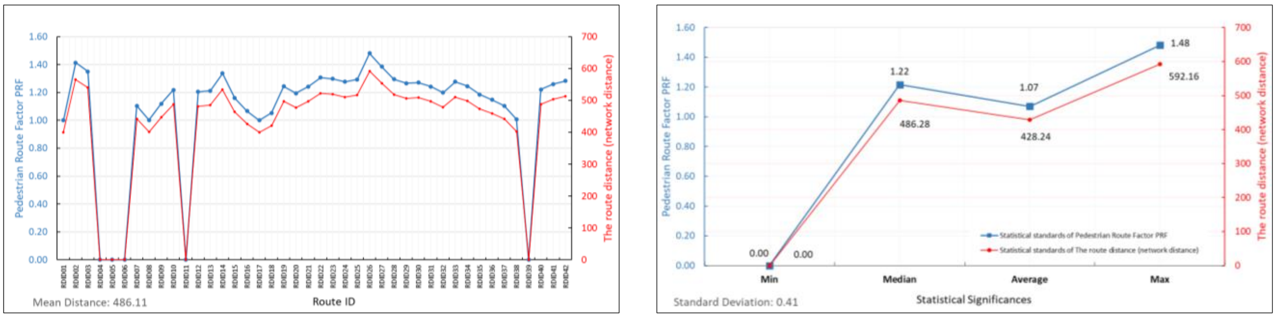

Figure 6. Left: The values of the Pedestrian Route Factor (PRF) and the shortest distance for 42 links that reach between the external points and the center of case study A (organic pattern); Right: The statistical standards (minimum, median, average, and maximum) of the Pedestrian Route Factor (PRF) and the route distance (network distance) of 42 links for case study A.

In sample B, 48 external points (egress/ingress) intersect the frontier of the sample (Figure 7). The route (network) distance responds to the shortest path that links the peripheral point to the center of the sample. From the 48 egress/ingress points, one (RDID08) does not join the center. The highest PRF value is about 1.55 times as long as the radius, as the length of the route is about 620.14 meters (RDID41). The PRF for both the median and average are 1.29 and 1.26, respectively; for the route (network) distance, the PRF is 514.57 and 503.50 meters, correspondingly. The D_{mean} is 514.21 meters (Figure 8). The northeast area of B, like the southwest area of A, has limited egress/ingress points due to the presence of a riverbank. Therefore, there are only three external points for A and B. Of the bordering points in B, two are considerably closer to each other (RDID36 and RDID37).

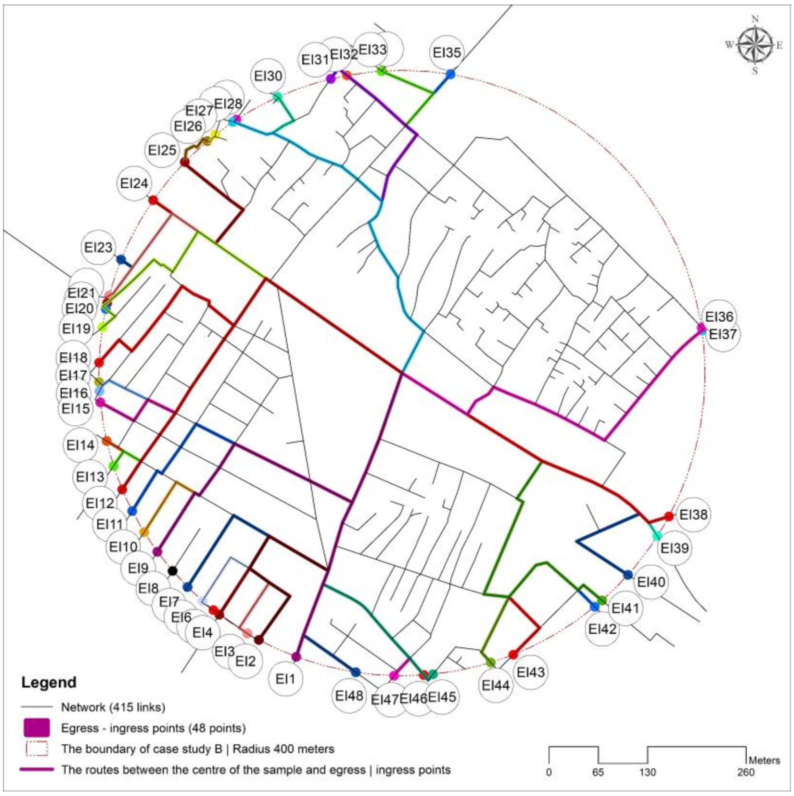

Figure 7. The route of the shortest distance (network distance) between the center of sample B and the peripheral (egress/ingress) points

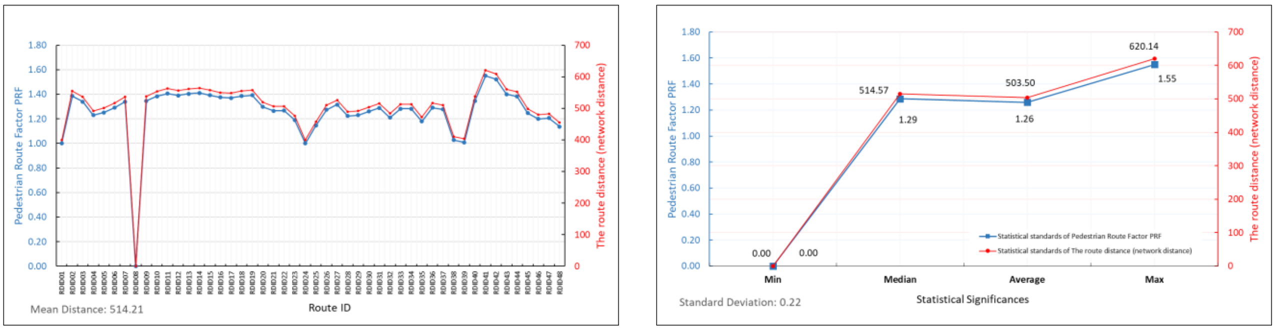

Figure 8. Left: The values of Pedestrian Route Factor (PRF) and the shortest distance for 48 links that reach between the peripheral points and the center of case study B (hybrid pattern). Right: The arithmetical values: minimum, median, average and maximum of the Pedestrian Route Factor (PRF) and the route (network) distance for 48 links for case study B.

It is possible to identify significant differences between the two selected neighborhoods, as each sample expresses a street pattern that reflects a different reading of the Pedestrian Route Directness. The upcoming sections compare the characteristics of the two urban areas, noting where they meet or diverge. Furthermore, this comparison helps to determine the disparity between the organic/spontaneous pattern (sample A) and the other samples that follow a more geometric/pre-planned pattern (sample B).

4.3. Ped-shed (PS)

The Ped-shed, or walkable catchment, measures the extent to which an area is reachable from the center of the selected urban areas through usable streets (routes). The indicator considers the land (plot, parcel) located along the adjacent street within a defined distance. The ped-shed includes developed lands, whereas the streets, parking, large green spaces, and river are excluded. The technique tracks the plots on both sides of a selected street defined by the center of the sample and its boundary. This determines the coverage area for the walking distance (five minutes) from and to the center of a neighborhood. It refers to the percentage of the area reachable from adjacent streets within walking distance. The Ped-shed indicator is formulated as follows by Equations 7 and 8:

$$PS_{built} = \frac{BL_{net}}{BL_{fly}} \tag{7}$$

$$PS_{plot} = \frac{PL_{net}}{PL_{fly}} \tag{8}$$

where PS_{built} is the Ped-shed for a built-up area, BL_{net} is the accessible developed land within a built-up area along the street that connects the center of the sample and a destination (walking or network distance). Meanwhile, BL_{fly} adopts the same technique using a bird's flight (geodetic or Euclidean distance). PS_{plot} is the Ped-shed for the plot area; PL_{net} denote the reachable developed plots along the street which link the center of the case study and the destination (walking or network distance); and PL_{fly} is the same method via bird flight (geodetic or Euclidean distance). While BL_{fly} and PL_{fly} represent the radius that equals 400 meters, BL_{net} and PL_{net} denote the routes examined within 400 meters, starting from the center of the sample towards the boundary based on the walking distance. Moudon et al. [66] referred to the effects of neighborhood design on pedestrian movement; their study involved 12 sites within a one-half-mile radius area, which is suitable for pedestrian travel, and covering an area of approximately 500 acres. The main finding is that small blocks with continuous and connected sidewalks play a crucial role in promoting pedestrian travel [71].

Hess [25] used the same technique under the term, "walking shed", to measure the connectivity of streets and pedestrian networks and their role in the activities and quality of life in six different neighborhoods. This measure was applied by Commission (WAPC) [72] Commission (WAPC) [73] to examine liveable neighborhoods and prepare a community design code. Jones [74] explored two neighborhoods (Ballajura and Shenton Park) in Western Australia by applying Ped-shed, while Porta & Renne [75] employed Ped-shed (walkable catchment) to test two urban centers in the Perth metropolitan area. The Ped-shed technique was also applied by Tal and Handy [39] to evaluate the walkability of nine neighborhoods in the city of Davis, California, while Remali [34] adopted the same method to study three different urban areas in the city center of Tripoli, Libya.

4.4. Effective Walking Area (EWA)

The Effective Walking Area (EWA) also considers the number of plots of developed land rather than the area. It is a ratio of the number of parcels (plots) within a (one-quarter mile) walking distance of a known node to the total number of parcels (plots) within a (one-quarter mile) radius of that node. Its values range between 0 and 1, where a higher value implies that more plots are within walking distance of the pre-defined point, indicating a more connected network [31, 39].

$$EWA = \frac{N_{net}}{N_{total}} \tag{9}$$

where EWA is the effective walking area, N_{net} is the number of plots within a given distance (400 meters - walking distance) from a node (center), and N_{total} is the total number of plots within a selected area (400 meters – radius) from the same node (center).

The Effective Walking Area (EWA) was used by Dill [31] to measure network connectivity for bicycling and walking in Portland, Oregon. Also, Tresidder [76] referred to EWA in studying different approaches to calculating connectivity. Tal & Handy [39] identified non-motorized accessibility in their study concerning the connectivity of a pedestrian network. In this research, the pedestrian route is computed by ArcMap 10.2.2 as the shortest distance between the center of the sample and the external nodes alongside the boundary of the case study. These routes are addressed within a 400-meter walking distance (network distance) starting from the center of the case study. All adjacent plots are calculated, and some of the selected streets examined in PS and EWA also connect the center of the sample and the outer area through external nodes (egress/ingress). After mapping the plots within a 400-meter walking distance (network distance) from the center of each single sample, the values of both the Ped-shed and Effective Walking Area are computed. The Ped-shed indicator is calculated according to two methods: the plot area and the built-up area. The Effective Walking Area calculates the ratio of the number of plots covered by a 400-meter walking distance to the number of plots reached within a 400-meter radius. In sample A (Figure 9), the Ped-shed is based on a plot area of 0.66, while for the built-up area, it is about 0.69.

Figure 9. Ped-shed and Effective Walking Area of case study A

Furthermore, the total number of Ped-shed is 1164 from 1753 plots, representing the overall plots for sample A; therefore, the Effective Walking Area ratio is 0.66. The plot number is a significant factor in determining the EWA value; indeed, sample A represents an organic pattern, meaning the plot area is relatively small with an irregular layout. Additionally, the interrelationship between the network and adjacent plots is more coherent, as the street width is narrow and the metric distance between the plot and street is reduced. In sample B, the Ped-shed covers a plot area of about 0.57, while the value for the built-up area is 0.60. The number of plots comprises 1067 from a total of 1976; accordingly, the EWA ratio is 0.54. The plot size in hybrid area B is varied and combines an organic layout with planned plots. The oldest area (northeast) seems isolated, as it is enclosed by the riverbank and the newest street with high-rise buildings. In this regard, the connectivity between this area and the remaining spaces of hybrid area B also seems weak, as only two streets link the main street and the oldest part (as shown in Figure 10).

Figure 10. Ped-shed and Effective Walking Area of case study B

5. Quantifying Urban Walkability | Comparison and Discussion

5.1. Grid Pattern Ratio

The GPR indicator can be a conditioned and relative factor that integrates other physical urban dimensions to improve the level of connectivity, accessibility, and permeability of a street network. Nevertheless, the GPR is a significant measure when testing an area and determining the extent to which it strongly or weakly embraces both griddy streets and block patterns. As Figure 11 (Left) shows, the GPR_{weak} values of the two urban areas dominate, and A_{weak} means that the number of blocks with four-way corners is limited in all areas. Furthermore, GPR_{strong} values are also applied to the two cases, and B has the largest quantity of four-way corners. In some ways, limiting the number of 4-way intersections minimizes the connectivity and permeability of a street and affects accessibility through the network; this concern was noted for sample A.

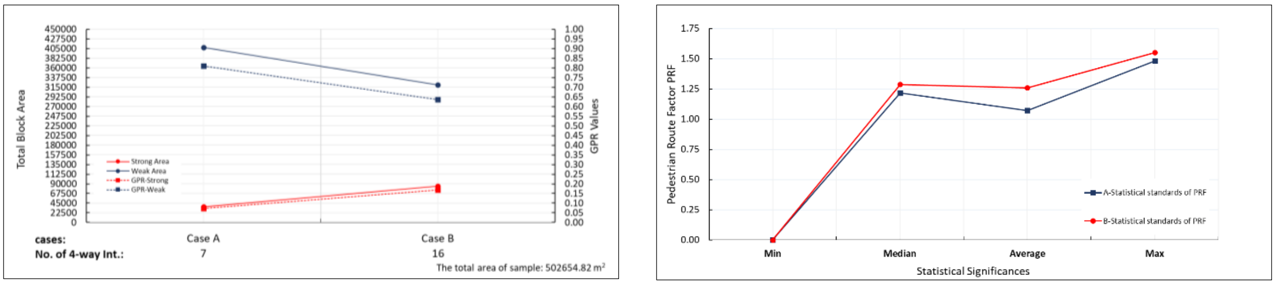

Figure 11. Left: A chart illustrates the values for A_{strong}, A_{weak}, GPR_{strong}, and GPR_{weak} for the two selected samples. Open areas are excluded (riverbank, green spaces, parking, squares, and undeveloped land). Right: The main differences among the four samples A and B regarding the minimum, median, average, and maximum statistical standards.

5.2. Pedestrian Route Factor:

Theoretically, the shortest distance between any external nodes (egress/ingress points) and the center of the sample indicates the radius of the case study, which in this case is equal to 400 meters. The zero values for organic areas in A and B mean that the external point does not reach the center; otherwise, the minimum distance is 400 meters, (see Figure 11, Right).

In comparison, the two selected areas share the same minimum value, which corresponds to the samples' unified radius (400 meters). The median value for sample A is 1.22, and for sample B is 1.29. Sample A has the lowest average at around 1.07, while the average for B is 1.26, (see Figure 12, Left). Amongst the primary statistical standards of the two samples (minimum, median, average, and maximum), A has the lowest values for all PRF ratios. The hybrid area of B tends to move analogically with A (Figure 12, Left). The PRF routes also differ significantly and are calculated from the average value for the PRF when the standard deviation (SD) is applied. Accordingly, the SD trendline starts with organic area A at 0.41 SD and then sharply decreases to 0.22 SD for B (Figure 12, Right)

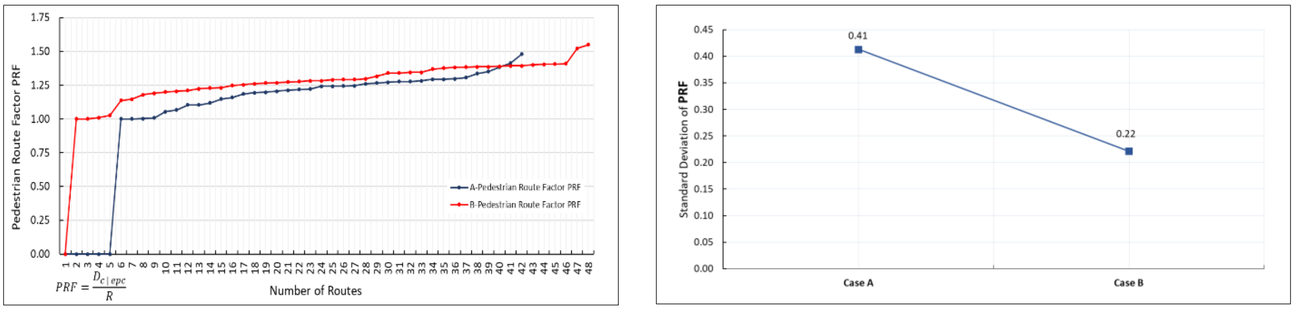

Figure 12. Left: The values of the Pedestrian Route Factor (PRF) for areas A and B. This exhibits a significant disparity among the four cases. Right: The standard deviation of the PRF as a significant value that explains the extent to which the routes' PRF for each sample differ from the average PRF value.

In addition, the organic area of sample A demonstrates less difference between its radius and the D_{mean} at 486.11 meters, as the disparity is only 86.11 meters. Accordingly, the routes in organic area A give a reasonable distance for movement. Also, the selected area in B shows a slight variance between D_{mean} at 514.21 meters and the 400-meter radius at 114.21 meters (Figure 13).

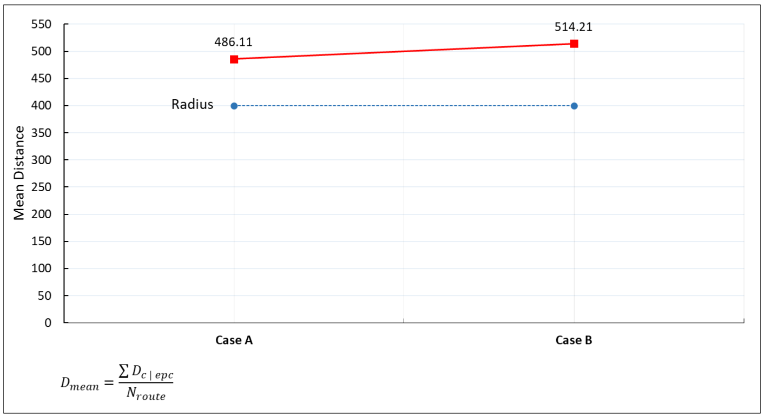

Figure 13. A chart displays the values of the mean distance for the two selected urban areas, besides the difference between these values and the radius

5.3. Ped-shed and Effective Walking Area

The Ped-shed and Effective Walking Area are used to separately calculate each selected sample and determine the results for the PS_{Built}, PS_{Plot} and EWA. Each case has unique values based on the total number of plots, plot areas, and built-up areas. Table 2 displays the plot areas and built-up areas, as well as the Ped-shed area as a plot and built-up area; the ratio between each category reflects this. Table 3 shows the number of plots classified by the total number, Ped-shed, Non-ped-shed, and ratio. The data in Tables 2 and 3 enable a meaningful comparison by capturing the degree of difference across the two selected urban areas within a 400-meter radius. Based on the net plot area (excluding open lands such as parking, riverbank, park, and undeveloped regions), sample A has the largest amount at about 369494.07 m^2, while B's plot area (net) is 353382.56 m^2.

Table 2. The plot areas, built-up area and Ped-shed as a plot and built-up area are followed by the ratio between each category

Case study ID	Total plot area	Total built-up area	Total open area	Net plot area	Total ped-shed plot area	Total ped-shed built-up area	Ped-shed to the net plot area of sample (plot area)
Case A	391615.93	392881.60	22121.59	369494.35	245681.02	227069.17	0.66
Case B	371732.40	263779.19	18549.85	353382.56	200673.00	159000.13	0.57

Table 3. The number of plots which are classified by the total number, Ped-shed, Non-ped-shed, and ratio

Case study ID	Total number of plots	Total number of plots (ped-shed)	Total number of plots (non ped-shed)	Ratio ped-shed number to total number
Case A	1753	1154	589	0.66
Case B	1976	1067	909	0.54

There is a slight disparity between the net plot areas of the samples. The result differs when considering the Ped-shed indicator across the cases. The trendline, in this regard, starts with the highest area in sample A at about 245681.02 m^2, while sample B has 200672.00 m^2. The PS_{Plot} value is highest in organic area A at 0.66, whereas for sample B, it is calculated at 0.57 (Figure 13, Left). A comparison between the built-up area for both plots and Ped-shed plots exhibits a significant disparity among the selected samples. The total built-up area of the plots in organic area A is about 327532.21 m^2, as most are entirely covered and the metric depth (setback) is relatively limited. Furthermore, the plot size is small, which allows for a greater number of plots within a particular area (Figure 14, Right). Indeed, the metric depth of most plots distinguishes the region. Similar to sample A, sample B consists of small plots, whether in its oldest or more modern parts. Also, the metric depth value is zero for many plots; thus, the total built-up area is 263230.47 m^2, representing the second-largest amount (Figure 14, Right).

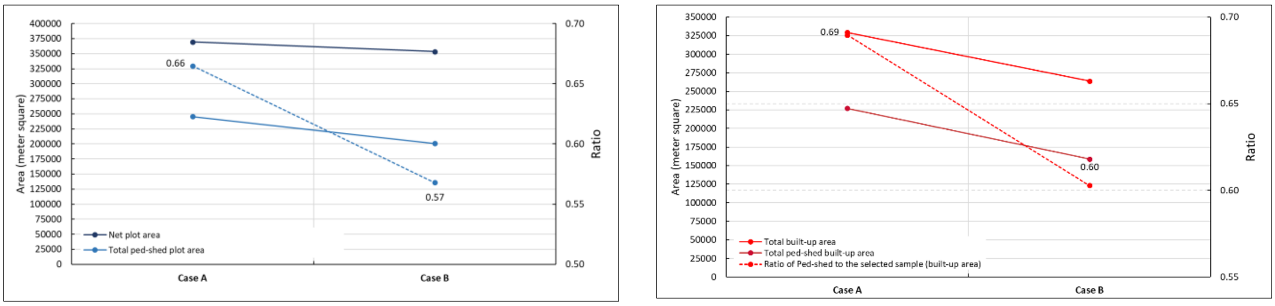

Figure 14. Left: Significant values for the net plot areas, the Ped-shed plot areas, and the ratio between them. Right: Significant values for the net plot built-up areas, the Ped-shed built-up areas, and the ratio between them for the four selected samples in A and B.

In terms of the Ped-shed built-up area, the trendline across the two samples shows a more significant amount for organic area A, with a built-up area of about 226211.77m^2, while sample B's built-up area is lower at 159000.13 m^2. The ratio of the Ped-shed to the selected sample (built-up area) illustrates a disparity among the two cases. The ratio for sample A is close to 0.69, while for sample B it is 0.60. There is a significant difference between the number of plots per sample for the Ped-shed and the total number of plots. The EWA value fluctuates across the samples, as A is the second highest at 0.66, while B has 0.54. The total number of plots and Ped-shed plots also vary between the two samples; sample B has a higher number of plots, at 1976, compared to its Ped-shed at 1067. In comparison, A has 1753 plots and 1164 Ped-shed plots (Figure 15, Left). From the comparisons between the built-up area, plot area and total number of Ped-shed plots, sample A exhibits a higher number of attainable plots when tracking the routes that start from the center to the 400-meter walking distance boundary. Although sample A has different street and plot patterns, the former represents a more organic pattern with substantial diversity in plot size. At the same time, the latter includes a more regular plot pattern and unified plot size (Figure 15, Right). In sample B, the reachable (built-up) plots decrease compared with A, while a comparison of three values - PS_{Built}, PS_{Plot} and EWA - reveals a slight difference between these indicators.

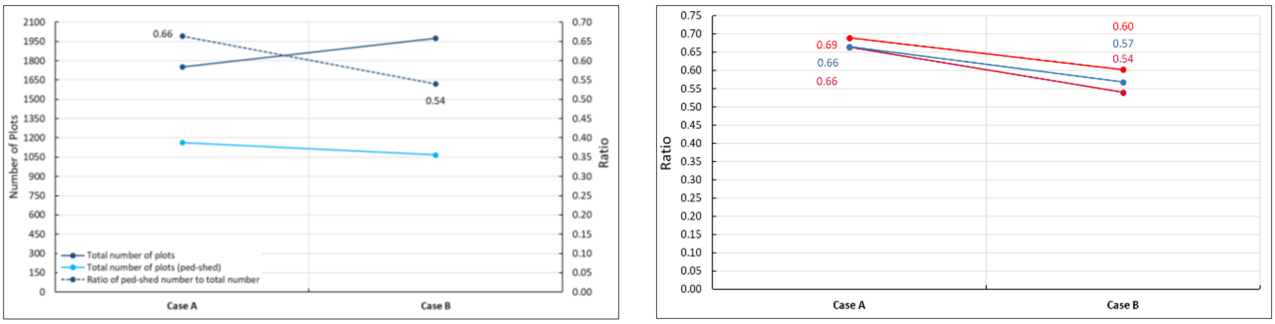

Figure 15. Left: The total number of plots and Ped-shed plots for the four selected urban areas in A and B, and the ratios between them. Right: The value of PS_{built}, PS_{Plot} and EWA for the two selected samples. The result shows a significant difference among these cases.

When comparing these findings with existing research, other studies noted a greater focus on traffic stream, safety, and the behavioral patterns of pedestrians [77]. In contrast, this research focused on the fine characteristics of the street pattern and its parameters and considered how these could differ between the historic street patterns and hybrid street systems of the selected neighborhoods. Furthermore, most of the previous studies considered local and global street patterns [78], while this study addressed the characteristics of street networks on both micro and macro scales.

5.4. Recommendations for the Field of Urban Design and Planning

Based on the results derived from this paper, which studied and developed an understanding of street network characteristics in urban design, the following recommendations can be made:

- The creation of pedestrian-friendly environments that encourage walking and highlight the needs of pedestrians should be prioritized. This includes creating more direct and convenient pedestrian routes, adopting regular block sizes, and ensuring the presence of sidewalks, crosswalks, and other pedestrian infrastructure.
- More urban areas should be created that facilitate movement and connectivity within the city. This could be achieved by creating intersecting streets, reducing block sizes, and increasing the number of public spaces and amenities that are easily accessible by foot.
- The needs of all residents should be considered, including people with disabilities and those who may have difficulty navigating the city. This means designing more direct and accessible pedestrian routes, providing ample public transportation, and creating accessible public spaces and amenities.
- Data-driven approaches should be used to inform decision-making processes, including data on pedestrian traffic patterns, public transportation use, and the effectiveness of different pedestrian infrastructure elements. These could then be used to inform design decisions that prioritize the needs of residents and visitors.
- Active transportation should be encouraged, such as walking and cycling, to reduce traffic congestion and promote healthy lifestyles. This could be achieved by creating more pedestrian- and bike-friendly infrastructures, providing bike-sharing programs, and promoting the use of public transportation.

6. Conclusion

This paper analyzes the relationship between urban form and street parameters, which is a critical area of research in urban planning and design. By studying two distinct neighborhoods and various street patterns, the paper provides valuable insights into how different urban forms affect street parameters. The historic organic pattern observed in area A is noteworthy, as this pattern is influenced by the community's implied and inherent order, reflecting a bottom-up approach to urban planning. As a result, the streets in sample A exhibit a high degree of variety in terms of shape and length. This variation is important as it can impact the three selected street parameters: GPR, PRD/PRF, PS, and EWA. Thus, sample A demonstrated more exceptional results among its selected street parameters, which highlights the potential benefits of a more bottom-up approach to urban design and planning. By incorporating community input and allowing for more spontaneous street patterns, urban planners and designers can create more diverse and adaptable urban environments that better meet the needs of residents.

The study found that neighborhoods with spontaneous or hybrid patterns, such as areas A and B, had greater diversity in their street networks; the level of network variety in organic area A and hybrid area B was found to be similar, indicating their potential positive impact on street parameters. The orderliness of the plot and neighboring streets emerged as a significant factor affecting other urban form ingredients, such as block size and street length. This relationship highlights the importance of balancing order and diversity in urban design to achieve a sustainable, resilient, and livable urban form. The study also found that areas A and B reflected the influence of a top-down approach on street layout.

Examining the relationship between street structure components, links (streets) and nodes (intersections) in two urban areas in Baghdad using three variables (GPR, PRD/PRF, and PS-EWA), has highlighted the importance of street connectivity, accessibility, and permeability for urban planning and design. It was noted that the GPR indicator, a conditioned and comparative parameter, could be usefully integrated with other urban indicators to improve street network connectivity, accessibility, and permeability. The PRD/PRF indicator was significant in comparing the historic organic pattern in A to other areas, such as the hybrid area in B. Increasing the quantity of the shortest trajectories between peripheral points and the center of the selected sample indicated greater connectivity and accessibility for a community. Thus, the study's findings offer insights for the design of resilient, livable, and sustainable urban environments.

To further examine the street network, two additional parameters - Ped-shed and Effective Walking Area (EWA) - were analyzed for each of the two urban areas. The Ped-shed indicator (plot or built-up) was found to have a significant impact on the overall urban form. Street patterns and plot characteristics play a vital role in shaping the urban context, which can affect the level of connectivity, accessibility, and permeability between points. These factors are critical in urban design and planning and can have a significant impact on urban dwellers' quality of life. The study also suggests that future research could explore other street network parameters and examine their relationship in terms of pedestrian movement, urban activities, social interactions, and the characteristics of the street edge at the micro-scale of the neighborhood. Such analysis could help urban planners and designers create more livable and sustainable urban environments.

Further research could be undertaken in similar urban areas to verify this study's results and further develop the methods and techniques employed. By replicating the study in different urban contexts, it is possible to test the generalizability of the findings and identify any contextual factors that may impact the results. The study recommends that urban designers prioritize the creation of pedestrian-friendly environments, enable more connected urban areas, consider the needs of all residents, use data-driven approaches to inform their decision-making process, and encourage active transportation to promote healthy lifestyles and reduce traffic congestion.

6.1. Research Limitations

This study is limited in the following areas:

- Using the selected parameters to evaluate street patterns may not be applicable or relevant to all urban contexts.
- While the arithmetic methods used in conjunction with GIS can provide quantitative data, they may not fully capture the qualitative aspects of accessibility, walkability, and safety, which can be more difficult to measure.
- The evaluation process may overlook other important factors that can impact the efficiency of street patterns, such as cultural norms, social behaviors, and environmental conditions.
- Other parameters that could be used to study street networks and thus influence the findings include connectivity and centrality measures, such as the degree of intersection, betweenness centrality, and closeness centrality. Block size and shape, land uses, and building types can also impact the walkability, access, and visual coherence of streets.
- The research's findings may not be generalizable to other cities or regions with different urban contexts, as the study focused solely on the City of Baghdad, Iraq.

7. Declarations

7.1. Author Contributions

Conceptualization, H.A.; methodology, H.A.; software, H.A.; validation, H.A., D.A., and S.A.; formal analysis, H.A.; investigation, H.A.; resources, H.S., D.A., and S.A.; data curation, H.A.; writing—original draft preparation, H.A.; writing—review and editing, H.A., D.A., and S.A.; visualization, H.A.; supervision, H.A.; project administration, H.A.; funding acquisition, H.A., D.A., and S.A. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] Moudon, A. V. (1997). Urban morphology as an emerging interdisciplinary field. Urban Morphology, 1(1), 3–10. doi:10.51347/jum.v1i1.4047.

[2] Moughtin, C. (2007). Urban Design: Street and Square. Routledge, Milton Park, United Kingdom doi:10.4324/9780080520278.

[3] Marshall, S. (2004). Streets and Patterns. Routledge, Milton Park, United Kingdom doi:10.4324/9780203589397.

[4] Pan, W., & Du, J. (2021). Towards sustainable urban transition: A critical review of strategies and policies of urban village renewal in Shenzhen, China. Land Use Policy, 111, 105744. doi:10.1016/j.landusepol.2021.105744.

[5] Al-Saaidy, H. J. E. (2024). A dramatic morphological transformation from a spontaneous, organic street pattern to pre-planned-based order: learning from Baghdad city. Urban, Planning and Transport Research, 12(1), 2287569. doi:10.1080/21650020.2023.2287569.

[6] Al-Saaidy, H. J. E. (2025). Issues and Morphological Dialectics of Baghdad City: Toward an Intellectual Framework for a Research Map Design. Journal of Urban Planning and Development, 151(1). doi:10.1061/jupddm.upeng-5242.

[7] Alobaydi, D., & Rashid, M. (2024). Morphological Evolution of Baghdad: Analyzing Urban Growth Patterns and Transformation Processes. Journal of Engineering, 30(12), 16–32. doi:10.31026/j.eng.2024.12.02.

[8] Mohammed, L. R., & Alobaydi, D. (2020). Evolution of the Urban Form of Historic Hit Citadel: Deriving a Schematic Model for Iraqi Fortified Cities. IOP Conference Series: Materials Science and Engineering, 745(1), 012180. doi:10.1088/1757-899x/745/1/012180.

[9] Mohammed, L. R., & Alobaydi, D. (2020). Studying Sustainable Actions of Syntactic Structures of Historic Hit Citadel: A Morphological Approach. IOP Conference Series: Materials Science and Engineering, 881(1). doi:10.1088/1757-899X/881/1/012034.

[10] Al-Saaidy, H. J. E. (2020). Urban Form Elements and Urban Potentiality (Literature Review). Journal of Engineering, 26(9), 65–82. doi:10.31026/j.eng.2020.09.05.

[11] Al-Saaidy, H. J. E. (2020). Urban Morphological Studies (Concepts, Techniques, and Methods). Journal of Engineering, 26(8), 100–111. doi:10.31026/j.eng.2020.08.08.

[12] Farhan, S. L., Alobaydi, D., Anton, D., & Nasar, Z. (2022). Analysing the master plan development and urban heritage of Najaf City in Iraq. Journal of Cultural Heritage Management and Sustainable Development. doi:10.1108/JCHMSD-07-2020-0101.

[13] Yang, J., Li, X., Du, J., & Cheng, C. (2023). Exploring the Relationship between Urban Street Spatial Patterns and Street Vitality: A Case Study of Guiyang, China. International Journal of Environmental Research and Public Health, 20(2), 1646. doi:10.3390/ijerph20021646.

[14] Lv, W., Wang, N., & Huang, Y. (2023). Study on the sustainability of ancient canal towns on the basis of the topological structure analysis of streets and lanes: A case study of the Xixing ancient town. PLOS ONE, 18(1), e0279979. doi:10.1371/journal.pone.0279979.

[15] Hillier, B. (1996). Cities as movement economies. Urban Design International, 1(1), 41–60. doi:10.1057/udi.1996.5.

[16] Hillier, B. (2007). Space is the machine: a configurational theory of architecture. Space Syntax, London, United Kingdom.

[17] Ozbil, A., Peponis, J., & Stone, B. (2011). Understanding the link between street connectivity, land use and pedestrian flows. Urban Design International, 16(2), 125–141. doi:10.1057/udi.2011.2.

[18] Hajrasouliha, A., & Yin, L. (2015). The impact of street network connectivity on pedestrian volume. Urban Studies, 52(13), 2483–2497. doi:10.1177/0042098014544763.

[19] Trichês Lucchesi, S., Larranaga, A. M., Bettella Cybis, H. B., Abreu e Silva, J. A. de, & Arellana, J. A. (2021). Are people willing to pay more to live in a walking environment? A multigroup analysis of the impact of walkability on real estate values and their moderation effects in two Global South cities. Research in Transportation Economics, 86, 100976. doi:10.1016/j.retrec.2020.100976.

[20] Yang, S., Chen, X., Wang, L., Wu, T., Fei, T., Xiao, Q., Zhang, G., Ning, Y., & Jia, P. (2021). Walkability indices and childhood obesity: A review of epidemiologic evidence. Obesity Reviews, 22(S1), 13096. doi:10.1111/obr.13096.

[21] Al Hashimi, H., & Alobaydi, D. (2023). Measuring spatial properties of historic urban networks. AIP Conference Proceedings, 2651. doi:10.1063/5.0117077.

[22] Albabely, S., & Alobaydi, D. (2023). Impact of Urban Form on Movement Densities: The Case of Street Networks in AlKarkh, Baghdad, Iraq. ISVS E-Journal, 10(7), 147-163.

[23] Chan, E. T. H., Schwanen, T., & Banister, D. (2021). Towards a multiple-scenario approach for walkability assessment: An empirical application in Shenzhen, China. Sustainable Cities and Society, 71, 102949. doi:10.1016/j.scs.2021.102949.

[24] Krüger, M. J. T. (1980). An approach to built-form connectivity at an urban scale: relationships between built-form connectivity, adjacency measures, and urban spatial structure. Environment and Planning B: Planning and Design, 7(2), 163–194. doi:10.1068/b070163.

[25] Hess, P. M. (1997). Measures of connectivity (Streets: Old Paradigm, New Investment). Places, 11(2), 1-9.

[26] Randall, T. A., & Baetz, B. W. (2001). Evaluating Pedestrian Connectivity for Suburban Sustainability. Journal of Urban Planning and Development, 127(1), 1–15. doi:10.1061/(asce)0733-9488(2001)127:1(1).

[27] Zlatkovic, M., Zlatkovic, S., Sullivan, T., Bjornstad, J., & Kiavash Fayyaz Shahandashti, S. (2019). Assessment of effects of street connectivity on traffic performance and sustainability within communities and neighborhoods through traffic simulation. Sustainable Cities and Society, 46, 101409. doi:10.1016/j.scs.2018.12.037.

[28] Al-Saaidy, H. J. E., & Alobaydi, D. (2021). Studying street centrality and human density in different urban forms in Baghdad, Iraq. Ain Shams Engineering Journal, 12(1), 1111–1121. doi:10.1016/j.asej.2020.06.008.

[29] Cervero, R., & Radisch, C. (1996). Travel choices in pedestrian versus automobile oriented neighborhoods. Transport Policy, 3(3), 127–141. doi:10.1016/0967-070X(96)00016-9.

[30] Reilly, M., & Landis, J. (2003). The influence of built-form and land use on mode choice. University of California Transportation Center, Berkeley, United States.

[31] Dill, J. (2004). Measuring network connectivity for bicycling and walking. 83rd annual meeting of the Transportation Research Board, 11-15 January, 2004, Washington, United States.

[32] Kim, J. (2007). Testing the street connectivity of new urbanism projects and their surroundings in Metro Atlanta Region. Proceedings, 6th International Space Syntax Symposium, 12-15 June, 2007, İstanbul, Turkey.

[33] Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: A new system of cross-scale spatial indicators. Building Research & Information, 40(5), 592–605. doi:10.1080/09613218.2012.703488.

[34] Remali, A. M. (2014). Capturing the essence of the capital city: Urban form and urban life in the city center of Tripoli, Libya. Ph.D. Thesis, University of Strathclyde, Glasgow, United Kingdom.

[35] Al-Saaidy, H. J. E. (2019). Measuring urban form and urban life four case studies in Baghdad, Iraq. Ph.D. Thesis, University of Strathclyde, Glasgow, Scotland.

[36] Handy, S. L. (1997). Urban form and pedestrian choices: Study of Austin neighborhoods. Transportation Research Record, 1996(1552), 135–144. doi:10.1177/0361198196155200119.

[37] Crane, R., & Crepeau, R. (1998). Does neighborhood design influence travel?: A behavioral analysis of travel diary and GIS data. Transportation Research Part D: Transport and Environment, 3(4), 225–238. doi:10.1016/S1361-9209(98)00001-7.

[38] Matley, T. M., Goldman, L. M., & Fineman, B. J. (2000). Pedestrian travel potential in Northern New Jersey: A metropolitan planning organization's approach to identifying investment priorities. Transportation Research Record, 2000(1705), 1–8. doi:10.3141/1705-01.

[39] Tal, G., & Handy, S. (2012). Measuring nonmotorized accessibility and connectivity in a robust pedestrian network. Transportation Research Record, 2012(2299), 48–56. doi:10.3141/2299-06.

[40] Dalvi, M. Q. (2021). Behavioural Modelling, Accessibility, Mobility and Need. Behavioural Travel Modelling, Routledge, Milton Park, United Kingdom. doi:10.4324/9781003156055-38.

[41] Ben-Akiva, M., & Lerman, S. R. (2021). Disaggregate Travel and Mobility-Choice Models and Measures of Accessibility. Behavioural Travel Modelling, Milton Park, United Kingdom. doi:10.4324/9781003156055-39.

[42] Alawadi, K., Hong Nguyen, N., Alrubaei, E., & Scoppa, M. (2021). Streets, density, and the superblock: neighborhood planning units and street connectivity in Abu Dhabi. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 16(2), 168–195. doi:10.1080/17549175.2021.1944281.

[43] Wang, F., Antipova, A., & Porta, S. (2011). Street centrality and land use intensity in Baton Rouge, Louisiana. Journal of Transport Geography, 19(2), 285–293. doi:10.1016/j.jtrangeo.2010.01.004.

[44] Porta, S., Strano, E., Iacoviello, V., Messora, R., Latora, V., Cardillo, A., Wang, F., & Scellato, S. (2009). Street centrality and densities of retail and services in Bologna, Italy. Environment and Planning B: Planning and Design, 36(3), 450–465. doi:10.1068/b34098.

[45] J.E. Al-Saaidy, H. (2020). Lessons from Baghdad City Conformation and Essence. Sustainability in Urban Planning and Design, IntechOpen Limited, London, United Kingdom. doi:10.5772/intechopen.88599.

[46] Thwaites, K., Mathers, A., & Simkins, I. (2013). Socially Restorative Urbanism. Routledge, London, United Kingdom. doi:10.4324/9780203467497.

[47] Carmona, M. (2021). Public Places Urban Spaces. Routledge, London, United Kingdom. doi:10.4324/9781315158457.

[48] Khder, H. M., Mousavi, S. M., & Khan, T. H. (2016). Impact of Street's Physical Elements on Walkability: A Case of Mawlawi Street in Sulaymaniyah, Iraq. International Journal of Built Environment and Sustainability, 3(1), 18–26. doi:10.11113/ijbes.v3.n1.106.

[49] Massingue, S. A., & Oviedo, D. (2021). Walkability and the Right to the city: A snapshot critique of pedestrian space in Maputo, Mozambique. Research in Transportation Economics, 86, 101049. doi:10.1016/j.retrec.2021.101049.

[50] Shields, R., Gomes da Silva, E. J., Lima e Lima, T., & Osorio, N. (2021). Walkability: a review of trends. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 16(1), 19–41. doi:10.1080/17549175.2021.1936601.

[51] Al-Hasani, M. K. (2012). Urban space transformation in old city of Baghdad–integration and management. Megaron, 7, 79.

[52] Alobaydi, D., & Rashid, M. (2017). A Study of the Morphological Evolution of the Urban Cores of Baghdad in the 19th and 20th Century. 11th international space syntax symposium at Instituto superior Técnico, University of Lisbon, Lisbon, Portugal.

[53] Alsaffar, N. H., & Alobaydi, D. (2023). Studying street configurations and land-uses in the downtown of Baghdad. 8th Engineering and 2nd International Conference for College ff Engineering – University ff Baghdad: COEC8-2021 Proceedings. doi:10.1063/5.0105420.

[54] Rashid, M., & Alobaydi, D. (2015). Territory, politics of power, and physical spatial networks: The case of Baghdad, Iraq. Habitat International, 50, 180–194. doi:10.1016/j.habitatint.2015.08.031.

[55] Sommer, B. B., & Sommer, R. (1997). A practical guide to behavioral research: Tools and techniques. Oxford University Press, Oxford, United Kingdom.

[56] Yin, R. (2014). Case Study Research: Design and Methods (5th ed.). Sage Publications, Thousand Oaks, United States.

[57] Aultman-Hall, L., Roorda, M., & Baetz, B. W. (1997). Using GIS for Evaluation of Neighborhood Pedestrian Accessibility. Journal of Urban Planning and Development, 123(1), 10–17. doi:10.1061/(asce)0733-9488(1997)123:1(10).

[58] Mehaffy, M., Porta, S., Rofè, Y., & Salingaros, N. (2010). Urban nuclei and the geometry of streets: The "emergent neighborhoods" model. Urban Design International, 15(1), 22–46. doi:10.1057/udi.2009.26.

[59] Rogers, A., & Vertovec, S. (Eds.). (2020). The urban context: ethnicity, social networks and situational analysis. Routledge, London, United Kingdom. doi:10.4324/9781003134930.

[60] G.I.S. Department (2016). The traditional area of Baghdad based on Polservice, Geokart, Poland, rectified by Department Of GIS, in Department of Geographic Information System GIS, Mayoralty of Baghdad. University of Technology, Baghdad, Iraq.

[61] R.S.GIS.U. (2017). The Georeferencing Aerial Imagery. The Official Letter, No.: 1578, Date: 01/11/2017: Remote Sensing and GIS Unit, Building and Construction Engineering Department, University of Technology, Baghdad. Iraq.

[62] Boarnet, M., & Crane, R. (2001). The influence of land use on travel behavior: Specification and estimation strategies. Transportation Research Part A: Policy and Practice, 35(9), 823–845. doi:10.1016/S0965-8564(00)00019-7.

[63] Greenwald, M. J., & Boarnet, M. G. (2001). Built environment as determinant of walking behavior: Analyzing nonwork pedestrian travel in Portland, Oregon. Transportation Research Record, 2001(1780), 33–42. doi:10.3141/1780-05.

[64] Porta, S., & Romice, O. (2010). Analysis brief: Comparative analysis of urban Fabrics. MSc. Thesis, Strathclyde University, Glasgow, Scotland.

[65] Sun, G., Lin, H., & Li, R. (2012). Measuring the Influence of Built Environment on Walking Behavior: An Accessibility Approach. Geographic Information Science, 187–197. doi:10.1007/978-3-642-33024-7_14.

[66] Moudon, A. V., Hess, P. M., Snyder, M. C., & Stanilov, K. (1997). Effects of Site Design on Pedestrian Travel in Mixed-Use, Medium-Density Environments. Transportation Research Record: Journal of the Transportation Research Board, 1578(1), 48–55. doi:10.3141/1578-07.

[67] Crane, R. (1996). On form versus function: Will the new urbanism reduce traffic, or increase it? Journal of Planning Education and Research, 15(2), 117–126. doi:10.1177/0739456X9601500204.

[68] Ballou, R. H., Rahardja, H., & Sakai, N. (2002). Selected country circuity factors for road travel distance estimation. Transportation Research Part A: Policy and Practice, 36(9), 843–848. doi:10.1016/S0965-8564(01)00044-1.

[69] Levinson, D., & El-Geneidy, A. (2009). The minimum circuity frontier and the journey to work. Regional Science and Urban Economics, 39(6), 732–738. doi:10.1016/j.regsciurbeco.2009.07.003.

[70] Huang, J., & Levinson, D. M. (2015). Circuity in urban transit networks. Journal of Transport Geography, 48, 145–153. doi:10.1016/j.jtrangeo.2015.09.004.

[71] Hess, P. M., Moudon, A. V., Snyder, M. C., & Stanilov, K. (1999). Site design and pedestrian travel. Transportation Research Record, 1999(1674), 9–19. doi:10.3141/1674-02.

[72] WAPC. (2000). Liveable Neighbourhoods: Street Layout, Design and Traffic Management guidelines. Western Australian Planning Commission, Perth, Australia.

[73] WAPC. (2009). Liveable neighbourhoods: a Western Australian government sustainable cities initiative. Western Australian Planning Commission, Perth, Australia.

[74] Jones, E. J. (2001). Liveable Neighbourhoods. World Transport Policy & Practice, 7(2), 38-43.

[75] Porta, S., & Renne, J. L. (2005). Linking urban design to sustainability: Formal indicators of social urban sustainability field research in Perth, Western Australia. Urban Design International, 10(1), 51–64. doi:10.1057/palgrave.udi.9000136.

[76] Tresidder, M. (2005). Using GIS to measure connectivity: An exploration of issues. Ph.D. Thesis, Portland State University, Portland, United States.

[77] Lee, S., & Lee, M. H. (2021). Impact of neighborhood environment on pedestrian route selection among elementary schoolchildren in Korea. International Journal of Environmental Research and Public Health, 18(13), 7049. doi:10.3390/ijerph18137049.

[78] Costa, M., Marques, M., & Moura, F. (2021). A circuity temporal analysis of urban street networks using open data: A Lisbon case study. ISPRS International Journal of Geo-Information, 10(7), 453. doi:10.3390/ijgi10070453.