Patterns of streets connection for sustainable urban development in Kota Bharu, Kelantan, Malaysia

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Abstract. Street network attributes, including street connectivity, street integration, and pedestrian accessibility, are closely interrelated concepts that play an important role in achieving the sustainable approach challenges facing all large cities throughout the world. However, the lack of awareness of sustainable development in both the city center and villages in the suburban area results in a low value of street connectivity, less direct route to the destination, and discouraging pedestrians from moving. This research aims to examine street connectivity and street integration patterns that form from street connections at existing streets in Kota Bharu Kelantan. DepthmapX software was used to analyze street connectivity and integrations to identify and compare the existing street influencing people to move from one destination to another in Kota Bharu, Kelantan. The streets in the Kota Bharu, Kelantan city center area are chosen as the study site to investigate the street connectivity and integration values. Data analysis using DepthmapX software was performed after digitizing the map in AutoCAD software. Findings show that street connectivity and integration are of higher value when the streets are well connected to other streets in the main area and attraction area. The conclusions of this paper can help landscape architects and urban planners optimize the achievement of well-connected street networks that produce directness routes in short-distance destinations to develop a sustainable urban environment.

1 Introduction

The linked street network forms to connect people from one destination to another destination. The well-connected street encourages people to move, making the area physically active and liven up the surrounding. Street connectivity is the connection between streets in a town. The higher connectivity formed when more streets are connected leads to the more places linked to each other. Besides, previous studies defined street connectivity as the number of nodes that are connected to other nodes in which a node represents a space or an intersection [1-2]. In comparison, Zlatkovic et al. (2019) defined street connectivity as a

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measure of the density of network connections and the directness of paths [3]. Other studies highlight street connectivity as an element of walkability associated with urban configuration [4].

A study in transport policy exposed that street connectivity influenced decisions to walk for short trips to reach a destination [5]. In addition, urban and planning studies stated that network links or connections and the shortest path led to the increasing number of metro users and the number of people traveling [6]. But, accident analysis and prevention studies concerning safety factors found that street integration can be defined as the relationship between a street and another street, a connection that encourages and influences people to move. In other words, walking decisions were influenced by built environment designs that accommodated comfort, pleasure, socialization, and more-than-human encounters, which can be achieved through well-connected streets [10]. A study in health and place mentions that street integration influences walking and promotes physical activities sufficient for health benefits, and high street integration can increase accessibility from other streets [11]. Their study was extended and found that street connectivity was associated with travel behavior which exposed people to more connected street layouts and encouraged walking [12].

However, many studies on street connection have investigated the association of street network connectivity with walkability in the built environment. Further studies are required to provide an in-depth understanding to produce sustainable and better accessibility street connections for achieving the community's needs. Therefore, this paper investigates and compares the street connection pattern in the city center that forms within different surrounding environments and development that affect people moving. This study is extended by discussing the issue of street connection in the built environment field, including the environmental sustainability disciplines.

2 Introduction

2.1 Site Description

The study site is located in Kota Bharu, Kelantan, Malaysia, which serves as the state capital of Kelantan. This area was selected according to its relatively high traffic volume and built environment factors as a focal point in the city center. Besides, Kota Bharu is one of the cultural towns in Malaysia [13]. Therefore, this study used the street network of Kota Bharu Town to examine the influence of street connectivity and street integration pattern in a cultural town.

2.2 Data Preparation

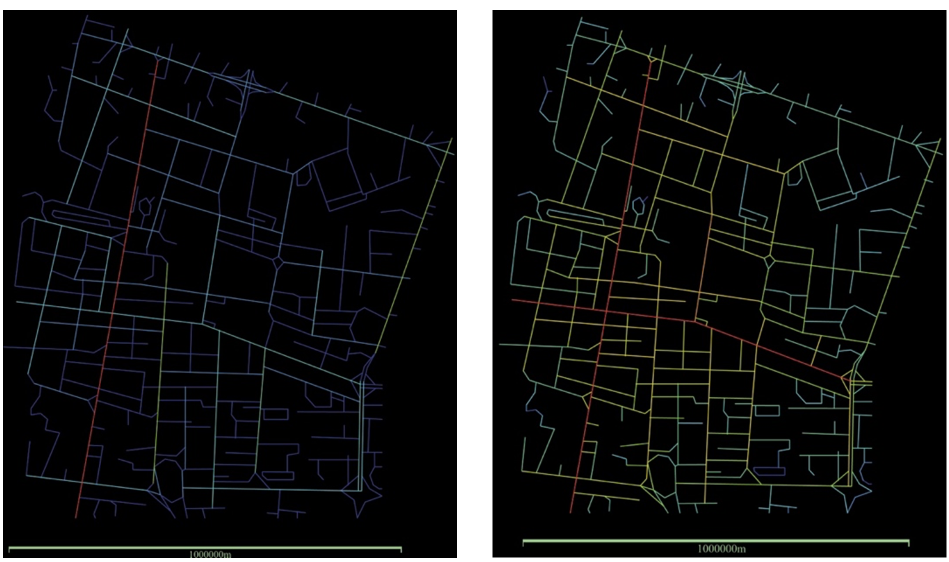
The Map of Kota Baharu Town was digitized using AutoCAD software. The map was analyzed using DepthmapX software. Two indicators were analyzed, which are street connectivity and street integration. Street connectivity data was used to examine the connection between streets in a town where the higher value of connectivity means more streets connected and linked to each other. Street integration data was used to examine the relationship between a street and another street in the form of a connection that encourages and influences people to move. However, this study focuses on the physical environmental factors that could influence pedestrian movement in an urban environment. Thus, this study excluded other two space syntax principles such as spatial visualization and interaction as discussed in space syntax theory.

2.3 Street Connectivity and Street Integration Analysis

The street connectivity and integration indicators were developed using DepthmapX software. According to space syntax theory employed in DepthmapX software, an axial-line represents the movement of pedestrian in a street. Hence, the intersection of the axial-lines represents the connection and determines the number of connectivity. Meanwhile, the calculation of street integration developed by Hillier and Hanson to determines the inferences factor (value) to defines the influence of the street which also indicates by high and low value at the similar axial-lines [2]. This study employed a color differentiation approach to determine the value of street connectivity and integration. Results from the analysis showed color differences from the highest value (red) to the lowest value (indigo) of connectivity and integration. This study identified four connectivity patterns based on the color formed from the analysis data from DepthmapX software.

3 Results and Discussion

The street network of Kota Bharu Town was analyzed according to two indicators which are (i) street connectivity and (ii) street integration. Results show a higher value for street connectivity, especially on the main street in commercial areas of the city center (See Figure 1). While a higher value of street integration is found in the zones surrounding the city center. The streets with the highest values for both indicators are shown in red color as in Figure 1.



(a) Street Connectivity (b) Street Integration

Fig. 1. The results of the street network of Kota Bharu Town.

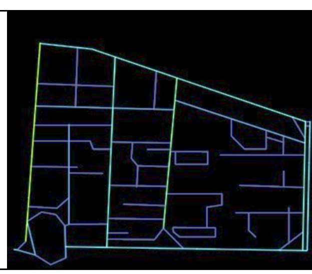
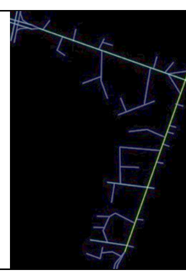
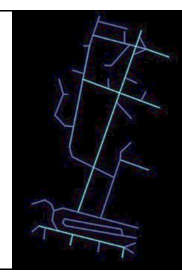
The patterns identified on the map are that the highest-value streets are located in the city center area and serve as the main street that link to other streets and connected to multiple destinations.

3.1 Street Connectivity Patterns

This study identified four patterns of street connectivity form based on the color pattern from the result of DepthmapX analysis. The patterns are (i) linear, (ii) parallel line, (iii) perpendicular branching, and (iv) duo branching. Table 1 summarises street connectivity patterns that were identified from the analysis. The street connectivity values are varied according to color differences that overlap as shown by the red color representing the highest connectivity value and the indigo color representing the lowest connectivity value.

The first pattern identified in this study is linear. The linear pattern is shown by one linear red line on the street connectivity map, representing the highest connectivity value, 32, while the lowest value is 1. Thus, the pattern indicates that the network has the highest value of the street in influencing pedestrians to move to other streets that are connected in one long street. Next the second pattern is the parallel line pattern. The parallel line pattern shows four straight lines in parallel positions connected by other streets. The four lines in parallel position represent the four high values in this pattern, with yellow as 18 connections and followed by blue with 14, 13, and 10 street connections, while the lowest value is 1. Then, the third pattern identified from the street connectivity analysis is perpendicular branching. This pattern shows that the two high values of street connectivity, respectively in yellow and blue, are perpendicularly connected with 17 and 13 connections while connected with other streets with lower values with one connection. Lastly, the pattern of duo branching indicates the two high connectivity forms separately shown by blue color and connected with the lower streets with indigo color. The highest value of street connectivity in this pattern indicates 10 connections while the lowest value with 1 connection. Four patterns formed for duo branching in Kota Bharu Town compare to others with one formation only for each pattern identified in the street network.

Table 1. The summary of patterns of street connectivity.

Type of Street Connectivity Patterns	Linear	Parallel line	Perpendicular Branching	Duo Branching
Connectivity Pattern				
No. of Streets	40	77	58	48
Highest Connectivity	32	18	17	10
Lowest Connectivity	1	1	1	1
Identified on Site	1	1	1	4

This study suggests that the highest street connectivity is formed when the street has a long straight path with a connectivity value of 32 due to the other streets being connected in one long street (Sultanah Zainab Road). In addition, the highest value of street connectivity in the city center serves as the main street (Sultanah Zainab Road) to connect people from a

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block to other blocks of a street network in connecting them to various destinations. Sultanah Zainab Road, with the highest value in the linear pattern, serves as a main street in Kota Bharu Town, connected to other streets in the city center. Besides, the street is located to connect important places such as commercial block and government offices block as well as to connect with the tourist place block such as Dataran Rehal, Muhammadi Mosque, Islamic Museum, Istana Jahar, Istana Balai Besar, Padang Merdeka, Pasar Siti Khadijah, Bulatan Jam Besar and other food attraction or restaurants (Figure 2).

Fig. 2. The linear pattern of street connectivity identified in Kota Bharu Town.

Fig. 3. Parallel line pattern of street connectivity identified in Kota Bharu Town.

The parallel line pattern indicates parallelly four streets, namely Temenggung Road, Dato' Pati Road, Doktor Road, and Mahmood Road, connected by other streets in the city center. The high connectivity streets in parallel line patterns are designed to connect destinations in the commercial and government office blocks in the city center. For example, Doktor Road is designed to connect people to the banks such as RHB, CIMB, and Maybank, jewelry shops, hotels, restaurants, bus stations, and government offices such as KWSP office, Lembaga Tabung Haji, and Kota Bharu Municipal Council (Figure 3).

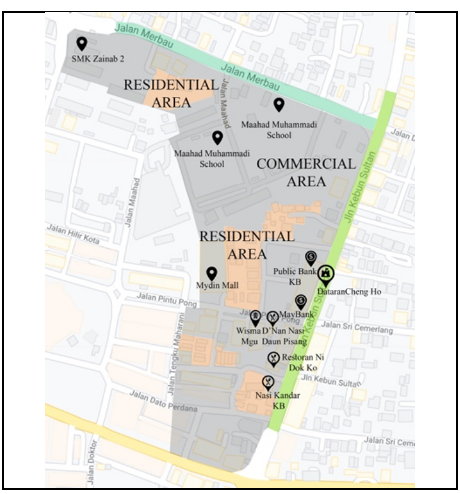


Fig. 4. The perpendicular branching pattern of street connectivity identified in Kota Bharu Town.

Fig. 5. Duo branching of street connectivity identified in Kota Bharu Town.

The perpendicular branching pattern indicates the two high values of street connectivity: Kebun Sultan Road and Merbau Road, which are perpendicularly connected in the street network system. The pattern functions as main streets to a mix-use block of commercial and residential areas nearby the suburbs area and at the edge of the city. For instance, Kebun Sultan Road and Merbau Road are used to connect the residential area with the destinations related to local daily needs, such as school areas, malls, banks, and restaurants (Figure 4).

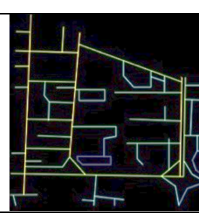
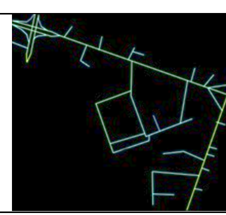
Lastly, the duo branching pattern of street connectivity forms two streets, namely Post-Office Lama Road and Tok Semian Road, by connecting with two different blocks such as residential (villages) and commercial blocks (Figure 5). Similar to the perpendicular pattern, the duo branching pattern functions to connect locals with the destinations for their daily needs. Therefore, both patterns suggest less traffic congestion compared to the other patterns of street network, which are linear and parallel line patterns. The traffic congestion for the street connectivity patterns is influenced by the location of streets either in the city center or the edge of the city, an association of the street network system with residential blocks, and the destination of public attractions.

This finding explained that the movement flow of pedestrians is better when the route is linked well to the destinations [14]. Besides, more streets connected in a street network encourage people to travel from one destination to another. The finding indicates that a well-connected street network or higher connectivity is associated with destination availability and more walking frequency for transportation [15]. The linkages with the destinations in a street network reflect the traveling distance to the destination and influence people to walk other than other factors [5]. Thus, the linear pattern becomes the significant street connectivity pattern in a street network as the main street for a city center.

3.2 Street Integration Patterns

Street integration represents the relationship and influences of a street with other streets in the street network. A street with high integration indicates a strong influence on the other street in pedestrian movement. This study identified four patterns of street integration formed based as shown in Table 2 namely, (i) perpendicular center, (ii) corner spread, (iii) parallel line, and (iv) branching edge. The results from Table 2 show that the street integration values formed in varies according to color. The red color represents the highest integration value, and the indigo color represents the lowest.

Table 2. The summary of patterns of street integration.

Type of Street Integration Patterns	**Perpendicular Center**	**Corner Spread**	**Parallel Line**	**Branching Edge**
Integration Pattern				
No. of Streets	79	71	74	53
Highest Integration	2.05	1.97	1.64	1.36
Lowest Integration	0.68	0.99	0.57	0.74
Identified on Site	1	1	1	1

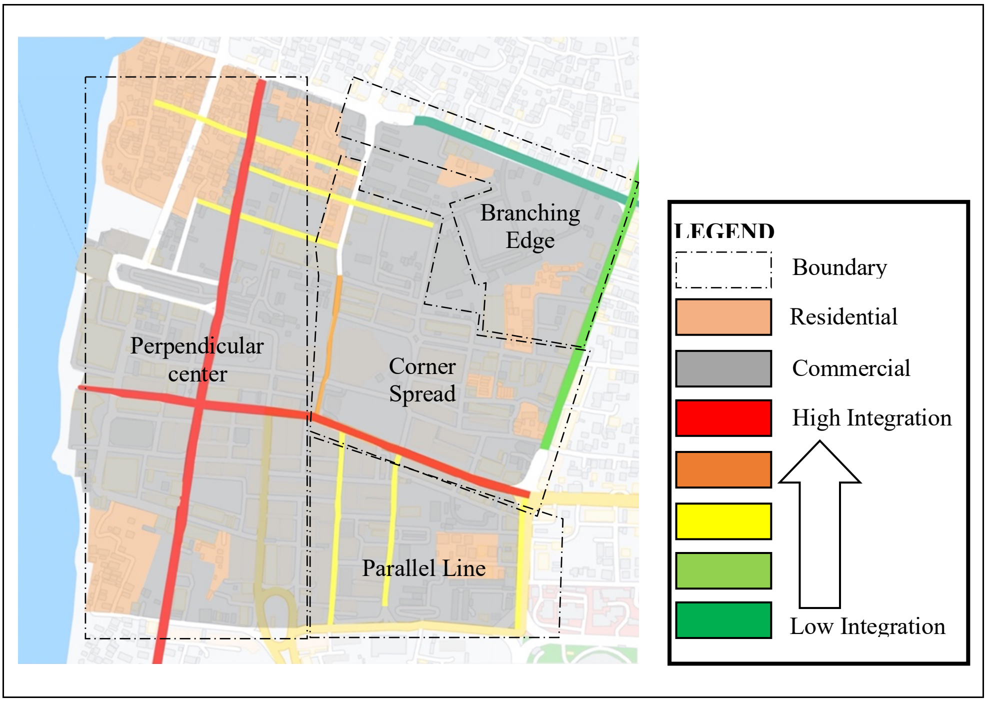


Fig. 6. The four patterns of street integration in the street network of Kota Bharu.

The first pattern that was identified in this study is the perpendicular center. The perpendicular center pattern shows two lines perpendicular to each other and represents the highest value of integration, which is 2.05, while the lowest is 0.68. The result means that the highest value formed at two streets as the main street perpendicularly influences other streets, indicating people move to the city's center. The perpendicular center pattern is located at the tourist attraction spots to create a well street connection between other streets and destinations.

Then the second pattern identified is the corner spread pattern. The corner spread pattern consists of the two high values in red color which is the highest value at 2.05 and followed by the orange color at 2.04, while the lowest value is 0.99. The second pattern indicates that the street network influences pedestrians to move to the corner block in the city. The high integration streets at the corner are used to facilitate people to move to important destinations such as commercial and government offices, even though the pattern is located at the corner block.

Next, the third pattern identified from the integration analysis is the parallel line pattern. Three high street integration in parallel positions shows the parallel line pattern and connect with other streets. The street integration value of the three parallel lines represents in yellow, respectively 1.72, 1.61, and 1.60, while the lowest value is 0.57. Similar to the corner spread pattern, the parallel line pattern is used to influence people to reach commercial and government offices.

Lastly, the branching edge pattern was identified as the fourth integration pattern of the street network, where the highest value with 1.36, shown in green color, and the lowest value with 0.74. The pattern consists of a slight difference between the highest and lowest integration values, indicating that the streets' average function is to move people from one destination to another destinations. Branching edge patterns show low street integration value because most streets are surrounded by residential areas such as Kampung Sultan and Kampung Pak Nik Ya.

The finding of this study suggests that the highest street integration is shown when the street has a long straight path and is connected to many numbers of streets. The high number of connections with other streets creates the street with the highest integration important to the street network in influencing people to move the important destinations in the city. In addition, streets located at the city's center influence the street to become an important component in the street system. Another study indicates that a street is used to link and facilitate people to find the location and destination of a place where the activities are held on [15]. Therefore, the finding implies that streets serve as a connection in carrying out daily activities in the community. Streets with high accessibility, well-connected to other main streets, and linked to other attractions may influence people to move and travel, thus contributing to high integration. The surrounding urban fabric influences street integration, either the area surrounded by attraction spots with higher integration or vice versa to the residential area.

4 Conclusion

This paper investigates the street network connectivity and integration pattern that form from the street connection among pedestrians at the existing street in Kota Bharu Kelantan. As such, the finding suggested that well-connected streets to other main streets were associated with pedestrian movement, affecting the value of street network connectivity and integration. Additionally, connected and accessible street networks promoted physical activities encouraging people to walk to their destinations. Besides, the finding suggested that the street connection for pedestrians was well-connected in the city center and the area surrounding the attraction area, compared to the area of the villages. The primary outcome of this study concludes the connection pattern that classifies the streets where improvements in the physical environmental factors might offer the most benefit for promoting pedestrian mobility. Thus, this paper focused on the connection pattern by analyzing street connectivity and street integration using Depthmapx software. The highest value mainly showed in the attraction and focal point area. This study should be extended in the scope of the built environment field that includes environmental sustainability attributes to achieve a well-connected street in Kota Bharu. Moreover, including other space syntax domain such as spatial visualization and interaction for the future research may leads to the comprehensive understanding of pedestrian behavior for the urban planning consideration. This study could help optimize the street networks that produce short-distance travel and direct routes for improving pedestrian mobility. In sum, a good street connection is toward developing a walkable and healthier city, and it could be helpful for urban planners and landscape architects to detect priority streets for action.

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References

1. F. van der Hoeven, A. van Nes, Tunn. Undergr. Sp. Tech. **40,** 64 (2014).
2. I. Said, W.S.N. Wan Mohamad, Int. J. Adv. Sci. Eng. Inf. Tech. **7**, 1464 (2017).
3. M. Zlatkovic, S. Zlatkovic, T. Sullivan, J. Bjornstad, S.K.F. Shahandashti, Sustain. Cities Soc. **49**, 101409 (2019).
4. M.J. Koohsari, K. Oka, N. Owen, T. Sugiyama, Health Place **58**, 102072 (2019).
5. S. Ferrer, T. Ruiz, Transp. Policy **67**, 111 (2018).

https://doi.org/10.1051/bioconf/20237305013

6. G. Sun, D. Wallace, C. Webster, Land Use Policy **90**, 104328 (2020).
7. W.E. Marshall, N.W. Garrick, (2011). Accident Anal. Prev. **43**, 769 (2011).
8. W.S.N. Wan Mohamad, N.I.S. Lokman, R. Hasan, R., K. Hassan, N. Ramlee, M.R. Mohd Nasir, Y. Gul, K.A. Abu Bakar, (2021) IOP Conf. Ser.: Earth Environ. Sci. **881**, 012058 (2021).
9. L.B. Yeo, W.S.N. Wan Mohamad, R. Hasan, N.I. Othmani, N.H. Abdul Hamid, N. Ramlee, O.T.S. Yeo, IOP Conf. Ser.: Earth Environ. Sci. **1053**, 012026 (2022).
10. J. Dean, S. Biglieri, M. Drescher, A. Garnett, T. Glover, J. Casello, Health Place **64**, 102352 (2020).
11. M.J. Koohsari, T. Sugiyama, S. Mavoa, K. Villanueva, H. Badland, B. Giles-Corti, N. Owen, (2016) Health Place **38**, 89 (2016).
12. M.J. Koohsari, T. Sugiyama, A. Shibata, K. Ishii, Y. Liao, T. Hanibuchi, N. Owen, K. Okaa, Health Place **45**, 64 (2017).
13. S.A. Mohamed, N.H.A. Hamid, N.I. Othmani, N.S. Kurzi, R. Hasan, W.S.N. Wan Mohamad, Z. Zahari, IOP Conf. Ser.: Earth Environ. Sci. **1102**, 012071 (2022).
14. K. Nakamura, IATSS Res. **39**, 156 (2015).
15. M.J. Koohsari, T. Sugiyama, K.E. Lamb, K. Villanueva, N. Owen, Prev. Med. **66**, 118 (2014).
16. P. Jones, S. Marshall, N. Boujenko, IATSS Res. **32**, 14 (2008).