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The Effects Street-Network Configuration in Modelling Walkability Through Space Syntax

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Abstract

This study investigates street network connectivity in an informal settlement, Kampong Taman Sari, Bandung. It refers generally to the informal residential area with minimum facilities and urban services. The majority of this settlement depict irregular patterns and narrow paths or alleys. Thus, kampong inhabitants mainly rely on walking, biking, and riding motorcycles to access key urban features and functions. This purpose study is to examine the potential connectivity not only for accessibility but also for evacuation movement in an informal settlement. This investigation also aims to understand an associative relation between street-network configuration and informal settlement patterns with the probability distribution of pedestrian movement. This study utilizes computational street network analysis through the space syntax method that consists of two distinctive evaluations, such as axial analysis and visual graph analysis. The following result depicts the spatial accessibility, integration, permeability, and walkability as well as connectivity based on this relation. Experimenting in modelling a walkable kampong in the urban environment will conduce to urban design qualities of street environment and street network layout for pedestrians or users.

INTRODUCTION

The informal settlements, kampong, are a common issue in the rapid growth of metropolitan cities, especially in Indonesia. Kampong in Indonesian is unremarkably known a unique type of urban settlement with poor condition physically and economically, but is not poor socially (Funo et al., 2002). This case study investigates Kampong Taman Sari, Bandung, which refers generally to the informal settlement with minimum facilities and urban services (Tambunan et al., 2021). The majority of these settlements often appear in irregular patterns and narrow paths or alleys (Shirleyana et al., 2018). As a consequence, this study seeks to comprehend how kampong dwellers in urban area mainly depend on walking, biking, and riding motorcycles to access key urban features and functions. These alleys are merely potential connectivity for informal inhabitants, but less appropriate for accessibility network and evacuation movement in the kampong. In addition, the urban structural Kampong Taman Sari develops naturally and spontaneously to a densely populated area, in which the existing condition is growing uncontrolled and unplanned, from buildings to street patterns. In terms of this, it neglects many who dwell in a highly accessible location but have lacking potentiality to easily move or access key urban functions and features (Hidayati et al., 2021).

Street connectivity patterns, on the other hand, are a walkability component that is related to urban form with street layout routes between two locations (Handy et al., 2003). A well-street connectivity network has been assessed consistently related to higher levels of walking (Badland et al., 2008) in the neighborhoods. In other words, the spatial structure of kampong is entirely necessary to create walkability in an urban environment as well as urban sustainability, not only for the increasing connectivity for pedestrians/users but also for the preparation of mitigation in evacuation planning (Tambunan et al., 2021).

The mentioned explanation above is a challenge, indeed, which is for urban kampongs since grows unintentionally in the neighborhood. The irregular patterns and forms are broadly identified as self-organized production of settlement, but it is not chaotic in a new urban environment (Dovey et al., 2020). Therefore, experimenting with this method will be mainly practicable for architects, urban designers, and urban planners to contribute the good impacts in neighborhoods.

Nowadays, the popularity of space syntax has risen rapidly in the fields of architecture, urban design, urban planning, and transportation. Generally, the theory of space syntax is pioneered on the theory of the social logic of space (Hillier & Hanson, 1988) that resembles a general prediction about how people define place in the urban environment, the impact perception of these spaces, socio-economic behavior and relationships (Agael & Özer, 2017). The previous works by researchers are experimenting and applying space syntax in varying scales, such as buildings, neighbourhoods, or entire regions (Nes & Yamu, 2021). This approach is an alternative method to examine buildings or street-network connectivity that focuses on topological (Hillier & Hanson, 1988) distance amongst networks (Bafna, 2003) and analyze the relationships between space and users' behavior (Turner et al., 2005). It also defines the pattern of public space that links settlement buildings (Hillier, 2002). Briefly, this depicts how accessible or permeable a street network to other networks (Koohsari et al., 2019) and space syntax identifies how spatial configuration in kampong can be used to infer the patterns of movement flow (Conroy-Dalton, 2003; Hillier, 2012).

Axial Analysis

Before analyzing through space syntax, identifying the map basically needs to be converted into an axial format to generate axial analysis in space syntax. Axial analysis is defined to examine the interconnectivity in the routes' degree movement (Nes & Yamu, 2021). It adjusts axial lines that comprise the human way to move in a linear manner of sightline through urban street and road network (Hillier & Hanson, 1984).

Using this method works with a basic element of axial line, which indicates the movement paths and forms in the built environment. It represents the whole length of a street in a network that is linked to other streets (Hillier et al., 1993). This analysis is to simulate connectivity and integration to estimate the level of accessibility of streets in the urban environment. Axial connectivity is to identify the accessibility level that is to be accessed from a variety linked streets directly, while axial integration is to measure the degree of potential movement and the total number of direction changes (Hillier & Hanson, 1988). All axial lines analysis indicates the movement paths, steering direction modification with longest and the fewest sightline (Nes & Yamu, 2021) through the index attributes

Visual Graph Analysis

Visual Graph Analysis (VGA) is a space syntax method for measuring some socio-spatial properties of the built environment by representing the map of ground plan into a grid (Amini Behbahani et al., 2017). This mapping represents the releasing pedestrians into the environment and accessing the visual accessibility information for its current location from the visibility graph, which informs its choice of next destination (Turnet et al., 2017). It also can evaluate the visibility in environmental space with incorporate the movement pattern which accords the evaluation of human visual perspective. Principally, the VGA measurement explains the inter- visibility of space according to the urban morphology that clustering coefficient, global integration measurement, and local control measurement (Othman et al., 2019). By looking at correlation at both local and global measurement may capture the common experience of the space or area and it may identify an exploring of spatial experience. These graphs also describe a spatial configuration with reference to visibility and accessibility. Constructing a visibility graph analysis will form potential nodes of the graph and define some sort of grid which is related to human perception of an environment in human movement scale (Varoudis, 2014).

Identifying Characteristic of Case Study

Kampong Taman Sari, the main characteristic of the site, is posited in *Taman Sari* (Figure 1) and closed to *Cikapundung* River, Bandung. This area is an informal settlement that grows densely populated area with the unplanned and uncontrolled urban structure and patterns in urban area. Based on observation, most of buildings are residential areas with narrow streets and alleys which are classified into three street typologies (Table 1).

Based on observation, these streets are divided based on the width of streets (Table 1), typology I is the only street that can be accessed by vehicles, whilst typology II and III are the streets that can be accessed merely by pedestrians and bikers. In terms of this, the street condition is inconvenient to walk or move for users or pedestrians because the width of street is too narrow, poorly accessible, and less integration. For outer users, they get lost due to insufficient visual connection in this location.

Fig. 1. Observing existing area

Table 1. The street typology

Street typology	Descriptions
Typology I	A, B; the width of street >2.5 metres
Typology II	C, D, E; the width of street 1-2.5 metres
Typology III	F, G, H; the width of street <1 metres

Source: Authors

METHODOLOGY

The goal of this study is to determine and understand accessibility and connectivity to measure informal settlement streets in *Kampong Taman Sari* more walkable and accessible for dwellers or other users. Experimenting in modelling a walkable kampong in the urban environment have deductions for urban health and environmental well-being that leads to sustainability. This method will provide particular impacts in urban design qualities of street environment and street network layout for pedestrians or users. Regarding this intention, this study employs computational street-network analysis using space syntax to indicate that the pedestrian or users can adapt the street environment and usable space (Beavon et al., 1994), find out the walkable potentiality in neighbourhood (Leslie et al., 2007), and allow people to orientate through it (Nes & Yamu, 2021). Yet, applying this approach has already-known and established research globally. This applied method will contribute to create a well-functioning built environment which concerns on dealing the configuration pathway network to enhance the walkability in compact area, especially *Kampung Taman Sari*.

This study involves three phases that would be likely to generate walkability modelling; (a) identifying characteristics of boundary constrain from the location of the case study, (b) constructing axial analysis, and (c) constructing the visibility graph analysis. These phases will result in the degree of intelligibility and synergy measurement concept.

RESULTS AND DISCUSSION

Axial Analysis

In this paper, axial analysis is conducted two times simulation to identify connectivity, local integration, global integration, and choice, firstly in the existing map (Figure 2) and secondly, the potential upgrading of street-network (Figure 3).

The figure 2 depicts that the street network in this area is less accessible because the streets or alleys have limited size, particularly typology II and III (1-2.5m and <1m). Based on this analysis, this street-networks appears the highest connectivity index at 94, compared to a new scenario, while the lowest connectivity index is at 1. It means that this area is less walkable for pedestrians or users in *Kampong Taman Sari* with poorly accessible and lacking integration.

Meanwhile, the figure 3 reveals that there are new potential street-network structures to connect the streets from an informal settlement to other streets. We likely widen and upgrade the potential paths or alleys, and then simulate again to see the changes. This scenario appears that the connectivity level increases significantly to 124. It also could be shown, the location which has the highest connectivity is in the *Jalan Taman Sari* and *Jalan Plesiran* (Figure 3). Regarding this result, if there is an unpredictable condition, such as natural disaster or fire in this *kampong*, the dwellers have alternative paths to evacuate due to the number of given street-network. It also can be depicted that the alleys are connected to other main streets.

Fig. 2. The connectivity degree in the existing area

Fig. 3. The connectivity degree in the new scenario of potential street-network

Afterwards, other results identify the axial integration index which presents the accessibility degree of the streets in the urban system and also relates to the connectivity (Yamu et al., 2021). The axial integration consists of two categories, local integration and global integration. The local integration refers to the accessible streets that are connected to its neighbour streets for pedestrian or cyclists' movement, while the global integration represents the accessibility of a street to all other streets as a citywide integration for entire users, from vehicular movement to pedestrian, in the urban system taking into consideration the total calculation of direction changes (Hillier, 2007).

Global integration (Rn) initially is analyzed for the existing map (Figure 4), then leads to the highest and the lowest global integration index. The former feature is 1.7654 in *Jalan Cihampelas*, while the latter feature is 0.67 in *Jalan Plesiran*. It identifies that *Jalan Cihampelas* is more accessible for the whole users, including pedestrians, bikers, cyclists, and car drivers, but it is less concerned for pedestrian movement. Following that, authors tend to make possible scenarios to widen and open the potential paths (Figure 5) to support this transportation and walking. As a consequence, there is an increase in the global integration index. The highest feature is just under 1.5 in *Jalan Cihampelas*, while the lowest feature is just over 0.5 in every alley, *Kampong Taman Sari*. It also can be shown that *Jalan Plesiran*, *Jalan Kebon Bibit*, and *Jalan Kebot Bibit Barat* have more integration to connect other street networks.

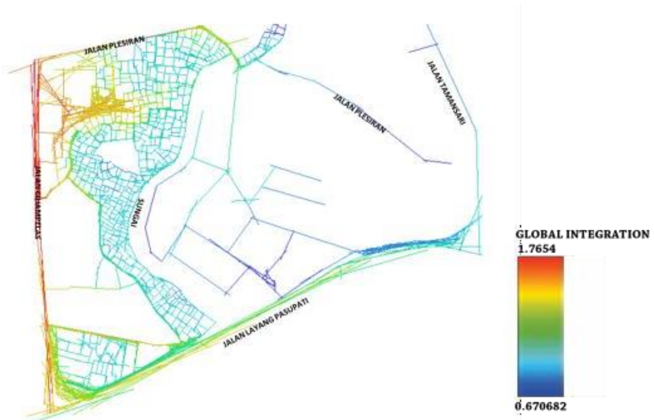

Fig. 4. The global integration degree in the existing area

Fig. 5. The global integration in the new scenario of potential street-network

Local integration (Figure 6) is a key to access the value index of all streets within a certain radius, then the result (integration R-3) refers to the axial lines well-connected the streets to the neighborhood streets for investigating pedestrian movement and the number of direction changes in the urban environment. The highest index for the existing area is at 5.59983 and the lowest index is at 0.3333. It defines that there are five possible direction changes for one root node or the distance of depth which has four steps. Then, based on the potential scenario (Figure 7), the highest index is at 5.8893, and the lowest index is at 0.3333. The results are similar to the existing area, in which there are unchangeable impacts. Thus, the higher local integration index of the street network or the higher the distance depth will affect the lower accessible streets and also the lower the burglary risk (López et al., 2007).

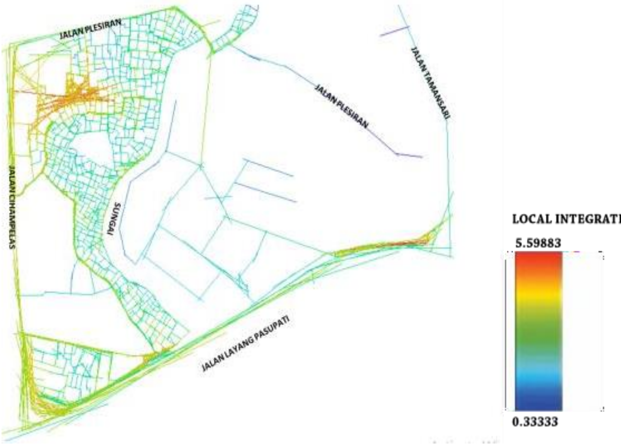

Fig. 6. The local integration degree in the existing area

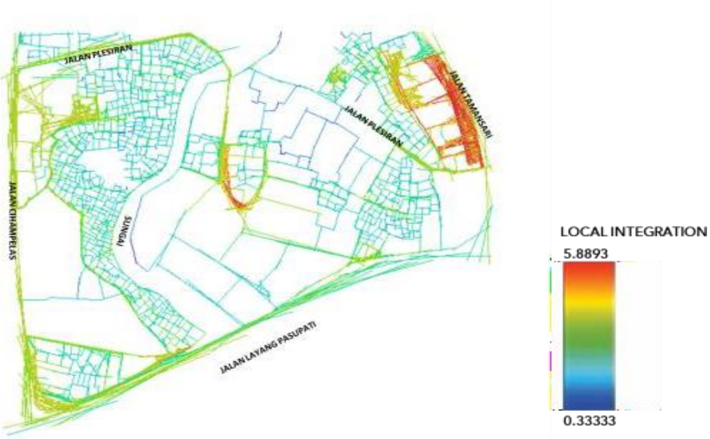

Fig. 7. The local integration degree in the new scenario of potential street-network

Following that, the choice analysis refers to the potentiality of through-movement that identifies a route choice or the shortest distance from people in an urban system. The highest choice degree in the existing area (Figure 8) is just over 0.3 while the lowest is at 0. It determines that these streets are not chosen by people as the main route to travel or move. There is an opposite condition between existing simulation and potential scenario simulation (Figure 9), in which the latter feature shows an index of 2.12 (Jalan Plesiran) that is seven times higher than the existing simulation. It is considered that this potential street network appears the possibility in route choice.

Fig. 8. The choice degree in the existing area

Fig. 9. The choice degree in the new scenario of potential street-network

Visual Graph Analysis

This analysis is to measure the visibility relationships index between spaces and the built environment. It also identifies that the location is more visible at every angle. According to this simulation result (Figure 10 and 11), the visibility measurement has a similar visibility degree between the existing area and the upgraded area. The majority of the color area is closed to blue which notifies the area is low accessible in the visibility. It is difficult for the observers, visitors, or pedestrians to see visibly in this kampong. In contrast, *Jalan Pasupati* is the only street that can visible for the users due to its red color. It could be seen that the blue color streets in the kampong area reveal more private streets.

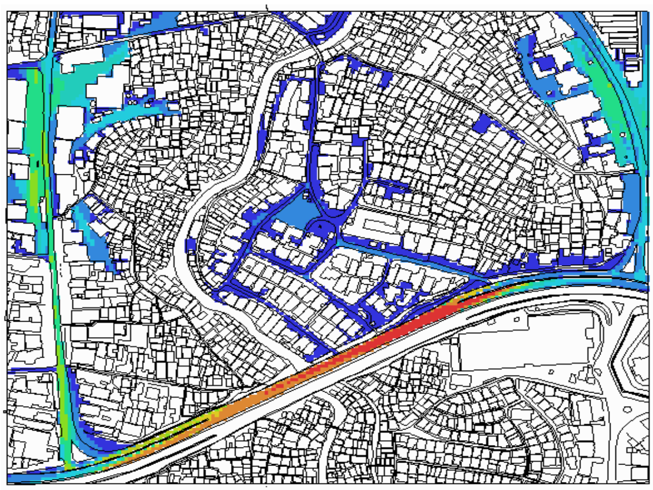

Fig. 10. The visibility degree in the existing area

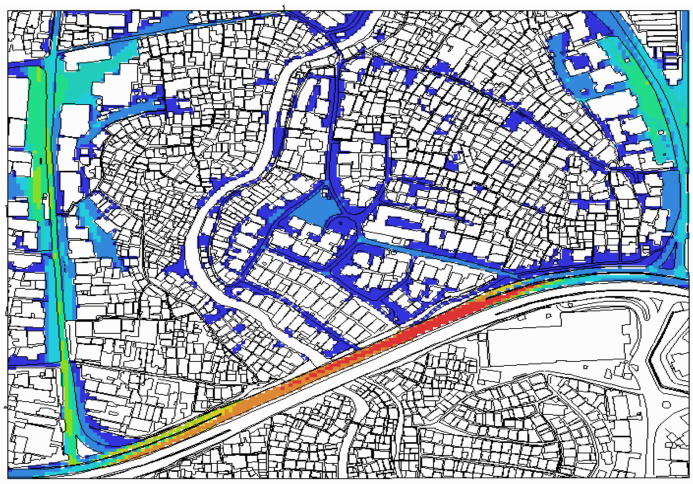

Fig. 11. The visibility degree in the new scenario of potential street-network

All findings above show the comparison of experimenting (before and after) simulation between the existing area and the street proposal design in the street-network configuration through modelling walkability in *Kampong Taman sari* (Table. 2). The following result in the new scenario of potential street network, especially upgrading and widening the street quality in this area, reveals the new value index for four measurements, such as connectivity, global integration, local integration, and choice in axial analysis. These upgraded and wide streets affect the connectivity of street-network in this kampong, in which the area more accessible and more integrated for pedestrians.

Table 2. The measurement results of axial analysis

Kampong Taman Sari	Case Iteration	Connectivity	Global Integration (Rn)	Local Integration (R3)	Choice
Existing simulation (before)	1	94	1.7654	5.59983	0.346564
Potential street-network simulation (after)	1	124	1.42238	5.8893	2.12

These experiment result idea of intelligibility that solely refers to scatterplots which are identifying the relationship types between two variables. This paper reveals the correlations between integration (local and global integration) and connectivity values of axial lines in street-network configuration that leads to intelligibility concept (Hillier & Hanson, 1988) in urban environment system (Figure 12 and Figure 13). Meanwhile, the correlation between global integration and local integration result in the concept of synergy (Hillier & Hanson, 1988). The simulated existing area appears at the blue color which means poorly accessible or unintelligible environment (Figure 12), while the simulated new potential street network (Figure 13) depicts various colors, which define more intelligible environment, compared to the existing area, due to this new street-network configuration.

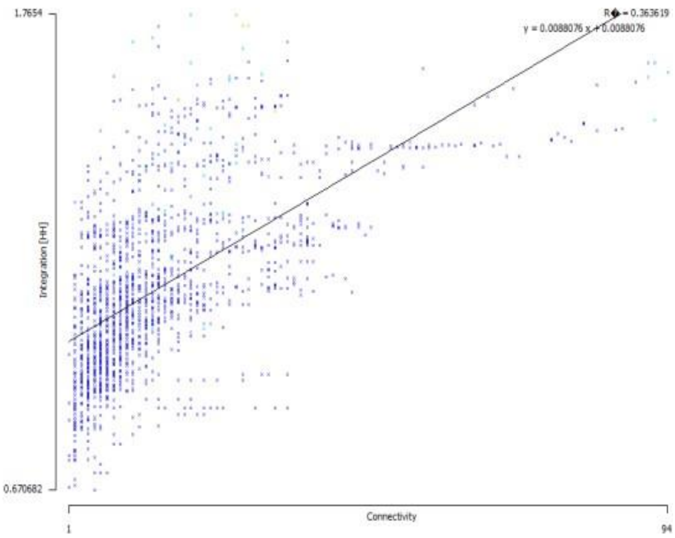

Fig. 12. The intelligibility measure between integration and connectivity in the existing area

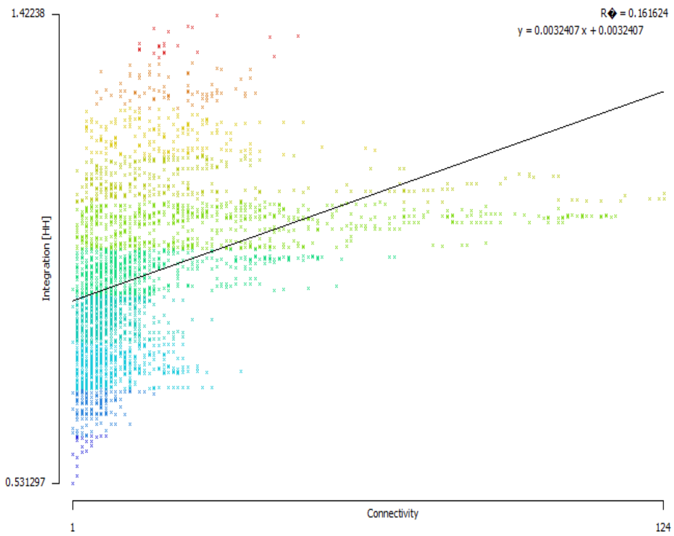

Fig. 13. The intelligibility measure between integration and connectivity in the new scenario of potential street- network

Another result, the synergy concept (Hillier, 2008) measures the correlation and the structure between local integration (R3) and global integration (Rn) in the neighbourhoods. The synergy degree calculates the integration value (R), which affects distribution of spatial in this area, and when the R is smaller than 0.5, it means the correlation between local and global integration is low movement distribution (Fang et al., 2021). The simulated existing area (Figure 14) depicts that the R degree is 0.46 and the under-trend line show has low spatial distribution. The simulated new potential street network (Figure 15), on the other hand, shows that the R-value is 0.3, which is lower than the figure of the simulated existing area. However, the under-trend line has various colors, which determines that the new network structures have better spatial distribution than the existing area.

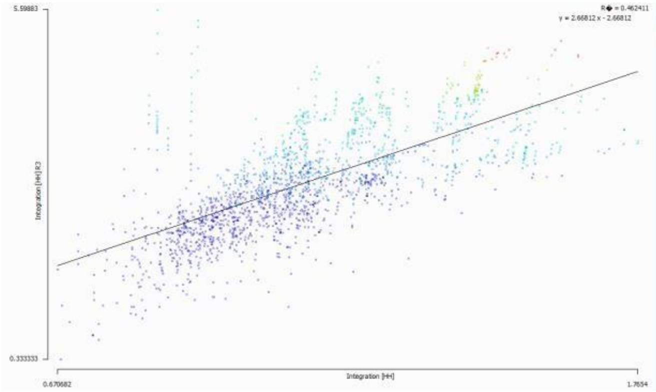

Fig. 14. The synergy measure between local integration and global integration in the existing area

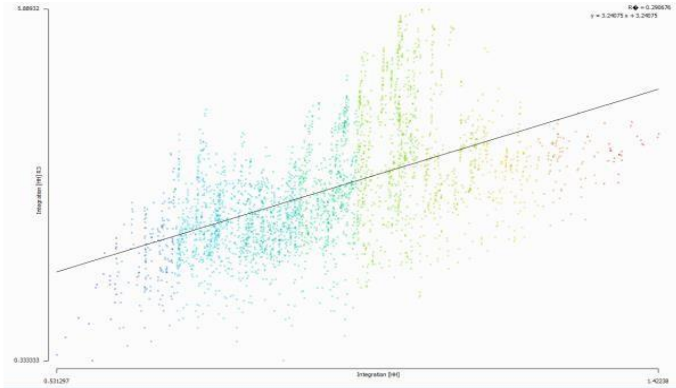

Fig. 15. The synergy measure between local integration and global integration in the new scenario of potential street-network

CONCLUSION

All simulations mentioned above are considering the findings that experimenting in street network configuration approach is a developing strategy to understand deeply the correlation between streets, pedestrians, and environment in the urban system. This experiment compares the simulated existing area and the simulated upgrading area. Both of these areas show significant impacts in the degree of connectivity, local and global integration, choice in the axial analysis and visual connectivity in the visibility graph analysis. All investigations lead to intelligibility and synergy concepts that identify the relationships between those variables. The former feature is to prove an intelligible or unintelligible environment in this *kampong*, while the latter feature is to examine the spatial distribution of users. Experimenting space syntax theory in this case study exemplifies an applying the established method in research. This experimental method contributes to create a well-functioning built environment which highlights on dealing and upgrading pathway or street network to enhance walkability and accessibility for dwellers in compact area, Kampong Taman Sari.

A walkable kampong modelling in the urban environment has implications. Firstly, this method can evaluate the pattern of accessibility, permeability, integration of networks and visual perspective of users in kampong topologies, particularly in Indonesia. These topologies are more communal for pedestrians rather than other users. It is also less viewed area and more private streets and spaces in the urban system for other users. Secondly, experimenting in modelling a walkable kampong in the urban environment will provide for urban health and environmental well-being that leads to sustainability. It can be proven by pedestrian movement or spatial distribution of users in this kampong. In addition, this experiment will conduce to urban design qualities better of street environment and street network layout for pedestrians or dwellers' sightlines.

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