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GIS ANALYSIS OF NEIGHBOURHOOD ENVIRONMENT DETERMINANTS THAT INFLUENCE WALKABILITY IN PENANG, MALAYSIA

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Abstract

Understanding the relationship between urban design and physical activities is crucial. Studies have identified three key neighbourhood environment indices that enhance walkability. This research investigates the influences of these indices on residents' walkability to community facilities in two neighbourhoods in Penang Island, Malaysia. Using geographic information system (GIS) technology, we analyse the effect of the built environment on walkability through buffering and thematic map analyses. Pulau Tikus features medium- and low-density housing with enriched community facilities, whilst Tanjung Tokong has a higher residential density, more road intersections and more diverse housing options. Findings indicate that Pulau Tikus offers better amenity accessibility, whilst Tanjung Tokong's high-rise residential buildings and diverse housing types enhance walkability. This study highlights the relationship amongst residential density, road intersections, mixed land use and walkability in two residential neighbourhoods. Higher residential density and more road intersections increase walking activity, whilst mixed land use further influences resident mobility patterns. These insights can aid urban planners in designing more walkable, liveable and sustainable neighbourhoods.

***Keywords**:* GIS, Walkability, Neighbourhood Planning, Sustainable Urban Environments and Community Facilities

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INTRODUCTION

Walking is a common physical activity for many people, and it ranks amongst the most popular forms of exercise worldwide. The built environment has been demonstrated to positively influence physical activities, particularly walking (Baobeid et al., 2021a). However, despite the positive influence of physical activities, engaging in them is still difficult for people. As traffic congestion and car travel concerns grow across communities nationwide, researchers have focused on how land use affects travel behaviour. Evidence that the built environment influences the physical activity behaviour of individuals, particularly walking, is growing (Karwand et al., 2024). Research has shown that various aspects of the built environment, such as residential density, land use mix, street connectivity, walking facilities, aesthetics and safety from crime, can significantly affect walking behaviour (Paydar et al., 2020; Saelens & Handy, 2008).

Walking is recognised as an important activity that can reduce the risk of several health issues, including coronary heart disease, stroke, diabetes, hypertension, various types of cancer and depression (World Health Organization, 2022). According to Ipsos Press (2023), Malaysia recorded the highest level of obesity amongst Southeast Asian countries. The National Health and Morbidity Survey (2019) conducted by the Ministry of Health Malaysia reported that the prevalence of overweight and obesity amongst Malaysian adults was recorded at 50.1%. In addition, the survey found that 25.1% of Malaysian adults are physically inactive, and only 45% of adolescents in the country engage in regular physical activities, particularly walking.

Walkability is defined as the ability to walk to services and amenities safely within a reasonable distance. Research has indicated that a compact and interconnected urban environment, which includes a variety of densities and land uses, reduces distance between key destinations. This proximity encourages people to walk as a mode of transportation (Vichiensan & Nakamura, 2021). Pentella (2009a) highlighted that the walkability of an area is shaped by the design of the built environment and its various features. Crucial community features frequently include how close locations are to one another and how easily people can travel between them. A substantial body of literature indicates that factors, such as street connectivity, residential density and the presence of community facilities (mixed land use), are related to walking activity (Leh et al., 2015). Associations between neighbourhood environmental factors and physical activities, such as walking, have been observed.

Numerous studies have aimed to identify the key factors of walkability that significantly affect the design of the built environment, facilitating increased pedestrian activity within neighbourhoods. Accordingly, the current study aims to identify neighbourhood environmental factors that influence the ability of residents to walk to community facilities in two different neighbourhoods on

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Penang Island, Malaysia. Understanding these factors is essential, because walking, whether for practical purposes or recreation, provides significant health benefits, including improvements in cardiovascular and mental well-being (Baobeid et al., 2021b).

LITERATURE REVIEW

Measuring Neighbourhood Environment Indices

Neighbourhood environment indices can be assessed using geographic information system (GIS) technology and self-reported tools, such as questionnaires (Weliange et al., 2021). GIS-derived walkability measures consider various factors, including residential density, land use mix, retail floor area ratio and street connectivity (Adams et al., 2014). Self-reported instruments can evaluate pedestrian environments by capturing elements, such as the presence and condition of sidewalks, aesthetic appeal, safety from crime and traffic conditions (Shigematsu et al., 2009).

Frank et al. (2005) and Leslie et al. (2006) confirmed that residential density, land use mix and street connectivity are significant factors that influence walkability. A ‘highly walkable’ neighbourhood is characterised by high street connectivity, diverse land use and high residential density. Neighbourhood environment indices can be objectively assessed using GIS software or through observational data collected within the neighbourhood (Leslie et al., 2006).

Influences of Residential Density, Street Connectivity and Land Use Mix on Walkability

Residential density is determined by the number of households per square kilometre (Glazier et al., 2014). In highly dense areas, where congestion and limited parking space frequently hinder automobile travel, people are likelier to walk than drive. Conversely, walking is more prevalent in low-density regions with serene natural surroundings and ever-changing vistas. Increasing neighbourhood density is in line with conventional theory, which predicts a reduction in trip distances, an increase in walking activities and a potential decrease in overall automobile use. In addition, Residents in denser communities, which feature better street connectivity and a diverse mix of land uses, report higher levels of walkability compared with those living in low-density, poorly connected and single-use neighbourhoods (Frank et al., 2006; Saelens et al., 2003).

Street connectivity refers to the density of intersections wherein three or more streets meet within a specific area, typically measured per square kilometre (Wagai, 2016). This connectivity influences the efficiency of travel routes between residential areas, shops, workplaces and other destinations. Neighbourhoods designed with grid-patterned street networks typically exhibit higher levels of connectivity than those with winding, curvilinear layouts (Choi

& Ewing, 2021). Increased street connectivity promotes walking as a mode of transportation by reducing obstacles and minimising major road crossings (Koohsari et al., 2014).

Land use mix access refers to amenities, such as residential, commercial, educational and recreational facilities, within an 800 m radius, as defined by Frank et al. (2005). Research has consistently shown that people are likelier to walk and cycle in neighbourhoods with higher residential density, a mix of land uses and connected streets. Conversely, individuals are less inclined to walk in single-use industrial districts and single-family suburbs, where destinations are far apart and the scenery is uninviting.

According to Saelens et al. (2003), towns with higher residential density, a mix of land uses and grid-like street patterns that feature short block lengths encourage more walking than larger, less connected areas. Leslie et al. (2005) listed five neighbourhood environmental characteristics that are correlated with walkability. These elements are provided in Table 1.

Table 1: Neighbourhood environmental characteristics that influence walkability.

Neighbourhood Environmental Characteristics	Description
Residential density	Dense neighbourhoods encourage mixed-use development, expanding retail/services and shortening walking distances between destinations.
Street connectivity	Higher intersection densities create more walking routes, improving neighbourhood connectivity and shortening distances to destinations for increased accessibility.
Land use mix	Varied retail and services encourage frequent and short walks, creating vibrant neighbourhoods with diverse and captivating environments for pedestrians.
Public transit density	Accessible bus stops shorten distances, promoting walkability and facilitating movement between leisure activities, work and home.
Land use crime density	High crime rates deter walking, boosting reliance on cars and alternative transport due to pedestrian insecurity in neighbourhoods.

Source: Leslie et al. (2005)

Influence of Built Environment Characteristics on Pedestrian Friendliness

Several studies have shown that the microscale characteristics of the built environment, such as elements and features that are directly perceptible to pedestrians on the streets, play a significant role in determining an area's pedestrian friendliness (Nagata et al., 2020). Key features that enhance walkability include well-maintained sidewalks, shaded trees, safety amenities,

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adequate street lighting, aesthetic appeal and access to public transportation facilities (Basu et al., 2023).

Khisty (1994) identified seven factors that help reduce barriers to walking: increased attractiveness, improved comfort, greater convenience, higher population density, mixed land use, safety, system coherence (directness) and continuity (completeness). The study conducted by Saelens and Sallis (2002) resulted in the creation of the Neighbourhood Environmental Walkability Scale. This scale assesses residents' perceptions of various design features in their neighbourhoods that are related to physical activities. These features include residential density, mix of land uses, street connectivity, infrastructure for walking and cycling, neighbourhood aesthetics, traffic conditions, safety from crime and overall satisfaction with the neighbourhood. Handy et al. (2002) identified six dimensions of the built environment that influence walking choices: density and intensity, land use mix, street connectivity (including directness and the availability of alternative routes), street scale, aesthetic qualities and regional structure (pertains to the distribution of activities and transportation throughout the region). Moreover, environmental variables that correlate with walking activities include local neighbourhood features, such as convenient facilities, shops, parks and an aesthetically pleasing and safe environment.

Therefore, the current study focuses on neighbourhood environmental indices assessed through GIS, specifically examining residential density, mixed land use and street connectivity.

RESEARCH METHODOLOGY

Study Area

This study aims to identify neighbourhood environmental factors that affect residents' walkability in two different areas of Penang Island, Malaysia. The study was conducted in Penang, Malaysia's island region, focusing on the neighbourhood areas in Pulau Tikus and Tanjung Tokong. These neighbourhoods, with their diverse residential densities that range from low to high, along with their varying land use patterns and road intersection densities, provide an ideal setting for a comprehensive analysis of how different density levels affect walkability. According to Jafari et al. (2023), walkable neighbourhoods are characterised by higher residential densities, proximity to destinations, connected street networks and diverse mixed land uses, which are all key aspects of the built environment that are associated with walking.

The overall land area of Pulau Tikus is 124 ha, whilst Tanjung Tokong covers 150 ha. GIS was used to collect and analyse data. Each study area was divided into three neighbourhood units labelled NA1, NA2 and NA3, as shown in Figures 1(a) and 1(b). The sizes and boundaries of the neighbourhoods adhere to the Green Neighbourhood Guidelines set by the Federal Department of Town and Regional Planning Malaysia. According to Barton et al. (2003), the average walking distance is 1 km, and very few people walk more than 2 km. The accepted threshold for walking to local facilities is 400 m, whilst the suggested threshold for walking to a town centre is 800 m.

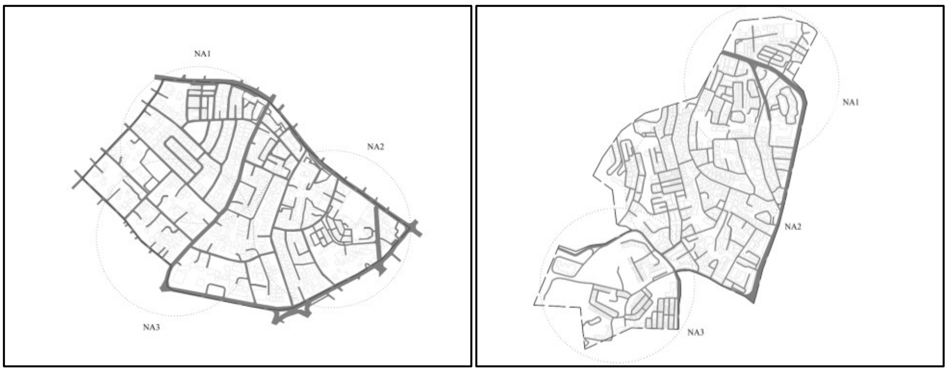

Figure 1: (a) Neighbourhood of Pulau Tikus, Penang (b) Neighbourhood of Tanjung Tokong, Penang
Source: The author

Research Instrument

The research instrument used for data collection is ground truth verification (GTV), which entails the validation of mapped data against actual ground conditions. GTV involves validating mapped data against actual ground conditions. It typically refers to observations or measurements conducted on the Earth's surface to confirm remote sensing data and support GIS analysis. This approach demonstrates considerable precision when delineating geographic attributes under assessment, typically for categorising 'points' into specific land use/cover classifications. The purpose of obtaining GTV is to assist in calibrating and interpreting remotely sensed or GIS data by confirming actualities.

The current research utilized secondary data that comprised Penang land use maps sourced from the Geospatial Information Management Unit, Penang, which conducted GTV surveys to validate the accuracy of land use data attributes. In the present study, survey was performed with the aid of aerial photographs, Google Maps and OpenStreetMap. The survey aimed to update the classifications and attributes of the land use map to reflect current land use in the study area. The findings from this verification were incorporated into the map, ensuring that it included the most recent land use data and attributes before any GIS spatial analysis was conducted.

GIS Spatial Analysis

GIS spatial analysis refers to a collection of techniques wherein outcomes vary depending on the alteration of the location of the object under analysis. It is also characterised as a method that is capable of dealing with an occurrence's spatial

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scale and patterns. The current study utilised two types of GIS spatial analysis: buffering and thematic map analyses. Buffering is used to identify areas around specific geographic features by creating a buffer zone around them. Once the buffer zone is established, features can be selected or identified based on their location, i.e. whether they fall within or outside this perimeter. Meanwhile, a thematic map focuses on a particular theme related to a geographic area. This type of map uses spatial data to illustrate the distribution and location of a specific phenomenon, visually representing patterns in the data.

Three neighbourhood environmental characteristics, namely, residential density, street connectivity and land use mix, were selected for analysis. These large-scale aspects of neighbourhood design are frequently studied for their associations with physical activities (Frank et al., 2004; Leslie et al., 2007). Street connectivity, land use mix and residential density are correlated. Analysing these three neighbourhood characteristics allows for the assessment of how 'walking-friendly' a neighbourhood is. The employed GIS spatial analysis methods and the process for conducting these analyses for each examined index are detailed in Table 2.

Table 2: Process of conducting spatial analysis by using GIS in the current study.

Indices	**Explanation**	**Type of GIS spatial analysis**
Residential density, Road intersection, Nonresidential components of mixed land use, and Residential mixed land use	The size of the neighbourhood boundary (400 m), generated from buffering analysis, served as the starting point for conducting the analysis.	Buffering analysis
Residential density	Created using the 'density' attribute as the theme to represent types of residential density layers, and densities within the buffer boundary are analysed.	Thematic map
Road intersection	The total numbers of 3–4-way intersections within the buffer boundary are analysed.	Thematic map
Nonresidential components of mixed land use	Created using 'Gunatanah' attributes as the theme to represent community facilities land use layers, and features within the buffer boundary are identified and calculated.	Thematic map
Residential mixed land use	Utilising the attributes of 'infrastructure and utilities' to represent different types of housing	Thematic map

Indices	Explanation	Type of GIS spatial analysis
	layers, the analysis focuses on houses located within the buffer boundary.	

Source: The author based on Geographic Information Unit and Department of Town and Planning Malaysia (2012)

ANALYSIS AND DISCUSSION

The findings of this study are categorised based on three selected indices: residential density, road intersections and mixed land use. In addition, the analysis of mixed land use is further divided into nonresidential components and residential mixed land use.

Residential Density

In Penang, residential density is assessed by measuring gross density, which considers the number of housing units per acre, including areas designated for streets, parking, open spaces and nonresidential buildings. Residential density is categorised into four levels: (1) low density (1–8 units per acre), (2) medium density (9–24 units per acre), (3) medium–high density (25–50 units per acre) and (4) high density (51–75 units per acre). Figures 2(a) and 2(b) illustrate the residential density in both neighbourhood units, with darker colours representing higher levels of residential density.

The results indicate that residential density affects walkability patterns in Pulau Tikus and Tanjung Tokong. In Pulau Tikus, Neighbourhood Area 1 (NA1) has three types of residential density: low, medium and medium–high. By contrast, NA3 consists solely of low-density housing. The analysis indicates that two out of three neighbourhoods mostly have medium- and low-density housing, whilst only one neighbourhood primarily has high-density housing. The result of Tanjung Tokong exhibited three types of residential density: high, medium–high and low. It also showed that all three neighbourhoods had mostly medium- and high-density houses. A conclusion is drawn that Tanjung Tokong has more high-density houses than Pulau Tikus. Previous research has demonstrated that higher residential density enhances neighbourhood walkability (L. D. Frank et al., 2005; Jafari et al., 2023; B. E. Saelens et al., 2003). Density is considered a cornerstone of walkability in a neighbourhood, because without higher residential densities, having destinations within local access and mixed land uses is not feasible.

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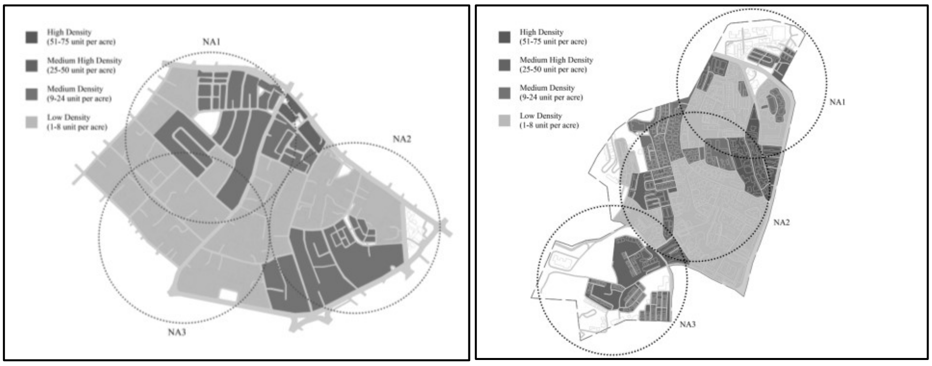

Figure 2: (a) Residential density of Pulau Tikus, Penang (b) Residential density of Tanjung Tokong, Penang
Source: The author

Road Intersection

The analysis of road intersections focuses on determining the number of 3-to-4-way intersections within a neighbourhood unit (Figure 3). In Pulau Tikus, NA1 has the highest number of road intersections, totalling (53), whilst NA3 has the lowest, with only (37). Meanwhile, in Tanjung Tokong, NA2 has more road intersections (94) than the other units, whilst NA3 has the fewest (40). The analysis reveals that Tanjung Tokong has 193 intersections, more than those of Pulau Tikus.

The analysis of road intersections indicates a consistent trend akin to the observed outcomes in walking trips within the neighbourhood, indicating that residents in Tanjung Tokong are engaged in more walking activities than those in Pulau Tikus. In addition, Tanjung Tokong comprises a more significant number of high-rise residences, facilitating numerous shortcuts within housing units, increasing accessibility and providing residents with more routes to reach community facilities by walking. Studies conducted by Frank et al. (2005), Pentella (2009) and Saelens et al. (2003) highlighted that road intersections are associated with street connectivity. A higher number of road intersections provide more potential walking routes and greater accessibility (Federal Highway Administration, 2022; Jabbari et al., 2021). Moreover, improving street connectivity leads to shorter distances towards destinations.

Figure 3: (a) Road intersections of Pulau Tikus, Penang (b) Road intersections of Tanjung Tokong, Penang
Source: The author

Mixed Land Use

This study identifies seven types of community facilities for analysis within the neighbourhood unit: shops, parks/recreational areas, elementary schools, secondary schools, places of worship and bus stops. The results for nonresidential mixed land use in Pulau Tikus show that six community facilities are situated within a 400 m walking distance (NA1, NA2 and NA3), as illustrated in Figure 4(a).

Figures 5(a) and 5(b) illustrate the residential mixed land use, with different colours representing various types of houses. In Pulau Tikus, the results for residential mixed land use reveal four house types in zones NA1 and NA2: bungalows, terrace houses, semi-detached houses and apartments. By contrast, zone NA3 has the fewest house types, featuring only bungalows. Tanjung Tokong comprises two neighbourhood areas (NA1 and NA2), with each area consisting of five houses: bungalows, semi-detached terraces, apartments and flats. Simultaneously, NA3 includes only three house types: bungalows, terraces and apartments.

The study on mixed land use for nonresidential components indicates that Pulau Tikus has a higher number of community facilities within a 400 m walking radius compared with Tanjung Tokong. Furthermore, Pulau Tikus offers more community facilities than Tanjung Tokong. Studies by Leslie et al. (2005), Pentella (2009b) and Saelens et al. (2003) suggested that mixed land use encourages residents to walk in their neighbourhoods. However, in terms of residential mixed land use, Tanjung Tokong has a wider variety of housing types than Pulau Tikus. These thematic map analyses indicate that greater residential mixed land use contributes to improved walkability.

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Figure 4: (a) Mixed land use (nonresidential) of Pulau Tikus, Penang (b) Mixed land use (nonresidential) of Tanjung Tokong, Penang
Source: The author

Figure 5: (a) Mixed land use (residential) of Pulau Tikus, Penang (b) Mixed land use (residential) of Tanjung Tokong, Penang
Source: The author

CONCLUSION

This study examined the effects of residential density, street connectivity and mixed land use on walkability in the Pulau Tikus and Tanjung Tokong neighbourhoods of Penang, Malaysia. Using GIS data, the study effectively identified key aspects of the built environment that were relevant to pedestrian activities through buffering and thematic map analyses.

The findings emphasize the significant influences of residential density, road intersection density and mixed land use on walkability patterns in the studied neighbourhoods. This observation is aligned with previous research, highlighting the importance of diverse amenities, ample road intersections and high residential density in fostering walkability (Baobeid et al., 2021a; Yang, 2023). Tanjung Tokong exhibits higher residential densities and a more significant number of road intersections, theoretically enhancing walkability by offering increased accessibility and route options. Despite these advantages, however, Pulau Tikus demonstrates a higher level of walkability, which is likely attributed to diverse community facilities and a well-integrated mixed land use environment within walking distance. This finding suggests that although factors, such as density and street connectivity, are pivotal for walkability, the availability of nearby amenities and varied housing options also play a crucial role in promoting pedestrian activities.

The current study adds to the growing literature on built environment factors and their effect on physical activities. Through the proficient utilisation of GIS data, spatial analysis has been proven effective in delineating and identifying components of the built environment that are crucial to walkability. This finding reaffirms the significance of integrating GIS methodologies into physical activity research. In addition, this study enhances urban walkability by promoting higher residential densities, increasing street connectivity and developing mixed-use areas with strategically located community facilities.

Although this study delves into the influence of various neighbourhood environmental factors on walkability, its scope remains limited by a narrow focus on a few determinants of walking behaviour. Broadening its examination to encompass critical elements, such as footpath conditions, accessibility, proximity to facilities, transportation options, topographical features, barriers and urban design attributes, including building orientation, lighting and green spaces, is imperative for future research (Giles-Corti & Donovan, 2003; Handy et al., 2002; Rodríguez & Joo, 2004). In addition, exploring a wider range of GIS variables associated with physical activities can provide a more comprehensive understanding of walkability. Doing so will more effectively help capture the long-term effect of urban planning interventions on pedestrian-friendly environments.

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DISCLOSURE STATEMENT

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

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