SPATIAL WALKABILITY INDEX (SWI) OF PEDESTRIAN ACCESS TO RAIL TRANSIT STATION IN KUALA LUMPUR CITY CENTER

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Abstract

Walkability is crucial for sustainable transportation in cities but measuring it may be difficult due to unclear criteria that could be used as well as the methods available. This study aims to measure the Spatial Walkability Index (SWI) of pedestrian access to rail transit stations in Kuala Lumpur City Center by using a comprehensive set of criteria including Connectivity, Land use mix, Comfort, Security, and Safety, which are all represented as ground measurable parameters in this study. SWI was derived using Analytical Network Process (ANP) and GIS analysis. ANP is a decision-making technique that uses pairwise comparison to derive the weightage of the ground measurable parameters which then were used to determine the SWI for pedestrians by using GIS proximity analysis. In this analysis, the weightage of parameters located on the road were used as basis in deriving the SWI. As a result, the SWI for pedestrian access to rail-transit stations in KL City Center was determined. The results revealed that the SWI for most of the area was in average level. Based on analysis conducted, the SWI was greatly influenced by its criteria, proving how ANP can aid in analyzing the SWI by incorporating the weightage of its criteria.

Keywords: ANP, GIS, MCDA, rail transit, walkability

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INTRODUCTION

Walkability is one of the keys in enhancing the sustainable transportation in a city. A walkable environment in a city could help in the reduction of reliance on private motor vehicles by encouraging more people to use active or public transportation instead. Walkability supports the concept of sustainable transportation, where it finds a proper balance between (current and future) environmental, social, and economic qualities (Litman, 2003; WCED, 1987). This concept is crucial in achieving sustainable transportation in the future due to its relation to supply, demand, and resource management (Rosalin et al., 2019). The concepts that imply the effect of economic, social, and environmental factors are Sustainable Development Goals (SDGs) and Transit Oriented Development (TOD).

SDGs are a global agenda for sustainable cities and communities to help transform our world toward a better sustainable future for people, the planet, prosperity, peace, and partnership. The SDGs set universal goals that balance the three dimensions of sustainable development, which are social, environmental, and economic (Department of Statistics Malaysia (DOSM), 2000). Malaysia is currently focusing on the development of the public transport infrastructure as the government sees the importance of public transportation to the urban community, especially the Rail Transit Service.

Besides, the TOD concept aims to help improve the economy and quality of life to manage a more comfortable and organized way according to their respective capabilities (Rahmat et al., 2016). The basic elements of TOD are designed for compact land use mix, creating a high-quality pedestrian-oriented environment and place at easily accessible locations. These elements must be included in a radius of 400 meters from the transit station. In Malaysia, the concept of TOD has been implemented by the Public Land Transport Agency (APAD) to plan public transport by applying the concepts of Mix, Densify, Compact, Shift, Walk, Cycle, Connect, and Transit.

Hence, the measurement of the walkability of pedestrian access to rail transit stations is required to support the concept of SDGs and TOD for sustainable transportation within the Kuala Lumpur City Center. Walkability is determined by calculating the walkability index. The walkability index is used to assess the walkability of the environment (Naharudin et al., 2020). In this study, the walkability index measurement was obtained using mixed methods, namely the Analytical Network Process (ANP) and Geographical Information System (GIS). The mixed methods translate the human perceptions of their feelings and experiences using the pedestrian access and spatially interpret them in the GIS environment. Therefore, this study was conducted to evaluate pedestrian access to rail transit stations in order to implement sustainable transportation in the Kuala Lumpur City Center.

LITERATURE REVIEW
Concept of Walkability
Walkability is related to how friendly an area of pedestrian networks is to the user (Lo, 2009; Abley et al., 2011; Ozbil et al., 2015; Frilund, 2017; Razali et al., 2017; Naharudin et al., 2017; Khalaf & Ja'afar, 2020; Jian et al., 2020; Wan Mohammad et al., 2021; Tobin et al., 2022). It may be influenced by the built environment in the walking area, such as amenities and facilities (Ariffin & Zahari, 2013; Lu, 2017; Ramakreshnan et al., 2020; Fonseca et al., 2022). A well-built environment should encourage more people to walk, and it should include the elements of safety and comfort. This is supported by the concept of Crime Prevention through Environmental Design (CPTED). The concept focuses on developing a good walking area to aid in crime prevention, thus encouraging more people to walk instead of relying on car or other private motor vehicles.

In addition to safety and comfort, walkability also focuses on convenience in terms of travelling time and distance. A reasonable walking distance of 30 minutes or less is a good practice for providing a walkable area (Both et al., 2022). Furthermore, walkability also focuses on having connectivity and accessibility of pedestrian network to various land use mixes, such as high density of neighborhood to the rail transit station and services area as this could also encourage different walking activities as people may travel for different purposes (Cervero, 2002; Hamid et al., 2015; Padon & Lamtrakul, 2019; Yun et al., 2020). Therefore, walkability could help in reducing the use of private vehicles and increase the ability to access the various mixed areas by foot as well as reduce our carbon footprint.

Walkability Criteria
Before measuring the walkability index, it is crucial to define the criteria and parameters. The criteria to measure the walkability index can be defined as the quantitative variables that are useful for demonstrating a complex phenomenon (EEA, 2005). However, it is challenging to select a set of criteria that provides comprehensive coverage of the reflected issue (Castillo & Pitfield, 2010). In this walkability index study, the criteria selection must be related to the definition of walkability, quantifiable, and understandable by users. The required data must be available easily at a reasonable cost (Li et al., 2009; Yigitcanlar & Dur, 2010; Zito & Salvo, 2011; Haghshenas & Vaziri, 2012).

To measure the walkability of pedestrian access to rail transit stations, it is essential to identify the appropriate criteria. In this study, the selection of criteria was based on a comprehensive review of previous studies and government policies. A thorough analysis of 52 previous studies was conducted to identify commonly used criteria. Additionally, a review of relevant government policies such as the Kuala Lumpur Structure Plan 2040, National Transport Policy 2019-2030, National Land Public Transport Master Plan, and

Putrajaya Structure Plan 2025 was conducted to align with Malaysia's planning and strategies for walkability issues.

Figure 1 summarizes the frequency of criteria employed in walkability studies. Based on the review, Security and Safety are the most commonly adopted criteria, appearing in 32 out of the 52 studies analysed. Close behind is Connectivity, utilized in 27 out of the 52 studies. Comfort on the other hand were employed in 21 out of 52 studies, indicating their significance in the research. Lastly, the criteria of Landuse Mix, appearing in only 15 out of the 52 studies.
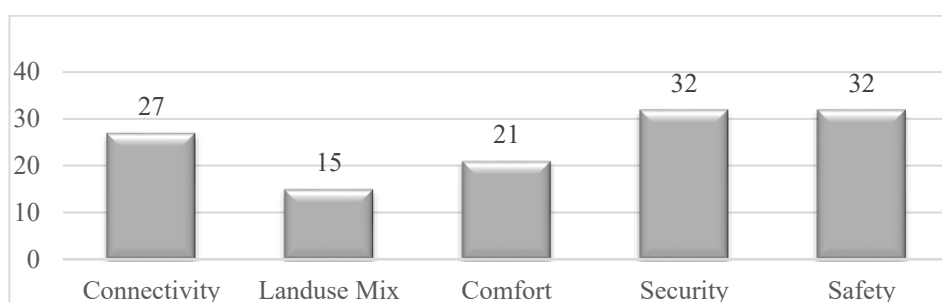

Figure 1: Summary of Criteria used in previous studies

MCDA

Multi-criteria decision analysis (MCDA) is a process of evaluating alternatives based on multiple criteria. Multi-attribute decision-making is used when the problem is to evaluate a finite set of alternatives and select the best one based on a set of attribute scores. Traditionally, multi-criteria decision-analysis techniques assume spatial homogeneity within a study area, although the criteria often vary across space in many decision-making problems (Tkach & Simonovic, 1997; Malczewski & Rinner, 2015).

MCDA is conducted using several techniques, namely Ranking, Rating, and Pairwise Comparison. Ranking techniques involve assigning priorities to criteria based on the decision maker's preferences (Malczewski & Rinner, 2015). Rating techniques involve assigning weights to criteria using a predetermined scale (Malczewski & Rinner, 2015). However, the effectiveness of these two techniques is limited by the number of criteria that need to be ranked or rated.

Pairwise comparison is a useful decision-making method, particularly in situations where multiple criteria are present to be considered. This technique allows decision-makers to determine the relative importance of each criterion and identify the most critical factors in the decision-making process. By comparing each criterion with every other criterion, pairwise comparison can help decision-makers create a hierarchy of criteria based on their relative importance. The Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP) is another popular method that uses pairwise comparison to prioritize criteria in

decision-making**.** The ANP pairwise comparison determines the importance of the criteria based on scale judgments from 1 to 9, with 1 representing the least important and 9 representing the most important.

ANP structures the MCDA into a network. Meanwhile, the AHP structures the decision problem into a hierarchy. Pairwise comparison is adopted into the ANP method where it is most appropriate since it allows interdependencies between the criteria despite the hierarchy (AHP), which is suitable for the walkability criteria that can influence each other (Saaty & Vargas, 2006). AHP is useful for simple decision-making problems with a limited number of criteria and alternatives, and ANP is more appropriate for complex decision-making problems with redundancies and feedback among criteria.

GIS in Measuring Walkability

The combination of GIS and MCDA approach is an efficient method for walkability analysis as it is capable of dealing with various factors that would potentially impact walkability (Nasef, 2021). The study by Naharudin et al. (2017) adopted the GIS-MCDA to measure the walkability to and from LRT stations in Kuala Lumpur City Center. A study by Nasef (2021) also used GIS-MCDA for walkability assessment between two counties in Sweden. Azlan and Naharudin (2020) used GIS-MCDA to measure the safety index for pedestrian paths. The combination of MCDA with GIS allows the integration of the ground data and human perception data collected via surveys or questionnaires as the attributes for better analysis and understanding of walkability. GIS is powerful in storing, editing, and manipulating spatial data for better analysis and visualization. GIS allows the ground data, such as facilities along the walking area, to be represented spatially in GIS software.

RESEARCH METHODOLOGY

Figure 2 shows the methodology flowchart used in this study. The study was conducted in five (5) stages.

The first stage involves criteria selection based on a literature review, which aims to analyze previous studies that measured the walkability index. As no universal criteria exist for measuring the SWI worldwide, this study combines human perception with spatial data to accurately measure the walkability index. In this study, the criteria selected are 1) Connectivity, 2) Land use mix, 3) Comfort, 4) Security, and 5) Safety. Seventeen (17) measurable ground parameters represent each criterion to calculate the SWI and present it spatially in the GIS environment.
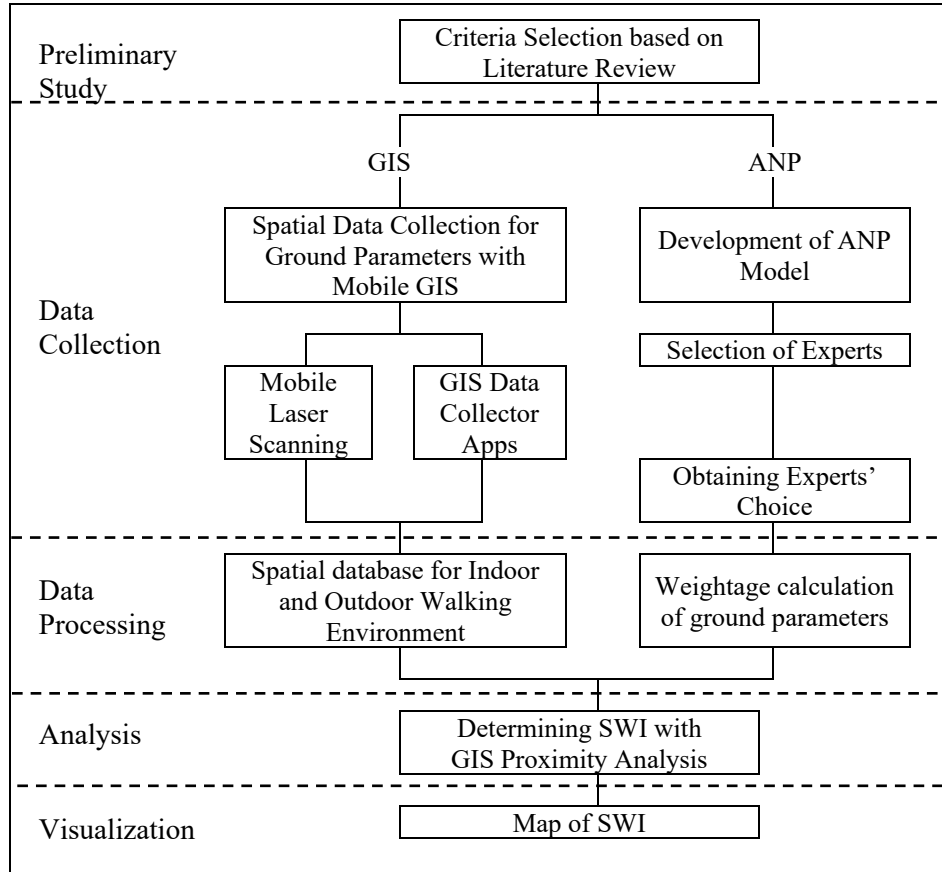
Figure 2: Methodology Flowchart

The GIS method uses mobile GIS to collect spatial data representing the ground parameters. The spatial data is divided into two, namely indoor and outdoor spatial data. A handheld mobile laser scanning was used for indoor data collection, and a smartphone GIS data collector was used for outdoor data collection. The spatial data collected was then imported into the GIS software. The data was then cleaned and edited to ensure the spatial data was ready for use in data analysis.

The ANP method involves several approaches that are developed from the ANP model to illustrate the relationships between the goals, criteria, and sub-criteria/elements. Then, the selection of experts was derived from ten experts who are familiar with the subject matter. The experts' ratings were obtained by the ANP survey, which was developed based on pairwise comparison techniques. Finally, the weightage for criteria and ground parameters was calculated based on Equation 1.

$$Aggregated\ priorities,\ W_k = \frac{\sum_{p=1}^{n} C^*_{kp}}{n}\ for\ all\ k = 1,2\dots n, \quad (1)$$

As mentioned previously, this study involved several experts. Thus, a group judgment needs to be derived using a geometric mean based on Equation 2.

$$Geometric\ mean = \sqrt[xn]{x1.x2.x3\dots.xn} \qquad (2)$$

$$where\ x1, x2, x3 \dots.. xn\ is\ the\ number\ of\ expert\ judgements$$

Then, the weightage for ground parameters was joined with the spatial data collected as their attributes. Then, near analysis, which is a part of proximity analysis, was used to obtain how many ground features were located within one road. Then, the total weightage of every route was calculated by using Equation 3.

$$SWI = (CON+MIX+CFT+SEC+SAT)\ X\ 100 \qquad (3)$$

Where;

SWI = Spatial Walkability Index
CON = Street Connectivity
MIX = Land Use Mix
CFT = Comfort
SEC = Security
SAT = Safety

ANALYSIS AND DISCUSSION
Weightage of Criteria and their Ground Parameter
The weightage for each criteria and their ground parameters were calculated based on the experts' choice given by selected group of experts from academicians and industrial experts, as summarized in Table 1. They were selected due to their experiences in studying and working on walkability issues. This study chose to have a balance number of academician and industrial experts to have a balance perspective from both sides. The experts' choices were obtained by using a pairwise comparison method as explained in previous section.

Table 1: Expert Judgements Descriptions

Experts		Descriptions
Academician	A1	Professor from local university
	A2	Professor from local university
	A3	Professor from local authority
	A4	Graduate student from local university
	A5	Graduate student from local university
Industrial Experts	I1	Local Authority
	I2	Local government from town planners
	I3	Local government from transport planners
	I4	Consultant
	I5	Consultant

The highest weightage value obtained was Security criteria, with a value of 0.245. Next, the highest weightage was Safety criteria, with a value of 0.224, followed by Connectivity criteria, with a value of 0.170. Meanwhile, the lowest weightage value was obtained for Land use criteria, with a value of 0.143.

Table 2: Final Weightage from group judgements

Criteria/Ground Parameter	Group Judgements
CONNECTIVITY	0.170
Intersection	0.095
Cul de sec	0.065
Dead End	0.060
LAND USE MIX	0.143
Residential Area	0.027
Job Area	0.023
Educational area	0.029
Industrial area	0.018
Existing Rail Transit Station	0.032
COMFORT	0.166
Benches	0.023
Signage	0.056
Information counter	0.030
Row of tree	0.062
SECURITY	0.245
Pedestrian Bridge	0.096
Pedestrian Subway	0.061
Street Light	0.109
SAFETY	0.224
Crossing Safety	0.063
Traffic Light	0.068

The rank of priorities for each criterion is similar to previous studies as shown in Figure 1, but there are also differences which may be due to how the criteria was interpreted in other studies that may not be similar with this study. For example, there are studies used Safety and Security interchangeably as they are quite similar. However, looking at the weightage of both, they are still the most important criteria in walkability as no matter what, pedestrian safety and security must always be prioritized the most.

The weightage derived for each ground parameters reflect how ANP works in deriving weightage for criteria and their subcriteria in a decision-making analysis. As mentioned earlier, experts have identified Security as the most important criterion for measuring the SWI. Thus, as in ANP, the weightage of subcriteria was influenced by weightage of main criteria, both Street Lights and Pedestrian Bridges weighed as the most important too. Similarly, the ground parameters for Landuse Mix, Existing Transit Stations, Educational Areas, Residential Areas, Job Areas, and Industrial Areas all have the lowest weightages among other ground parameters as they are influenced by the weightage of their main criteria (Landuse Mix) which is the lowest among all, thus they also received low weightages.

SWI of Pedestrian Access to Rail Transit Station
The calculated SWI were classified into five (5) classes by using Jenks method as shown in Table 3. The Classes of A to E, represent a distinct level of walkability where Class A indicates very high walkability; Class B is a high walkable area; Class C is moderate; Class D is low walkability; and Class E is very low walkability.

Table 3: SWI Classes

SWI	Class	Walkable
0.000 – 1.808	E	Very Low
1.809-5.915	D	Low
5.916– 13.137	C	Moderate
13.138 – 28.272	B	High
28.273 – 100.000	A	Very High

Based on Figure 2, most primary roads are classified as Class E with values 0 to 1.808. The primary roads, which connect the basic network within the state and link state capitals and towns, are the main access to private vehicles and public transport in Kuala Lumpur city center. The development of expressways and Federal roads, such as Lebuhraya Sultan Iskandar, Jalan Tun Razak, Jalan Damansara, and Jalan Istana, connecting the sub-urban with Kuala Lumpur City Center, has also increased the dependency on private vehicles. This is likely due

to the limited connection of pedestrian networks with primary roads, making pedestrian destinations unfeasible within walking distance.
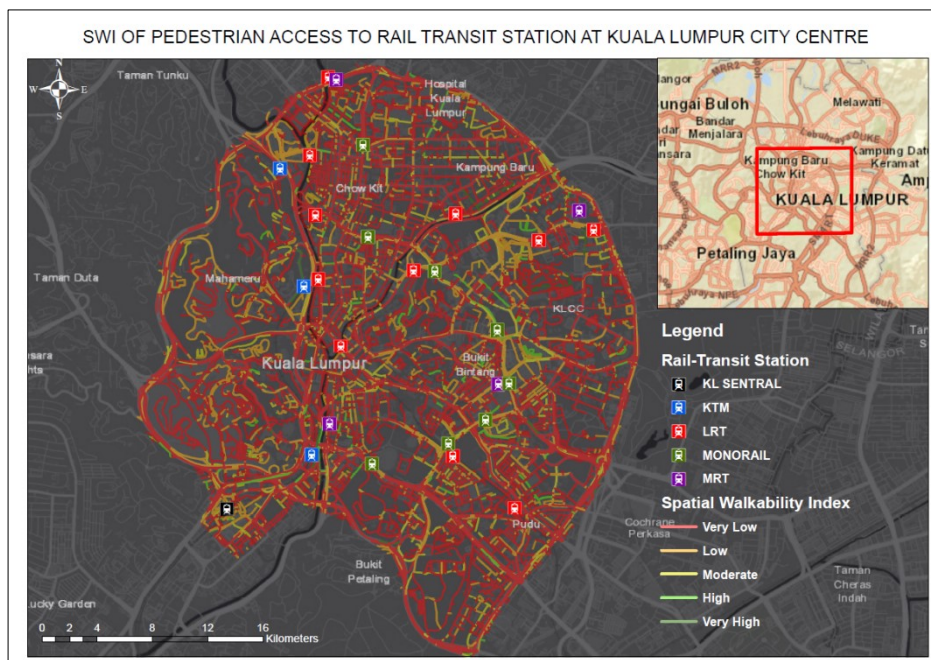

Figure 3: SWI of pedestrian access to rail transit station in KL City Center

However, in the crowded areas within the city, such as Bukit Bintang, KLCC, and Chow Kit, the resulting SWI was Class C, with values ranging from 5.916 to 13.137. These areas are known as the center of Kuala Lumpur, surrounded by various land use mixes, such as entertainment areas, commercial areas, working areas, and transit station areas. Additionally, these areas are attractive to local people and tourists due to exclusive shopping malls like Pavillion, Lalaport, Suria KLCC, Time Square, and SOGO. The well-built environment in these areas focuses on pedestrians, with facilities such as streetlights, pedestrian walkways, benches, and good signage, which contribute to walking activities. Moreover, the attractive areas are located within walking distance, eliminating the need for private vehicles.

The existing rail transit station is considered important for measuring the SWI. Among the four types of land use mixes, the weightage value for the existing rail transit station was higher, indicating its greater importance. The experts judged that access to rail transit stations are more important than access to residential, job, educational, and industrial areas. Rail transit is an essential public transport option in Kuala Lumpur City Center, comprising Light Rapid

Transit (LRT), Mass Rapid Transit (MRT), and monorail systems. This study obtained the SWI along the pedestrian access to a rail transit station in Classes A to C, as shown in Figure 4.
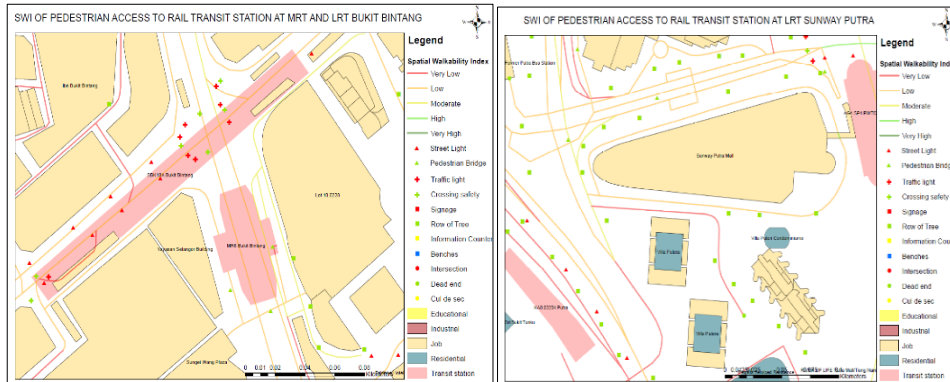

Figure 4: SWI of pedestrian access at MRT and LRT Bukit Bintang and Sunway Putra Mall varied from Class A to Class C
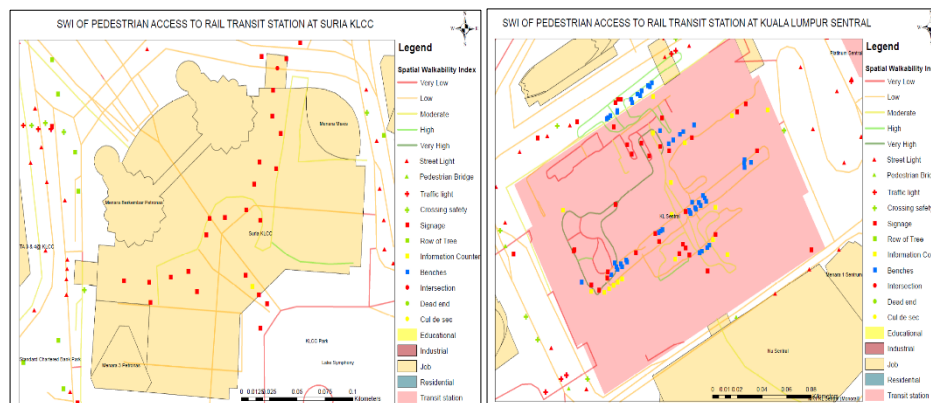

Figure 5: SWI of pedestrian access at indoor buildings, Suria KLCC and KL Sentral

In this study, the measurement of SWI is not limited to the outdoor environment but also includes the indoor building. Pedestrians tend to enter indoor buildings rather than walk around them as it reduces both distance and travel time. The buildings in Kuala Lumpur City Center, such as shopping malls and transit stations, were built to connect to outdoor pedestrian walkways to provide comfort and convenience to pedestrians and public transport users. Pedestrians can find various walking directions inside a building, which may not be possible with physical pedestrian access. Additionally, it protects them from the rain and hot sun. Figure 5 illustrates the SWI of pedestrian access in Suria

KLCC and Kuala Lumpur Station Center. The figure shows that ground parameters in indoor buildings, such as benches, signage, and information counters, have an average weightage value as assessed by the experts. Thus, the SWI of pedestrian access in these buildings falls between Classes B and C. These ground parameters help pedestrians navigate the buildings and reach their destinations.

SWI of Existing Rail Transit Station
The SWI for existing rail transit stations was determined through proximity analysis, which calculated the highest SWI of pedestrian access within a 400m buffer around the station. This was based on the TOD concept, which located transit stations within 400m walking distance in mixed land use areas. The intersection analysis was used to extract the SWI values for pedestrian access within 400m of each existing rail transit station. Table 2 summarizes the SWI values for each station, with KTM Bank Negara having the highest SWI of 99.507, followed by MRT Bukit Bintang with 99.489. These SWI values indicate that all the rail transit stations were properly planned and developed according to the TOD concept. While some stations have lower SWI values due to a lack of ground parameters, they still meet the TOD concept requirements as they are located within various land use mixes and at easily accessible locations.

Table 4: SWI of existing rail transit within selected rail transit station in Kuala Lumpur City Center

LRT/MRT Station	SWI of Existing Rail Transit
KL Sentral	99.116
LRT Hang Tuah	99.036
MRT Bukit Bintang	99.489
LRT Bukit Nanas	98.519
Ampang park	99.204
LRT PWTC	98.432
KTM bank negara	99.507
LRT KLCC	99.301
LRT Pudu	99.314

The location of KTM Bank Negara provides good connectivity between the nearby office work areas, Bank Negara, and the entertainment areas, namely SOGO, Jalan Tar, and Masjid India. These locations are aligned with the TOD concept, which requires rail transit stations to be situated in easily walkable areas with diverse land use mixes. The high SWI value of pedestrian access at LRT Bank Negara confirms its contribution to the SWI of existing rail transit stations. Additionally, the implementation of ANP techniques also contribute to the value of criteria used to measure the SWI.

METHODS' SENSITIVITY TEST FOR MEASURING SWI

To validate the methodology used for SWI measurement, a virtual Street Lights parameter was added in the analysis. This addition aimed to analyse enhance the accuracy and reliability of the methods. As a result, the SWI for the specific route was re-computed, and the classification was updated to Class C, as depicted in Figure 6(a).

Furthermore, the methods was validated by analysing the inclusion of indoor walking environment in the walkability assessment. This was necessary because this study highlighted the importance of including the indoor walking environment in walkability assessment when many other studies did not do so as discussed previously. Consequently, in this study, the indoor walking environment had contributed significantly to the highest SWI of the existing rail transit station. To evaluate the impact of the indoor walking environment, the data pertaining to indoor walking environment connecting the KLCC LRT station with Suria KLCC, was removed, and the SWI was recomputed. Upon re-computation, the SWI for the indoor area of Suria KLCC resulted in classifications ranging from class C to E (previously A to C) as illustrated in Figure 6(b). This validated the needs on including indoor walking environment in enhancing the walkability assessment.
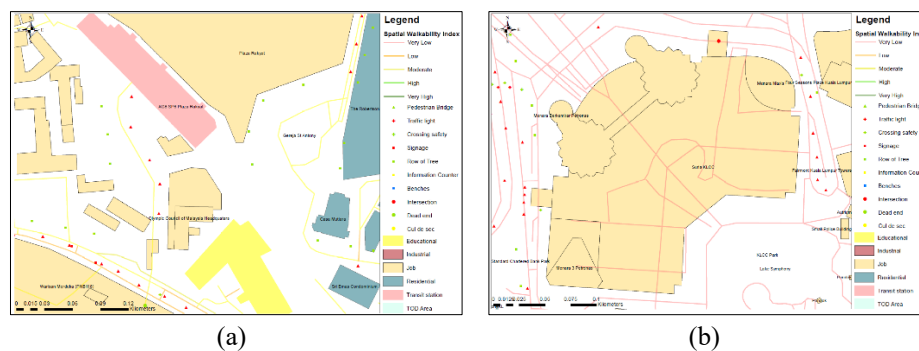

(a)	(b)

Figure 6: SWI Sensitivity Testing when Virtual Streetlights was added (a) and Indoor Environment removed (b)

In conclusion, the methods utilized in this study to compute the SWI underwent validation to assess its accuracy. The results demonstrated that the SWI were influenced by the inclusion or exclusion of various ground parameters within the analysis. This indicates that the framework is capable of capturing and reflecting the impact of different factors on walkability. Thus, the methods can be considered reliable and suitable for further analysis and research pertaining to walkability assessments.

CONCLUSION

This study aims to measure the walkability index of pedestrian access to rail transit stations. This study began by defining a set of criteria for measuring walkability through an inclusive review of literature and national policies. The validity of these criteria was further supported by verification from experts, including academics and urban planners. Furthermore, this study employed the ANP technique to determine the degree of importance for the walkability criteria. By utilizing pairwise comparison methods, the degree of importance for each of the criteria and their ground parameters were obtained. The preferences expressed by the experts were helpful in determining the final weightage, based on their experience with walkability issues. Then, by using the weightage, the SWI for pedestrian access to rail transit stations were determined by using GIS analysis. The computation within a GIS environment allows for better analysis and interpretation of the SWI, particularly through the visualization and mapping of results.

This study introduced novelty in measuring the walkability in Malaysia. It incorporated existing studies and national policies to establish criteria for measuring walkability. It also introduced the integration of indoor walking environments, making the SWI more realistic based on real-world situations. In conclusion, the study's walkability framework, despite low SWI in Kuala Lumpur City Centre, shows potential by including various criteria and indoor walking environments. This enhances walkability assessment compared to not including these factors.

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