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A DECISION SUPPORT TOOL FOR A WALKABLE INTEGRATED NEIGHBOURHOOD DESIGN USING A MULTICRITERIA DECISION-MAKING METHOD

Summary. Growing concern about transportation emissions and energy security has persuaded urban professionals and practitioners to pursue non-motorized urban development. They need an assessment tool to measure the association between the built environment and pedestrians' walking behaviour more accurately. This research has developed a new assessment tool called the Walkable Integrated Neighbourhood Design (WIND) support tool, which interprets the built environment's qualitative variables and pedestrians' perceptual qualities in relation to quantifiable variables. The WIND tool captures and forecasts pedestrians' mind mapping, as well as sequential decision-making during walking, and then analyses the path walkability through a decision-tree-

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making (DTM) algorithm on both the segment scale and the neighbourhood scale. The WIND tool measures walkability by variables clustered into five features, 11 criteria and 92 subcriteria. The mind-mapping analysis is presented in the form of a 'Walkability_DTM-Mind-mapping sheet' for each destination and the overall neighbourhood. The WIND tool is applicable to any neighbourhood cases, although it was applied to the Taman Universiti neighbourhood in Malaysia. The tool's outputs aid urban designers to imply adaptability between the neighbourhood environment and residents' perceptions, preferences and needs.

Keywords: walkability; walkable city; assessment model; pedestrian behaviour; decision-tree-making; decision support tool.

1. INTRODUCTION

Growing concern about transportation emissions and energy security has led to green urban development policies, strategies and techniques (Mikalsen et al., 2009). Urban and transportation professionals are trying to change conventional urban design and planning strategies in order to reduce the travel demand as much as possible. For instance, the compact city strategy supports the use of non-motorized modes of travel, which can considerably reduce CO_2 and other hazardous transportation emissions. Indeed, walkable urban design and planning can absolutely contribute to this goal. The professionals and practitioners of green urban development can persuade people to select walking rather than other available modes. Since the last decade, there is a number of studies enabling us to better understand and measure more accurately the association between the built environment and individuals' walking behaviour, with the goal of CO_2 reduction and fuel savings. Croucher et al. (2007) and Zhang et al. (2014) state that, although many studies find that walking behaviour is influenced by neighbourhood environment characteristics and form, the terminologies 'walkable' and 'walkability' are still being investigated (Tiwari, 2015; Forsyth, 2015). Saelens et al. (2003) find that residents who live in a high-walkable neighbourhood take almost 200% more walking trips than residents in low-walkable neighbourhoods. According to a report by Parsons Brinckerhoff Quade and Douglas Inc. (1993), the pedestrian-oriented environment of Oregon in the US state of Portland could achieve a 10% reduction in vehicle-miles travelled (Leslie et al., 2007).

2. RESEARCH BACKGROUND

Urban and transportation researchers have developed several urban walkability assessment models and decision support tools. The investigation into urban walkability assessment studies shows inconsistencies in the built environment's 'qualitative variables measurements' and 'perceptual qualities'. These studies highlight that the interpretation of qualitative and quantifiable variables is very difficult work. The research conducted by Ewing et al. (2006) and Saelans et al. (2003) indicates a tight relationship between 'perceptual qualities' and 'personal reactions' in walking behaviour studies. Meanwhile, the association between 'perceptual qualities' and 'personal reactions' in walkable neighbourhood design has not been studied in depth. Ewing et al. (2007) has proposed a measurement protocol for perceptual qualities and personal reactions as walkable urban design attributes; however, it has not yet been practically applied in empirical studies. Urban walkability is measured across diverse attributes and principles. For example, Bradshaw (1993) has developed a neighbourhood walkability rating system, which evaluates proximity and connectivity as the measures of walkability. His model involves a set of indicators including density, persons per acre, off-road parking spaces per household, the number of sitting spots per household, the chance of meeting someone while walking, the ranking of safety, the responsiveness of transit services, the number of neighbourhood places of significance, acres of parkland and pavements. Cervero and Radisch (1996) have measured the urban walkability based on mixed land use, grid-like street patterns, and integrated networks of pavements and pedestrian paths. Offering support, Leyden (2003) and Shafray and Kim (2017) state that a walkable neighbourhood, as a traditional or complete neighbourhood, can be found mostly in older cities, which have mixed land uses within walking distances. Ewing et al. (2007) have studied walkability based on the association between urban sprawl and traffic, air pollution, central city poverty and the degradation of scenic areas to highlight walkability aspects. The measures of their study included residential density, neighbourhood mixed land use, the strengths of centres and the accessibility of street networks. Leslie et al. (2007) have also measured walkability with regard to the ease of street crossing, pavement continuity, street connectivity and topography. Although the researchers have considered numerous attributes for walkability measurement, an integrated package of environmental and social quantities remains certain.

Existing urban walkability rating systems/tools have employed diverse methods to subjectively and/or objectively measure the association between built environment walkability and pedestrians' walking behaviour. The methods are: geographic information systems (GIS), audit tools, recall questionnaires, self-report tools and sensor motion. For instance, Lesli et al. (2007) and Bejleri et al. (2011) have applied GIS to measure built environment features (through connectivity, land use attributes, dwelling density and net retail area, which may influence adults' physical activity). Moudon et al. (2006) have developed an audit tool to measure environmental variables of neighbourhood walkability based on residential density, street block lengths around homes, distance from home to daily retail facilities and to different destinations. Reviewing the urban walkability assessment models shows that the auditing method is a the most selected and trustable method (Pikora et al., 2003; Clifton et al., 2007; Reid, 2008; Millington et al., 2009, Forsyth et al., 2010; Cerin et al., 2011). The current research has reviewed the existing auditing-based walkability assessment tools. Table 1 presents the content analysis of the reviewed models/tools, which are synthesized based on the type of data (i.e., subjective: 'S', objective: 'O'), unit setting (area, segment or intersection), 3Ds (design, density, diversity) and environmental quality aspects. According to Table 1, design and quality are the most important factors in urban walkability rating systems/tools.

Table 1
Content analysis on auditing-based urban walkability assessment models/tools

No.	Citation	Assessment model/tool	Data type	Unit setting	Design						Density	Diversity	Quality	
					Distance	Pavement	Roads	Intersection	Vehicles	Lateral	Demographic	Land use	Safety	Comfort/ convenience
1	O'Hanlon, and Scott, (2011)	Healthy Communities: The Walkability Assessment Tool	S & O	Area	-	√	-	√	-	-	√	-	-	√
2	Clean Air Initiative for Asian Cities Center (2011)	Walkability Survey Tool	S & O	Area	-	√	√	√	√	-	√	-	√	√
3	Cerin et al. (2011)	The Environment in Asia Scan Tool-Hong Kong Version (EAST-HK)	S & O	Area	-	√	-	√	-	√	-	-	√	-
4	Zaly Shah (2010)	P-Index	S & O	Segment	-	√	-	√	√	-	-	-	√	-
5	Michael et al. (2009)	Neighbourhood Audit Instrument (PIN3)	S & O	Area	√	√	√	√	√	-	√	√	√	-
6	Abley et al. (2009)	Community Street Review	S & O	Segment	-	√	√	√	√		√	-	√	-
7	Clifton (2007)	Pedestrian Environment Data Scan (PEDS) Tool	S & O	Segment	-	√	-	√	√	√	-	-	√	-
8	Zegeer et al. (2006)	Pedestrian Intersections Safety Index (Ped ISI)	S	Segment	-	√	√	√	√	-	-	-	√	-
9	Ewing et al. (2006)	Measurement Instrument for Urban Design Quantities Related to Walkability	S	Segment/ intersection	-	√	-	√	√	-	√	-	√	√
10	Hoehner et al. (2007)	Active Neighbourhood Checklist	S & O	Segment	-	√	√	√	√	√	-	√	-	√
11	Kim et al. (2004)	Level of Service (LOS) Indicator	S	Segment	-	√	-	-	-	-	√	√	-	-
12	Landis et al. (2005)	Pedestrian Level of Service Model (Modelling the Roadside Walking Environment)	S & O	Segment	-	-	√	√	√	√	-	-	√	-
13	Michael et al. (2009)	Senior Walking Environmental Assessment Tool (SWEAT)	S	Segment/ Intersection	√	√	-	√	-	√	-	-	√	√
14	Brownson et al. (2004)	Analytic and Checklist Audit Tool	S & O	Area	-	√	-	-	-	√	-	√	√	√
15	Harkey and Zegeer (2004)	PEDSAFE	S	Segment	√	√	-	-	√	-	-	-	√	√
16	Dannenberg (2004)	Walkability Audit Tool	S & O	Segment	√	-	√	√	√	-	-	-	-	√
17	DOT (2003)	Walkability Checklist	S	Area	-	√	√	√	√	√	-	-	-	√
18	Saelens et al. (2003)	Neighbourhood Environment Walkability Scale	S & O	Area	-	-	√	-	-	-	√	-	-	-
19	Wellar (2003)	Basic Walking Security Index	S & O	Intersection	-	-	√	-	-	-	-	-	-	-
20	Shriver (2003)	Walkable Places Survey (WPS) Tool	S & O	Area	√	√	-	√	√	√	-	√	√	√
21	Kirtland et al. (2003)	Perceptions of Environmental Supports Questionnaire	S	Area	√	√	-	√	√	√	-	√	√	√
22	Addy et al., (2004)	Environmental Supports for Physical Activity Questionnaire	S	Area	-	√	-	√	-	√	√	-	√	√
23	Yang et al. (2002)	Neighbourhood Quality Index	S & O	Area	-	√	√	√	√	-	√	√	√	-
24	National Center for Bicycling & Walking (2002)	Community Assessment Tool	S & O	Area	√	-	√	√	√	-	√	√	√	-
25	Gallin (2001)	Pedestrian Level of Service	S & O	Segment	-	√	√	√	√	√	-	√	√	√
26	Portland Planning Department (2002)	Pedestrian Potential Index	S & O	Area	√	√	-	√	-	-	-	-	√	√
27	Jaskiewicz (2001)	Pedestrian Level of Service	S & O	Segment	-	√	√	√	√	√	-	-	√	-
28	Khisty (1997)	Qualitative Level of Service	S & O	Area	√	√	√	√	-	-	-	-	√	√
29	Fort Collins (2002)	Pedestrian Level of Service	S	Segment	√	√	√	√	√	-	-	√	-	√
30	Bradshaw (1993)	Walkability Index	S & O	Area	-	√	-	-	√	-	√	√	√	√
31	Brinkerhoff (1993)	Pedestrian Environmental Factor	S	Segment	-	√	-	-	√	√	-	-	√	√
				Frequency	10	27	16	25	21	13	11	12	24	19

Note: 'S' refers to subjective-based research and 'O' refers to objective-based research.

3. PROBLEM STATEMENT

A few urban walkability rating systems/tools have used multicriteria decision-making (MCDM) methods, namely: 1) Pedestrian Infrastructure Prioritization (PIP) Decision System (Moudon et al., 2006) from the University of Washington, US; 2) PEDSAFE (Harkey and Zegeer, 2004) from the University of North Carolina, US; and 3) Pedestrian Performance Measure System (Dixon et al., 2007) from the University of Delaware, US. These assessment tools have been developed for transportation planning and urban planning purposes. Meanwhile, there is no walkability assessment model for urban designers to evaluate pedestrians' decision-making in route selection. On the other hand, policymakers, urban planners and designers are seeking to develop an assessment tool for measuring neighbourhood walkability coupled with the inclusive users' (i.e., pedestrians') cognitive behaviour, which is applicable globally. In this regard, Badland and Schofield (2005) state that there is a crucial need to systematically enhance existing assessment tools regarding the end user approach (i.e., pedestrian approach). In particular, pedestrians' sequential decision-making about route selection has not been applied in the existing urban walkability assessment tools, while sequential decision-making (as DTM) has the potential to be applied in pedestrian behaviour analysis. Pedestrians' sequential decision-making can cover two descriptive focuses: how pedestrians actually make decisions and how a normative vision should be made, based on their decisions (Svenson, 1998).

Therefore, capturing and forecasting pedestrians' sequential decision-making during walking require advanced walkability assessment modelling integrated with the DTM method. Such modelling can evaluate how a neighbourhood's physical and environmental qualities influences residents‘ (i.e., pedestrians') walking behaviour, in turn warranting their DTM approach. In this regard, the current research has developed a new walkability assessment tool called the WIND support tool. Juxtaposing the outputs of this tool helps urban designers to make future decisions about path development through implying much more adaptability between neighbourhood environment characteristics and residents' needs, preferences and perceptions.

While there are diverse walking typologies depending on destination type and activity schedule (including walking for shopping, walking to school, walking to work, walking for recreation, walking for shopping, walking to religious places), the scope of the current study is walking for shopping. This type of walking is a non-scheduled walking; thus, a broad range of sampling size is offered, including older people, young people, children and parents, in the form of individuals or groups with a wide range of preferences, satisfaction levels and attitudes.

4. MATERIALS AND METHODS

4.1. Variables

The WIND support tool has been developed based on two philosophical approaches to defining walkability. This model indicates that walkability can be been defined as a 'well-designed' walkable urban environment or a 'most-in-use' walkable urban environment. The current study presents the 'most-in-use' concept of urban walkability, as the other concept has been presented in other work. Urban designers and planners claim that walkable paths have a pedestrian-oriented design. But, in reality, such paths may not be used by pedestrians. In this regard, the 'most-in-use' urban walkability assessment model aims to investigate and quantify the paths that reflect pedestrians' needs and preferences, which are neither well-designed nor facilitated; pedestrians are mostly looking for a short path to their destination. Most-in-use walkability is a measure of the urban form and the quality and availability of pedestrian infrastructure availability, including facilities and amenities, as well as the promotion of efficiency and safety of pavements, walkways and pedestrian bridges.

According to Kockelman (1997) and Clifton et al. (2007), it is essential to indicate a comprehensive list of walkability variables for use in walking assessment modelling. To date, a few walkability variables have been empirically analysed and measured for their influence on walking behaviour. The current research has identified a comprehensive list of walkability variables clustered into three layers (Layer 1: features, Layer 2: criteria, Layers 3: subcriteria) in association with pedestrians' decision-making and route selection behaviours. The list of walkability variables has been extracted through an in-depth critical review of walkability assessment studies. An expert input study was conducted to validate the list of walkability variables. Eight experts with knowledge and experience of green urban development, decision-making science, cognitive behavioural science and assessment tool development have validated them as presented in Table 2. In this table, the 'most-in-use' urban walkability assessment model involves 108 walkability variables, clustered into five walkability features, 11 walkability criteria and 92 walkability subcriteria.

4.2 Mind-mapping method

Behavioural mind mapping is a method related to various aspects of behaviour in physical spaces where people are observed (Ittelson, 1986). Ittelson (1986) expresses that behavioural mapping is a specific technique for studying environmental influences on behaviour. For him, mind mapping or map building is a mental-mapping approach to investigate why and how people reach a place. Mind mapping captures and indicates the spatial knowledge of people (i.e., respondents) of their living area, as well as the spatial relation of a place to adjacent structures including paths and routes. In this regard, the WIND support tool has employed the mind-mapping method as a trustable measure for capturing pedestrians' individual rationale for their preferred route from the origin (i.e., home) to three destinations (i.e., shopping centres). Mind mapping was included in the first part of a questionnaire survey form, which is presented in the following section.

Table 2

Summary of literature review and expert study for identifying path walkability assessment variables

Features	Criteria	Subcriteria	EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8	Con.	Non-validated subcriteria
F1. Sense of safety and security [*Ref.:* Bradshaw, 2003; Moudon, 2002; Harkey and Zegeer, 2004; Saelens et al., 2003; Lynch and Hack, 1984; Ewing, 2000; Boarnet, 2003; Crane and Crepeau, 1998; Jacobs et al., 2002; Duncan et al., 2005]	**F1.C1.** Safety facilities on pavements	**S15.** Driveway dropped kerbs, **S23.** Existence of pedestrian crossing, **S2.** Width of utility zones, **S19.** Shelters, **S4.** Length of tree canopies, **S10.** Releasing visual obstacles/nuisances, **S16.** Pavement steepness, **S26.** Existence of bike lanes, **S24.** Existence of on-street parking, **S32.** Informing intersection blindness, **S33.** Mid-block crossing, **S34.** Providing an overbridge	■	■	■	□	■	◧	■	■	V.	Except for these sub-criteria, not approved
	F1.C2. Slowing traffic speed at pedestrian crossing	**S23.** Existence of pedestrian crossing, **S29.** Number of traffic lanes, **S14.** Traffic signals, **S30.** Traffic calming devices, **S37.** Drivers' respect for pedestrians, **S36.** Slow traffic speed	■	■	■	◧	■	■	■	◧	V.	Except for these subcriteria, not approved
	F1.C3. Security during the day and at night	**S7.** Pavement lighting, **S13.** Number of intermediaries, **S4.** Length of tree canopies, **S8.** Number of street trees, **S10.** Releasing visual obstacles/nuisances, **S32.** Uncrowded route, **S35.** Street surveillance, **S47.** Street-facing entrances, **S49.** Street-level façade transparency, **S46.** First-floor use of buildings, **S48.** Upper-floor windows	□	■	■	■	■	■	□	■	V.	Except for these subcriteria, not approved
F2. Connectivity [*Ref.:* Boarnet, 2003; Emery, 2003; Harkey and Zeeger, 2004; Boarnet, 2004; Ewing, 2005; Moudon, 2002; Duncan et al., 2005]	**F2.C1.** Pavement accessibility	(*) Pavement networking, **S5.** Length of sidewalks, **S1.** Width of walking zones, (*) Continuity of diverse activity, **S6.** Length of segments, **S32.** Informing intersection blindness, **S52.** Street signage	■	◧	■	■	◧	■	■	■	V.	Except for these subcriteria, not approved
	F2.C2. Physical connectivity	**S16.** Pavement steepness, **S47.** Street-facing entrances, **S52.** Street signage, **S6.** Length of segment	■	■	■	■	■	■	■	□	V.	Except for these subcriteria, not approved
F3. Comfort [*Ref.:* Dixon, 1996; Moudon, 2002; Harkey and Zegeer, 2004; Saelens et al., 2003; Jacobs et al., 2002; Ewing, 2000, Boarnet, 2003]	**F3.C1.** Physical comfort	(*) Good location of service utilities, **S3.** Amount of street furniture, **S7.** Pavement lighting, **S13.** Number of intermediaries, **S19.** Shelters, **S25.** Planting deciduous trees, **S31.** Existence and width of medians, **S24.** Existence of on-street parking, **S38.** Human ergonomic scale	◧	■	■	◧	◧	■	■	■	V.	Except for these subcriteria, not approved
	F3.C2. Environmentally comfort	**S1.** Width of walking zones, **S11.** Types of sidewalk pavement, **S8.** Number of street trees, **S16.** Pavement steepness, **S20.** Windy climate, **S22.** Uncrowded route, **S51.** Height and types of fences, S40. Street reserve	■	■	■	◧	□	■	■	■	V.	Except for these subcriteria, not approved
F4. Convenience [*Ref.:* Southworth and Ben Joseph, 2003; Boarnet, 2003; Emery, 2003; Harkey and Zeeger, 2004; Boarnet, 2004; Ewing, 2005]	**F4.C1.** Functionality of diverse activities	**S29.** Number of traffic lanes, **S31.** Existence and width of medians, **S6.** Length of segment, **S28.** Width of traffic zones, **S44.** Width of buildings	■	◧	■	■	◧	■	■	■	V.	The rest not approved
	F4.C2. Easy access without obstacles	**S10.** Releasing visual obstacles/nuisances, **S14.** Traffic signals, **S16.** Pavement steepness, **S22.** Uncrowded route, **S24.** Existence of on-street parking, **S33.** Mid-block crossing, **S51.** Height and types of fences, **S53.** Public parking next to street, **S36.** Slow traffic speed	□	■	◧	■	■	■	■	■	V.	Except for these sub-criteria, not approved
F5. Attractiveness and aesthetics [*Ref.:* Southworth and Ben Joseph, 2003; Boarnet, 2003; Emery, 2003; Harkey and Zeeger, 2004; Boarnet, 2004; Ewing, 2005; Moudon, 2002]	**F5.C1.** Street enclosure	**S15.** Width of kerb-to-kerb roadway, **S2.** Width of utility zones, **S41.** Building setbacks, **S55.** Width of buffer zone, **S40.** Street reserve, **S42.** Diversity of buildings, **S50.** Mixed functionality of adjacent buildings, **S54.** Enclosure ratio	■	◧	■	■	■	□	■	■	V.	Except for these sub-criteria, not approved
	F5.C2. Vibrancy and vitality	(*) Planting diversity, **S7.** Pavement lighting, **S9.** Width of landscaping strips, **S11.** Types of pavement surface, **S17.** Intangible senses, **S25.** Planting deciduous trees, **S4.** Length of tree canopies, **S8.** Number of street trees, **S12.** Building a vital atmosphere on pavements, **S18.** Street interface, **S43.** Height of buildings, **S48.** Upper-floor windows, **S45.** Skyline height	■	■	■	◧	■	■	□	■	V.	Except for these sub-criteria, not approved

Note: **Citation:** refers to preliminary literature results during the first research methodology step. **(*):** refers to walkability subcriteria added in the process of closed group discussions with experts. **EX:** first expert judgement, **Con.:** conclusion (referring to the overall agreement of researchers on expert validation in the second research methodology step)■ the expert approved this parameter. □ the expert did not approve this parameter. ◧: the expert fairly approved this parameter. **Con.**: refers to the conclusion of expert input validations. **V.**: this flexible parameter is validated based on having more than 80% agreement (mean and/or mentioned).

4.3 Decision-tree-making method

The WIND support tool uses the DTM method for collecting and analysing pedestrians' decision-tree patterns in route selection from the origin (i.e., their home) to three destinations (i.e., shopping centres). The DTM method has four potential advantages to be exploited when developing the WIND support tool. The following briefly explains these advantages:

- First, most of the previous walkability studies have focused on urban and neighbourhood scales, while they are lacking with data at the individual (i.e., pedestrian) level (Boarnet, 2005). These walkability studies have also assigned the same environmental score to all residents in a neighbourhood without involving the route's quality data and information (Park, 2008). Subsequently, the environmental characteristics of the selected route were inaccurately generalized to characteristics of the overall neighbourhood (Krizek, 2006). Nevertheless, the individual's personal walking experience and preferences may vary (Park, 2008). Therefore, the urban scale has shortcomings in terms of the individual's walking behaviour analysis in the route selection study.
- Second, walkability studies on the urban scale erroneously treat all streets in a neighbourhood equally (Schlossberg, 2004), while route-level walkability based on DTM enables us to assign a score to each street and segment.
- Third, self-selection is one of the drawbacks of neighbourhoods' comparative studies (Cervero and Duancan, 2003). According to Handy et al. (2006), the deficit obtained from such studies might be confounded with individuals' preferences and attitudes, such that researchers are not able to identify whether an environmental factor or human attitude affects their walking behaviour. Indeed, pedestrians' DTM analysis may not be completely free from self-selection, but could be a trustable alternative to find out the main causes of self-selection. Accordingly, the current plans to analyse pedestrians' DTM in terms of route selection seek to clarify further the relation between environmental factors or pedestrian attitude.

The WIND support tool determines the walkability weight of the facilitated paths within the neighbourhood area by pedestrians' DTM. The analysis of path walkability variables (including Layer 1, Layer 2 and Layer 3) will follow by using Equations 1 to 3. It will indicate the priority of path walkability needs in this under-surveyed neighbourhood area. Equations 1 and 1a are used to evaluate the response to walkability variables, including Layer 1 (walkability features (F_i)), Layer 2 (walkability criteria (C_j)) and Layer 3 (walkability subcriteria (S_k)). The 'average rate value' of each variable $(AvRVF_iC_jS_k)$ is calculated by the following equation;

$$AvRVVF_iC_jS_k = \frac{\sum_{r=1}^{n} RVVF_iC_jS_k \text{ (rate value of each variable by respondent nomber (r))}}{\text{Total number of respondent (n)}} \quad (1)$$

where '$R_rRVVF_iC_jS_k$' is the abbreviation for rate value of each variable $(RVVF_iC_jS_k)$ by r^th respondent (Rr). It will be calculated using Formula 1a.

$R_rRVVF_iC_jS_k$ is the 'minimum possible rate of the variable by respondent' (rate of the variable by r^th respondent - 1). (1-a)

Equation 2 is used for variables involved in Layer 1 (i.e., walkability features).

The 'actual rate value' of each walkability feature $(AcRVF_i)$ =

$$(AvRVF_i) \times \sum_{j=1}^{3} a(AvRVF_iC_j \times Max(AvRVF_iC_jS_1 : AvRVF_iC_jS_k) \quad (2)$$

where:

- F_i is the feature number 'i', in which 'i' can be 1, 2, 3, 4 or 5
- C_j is the criteria number 'j', in which 'j' can be 0, 1, 2 or 3
- S_k is the subcriteria number 'k' which 'k' can be 0, 1, 2, 3, 4, 5, 6, 7 or 8

The WIND tool shows the grounded capacity of each path segment to be benchmarked in the area of study. Based on the score of each variable in Layer 3 ($F_iC_jS_k$), it is possible to propose the final priority of the destination walkability (meco-scale). The model results can be used as the benchmark for urban managers in pursuit of future neighbourhood development/redevelopment and corrective actions. This process will provide a walkability index for two applications: firstly, a walkability index for each destination (meso-scale); second, a walkability index for the overall neighbourhood area (macro-scale).

The WIND support tool has formulated the following model to measure a 'path segment walkability index score' (as the micro-scale) (Equation 3):

Path segment walkability index score F_i = $\frac{\sum_{i=0}^{5} AcRVFi}{46.4}$ = $\frac{1}{46.4}$ ×

(3)

		AcRVF of 'connectivity'		**AcRVF** of 'comfort'		**AcRVF** of 'convenience'		**AcRVF** of 'attractiveness and aesthetics'
([ ]	+	[ ]	+	[ ]	+	[ ]	+	[ ])

5. ANALYSIS

5.1. Mind-mapping analysis

The research has applied the WIND support tool to the Taman Universiti neighbourhood in the city of Skudai, Malaysia. The Taman Universiti neighbourhood has various land uses (including residential, commercial, school, mosque, shopping centre and public facilities) located within standard pedestrian walking distances. As the research has focused on walking for shopping, the Taman Universiti neighbourhood was selected due to its accessibility to three large-scale centres. In addition, in the Taman Universiti neighbourhood, the distance between each pair of shopping canters is a standard distance (400-500 m = 5 min).

Part I of the questionnaire illustrated three identical images from Google Maps of the Taman Universiti neighbourhood, on which each shopping centre was marked separately (see Figure 1). This part asked each participant to, first, mark their home location on the map and, second, draw their preferred path from home to each of shopping centres, one by one. A total of 120 residents participated in the survey, representing the 2,500 householders in the Taman Universiti neighbourhood. The WIND support tool identifies the most-in-use path by overlapping all paths drawn by respondents on a single map. Then, it measures the walkability weight of each walkability variable. The weights show the impact degree of each walkability variable in the respondent's decision-making.

Fig. 1. Taman Universiti neighbourhood boundary in the city of Skudai, Malaysia (the location of the three shopping centres is marked)

The mind-mapping data were collected via the survey and then analysed, showing that the three maps corresponded to each destination (i.e., a shopping centre). The walkability of the path segments was identified through different indexing grades shown with different colour codes from Grade 1 (i.e., superior) to Grade 6 (i.e., not certified) (see Table 3). The grades have been identified, based on the frequency of the selection of the segment by respondents.

Table 3

Indexing grades of the path walkability assessment model

Grade	Colour code	Frequency in selection	Description and recommendations
Superior		>110	▪ Well-designed and pedestrian-friendly constructed pavement, which satisfies users; minor improvements, if any, needed
Good		90-110	▪ Constructed pavement accommodates users; minor improvements may lead to a superior rating
Fair		50-90	▪ Usable pavement on which some users do not feel a high level of walkability; improvements, such as better facilities and amenities, may be needed
Poor		20-50	▪ Usable pavement on which many users do not feel a high level of walkability; significant improvement, such as a lack of facilities and amenities, probably needed
Very Poor		5-20	▪ Non-usable pavement on which users do not even feel a medium level of walkability, with low standard conditions, should be improved
Not certified		0-5	▪ No pavement or walkway

Figure 2 illustrates the result of the mind-mapping data analysis of path segment walkability to the shopping centre A. As can be seen, the main path to Shopping Centre A has been determined as the well-designed route, which has an acceptable level of safety, security and comfort. There are some path segments that have been identified as less well-designed path segments, while there are a few path segments that have not even been recognized as well-designed paths.

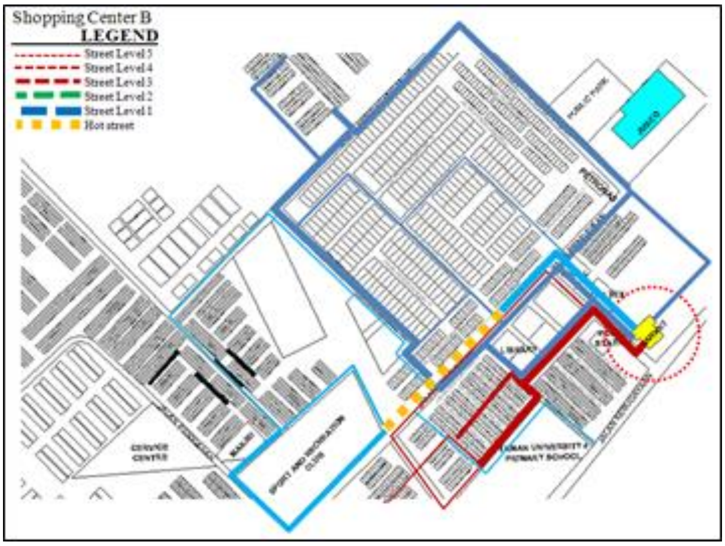

Fig. 2. Result of the mind-mapping analysis of the path segment walkability index for Shopping Centre A

Figure 3 shows the result of the mind-mapping data analysis of path segment walkability in Shopping Centre B, while Figure 4 illustrates the result of the mind-mapping data analysis for Shopping Centre C. Similar to the data analysis result for Shopping Centre A, the main streets have been determined as well-designed paths towards the respective destinations.

Fig. 3. Result of the mind-mapping analysis for the path segment walkability index for Shopping Centre B

Fig. 4. Result of the mind-mapping analysis for the path segment walkability index for Shopping Centre C

5.2. Decision-tree-making analysis

Part II of the questionnaire was designed to capture residents' DTM towards each of the shopping centres. The data were collected using the combined scaling method (CSM), as it can indicate the participants' responses through scoring and ranking the items (Stangor, 2007). The CSM is also able to either rank or sort the items (Stangor, 2007) and assigns a unique number to the index components in a 'minimum to maximum' range. The participants were asked to separately sort the layers of walkability variables.

Example - F3. Comfort for Shopping Centre A:

As an example, the DTM data collection and analysis for the model for the feature 'comfort' (F3) for Shopping Centre A is presented as follows. The feature layer (Layer 1) involves five items, where 1 is the 'most important' item and 5 is the 'least important'. The participants were asked to separately conduct the sorting for each of the three destinations (i.e., shopping centres). Table 4 shows the responses collected and analysed by applying the WIND support tool's equations. Referring to Table 4, the first row shows the sorting range of the layer (here, Layer 1 features), which is from 1 to 5. The second row indicates the number of times that each sorting scale was selected. For instance, the feature was selected as the 'most important' item on seven occasions, while it was selected as the 'least important' item on two occasions. The third row indicates the weight value of each sorting. The 'most important' item has the highest weight value (equal to 5), while the 'least important' item has a value equal to 1. The fourth row multiplies the second row with the third row, and the total sums up the values of the fourth row. The total number should be subtracted from the minimum of the range to find out the 'actual weight value' of the feature within the 'minimum to maximum' range. To find out the 'actual satisfactory percentage', the 'actual weight value' should be divided by the 'limitation range'. For example, when an 'actual weight value' of 56 is divided by a 'limitation range' of 96, this equals 0.5833; therefore, the 'actual satisfactory percentage' is 58.33%. This DTM calculation process has been repeated for all walkability variables.

Table 4

DTM analysis of F_1: comfort for Shopping Centre A

Ranking score		1	2	3	4	5
Quantity		7	2	9	4	2
Value		5	4	3	2	1
Quantity × value		35	8	27	8	2
Total		80				
Actual weight value		80-24=56/96=58.33				

Total (sum): 35+8+27+8+2=80
Maximum: 24×5=120
Minimum: 24×1=24
Range (maximum-minimum): 120-24=96
Actual weight value of 'comfort' in the 'range' (total-minimum): 80-24=56
'Actual satisfactory percentage' of

'comfort': $= \frac{ActualWeightValue}{Range} \times 100\% = \frac{56}{96} \times 100\% = 58.33\%$

Table 5 presents the walkability weights of the subcriteria for three destinations (i.e., Shopping Centres A, B, and C). The walkability survey shows that the subcriterion 'driveway dropped kerbs' was the most important variable ($WIND_{F1.C1.S1.}$=25.43%) influencing pedestrians in their route selection for Shopping Centre A. Meanwhile, 'street-facing entrances' and the 'amount of street furniture' were the most important variables for Shopping Centres B and C, i.e., $WIND_{F2.C2.S2.}$=24.19% and $WIND_{F3.C1.S2.}$=29.74%, respectively.

Table 5 also presents the overall neighbourhood walkability, which is the average of walkability weights for the three shopping centres. The WIND survey analysis determines that walkability in the Taman Universiti neighbourhood is mainly influenced by the existence of a pedestrian crossing ($WIND_{F3.C1.S2.}$=24.25%); in contrast, street surveillance has the least impact on the Taman Universiti neighbourhood's walkability ($WIND_{F1.C3.S7}$=4.82%).

Table 5

Weights of subcriteria for three shopping centres (A, B, C) and overall neighbourhood

Walkability features	**Walkability criteria**	**Walkability subcriteria**	**Shopping Centre A (%)**	**Shopping Centre B (%)**	**Shopping Centre C (%)**	**Overall neighbourhood (%)**
F1. Sense of safety and security	**F1.C1.** Safety facilities on pavements	**F1.C1. S1** Driveway dropped kerbs **F1.C1. S2** Existence of pedestrian crossing **F1.C1. S3** Width of utility zones **F1.C1. S4** Shelters **F1.C1. S5** Length of tree canopies **F1.C1. S6** Releasing visual obstacles/nuisances **F1.C1. S7** Pavement steepness	25.43 27.54 24 24 15.53 8.1 21.67 12.59 9.54 4.76 10.05	19.12 19.42 16.73 12.34 10.68 3.22 11.56 8.23 6.89 6.87 18.78	18.64 25.8 11.25 12.82 10.28 13.82 7.57 8.77 14.37 9.04 16.94	21.06 24.25 17.33 16.39 12.16 8.38 13.60 9.86 10.27 6.89 15.26

		F1.C1. S8 Existence of bike lanes **F1.C1. S9** Existence of on-street parking **F1.C1. S10** Informing intersection blindness **F1.C1. S11** Mid-block crossing **F1.C1. S12** Providing an overbridge	10.81	8.62	8.92	9.45
	F1.C2. Slowing traffic speed at pedestrian crossing	**F1.C2. S1** Existence of pedestrian crossing **F1.C2. S2** Number of traffic lanes **F1.C2. S3** Traffic signals **F1.C2. S4** Traffic calming devices **F1.C2. S5** Drivers' respect pedestrians **F1.C2. S6** Slow traffic speed	24.96 19.07 24.36 3.7 4.76 11.78	8.23 14.69 15.68 4.70 5.48 12.67	17.66 19.39 22.16 11.42 7.90 19.47	16.95 17.72 20.73 6.61 6.05 14.64
	F1.C3. Security in the day and at night	**F1.C3. S1** Pavement lighting **F1.C3. S2** Number of intermediaries **F1.C3. S3** Length of tree canopies **F1.C3. S4** Number of street trees **F1.C3. S5** Releasing visual obstacles/nuisances **F1.C3. S6** Uncrowded route **F1.C3. S7** Street surveillance **F1.C3. S8** Street-facing entrances **F1.C3. S9** Street-level façade transparency **F1.C3. S10** First-floor use of buildings **F1.C3. S11** Upper-floor windows	19.07 13.94 9.58 11.48 8.4 20.04 6.35 22.87 11.04 9.94 8.03	6.97 8.55 9.49 6.48 4.6 12.06 2.97 7.87 9.45 9.49 14.73	12.64 10.93 14.57 19.95 5.57 18.94 5.14 14.78 20.21 18.97 6.45	12.89 11.14 11.21 12.64 6.19 17.01 4.82 15.17 13.57 12.80 9.74
F2. Connectivity	**F2.C1.** Pavement accessibility	**F2.C1. S1** Pavement networking **F2.C1. S2** Length of pavements **F2.C1. S3** Width of walking zones **F2.C1. S4** Continuity of diverse activity **F2.C1. S5** Length of segments **F2.C1. S6** Informing intersection blindness **F2.C1. S7** Street signage	22.92 22.5 21.9 9.63 11.36 25.67 8.44	16.48 15.03 17.18 12.39 10.96 8.26 7.93	18.96 24.64 27.49 21.35 16.04 15.50 11.03	19.45 20.72 22.19 14.46 12.79 16.48 9.13
	F2.C2. Physical connectivity	**F2.C2. S1** Pavement steepness **F2.C2. S2** Street-facing entrances **F2.C2. S3** Street signage **F2.C2. S4** Length of segment	19.85 21.66 7.44 21.40	20.7 24.19 9.90 22.89	13.05 21.93 20.13 18.90	17.87 22.59 12.49 21.06
F3. Comfort	**F3.C1.** Physical comfort	**F3.C1. S1** Good location of service utilities **F3.C1. S2** Amount of street furniture **F3.C1. S3** Pavement lighting **F3.C1. S4** Number of intermediaries **F3.C1. S5** Shelters **F3.C1. S6** Planting deciduous trees	21.37 16.55 15.80 9.63 10.38 26.67 8.48 7.82 18.65	17.47 15.90 12.92 10.21 10.65 15.12 8.09 10.08 9.45	25.88 29.75 14.67 14.67 11.66 14.94 19.68 13.80 8.62	21.57 20.73 14.46 11.50 10.90 18.91 12.08 10.57 12.24

		F3.C1. S7 Existence and width of medians **F3.C1. S8** Existence of on-street parking **F3.C1. S9** Human ergonomic scale design				
	F3.C2. Environmental comfort	**F3.C2. S1** Width of walking zones **F3.C2. S2** Types of pavement surface **F3.C2. S3** Number of street trees **F3.C2. S4** Pavement steepness **F3.C2. S5** Windy climate **F3.C2. S6** Uncrowded route **F3.C2. S7** Height and types of fences **F3.C2. S8** Street reserve	24.29 21.37 9.02 4.03 10.58 19.07 24.36 5.47	13.52 21.27 14.06 9.03 2.43 21.35 16.04 19.04	16.84 13.39 10.96 8.96 4.37 13.54 11.68 9.07	18.22 18.68 11.35 7.34 5.79 17.99 17.36 11.19
F4. Convenience	**F4.C1.** Functionality of diverse activities	**F4.C1. S1** Number of traffic lanes **F4.C1. S2** Existence and width of medians **F4.C1. S3** Length of segment **F4.C1. S4** Width of traffic zones **F4.C1. S5** Width of buildings	6.80 2.07 1.08 11.57 9.03	5.41 13.09 3.89 10.39 16.68	13.36 25.09 11.31 4.43 7.05	8.52 13.42 5.43 8.80 10.92
	F4.C2. Easy access without obstacles	**F4.C2. S1** Releasing visual obstacles/nuisances **F4.C2. S2** Traffic signals **F4.C2. S3** Pavement steepness **F4.C2. S4** Uncrowded route, **F4.C2. S5** Existence of on-street parking **F4.C2. S6** Mid-block crossing **F4.C2. S7** Height and types of fences **F4.C2. S8** Public parking next to street **F4.C2. S9** Slow traffic speed	6.77 6.98 4.38 5.13 3.41 4.01 2.74 20.15 11.50	9.36 6.53 7.73 8.83 5.44 4.35 4.36 6.63 1.37	13.60 13.84 10.50 10.74 6.65 14.08 13.36 7.53 15.29	9.91 9.12 7.54 8.23 5.17 7.48 6.82 11.44 9.39
F5. Attractiveness and aesthetics	**F5.C1.** Street enclosure	**F5.C1. S1** Width of kerb-to-kerb roadway **F5.C1. S2** Width of utility zones **F5.C1. S3** Building setbacks **F5.C1. S4** Width of buffer zone **F5.C1. S5** Street reserve **F5.C1. S6** Diversity of buildings **F5.C1. S7** Mixed functionality of adjacent buildings **F5.C1. S8** Enclosure ratio	21.49 20.15 11.57 9.03 6.94 4.63 15.68 22.94	4.29 4.13 4.30 6.63 6.63 11.37 6.35 13.84	3.82 4.13 3.2 7.12 7.53 15.29 14.78 11.40	9.87 9.47 6.36 7.59 7.03 10.43 12.27 16.06
	F5.C2. Vibrancy and vitality	**F5.C2. S1** Planting diversity **F5.C2. S2** Pavement lighting **F5.C2. S3** Width of landscaping strips **F5.C2. S4** Types of pavement surface **F5.C2. S5** Intangible senses **F5.C2. S6** Planting deciduous trees **F5.C2. S7** Length of tree canopies	22.10 25.26 15.79 20.8 6.55 11.48 8.4 20.04 22.87 11.99 15.79	12.29 13.29 9.56 8.39 6.43 12.67 16.95 15.57 8.77 18.78 12.67	6.65 2.72 4.03 4.43 7.05 9.57 8.77 14.85 10.94 13.98 13.30	13.68 13.76 9.79 11.21 6.68 11.24 11.37 16.82 14.19 14.92 13.92

		F5.C2. S8 Number of street trees **F5.C2. S9** Building a vital atmosphere on pavements **F5.C2. S10** Street interface **F5.C2. S11** Height of buildings **F5.C2. S12** Upper-floor windows **F5.C2. S13** Skyline height	8.02 11.76	22.10 20.83	6.83 11.03	12.32 14.54

6. RESULTS

The WIND support tool has analysed the overall neighbourhood walkability by overlapping the mind-mapping results of three shopping centres. This output of the model is presented in a map called 'Walkability_DTM_Mind-mapping sheet'. The mode has developed six grades (from superior grade to not certified) based on path walkability mind-mapping analysis scores (see Table 5). Referring to Figure 5, the sheet illustrates that the path segments near to Shopping Centre A have superior (i.e., Grade A) and good (i.e., Grade B) walkability conditions, while the path segments near to Shopping Centres B and C are mostly in fair to very poor conditions of walkability provision. In fact, Table 5 should help urban and transportation professionals as a design decision support tool to promote a neighbourhood's development as a walkable and pedestrian-friendly environment. Furthermore, this indexing tool can enable professionals and practitioners to come up with effective design and planning solutions, which encourage people to walk more and choose walking rather than other modes of travel.

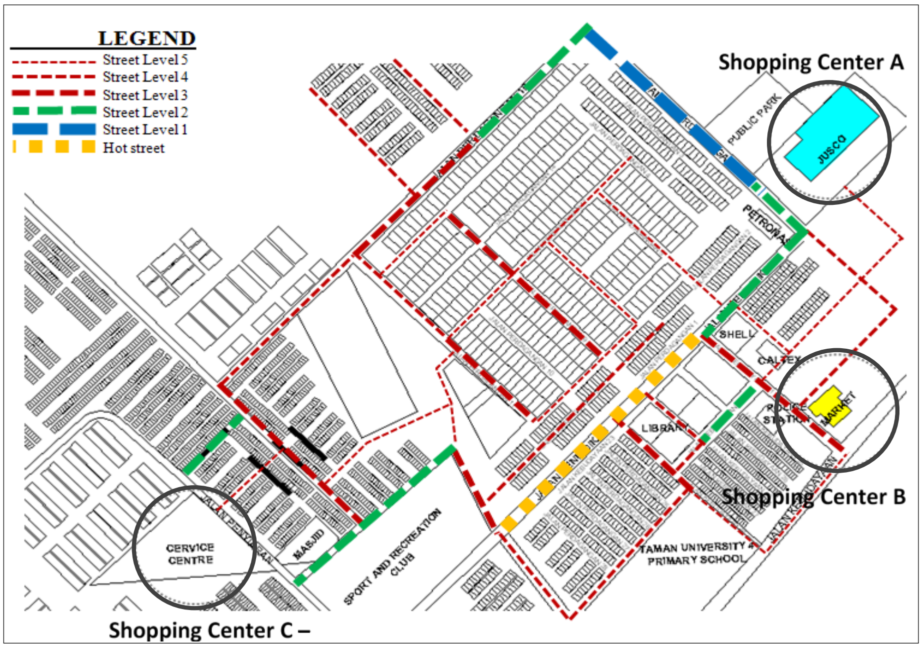

Fig. 5. The path walkability assessment model output for the overall neighbourhood

The model has applied Equation 3 to indicate the overall walkability score of the neighbourhood. The overall walkability score is folded into six clusters as follows:

Overall walkability score

- A) if 26.8-27.5: the neighbourhood makes a 'superior' contribution to its walkability
- B) if 26.1-26.7: the neighbourhood makes a 'good' contribution to its walkability
- C) if 25.4-26.0: the neighbourhood makes a 'fair' contribution to its walkability
- D) if 24.7-25.3: the neighbourhood makes a 'poor' contribution to its walkability
- E) if 24.1-24.6: the neighbourhood makes a 'very poor' contribution to its walkability
- F) if ≤ 24.0: not certified

The WIND tool resulted in an overall walkability score for the Taman Universiti neighbourhood of 25.22 (i.e., 1,170.6/46.4=25.22). Refereeing to the overall walkability score clustering, the Taman Universiti neighbourhood can be placed in Cluster C, i.e., fair, which means it has a well-designed and pedestrian-friendly environment, but some improvement needed to satisfy it residents.

7. DISCUSSION

There is rapidly growing interest in the study of walkability, which integrates the expertise of several disciplines, including urban design, urban planning, urban geography, transportation planning, architecture and landscape architecture, and public health. But, pedestrian behaviour is a complex and controversial issue in walkability assessment studies. Capturing and forecasting pedestrians' sequential decision-making while walking needs DTM-based assessment tools. On the other hand, a group of professionals in urban design and other related disciplines is following general and identical series of guidelines, codes and standards in sustainable neighbourhood development (Bereitschaft, 2017; Blecic et al., 2017). In fact, the decision made by this group of professionals is being similarly applied in different neighbourhoods with different environmental, economic, demographic and cultural characteristics. However, each neighbourhood has its own characteristics and, thus, needs its own adapted development plan. According to Park (2008), Coa et al. (2006) and Boarnet et al., (2005), changing urban forms cannot change people's behaviour, but changing urban areas based on people's attitudes, perceptions and self-selection could ameliorate their behaviour in both travel and walking, which is the duty of urban designers and urban planners. Hence, this research has developed WIND, which is a decision support tool for this purpose. This tool evaluates the neighbourhood's physical and environmental qualities influencing residents' walking behaviour in their DTM for route selection. The WIND support tool has a comprehensive list of walkability variables. Using this comprehensive list of 92 variables provides urban and transportation professionals with more accurate assessments and evaluations of neighbourhoods' walkability. Juxtaposing the model's outputs also helps urban designers to make future decisions about path development through implying much more adaptability between local neighbourhood environment characteristics and residents' needs, preferences and perceptions. This is because the variables of the walkability assessment model should be compatible with the urban context and texture in order to accommodate environmental settings and residents' self-selection attitudes, as well as guarantee the legacy of existing urban infrastructure. This model is more applicable for tropical regions while it can also be applied in other areas.

This research highlights that capturing pedestrians' DTM patterns when walking to three shopping centres in a neighbourhood provides the following advantages:

- First, the final path walkability DTM pattern of the neighbourhood completely matches the overall preferences and attitudes of the residents. The final pattern essentially guides urban designers and urban planners in their future corrective actions to enhance walkability and also upgrade walkability facilities within the surveyed neighbourhood. Significantly, this advantage allows urban designers and urban planners to provide a unique design that is oriented towards the pedestrian context for that neighbourhood. This advantage also helps them to rectify the problems by simply implementing 'general' pedestrian-oriented design guidelines and standards, which do not adequately consider end users and their attitudes and perceptions.
- Second, the research specifically rectifies the problems with individuals' self-selection behaviour. The research extracted the strengths and weaknesses for each of the three shopping centres in terms of quality of service to customers. This strikes a balance between the strengths and weaknesses of the shopping centres, while facilitating dipolar shopping land use within the neighbourhood. Thus, the final result of the research provides a balanced and equal chance for each shopping centre to be selected as a walking destination. On a micro-scale, it can considerably solve the self-selection problem of the neighbourhood. Moreover, this phenomenon helps residents to more easily decide on their residential location based on a shopping centre, which is one of the most effective factors in residents' self-selection (Handy et al., 2002).
- Third, the research supports urban designers and planners in managing their resources and budget more wisely. According to Boarnet (2005), upgrading and enhancing urban forms is costly, while improving the urban infrastructure is considerably less costly. In this regard, this research provides a highly reliable guide for urban designers and planners regarding accurate investment in redevelopment, reshaping or performing corrective actions in the surveyed neighbourhood. Urban developers can follow the final output of this walkability framework to achieve higher performance in enhancing walkability and walking facilities within the targeted neighbourhood, as well as better manage their resources and budget.
- Fourth, the research claims that focusing on psychological and sociological factors associated with residents' attitude and perception will lead to huge benefits by improving quality of life, well-being and health (United Nations Development Programme, 2012).

Currently, there is a debate among urban designers, planners and politicians about how sustainability and energy efficiency should be integrated with urban development. According to Hayashi et al. (1998), walking-related issues are a major concern for all countries around the world. In this case, only a few countries in the world have come up with green neighbourhood rating systems, including the US and Malaysia;

a) Leadership in Energy and Environmental Design for Neighbourhood Development (LEED-ND): LEED-ND is a ranking tool integrating urban development and building design from a sustainability perspective (USGBC, 2008). LEED-ND assesses neighbourhoods based on the following criteria: 'smart linkage and location', 'neighbourhood pattern and design', 'green infrastructure and buildings', 'innovation and design process', and 'regional priority', 'reducing vehicle miles travelled' and 'accessibility to jobs and services by foot or public transit' (USGBC, 2008).

b) Green Neighbourhood Index (GNI): The GNI is being developed by Malaysia federal and city planning officials in the Housing Ministry and local government. It provides basic instructions for programming at state and local levels in order to compile and formulate policies and strategies and promote the development of a neighbourhood into a ‘green neighbourhood’. The GNI is still at the drafting stage.

8. CONCLUSION

The research has developed the WIND support tool, which incorporates new urbanism, smart growth, and sustainability principles and strategies. The model has a middle-out approach to enhance urban walkability. It considers both top-down and bottom-up approaches to boost urban walkability by encouraging the participation of both government and private stakeholders in walkable urban growth and development. Hence, the proposed model is seen as an urban design decision support tool, which can be useful for urban designers and urban/transportation planners in deciding on future development/redevelopment and corrective actions.

The model has two outputs: i) a walkability index score for each path (including segments and streets) (as the micro-scale); ii) a walkability score index for the overall neighbourhood area (as the macro-scale). The output of the model is presented on a map called the ‘Walkability_DTM-Mind-mapping sheet’. The following sections present the output results of the most-in-use walkability assessment model for diverse applications: ‘path walkability index of destinations’ and ‘path walkability index of overall neighbourhood’.

This decision support tool provides a scored index to benchmark the walkability of urban neighbourhoods in cities, which should help all stakeholders in prioritizing their investments for any future development/redevelopment and corrective actions. Indeed, the proposed urban walkability assessment model will encourage greater correspondence between the characteristics of local neighbourhood environments and their residents’ needs, preferences and perceptions. In this context, the research will enhance the quality of the built environment and its connectivity, safety and security. By evaluating options for the accessibility of infrastructure in relationship to the available modes of travel infrastructure, the study will help determine how network connectivity and social accessibility can be achieved through low-energy and liveable urban development implementations.

The findings of the model can be used by various stakeholders, including policymakers, local authorities, urban design and planning professionals, and transportation planning professionals, consultants and practitioners. Indeed, the tool offers the potential to be applied globally. Moreover, tourists and tourist planners can make use of the output of this model, such as via a smartphone app. Hence, further study could focus on:

- descriptive study on the walkability index as smartphone app
- formulating the walkability index as a smartphone app
- developing a framework to assess the correlation of neighbourhood walkability via a smartphone app

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