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A Path Walkability Assessment Index Model for Evaluating and Facilitating Retail Walking Using Decision-Tree-Making (DTM) Method

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Abstract: Transportation is the major contributor of ever-increasing CO_2 and Greenhouse Gas emissions in cities. The ever-increasing hazardous emissions of transportation and energy consumption have persuaded transportation and urban planners to motivate people to non-motorized mode of travel, especially walking. Currently, there are several urban walkability assessment models; however, coping with a limited range of walkability assessment variables make these models not fully able to promote inclusive walkable urban neighborhoods. In this regard, this study develops the path walkability assessment (PWA) index model which evaluates and analyzes path walkability in association with the pedestrian's decision-tree-making (DTM). The model converts the pedestrian's DTM qualitative data to quantifiable values. This model involves ninety-two (92) physical and environmental walkability assessment variables clustered into three layers of DTM (Layer 1: features; Layer 2: Criteria; and Layer 3: Sub-Criteria), and scoped to shopping and retail type of walking. The PWA model as a global decision support tool can be applied in any neighborhood in the world, and this study implements it at Taman Universiti neighborhood in Skudai, Malaysia. The PWA model has established the walkability score index which determines the grading rate of walkability accomplishment for each walkability variable of the under-survey neighborhood. Using the PWA grading index enables urban designers to manage properly the financial resource allocation for inspiring walkability in the targeted neighborhood.

Keywords: walkability; green urban development; urban assessment; pedestrian behavior; decision making

1. Introduction

Transportation is the major contributor of ever-increasing CO_2 and Greenhouse Gas (GHG) emissions in all major cities in the world. Growing concern on transportation emissions and energy security has led to many mitigation policies, standards, and techniques [1]. However, urban and transportation professionals are rethinking how to reduce the travel rate and demand as much as possible; for instance, promoting non-motorized modes of travel. They are attempting to encourage people to change their travel behavior to a less energy-intensive mode of travel (i.e., walking). The walking mode supports simultaneously personal and public interests; it promotes the public health (physically and mentally) and contributes to less fuel consumption, less CO_2 and GHG emissions, and fewer road fatalities and accidents. Indeed, walkable and pedestrian-oriented urban design uses less land per traveler than driving, less energy resource consumption, less pollution and reduces driver frustration (www.walkinginfo.org).

Rapid urban growth has persuaded transportation professionals and practitioners towards urban walkability which focuses on pedestrian behavior and environment facility management [2,3]. The terminology "walkability" has raised concerns in urban design, urban and transportation planning, and public health since the early 2000s. The National Centre for Chronic Disease Prevention and Health Promotion (CDC) states "walkability is the idea of quantifying the safety and desirability of the walking routes" [4]. Clifton and Livi [5] expressed that walkability " ... can be considered in parallel with friendliness, because of variables included functional, safety, aesthetic and destination as well as security, comfort and convenience, continuity, system coherence, and attractiveness". Walkability is also recommended as being " ... a useful way to assess the characteristics of an area or a route, although it can be subjective" [6]. Frank et al. [7] defined walkability as " ... the extent to which the built environment is walking friendly, which enables the opportunity for a subjective or qualitative assessment against specific criteria". The Gindroz and Levine [8] suggested that the fundamental elements of New Urbanism and Smart Growth, as defined by the CNU, are the basis for walkable neighborhood development. New Urbanism and Smart Growth are advocating an energy-efficient and pedestrian-oriented design which motivates people to walk more and drive less. New Urbanism and Smart Growth constitute principles (including sustainability, connectivity, mixed-land uses and diversity, quality architecture, quality of life, quality urban design, smart transportation, amd urban compactness and density) that are being increasingly applied at different scales; from micro-scale (i.e., single path) to macro-scale (i.e., entire urban area). On the other hand, physical living activity studies have focused mostly on walking and cycling activities [9]. Accordingly, urban walkability studies have considered various walking typologies based on the destinations and temporal scheduling of trips (see Figure 1). Walking typologies include: walking for shopping and retail walking (which is a non-scheduled activity), walking to work, walking to school, and walking to religious place (which are scheduled activities). Regular walking as a form of recreation and exercise to improve individual's health also promotes walkability [10,11].

Furthermore, Rimer [12], Titze et al. [13], and Shafray and Kim [14] investigated walkability based on non-modifiable factors (e.g., age, gender, ethnicity, car ownership, education, etc.) and modifiable factors (e.g., beliefs, attitudes, preferences, and social and physical determinants). The modifiable factors are divided into individual, social, and neighborhood levels. The individual level, is the most basic level where the self-motivation is a momentum for walking; the social level is influenced by the social groups which an individual belongs to; and local neighborhood level is influenced by the physical facilities for individual and social group walking activities.

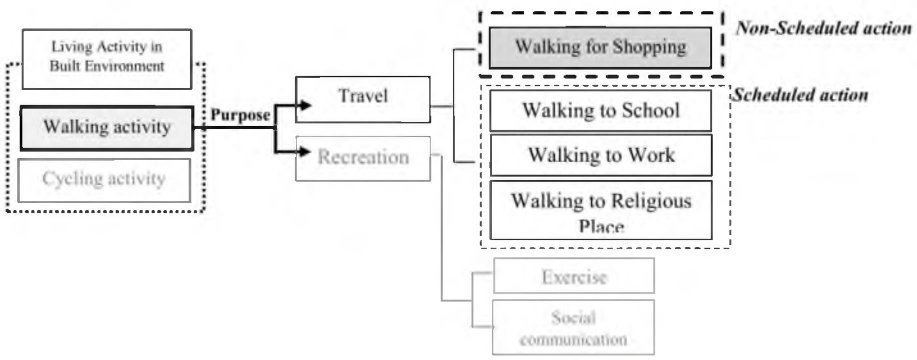

Figure 1. Taxonomy of walkability studies (Source: Shafaghat [15]).

2. Problem Statement

The investigation on previous studies in different disciplines (including urban planning, transportation planning, urban design, urban management, and landscape architecture) shows the inconsistencies in built environment perceptual qualities and qualitative variables measurements. Most of the statically-driven studies could not properly interpret the built environment perceptual qualities into measurable variables. The research conducted by Ewing et al. [16] improved the previous research by indicating a critical relationship between perceptual qualities and personal reactions in the walking behavior study, while path walkability in the scale of local neighborhood has not yet been investigated from the perspective of pedestrian's decision making on route selection. Policy-makers, urban planners and designers need a decision support tool for measuring neighborhood's walkability with the aid of residents' perceptual cognition on the physical and environmental qualities of the paths and routes. Although empirical investigation in the background of this study found a theoretical framework of positive association between walkability and pedestrian's decision making, no global solution for this problem could be found.

To date, several urban walkability assessment models have been developed which deal with pedestrian's walking behavior for travel and recreation purposes. These models have applied diverse methods to collect and analyze the data, such as Audit Tool, Geographic Information Systems (GIS), Recall Questionnaire, Sensor Motion, and Self-Report Tool. Mostly, the auditing method was applied in the urban walkability assessment model development. The most well-known urban walkability auditing tools are:; PEDSAFE [17], Pedestrian Location Identifuhuhier [18], Walkability Survey Tool [19], Neighborhood Audit Instrument (PIN3) [20], Pedestrian Environment Data Scan (PEDS) Tool [5], Pedestrian Intersections Safety Index (Ped ISI) [21], Measurement Instrument for Urban Design Quantities Related to Walkability [16], Active Neighborhood Checklist [22], Senior Walking Environmental Assessment Tool (SWEAT) [20], Walkability Audit Tool [23], and Neighborhood Environment Walkability Scale [24]. Most of the auditing-based walkability assessment models objectively measure the association between built environmental walkability and individuals' perception and preference on route selection, but cannot measure this correlation subjectively. In addition, the individual's multi-criteria decision-making (MCDM) approach has not been integrated into walkability assessment. The review of literature highlights only three assessment models integrating MCDM in walkability assessment: (1) PIP Decision System (developed by Moudon et al. [25]); (2) Pedestrian Performance Measure System (developed by Dixon et al. [26]); and (3) PEDSAFE [17]. However, these models measure walkability in urban planning scale not in urban design scale. Besides, no model adopts the decision-tree-making (DTM) method in pedestrian's walking behavior analysis and pattern recognition. Moreover, most walkability assessment models are local-based which make inter-study comparisons very difficult and uncertain. To bridge these gaps, this research moved forward to develop a global and inclusive user walkability assessment model. This is based on the premise of improving street networks' connectivity and accessibility that can generate safer, securer, more pedestrian-friendly street systems by shortening walking distances, providing more route choices, and reducing the need for crossing the streets. The model, called the "Path Walkability Assessment (PWA) Index Model", can forecast the pedestrian's DTM in determining the well-designed walking routes. This model is a decision support tool that aids urban designers for walkable neighborhood design and development. Using the outputs of this tool helps urban designers to adapt the local neighborhood environment characteristics with residents' needs, preferences, and perceptions.

Previous studies have commonly evaluated the pedestrian's walking behavior towards transit station, school, and working offices, which are scheduled activities (e.g., Frank and Pivo [27], Cervero (1996), Boarnet and Crane [28]). The current research focuses on shopping walking, a non-scheduled activity, hence shopping centers are the targeted destinations in the walkability assessment. To capture more accurately the pedestrian's DTM in shopping walking, the model plays with more than one shopping center as the target destination. Based on urban development polices, the maximum number of mega-scale shopping centers in a neighborhood is three; thus, the research considered three uni-functional shopping centers, which are considered the three case study areas in this study (see Figure 2). The research claims that conducting the model validation pilot study in three case study areas contributes to interpret and generalize the result properly.

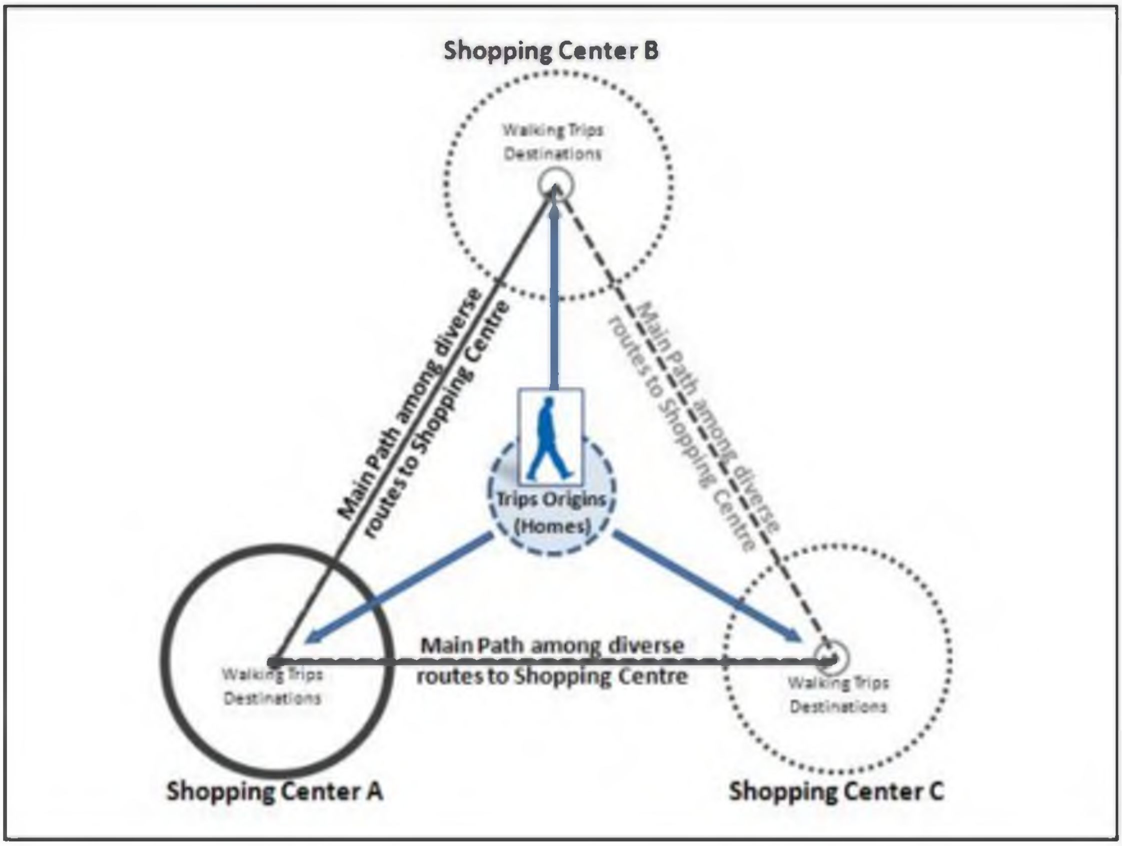

Figure 2. Path walkability assessment based on individual's decision-tree-making (DTM) within three shopping center alternatives.

3. Materials and Methods

3.1. Path Walkability Assessment Variables

The Path Walkability Assessment (PWA) index model has been developed based on two significant philosophies of walkability evaluation: "well-designed" urban walkability, and "most-in-use" path walkability. The current study presents the "well-designed" model, and the other concept will be presented in future works. The "well-designed" path walkability assessment index model evaluates whether the neighborhood has incorporated the walkability design codes and standards that well facilitate and fulfill pedestrian's preferences and needs. Figure 3 illustrates schematically how the "well-designed" path walkability assessment index model deals with three-layered walkability variables, and analyzes them based on pedestrian's DTM in walking route selection.

The PWA model involves ninety-two walkability variables (clustered into five walkability features, where each feature includes several walkability criteria and sub-criteria (see Appendix A)). The following summarizes the path walkability assessment features, criteria and sub-criteria that are involved in development of the PWA index model.

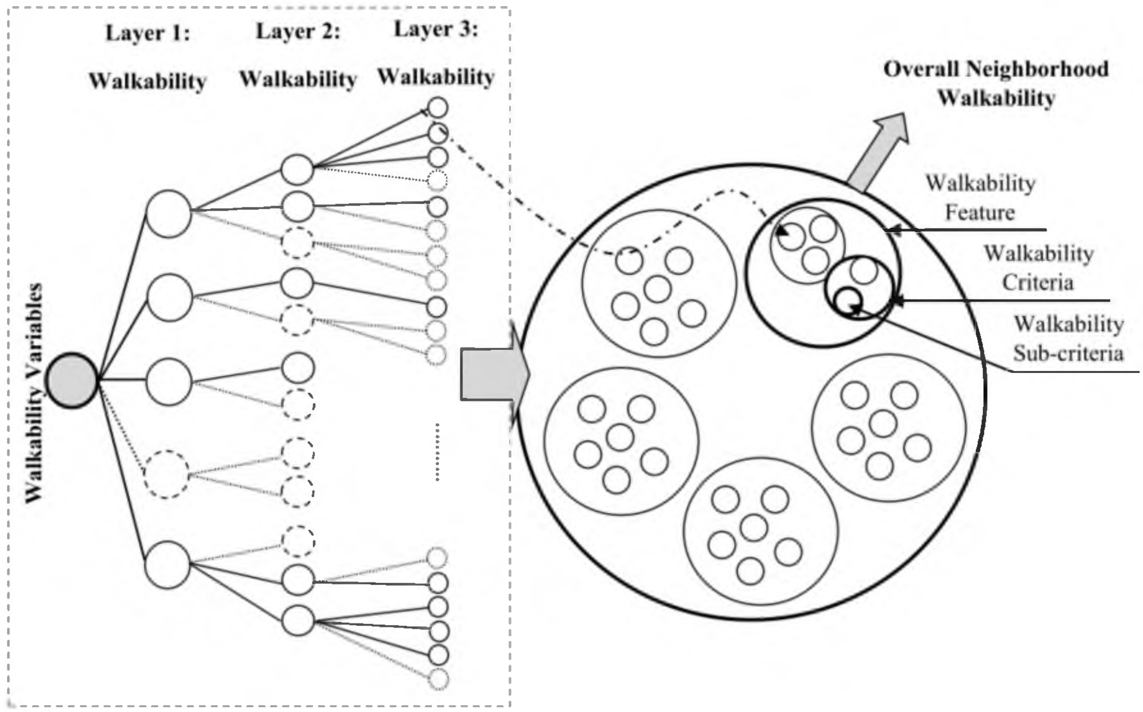

Figure 3. Schematic data collection and analysis of the "Well-designed" Path Walkability Index Assessment Model based on DTM method.

(a) Path Walkability Assessment Features:

Babiano [29] developed the pedestrian needs hierarchy, which, from bottom to top, includes mobility, protection, ease, enjoyment and identity (see Figure 4). Babiano [29] assumed that those lower in hierarchy must at least be partially "satisfied before those higher in order may become an important source of motivation". In fact, from bottom level to summit level, the initial physical needs of pedestrian are transformed to mental and spiritual needs. It can be referred to as the recent approach in urban design and planning, which incorporates urban form and pedestrian walking behavior, supported by Handy (2006): it is very important to consider attitude, perception, and self-selection behaviors of the pedestrian. Accordingly, the PWA model indicated the walkability assessment features (i.e., 1st Layer in DTM analysis) as: F1. Sense of Safety and Security; F2. Connectivity; F3. Comfort; F4. Convenience; and F5. Attractiveness and Aesthetic.

(b) Path Walkability Assessment Criteria and Sub-Criteria:

The walking trips are affected by form and characteristics of the neighborhood; however, a comprehensive list of neighborhood walkability criteria and the sub-criteria has not been yet established [5,30]. Kockelman [31] and Clifton et al. [5] expressed that it is essential to indicate the walkability criteria and sub-criteria for walking assessment modeling. In this regard, a comprehensive list of environmental and physical measures has been identified which have been either perceived or empirically tested in association with pedestrian's decision making in shopping walking. The research has extracted the path walkability assessment criteria (i.e., 2nd Layer in DTM analysis) and sub-criteria (i.e., 3rd Layer in DTM analysis) by reviewing the existing pedestrian indices and walkability assessment models through the available literature [32–61] (see Appendix A). The research has developed the PWA assessment model based on this list of walkability assessment variables as presented in the following sections.

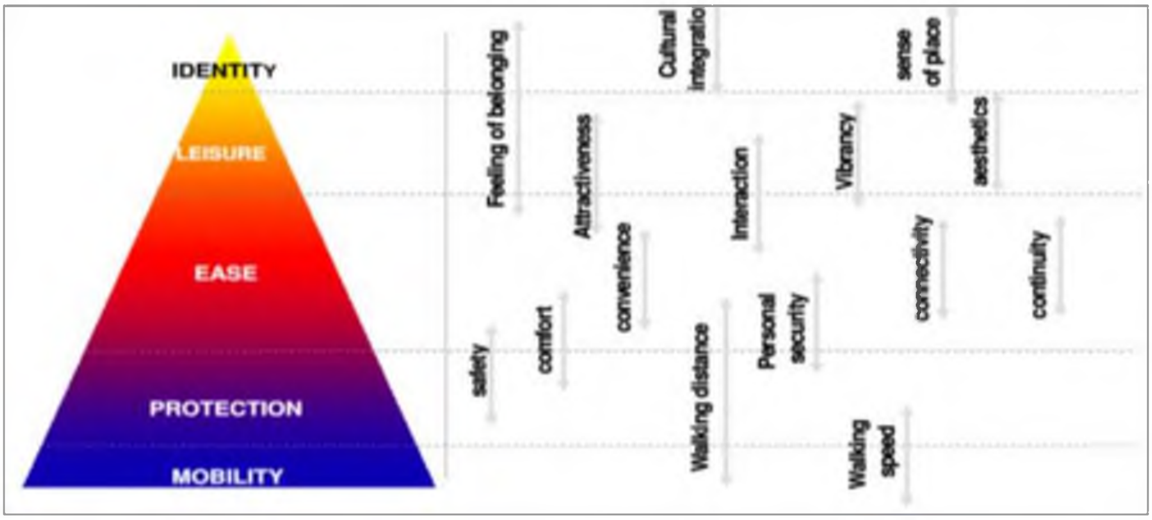

Figure 4. Pedestrian Needs Hierarchy (Adopted from Babiano [29]).

3.2. Methods

The PWA index model analyzes the respondent's DTM and priority needs for walking in an under-survey neighborhood area. The PWA model facilitates walking through the paths within the neighborhood by analyzing the path walkability variables (i.e., 92 walkability variables clustered into 3 layers of DTM analysis). the DTM method has been widely used in the area of sustainable urban development [62,63]. The DTM method is a helpful tool when it is possible to measure the probability of an event occurring and socio-economic beneficial of a particular decision made [64–66]. In terms of the complex decisions undertaken, the DTM provides qualitative data and quantifiable information in the urban design decision making process [67]. The application of the DTM method in an urban walkability study has great value in comparison to both conventional neighborhood urban form analysis and conventional path walkability analysis, especially in comparison to studies focused on mode-choice, trip chaining, and destination travel (e.g., trips to school, transit destination, or park). In the case of research with a combination of multiple trips and diverse destinations, the DTM analysis on individual's walkable path selection towards his/her target destination can yield valuable output and findings.

3.2.1. Decision Tree Making (DTM)

The PWA model has developed the following equations for analyzing the pedestrian's DTM. Equations (1)–(3) are used for evaluation of response for each variable based on his/her DTM. The include variables in 1st layer (Features (F_i-)), 2nd Layer (Criteria (C_j-)), and 3rd Layer (Sub-criteria (S_k-)). They calculate the "Average Weight Value of each Variable" ($AvWVF_iC_jS_k-$).

$$(AvWVF_iC_jS_k-) = \frac{\sum_{\mathrm{r}=1}^{\mathrm{n}} R_rRWVF_iC_jS_k \text{ (Rate Value" of each variable by respondant nomber)}}{\text{Total Nomber of respondant (n)} \times \text{RV Max}} \quad (1)$$

where "$R_rRWVF_iC_jS_k-$" is the abbreviation of Rate Weight Value of each Variable by rth Respondent (Rr). It is calculated using Equations (2) and (3).

$$\begin{aligned} R_rRWVF_iC_jS_k- \; &= \text{"least possible Rate Value of the Variable by respondent"} - \\ &\quad (\text{rate of the variable by rth Respondent} \; - \; 1) \end{aligned} \quad (2)$$

$$\text{RWV Max} = \text{"least possible Rate Value of the Variable by Respondent"} \quad (3)$$

where

- F_i is the feature number "i", and "i" can be 1, 2, 3, 4 or 5.
- C_j is the criteria number "j", and "j" can be 0, 1, 2 or 3.
- S_k is the sub-criteria number "k", and "k" can be 0, 1, 2, 3, 4, 5, 6, 7 or 8.

After analysis of response for each variable using Equations (1)–(3), the Equation 4 was applied for each feature (F_i-), then Equation 5 for each criteria (F_iC_j-) and Equation 6 for each sub-criteria ($F_iC_jS_k-$):

$$AcWVF_i \text{ (Actual Weight Value of each variable in 1st Layer)} = AcWVF_i- \quad (4)$$

$$AcWVF_iC_j- \text{ (Actual Weight Value of each variable in 2nd Layer)} = AcWVF_iC_j- \times AcWVF_i- \times 100 \quad (5)$$

$$AcWVF_iC_jS_k- \text{ (Actual Weight Value of each variable in 3rd Layer)} = AcWVF_iC_jS_k- \times AcWVF_iC_j- \times 100 \quad (6)$$

Based on the second definition of walkable path, study identified below the mathematical model to measure "Path Walkability Assessment (PWA) Score Index" for each sub-criteria of 3rd layer ($F_iC_jS_k-$) corresponding to the most usable path. Equation 7 is only used in the 3rd Layer where zero "0" is acceptable for "j" and "k".

$$\text{PWA Score Index } (F_iC_jS_k-) = \frac{AcWVF_iC_jS_k}{\sum_{i,j,k=1} AcWVF_iC_jS_k} \times 100 \quad (7)$$

3.2.2. Regression Analysis

The PWA index model used regression analysis to measure and analyze the path walkability into two scales, walkability index for each destination (meso-scale), and walkability index for the overall neighborhood area (macro-scale). To conduct regression analysis, Pearson correlation coefficients were calculated for both conceptual variables (i.e., overall neighborhood walkability) and the measured variables (i.e., shopping center walkability). In the current research, the regression coefficient was computed, which represents the effect of each measured walkability variables in the regression analysis and controls for the effect of other measured variables. The PWA model calculated the Regression Equation which conducts the actual prediction of the conceptual variable upon one or more measured variables. The regression Equation 8 is as follow:

$$\hat{Y} = \overline{Y} + r\,\frac{S_Y}{S_X}\,(X - \overline{X}) \quad (8)$$

where

$\hat{Y}$ (Y hat) refers to the predicted score of an individual on the dependent variable.

$\overline{Y}$ is the mean of independent variable, which is calculated as the sum of all of the scores divided by the sample size ($\overline{Y} = \frac{Y_1+Y_2+Y_3+\ldots+Y_n}{N}$).

X refers to the scores of dependent variables.

$\overline{X}$ is the mean of dependent variable, which is calculated as the sum of all of the scores divided by the sample size ($\overline{X} = \frac{X_1 + X_2 + X_3 + \ldots + X_n}{N}$).

S_Y and S_X, refer to the standard deviations of the X and Y, respectively ($S_X = \sqrt{\frac{\sum X^2 - \frac{(\sum X^2)}{N}}{N}}$).

r is the Pearson correlation coefficient.

The Pearson correlation coefficient is calculated based on Equation (9):

$$r = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{N}}{\sqrt{\left[\sum X^2 - \frac{(\sum x)^2}{N}\right]\left[\sum Y^2 - \frac{(\sum Y)^2}{N}\right]}} \quad (9)$$

where

X and Y refer to the score of dependent and independent variables, respectively.
N refers to the ample size.

In the regression analysis, the shopping center walkability is assumed as the independent variables, which is shown in the X axis, and the overall neighborhood walkability is the dependent variable, which is shown in the Y axis.

4. Analysis

Diverse urban neighborhoods can be evaluated through the PWA index model, since it has the potential to be applied in diverse urban contexts. This research has conducted a case study in the center of Taman Universiti neighborhood in city of Skudai, Malaysia. According to purposive sampling size method, 120 respondents (i.e., residents) have participated in the survey as representative of 2500 householders of the Taman Universiti neighborhood. The survey captured the residents' DTM patterns in their shopping walking towards three shopping centers within the Taman Universiti neighborhood (see Figure 5). The Taman Universiti neighborhood has great potential to replicate the scenario of this research. In this neighborhood, various types of land uses (including residential, commercial, school, mosque, shopping center, and public facilities) provide the opportunities to various human physical activities; specifically, walking. The shopping centers were located within standard and pedestrian-oriented distances (400–900 m); however, the residents are not satisfied with the current conditions of sidewalk, walkways, and pedestrian facilities. The absence of some walkability criteria within this neighborhood (e.g., blocked sidewalk, non-continuous sidewalk, and stepping up and down along roadside shoulders) make it inconvenient for residents to choose walking for their shopping. Thus, residents tend to use other modes, mainly the private car, for shopping purpose. The Taman Universiti neighborhood as an appropriate case study area for validating the PWA model, and was selected for the following reasons:

(1) It was located in an urban setting (not suburb) providing a high accessibility to all shopping centers.
(2) It has large-scale shopping centers that can support a wide range of residents' needs.
(3) It has numerous shop-houses that function as the small-scale shops competing with those large-scale shopping centers, and accounting for a relatively large share of walking trips.
(4) Distance between each pair of shopping centers is in a normal walking distance (i.e., 400–900 m, equal to 5–10 min).
(5) It does not have a public space or parks, thus the shopping centers play roles as focal points that inspire neighborhood vitality and livability.

To conduct the survey, a structured fixed format self-report questionnaire was designed to capture DTM of the pedestrians (i.e., residents) for walking towards each of three shopping centers. The survey data were collected through the Combined Scaling Method (CSM). The CSM obtains respondent's perception through scoring and ranking the items [68]. The CSM method has potential to be integrated with the DTM analysis method. The CSM is the combination of two scaling methods: Categorical scaling and Ordinal Ranking scaling. The CSM assigns a separate number or letter to various index components from lowest to highest. Thus, the CSM provides a group of scores can be sorted by respondents (1 = strongly favorable to the concept, onward, to n = strongly unfavorable to the concept). In CSM, each score is chosen just one time in each cluster of variables. For example, if the cluster includes six criteria, the respondents are asked to sort them from one (i.e., most important criterion) to six (i.e., least important criterion). Following the DTM instruction, the CSM procedure has been conducted for the three layers of walkability variables in capturing the respondents' decision making on walking path selection towards each shopping center (A, B, and C).

Figure 5. Taman Universiti Neighborhood Boundary, in Skudai, Malaysia. The locations of shopping centers are marked.

4.1. DTM Analysis

The collected data from the questionnaires were transferred to the DTM equations of the model. As an example, the data collection and analysis for the walkability feature "Sense of safety and security" for the Shopping Center A (Jusco) survey is explained in the following.

Example: F1. Sense of safety and security

The first row of Table 1 shows the sorting range from 1 to 5 (because there are 5 walkability features). Second row shows the "selection times" by all respondents of the survey.

According to Table 1, the Sense of safety and security was selected seven times as the most important feature (i.e., degree 1) among four other walkability features, was nine times selected as degree 2, and was selected three times as degree 3, and so on. The third row reveals the "weight value" of each degree; as the least sorting degree (i.e., number 1) identifies as the highest value (i.e., value is 5), if the "sense of safety and security" was chosen as degree 1, it has the highest value 5 in comparison with other walkability features. The fourth row of Table 1 calculates the "selection times" multiplied by the "weight value". Total row describes the sum of amounts of the fourth row. Actually, the total number should be subtracted from the minimum number of the limitation range to find the "actual weight value" of the feature within the "minimum-to-maximum" range.

The limitation range is defined in this way. Minimum number can be recognized if whole respondent (for example, 24 persons) choose "Sense of safety and security" with the "weight value" of 1, meaning the minimum is 24 multiplied by 1, i.e. 24. The maximum number of the range is recognized if whole respondents (for example, 24 persons) choose "Sense of safety and security" as "weight value" of 5, thus the maximum number is 24 multiplied by 5, i.e. 120. The subtraction of maximum and minimum identifies the range. As can be seen in Table 1, the total 87 should be subtracted from minimum 24 to find 63 as the "actual weight value" of the factor "Sense of safety and security" in the range. To find the "Actual satisfactory percentage", the "actual weight value" should be divided by the "limitation range". For example, "actual weight value" of 63 should be divided by "limitation range" 96, which equals 0.6562. Then, the "Actual satisfactory percentage", will be 65.62%.

Table 1. Data Analysis calculation of "Sense of Safety and security" for Shopping Center A.

Sense of Safety and Security for Shopping Center A					
Ranking Score	1	2	3	4	5
Quantity	7	9	3	2	3
Value	5	4	3	2	1
Quantity × Value	35	36	9	4	3
Total			87		
Actual Weight Value			87 − 24 = 63		

Total (Sum) = $\sum 35 + 36 + 9 + 4 + 3 = 87$
Maximum Number = $24 \times 5 = 120$
Minimum Number = $24 \times 1 = 24$
Limitation Range = Maximum Number − Minimum Number = $120 - 24 = 96$
Actual Weight Value of the "Sense of safety and security" in the "Limitation range" =
Total − Minimum Number = $87 - 24 = 63$
"Actual satisfactory percentage" of the "Sense of safety and security" = $\frac{\text{Actual Weight Value}}{\text{Limitation Range}} \times 100\%$
$= \frac{63}{96} \times 100\% = 65.62\%$

This process should be done for the other four walkability features, eleven walkability criteria, and ninety-two walkability sub-criteria. The research processed the DTM of all participants involved in the pilot study. Table 2 shows the DTM analysis result for each destination (i.e., shopping center), individually, and inclusively (i.e., Overall Neighborhood).

Table 2. Walkability sub-criteria analysis for three shopping centers A, B, and C.

Features	Criteria	Sub-Criteria	Shopping Center A (%)	Shopping Center B (%)	Shopping Center C (%)	Walkability Index of Overall Neighborhood (%)
F1. Sense of Safety and Security	**F1.C1.** Safety facilities at sidewalks	**F1.C1. S1** Driveway Curb-cuts	25.43	19.12	18.64	21.06
		F1.C1. S2 Existence of Pedestrian Crossing	27.54	19.42	25.8	24.25
		F1.C1. S3 Width of Utility Zones	24	16.73	11.25	17.33
		F1.C1. S4 Shelters	24	12.34	12.82	16.41
		F1.C1. S5 Length of Tree Canopies	15.53	10.68	10.28	12.16
		F1.C1. S6 Releasing visual Obstacles/Nuisances	8.1	3.22	13.82	8.38
		F1.C1. S7 Sidewalk Steepness	21.67	11.56	7.57	13.60
		F1.C1. S8 Existence of Bike Lanes	12.59	8.23	8.77	9.86
		F1.C1. S9 Existence of On-street Parking	9.54	6.89	14.37	10.27
		F1.C1. S10 Informing the intersection blindness	4.76	6.87	9.04	6.89
		F1.C1. S11 Mid-block crossing	10.05	18.78	16.94	15.26
		F1.C1. S12 Providing over-bridge	10.81	8.62	8.92	9.45
	F1.C2. Slowing traffic speed at pedestrian crossing	**F1.C2. S1** Existence of Pedestrian Crossing	24.96	8.23	17.66	16.95
		F1.C2. S2 Number(s) of Traffic Lanes	19.07	14.69	19.39	17.72
		F1.C2. S3 Traffic Signals	24.36	15.68	22.16	20.73
		F1.C2. S4 Traffic Calming Devices	3.7	4.70	11.42	6.61
		F1.C2. S5 Drivers' respect to pedestrian	4.76	5.48	7.90	6.05
		F1.C2. S6 Slow Traffic speed	11.78	12.67	19.47	14.64
	F1.C3. Security in day and nights	**F1.C3. S1** Sidewalk Lighting	19.07	6.97	12.64	12.89
		F1.C3. S2 Number of Intermediary	13.94	8.55	10.93	11.14
		F1.C3. S3 Length of Tree Canopies	9.58	9.49	14.57	11.21
		F1.C3. S4 Number of Street Trees	11.48	6.48	19.95	12.64
		F1.C3. S5 Releasing visual Obstacles/Nuisances	8.4	4.6	5.57	6.19
		F1.C3. S6 Not-crowded Route	20.04	12.06	18.94	17.01
		F1.C3. S7 Street Surveillance	6.35	2.97	5.14	4.82
		F1.C3. S8 Street-Facing Entrances	22.87	7.87	14.78	15.17
		F1.C3. S9 Street-level Façade Transparency	11.04	9.45	20.21	13.57
		F1.C3. S10 First Floor Use of Buildings	9.94	9.49	18.97	12.80
		F1.C3. S11 Upper-Floor Windows	8.03	14.73	6.45	9.74
F2. Connectivity	**F2.C1.** Sidewalk accessibility	**F2.C1. S1** Sidewalks networking	22.92	16.48	18.96	19.45
		F2.C1. S2 Length of Sidewalks	22.5	15.03	24.64	20.72
		F2.C1. S3 Width of Walking Zones	21.9	17.18	27.49	22.19
		F2.C1. S4 Continuity to diverse activity	9.63	12.39	21.35	14.46
		F2.C1. S5 Length of Segments	11.36	10.96	16.04	12.79
		F2.C1. S6 Informing the Intersection blindness	25.67	8.26	15.50	16.48
		F2.C1. S8 Street signage	8.44	7.93	11.03	9.13
	F2.C2. Physical connectivity	**F2.C2. S1** Sidewalk steepness	19.85	20.7	13.05	17.87
		F2.C2. S2 Street-Facing Entrances	21.66	24.19	21.93	22.59
		F2.C2. S3 Street Signage	7.44	9.90	20.13	12.49
		F2.C2. S4 Length of Segment	21.40	22.89	18.90	21.09
F3. Comfort	**F3.C1.** Physical comfort	**F3.C1. S1** Well-locating of service utilities	21.37	17.47	25.88	21.57
		F3.C1. S2 Amount of Street Furniture	16.55	15.90	29.75	20.73
		F3.C1. S3 Sidewalk Lighting	15.80	12.92	14.67	14.46
		F3.C1. S4 Number of Intermediary	9.63	10.21	14.67	11.50
		F3.C1. S5 Shelters	10.38	10.65	11.66	10.90
		F3.C1. S6 Planting deciduous trees	26.67	15.12	14.94	18.91
		F3.C1. S7 Existence and width of medians	8.48	8.09	19.68	12.08
		F3.C1. S8 Existence of On-street Parking	7.82	10.08	13.80	10.57
		F3.C1. S9 Human Ergonomic Scale Design	18.65	9.45	8.62	12.24

Table 2. *Cont.*

Features	Criteria	Sub-Criteria	Shopping Center A (%)	Shopping Center B (%)	Shopping Center C (%)	Walkability Index of Overall Neighborhood (%)
	F3.C2. Environmentally comfort	**F3.C2. S1** Width of Walking Zones,	24.29	13.52	16.84	18.22
		F3.C2. S2 Types of Sidewalk Pavement,	21.37	21.27	13.39	18.68
		F3.C2. S3 Number of Street Trees,	9.02	14.06	10.96	11.35
		F3.C2. S4 Sidewalk Steepness,	4.03	9.03	8.96	7.34
		F3.C2. S5 Windy climate,	10.58	2.43	4.37	5.79
		F3.C2. S6 Not-crowded Route,	19.07	21.35	13.54	17.99
		F3.C2. S7 Height and types of Fences,	24.36	16.04	11.68	17.36
		F3.C2. S8 Street reserve	5.47	19.04	9.07	11.19
F4. Convenience	**F4.C1.** Functionality of diverse activities	**F4.C1. S1** Number(s) of Traffic Lanes	6.80	5.41	13.36	8.52
		F4.C1. S2 Existence and width of medians	2.07	13.09	25.09	12.16
		F4.C1. S3 Length of Segment	1.08	3.89	11.31	5.43
		F4.C1. S4 Width of Traffic Zones	11.57	10.39	4.43	8.80
		F4.C1. S5 Widths of Buildings	9.03	16.68	7.05	10.92
	F4.C2. Easy access without obstacles	**F4.C2. S1** Releasing visual Obstacles/Nuisances	6.77	9.36	13.60	9.91
		F4.C2. S2 Traffic Signals	6.98	6.53	13.84	9.12
		F4.C2. S3 Sidewalk Steepness	4.38	7.73	10.50	7.54
		F4.C2. S4 Not-crowded Route,	5.13	8.83	10.74	8.23
		F4.C2. S5 Existence of On-street Parking	3.41	5.44	6.65	5.17
		F4.C2. S6 Mid-block crossing	4.01	4.35	14.08	7.48
		F4.C2. S7 Height and types of Fences	2.74	4.36	13.36	6.82
		F4.C2. S8 Public parking next to street	20.15	6.63	7.53	11.44
		F4.C2. S9 Slow Traffic speed	11.50	1.37	15.29	9.39
F5. Attractiveness and Aesthetic	**F5.C1.** Street enclosure	**F5.C1. S1** Width of Curb-to-Curb Roadway	21.49	4.29	3.82	9.87
		F5.C1. S2 Width of Utility Zones	20.15	4.13	4.13	9.47
		F5.C1. S3 Building Setbacks	11.57	4.30	3.2	6.36
		F5.C1. S4 Width of buffer zone	9.03	6.63	7.12	7.59
		F5.C1. S5 Street reserve	6.94	6.63	7.53	7.03
		F5.C1. S6 Diversity of buildings	4.63	11.37	15.29	10.43
		F5.C1. S7 Mixed functionality of Adjacent Buildings	15.68	6.35	14.78	12.27
		F5.C1. S8 Enclosure ratio	22.94	13.84	11.40	16.06
	F5.C2. Vibrancy and vitality	**F5.C2. S1** Planting diversity,	22.10	12.29	6.65	13.68
		F5.C2. S2 Sidewalk Lighting,	25.26	13.29	2.72	13.76
		F5.C2. S3 Width of Landscaping Strips,	15.79	9.56	4.03	9.79
		F5.C2. S4 Types of Sidewalk Pavement,	20.8	8.39	4.43	11.21
		F5.C2. S5 Intangible Senses,	6.55	6.43	7.05	6.68
		F5.C2. S6 Planting deciduous trees,	11.48	12.67	9.57	11.24
		F5.C2. S7 Length of Tree Canopies,	8.4	16.95	8.77	11.37
		F5.C2. S8 Number of Street Trees,	20.04	15.57	14.85	16.82
		F5.C2. S9 Building a Vital Atmosphere in sidewalks,	22.87	8.77	10.94	14.19
		F5.C2. S10 Street Interface,	11.99	18.78	13.98	14.92
		F5.C2. S11 Heights of Buildings,	15.79	12.67	13.30	13.92
		F5.C2. S12 Upper-Floor Windows,	8.02	22.10	6.83	12.32
		F5.C2. S13 Skyline height	11.76	20.83	11.03	14.54

4.2. Regression Analysis

The PWA model conducted the regression analysis to find both individual and inclusive impacts of destinations (i.e., shopping centers) to pedestrian's walking path selection. The DTM analysis outputs of each destination was inserted as Score on Indicator (X) for regression analysis (see Tables 3–5). The following presents the regression analysis between each of shopping center (A, B, and C) and overall neighborhood walkability.

(A) Regression analysis between Shopping Center A Walkability and Overall Neighborhood Walkability (see Table 3):

$$SS = \sum (X - \overline{X})^2 = 5000.81$$

The variance (s^2) was calculated as below:

$$s^2 = \frac{SS}{N} = \frac{2226.39}{72} = 54.35$$

Then, the standard deviation (s) equals:

$$s = \sqrt{s^2} = 5.56$$

$$\text{Pearson correlation coefficient (r)} = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{N}}{\sqrt{\left[\sum X^2 - \frac{(\sum x)^2}{N}\right]\left[\sum Y^2 - \frac{(\sum Y)^2}{N}\right]}} =$$

$$\frac{8139 - \frac{751-606}{72}}{\sqrt{\left[7413 - \frac{564001}{72}\right]\left[10032 - \frac{367236}{72}\right]}} = 0.52$$

$$S_X = \sqrt{\frac{\sum X^2 - \frac{(\sum X^2)}{N}}{N}} = \sqrt{\frac{\sum 564001 - \frac{564001}{72}}{72}} = 8.78$$

$$S_Y = \sqrt{\frac{\sum Y^2 - \frac{(\sum Y^2)}{N}}{N}} = \sqrt{\frac{\sum 367237 - \frac{367237}{72}}{72}} = 7.09$$

$$\text{Regression Equation } (\hat{Y}) = \overline{Y} + r\,\frac{S_Y}{S_X}\,(X - \overline{X}) = 10.80 + 0.52\,\frac{7.09}{8.78}\,(X - 13.41) = 0.66696X + 5.2211$$

(B) Regression analysis between Shopping Center B Walkability and Overall Neighborhood Walkability (see Table 4):

$$SS = \sum (X - \overline{X})^2 = 1930.43$$

The variance (s^2) was calculated as below:

$$S^2 = \frac{SS}{N} = \frac{1930.43}{72} = 26.81$$

Then, the standard deviation (s) equals:

$$s = \sqrt{s^2} = 5.17$$

$$\text{Pearson correlation coefficient(r)} = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{N}}{\sqrt{\left[\sum X^2 - \frac{(\sum X)^2}{N}\right]\left[\sum Y^2 - \frac{(\sum Y)^2}{N}\right]}} = \frac{6209 - \frac{751-578}{72}}{\sqrt{\left[7413 - \frac{564001}{72}\right]\left[57032 - \frac{437236}{72}\right]}}$$

$$= 0.48$$

$$S_x = \sqrt{\frac{\sum X^2 - \frac{(\sum X^2)}{N}}{N}} = \sqrt{\frac{\sum 564001 - \frac{564001}{72}}{72}} = 8.78$$

$$S_Y = \sqrt{\frac{\sum Y^2 - \frac{(\sum Y^2)}{N}}{N}} = \sqrt{\frac{\sum 483239 - \frac{407275}{72}}{72}} = 6.23$$

$$\text{Regression Equation } (\hat{Y}) = \overline{Y} + r\frac{S_Y}{S_X}(X - \overline{X}) = 10.80 + 0.48\frac{6.23}{8.78}(X - 13.41) = 0.5361X + 5.6938$$

(C) Regression analysis between Shopping Center C Walkability and Overall Neighborhood Walkability (see Table 5):

$$SS = \sum (X - \overline{X})^2 = 2676.77$$

The variance (s^2) was calculated as below:

$$S^2 = \frac{SS}{N} = \frac{2676.77}{72} = 37.17$$

Then, the standard deviation (s) equals:

$$s = \sqrt{s^2} = 6.09$$

$$\text{Pearson correlation coefficient}(r) = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{N}}{\sqrt{\left[\sum X^2 - \frac{(\sum X)^2}{N}\right]\left[\sum Y^2 - \frac{(\sum Y)^2}{N}\right]}} = \frac{8139 - \frac{751-606}{72}}{\sqrt{\left[7413 - \frac{564001}{72}\right]\left[10032 - \frac{367236}{72}\right]}} = 0.52$$

$$S_x = \sqrt{\frac{\sum X^2 - \frac{(\sum X^2)}{N}}{N}} = \sqrt{\frac{\sum 564001 - \frac{564001}{72}}{72}} = 8.78$$

$$S_Y = \sqrt{\frac{\sum Y^2 - \frac{(\sum Y^2)}{N}}{N}} = \sqrt{\frac{\sum 367237 - \frac{367237}{72}}{72}} = 7.09$$

$$\text{Regression Equation } (\hat{Y}) = \overline{Y} + r\frac{S_Y}{S_X}(X - \overline{X}) = 10.80 + 0.52\frac{7.09}{8.78}(X - 13.41) = 0.5035X + 5.7131$$

Table 3. Statistical Regression analysis for Shopping Center "A".

Walkability Sub-Criteria	Score on Indicator	Mean Deviation Score	Mean Deviation Score Square
	(X)	$(X - \overline{X})$	$(X - \overline{X})^2$
F1.C1. **S1** Driveway Curb-cuts	25.43	11.54	133.1716
F1.C1. **S2** Existence of Pedestrian Crossing	27.54	13.65	186.3225
F1.C1. **S3** Width of Utility Zones	24	10.11	102.2121
F1.C1. **S4** Shelters	24	10.11	102.2121
F1.C1. **S5** Length of Tree Canopies	15.53	1.64	2.6896
F1.C1. **S6** Releasing visual Obstacles/Nuisances	8.1	−5.79	33.5241
F1.C1. **S7** Sidewalk Steepness	21.67	7.78	60.5284
F1.C1. **S8** Existence of Bike Lanes	12.59	−1.3	1.69
F1.C1. **S9** Existence of On-street Parking	9.54	−4.35	18.9225
F1.C1. **S10** Informing the intersection blindness	4.76	−9.13	83.3569
F1.C1. **S11** Mid-block crossing	10.05	−3.84	14.7456
F1.C1. **S12** Providing over-bridge	10.81	−3.08	133.171
F1.C2. **S1** Existence of Pedestrian Crossing	24.96	11.07	122.5449
F1.C2. **S2** Number(s) of Traffic Lanes	19.07	5.18	26.8324
F1.C2. **S3** Traffic Signals	24.36	10.47	109.6209
F1.C2. **S4** Traffic Calming Devices	3.7	−10.19	103.8361
F1.C2. **S5** Drivers' respect to pedestrian	4.76	−9.13	83.3569
F1.C2. **S6** Slow Traffic speed	11.78	−2.11	4.4521
F1.C3. **S1** Sidewalk Lighting	19.07	5.18	26.8324
F1.C3. **S2** Number of Intermediary	13.94	0.05	0.0025

Table 3. *Cont.*

Walkability Sub-Criteria	Score on Indicator	Mean Deviation Score	Mean Deviation Score Square
	(X)	$(X - \overline{X})$	$(X - \overline{X})^2$
F1.C3. S3 Length of Tree Canopies	9.58	−4.31	18.5761
F1.C3. S4 Number of Street Trees	11.48	−2.41	5.8081
F1.C3. S5 Releasing visual Obstacles/Nuisances	8.4	−5.49	30.1401
F1.C3. S6 Not-crowded Route	20.04	6.15	37.8225
F1.C3. S7 Street Surveillance	6.35	−7.54	56.8516
F1.C3. S8 Street-Facing Entrances	22.87	8.98	80.6404
F1.C3. S9 Street-level Façade Transparency	11.04	−2.85	8.1225
F1.C3. S10 First Floor Use of Buildings	9.94	−3.95	15.6025
F1.C3. S11 Upper-Floor Windows	8.03	−5.86	34.3396
F2.C1. S1 Sidewalks networking	22.92	9.03	81.5409
F2.C1. S2 Length of Sidewalks	22.5	8.61	74.1321
F2.C1. S3 Width of Walking Zones	21.9	8.01	64.1601
F2.C1. S4 Continuity to diverse activity	9.63	−4.26	18.1476
F2.C1. S5 Length of Segments	11.36	−2.53	6.4009
F2.C1. S6 Informing the Intersection blindness	25.67	11.78	138.7684
F2.C1. S8 Street signage	8.44	−5.45	29.7025
F2.C2. S1 Sidewalk steepness	19.85	7.77	60.3729
F2.C2. S2 Street-Facing Entrances	21.66	7.77	60.3729
F2.C2. S3 Street Signage	7.44	−6.45	41.6025
F2.C2. S4 Length of Segment	21.40	7.51	56.4001
F3.C1. S1 Well-locating of service utilities	21.37	7.48	55.9504
F3.C1. S2 Amount of Street Furniture	16.55	2.66	7.0756
F3.C1. S3 Sidewalk Lighting	15.80	1.91	3.6481
F3.C1. S4 Number of Intermediary	9.63	−4.26	18.1476
F3.C1. S5 Shelters	10.38	−3.51	12.3201
F3.C1. S6 Planting deciduous trees	26.67	12.78	163.3284
F3.C1. S7 Existence and width of medians	8.48	−5.41	29.2681
F3.C1. S8 Existence of On-street Parking	7.82	−6.07	36.8449
F3.C1. S9 Human Ergonomic Scale Design	18.65	4.76	22.6576
F3.C2. S1 Width of Walking Zones,	24.29	10.4	108.16
F3.C2. S2 Types of Sidewalk Pavement,	21.37	7.48	55.9504
F3.C2. S3 Number of Street Trees,	9.02	−4.87	23.7169
F3.C2. S4 Sidewalk Steepness,	4.03	−9.86	97.2196
F3.C2. S5 Windy climate,	10.58	−3.31	10.9561
F3.C2. S6 Not-crowded Route,	19.07	5.18	133.1716
F3.C2. S7 Height and types of Fences,	24.36	5.18	26.8324
F3.C2. S8 Street reserve	5.47	10.47	109.6209
F4.C1. S1 Number(s) of Traffic Lanes	6.8	−8.42	70.8964
F4.C1. S2 Existence and width of medians	2.07	−7.09	50.2681
F4.C1. S3 Length of Segment	1.08	−12.81	164.0961
F4.C1. S4 Width of Traffic Zones	11.57	−2.32	5.3824
F4.C1. S5 Widths of Buildings	9.03	−4.86	23.6196
F4.C2. S1 Releasing visual Obstacles/Nuisances	6.77	−7.12	50.6944
F4.C2. S2 Traffic Signals	6.98	−6.91	47.7481
F4.C2. S3 Sidewalk Steepness	4.38	−9.51	90.4401
F4.C2. S4 Not-crowded Route,	5.13	−8.76	76.7376
F4.C2. S5 Existence of On-street Parking	3.41	−10.48	109.8304
F4.C2. S6 Mid-block crossing	4.01	−9.88	109.8304
F4.C2. S7 Height and types of Fences	2.74	−11.15	124.3225
F4.C2. S8 Public parking next to street	20.15	6.26	39.1876
F4.C2. S9 Slow Traffic speed	11.50	−2.39	5.7121
F5.C1. S1 Width of Curb-to-Curb Roadway	21.49	7.6	57.76
F5.C1. S2 Width of Utility Zones	20.15	6.26	39.1876
F5.C1. S3 Building Setbacks	11.57	−2.32	5.3824
F5.C1. S4 Width of buffer zone	9.03	−4.86	23.6196
F5.C1. S5 Street reserve	6.94	−6.95	48.3025
F5.C1. S6 Diversity of buildings	4.63	−9.26	85.7476
F5.C1. S7 Mixed functionality of Adjacent Buildings	15.68	1.79	3.2041
F5.C1. S8 Enclosure ratio	22.94	9.05	81.9025
F5.C2. S1 Planting diversity,	22.10	8.21	67.4041
F5.C2. S2 Sidewalk Lighting,	25.26	11.37	129.2769
F5.C2. S3 Width of Landscaping Strips,	15.79	1.9	3.61
F5.C2. S4 Types of Sidewalk Pavement,	20.8	6.91	47.7481
F5.C2. S5 Intangible Senses,	6.55	−7.34	53.8756
F5.C2. S6 Planting deciduous trees,	11.48	−2.41	5.8081
F5.C2. S7 Length of Tree Canopies,	8.4	−5.49	30.1401
F5.C2. S8 Number of Street Trees,	20.04	6.15	37.8225
F5.C2. S9 Building a Vital Atmosphere in sidewalks,	22.87	8.98	80.6404
F5.C2. S10 Street Interface,	11.99	−1.9	3.61
F5.C2. S11 Heights of Buildings,	15.79	1.9	3.61
F5.C2. S12 Upper-Floor Windows,	8.02	−5.87	34.4569
F5.C2. S13 Skyline height	11.76	−2.13	4.5369
	$\sum X = 1278.6$	$\overline{X} = 13.89$	$\sum X (X - \overline{X})^2 = 5000.81$

Table 4. Statistical Regression analysis for Shopping Center "B".

Walkability Sub-Criteria	Score on Indicator	Mean Deviation Score	Mean Deviation Score Square
	(X)	$(X - \overline{X})$	$(X - \overline{X})^2$
F1.C1. S1 Driveway Curb-cuts	19.12	8.24	67.8976
F1.C1. S2 Existence of Pedestrian Crossing	19.42	8.24	67.8976
F1.C1. S3 Width of Utility Zones	16.73	5.55	30.8025
F1.C1. S4 Shelters	12.34	1.16	1.3456
F1.C1. S5 Length of Tree Canopies	10.68	−0.5	0.25
F1.C1. S6 Releasing visual Obstacles/Nuisances	3.22	−7.96	63.3616
F1.C1. S7 Sidewalk Steepness	11.56	0.38	0.1444
F1.C1. S8 Existence of Bike Lanes	8.23	−2.95	8.7025
F1.C1. S9 Existence of On-street Parking	6.89	−4.29	18.4041
F1.C1. S10 Informing the intersection blindness	6.87	−4.31	18.5761
F1.C1. S11 Mid-block crossing	18.78	7.6	57.76
F1.C1. S12 Providing over-bridge	8.62	−2.56	6.5536
F1.C2. S1 Existence of Pedestrian Crossing	8.23	−2.95	8.7025
F1.C2. S2 Number(s) of Traffic Lanes	14.69	3.51	12.3201
F1.C2. S3 Traffic Signals	15.68	3.51	12.3201
F1.C2. S4 Traffic Calming Devices	4.7	−6.48	41.9904
F1.C2. S5 Drivers' respect to pedestrian	5.48	−5.7	32.49
F1.C2. S6 Slow Traffic speed	12.67	1.49	2.2201
F1.C3. S1 Sidewalk Lighting	6.97	−4.21	17.7241
F1.C3. S2 Number of Intermediary	8.55	−2.63	6.9169
F1.C3. S3 Length of Tree Canopies	9.49	−1.69	2.8561
F1.C3. S4 Number of Street Trees	6.48	−4.7	22.09
F1.C3. S5 Releasing visual Obstacles/Nuisances	4.6	−6.58	43.2964
F1.C3. S6 Not-crowded Route	12.06	0.88	0.7744
F1.C3. S7 Street Surveillance	2.97	−8.21	67.4041
F1.C3. S8 Street-Facing Entrances	7.87	−3.31	10.9561
F1.C3. S9 Street-level Façade Transparency	9.45	−1.73	67.8976
F1.C3. S10 First Floor Use of Buildings	9.49	−1.69	2.8561

Table 4. *Cont.*

Walkability Sub-Criteria	Score on Indicator	Mean Deviation Score	Mean Deviation Score Square
	(X)	$(X - \overline{X})$	$(X - \overline{X})^2$
F1.C3. S11 Upper-Floor Windows	14.73	3.55	12.6025
F2.C1. S1 Sidewalks networking	16.48	5.3	28.09
F2.C1. S2 Length of Sidewalks	15.03	3.85	14.8225
F2.C1. S3 Width of Walking Zones	17.18	6	36
F2.C1. S4 Continuity to diverse activity	12.39	1.21	1.4641
F2.C1. S5 Length of Segments	10.96	1.21	1.4641
F2.C1. S6 Informing the Intersection blindness	8.26	−0.22	30.8025
F2.C1. S8 Street signage	7.93	−3.25	10.562
F2.C2. S1 Sidewalk steepness	20.7	9.52	90.6304
F2.C2. S2 Street-Facing Entrances	24.19	13.01	169.2601
F2.C2. S3 Street Signage	9.90	−1.28	1.6384
F2.C2. S4 Length of Segment	22.89	11.71	137.124
F3.C1. S1 Well-locating of service utilities	17.47	6.29	39.5641
F3.C1. S2 Amount of Street Furniture	15.90	4.72	22.2784
F3.C1. S3 Sidewalk Lighting	12.92	1.74	3.0276
F3.C1. S4 Number of Intermediary	10.21	−0.97	0.9409
F3.C1. S5 Shelters	10.65	−0.53	0.2809
F3.C1. S6 Planting deciduous trees	15.12	3.94	15.5236
F3.C1. S7 Existence and width of medians	8.09	−3.09	9.5481
F3.C1. S8 Existence of On-street Parking	10.08	−1.1	1.21
F3.C1. S9 Human Ergonomic Scale Design	9.45	−1.73	2.9929
F3.C2. S1 Width of Walking Zones,	13.52	2.34	5.4756
F3.C2. S2 Types of Sidewalk Pavement,	21.27	10.09	101.8081
F3.C2. S3 Number of Street Trees,	14.06	2.88	8.2944
F3.C2. S4 Sidewalk Steepness,	9.03	−2.15	4.6225
F3.C2. S5 Windy climate,	2.43	−8.75	76.5625
F3.C2. S6 Not-crowded Route,	21.35	10.17	103.4289
F3.C2. S7 Height and types of Fences,	16.04	4.86	23.6196
F3.C2. S8 Street reserve	19.04	0.38	0.1444
F4.C1. S1 Number(s) of Traffic Lanes	5.41	−5.77	33.2929
F4.C1. S2 Existence and width of medians	13.09	1.91	3.6481
F4.C1. S3 Length of Segment	3.89	−7.29	53.1441
F4.C1. S4 Width of Traffic Zones	10.39	−0.79	0.6241
F4.C1. S5 Widths of Buildings	16.68	5.5	30.25
F4.C2. S1 Releasing visual Obstacles/Nuisances	9.36	5.5	30.25
F4.C2. S2 Traffic Signals	6.53	−4.65	21.6225
F4.C2. S3 Sidewalk Steepness	7.73	−3.45	11.9025
F4.C2. S4 Not-crowded Route,	8.83	−3.45	11.9025
F4.C2. S5 Existence of On-street Parking	5.44	−2.35	5.5225
F4.C2. S6 Mid-block crossing	4.35	−7.96	63.3616
F4.C2. S7 Height and types of Fences	4.36	−11.18	124.9924
F4.C2. S8 Public parking next to street	6.63	−4.55	20.7025
F4.C2. S9 Slow Traffic speed	1.37	−9.81	96.2361
F5.C1. S1 Width of Curb-to-Curb Roadway	4.29	−6.89	47.4721
F5.C1. S2 Width of Utility Zones	4.13	−7.05	49.7025
F5.C1. S3 Building Setbacks	4.30	−6.88	47.3344
F5.C1. S4 Width of buffer zone	6.63	−4.55	20.7025
F5.C1. S5 Street reserve	6.63	−4.55	20.7025
F5.C1. S6 Diversity of buildings	11.37	0.19	0.0361
F5.C1. S7 Mixed functionality of Adjacent Buildings	6.35	−4.83	23.3289
F5.C1. S8 Enclosure ratio	13.84	2.66	7.0756
F5.C2. S1 Planting diversity,	12.29	1.11	1.2321
F5.C2. S2 Sidewalk Lighting,	13.29	2.11	4.4521
F5.C2. S3 Width of Landscaping Strips,	9.56	−1.62	4.4521
F5.C2. S4 Types of Sidewalk Pavement,	8.39	−2.79	7.7841
F5.C2. S5 Intangible Senses,	6.43	−4.75	22.5625
F5.C2. S6 Planting deciduous trees,	12.67	1.49	2.2201
F5.C2. S7 Length of Tree Canopies,	16.95	5.77	33.2929
F5.C2. S8 Number of Street Trees,	15.57	4.39	19.2721
F5.C2. S9 Building a Vital Atmosphere in sidewalks,	8.77	−2.41	5.8081
F5.C2. S10 Street Interface,	18.78	7.6	57.76
F5.C2. S11 Heights of Buildings,	12.67	1.49	2.2201
F5.C2. S12 Upper-Floor Windows,	22.10	10.92	119.2464
F5.C2. S13 Skyline height	20.83	9.65	93.1225
	$\sum X = 1024.12$	**$\overline{X} = 13.08$**	**$\sum X (X - \overline{X})^2 = 2745.526$**

Table 5. Statistical Regression analysis for Shopping Center "C".

Walkability Sub-Criteria	Score on Indicator	Mean Deviation Score	Mean Deviation Score Square
	(X)	$(X - \overline{X})$	$(X - \overline{X})^2$
F1.C1. S1 Driveway Curb-cuts	18.64	5.56	30.9136
F1.C1. S2 Existence of Pedestrian Crossing	25.8	12.72	161.7984
F1.C1. S3 Width of Utility Zones	11.25	−1.83	3.3489
F1.C1. S4 Shelters	12.82	−0.26	0.0676
F1.C1. S5 Length of Tree Canopies	10.28	−2.8	7.84
F1.C1. S6 Releasing visual Obstacles/Nuisances	13.82	0.74	0.5476
F1.C1. S7 Sidewalk Steepness	7.57	−5.51	30.3601
F1.C1. S8 Existence of Bike Lanes	8.77	−4.31	18.5761
F1.C1. S9 Existence of On-street Parking	14.37	1.29	1.6641
F1.C1. S10 Informing the intersection blindness	9.04	−4.04	16.3216
F1.C1. S11 Mid-block crossing	16.94	3.86	14.8996
F1.C1. S12 Providing over-bridge	8.92	−4.16	17.3056
F1.C2. S1 Existence of Pedestrian Crossing	17.66	4.58	20.9764
F1.C2. S2 Number(s) of Traffic Lanes	19.39	6.31	39.8161
F1.C2. S3 Traffic Signals	22.16	9.08	82.4464
F1.C2. S4 Traffic Calming Devices	11.42	−1.66	2.7556
F1.C2. S5 Drivers' respect to pedestrian	7.9	−5.18	26.8324
F1.C2. S6 Slow Traffic speed	19.47	6.39	40.8321
F1.C3. S1 Sidewalk Lighting	12.64	−0.44	0.1936
F1.C3. S2 Number of Intermediary	10.93	−2.15	4.6225
F1.C3. S3 Length of Tree Canopies	14.57	1.49	2.2201
F1.C3. S4 Number of Street Trees	19.95	6.87	47.1969
F1.C3. S5 Releasing visual Obstacles/Nuisances	5.57	−7.51	56.4001
F1.C3. S6 Not-crowded Route	18.94	5.86	34.3396
F1.C3. S7 Street Surveillance	5.14	−7.94	63.0436
F1.C3. S8 Street-Facing Entrances	14.78	1.7	2.89
F1.C3. S9 Street-level Façade Transparency	20.21	7.13	50.8369

Table 5. *Cont.*

Walkability Sub-Criteria	Score on Indicator	Mean Deviation Score	Mean Deviation Score Square
	(X)	$(X - \overline{X})$	$(X - \overline{X})^2$
F1.C3. S10 First Floor Use of Buildings	18.97	5.89	34.6921
F1.C3. S11 Upper-Floor Windows	6.45	−6.63	43.9569
F2.C1. S1 Sidewalks networking	18.96	5.88	34.5744
F2.C1. S2 Length of Sidewalks	24.64	11.56	133.6336
F2.C1. S3 Width of Walking Zones	27.49	14.41	207.6481
F2.C1. S4 Continuity to diverse activity	21.35	8.27	207.6481
F2.C1. S5 Length of Segments	16.04	2.96	8.7616
F2.C1. S6 Informing the Intersection blindness	15.50	2.42	5.8564
F2.C1. S8 Street signage	11.03	−2.05	4.2025
F2.C2. S1 Sidewalk steepness	13.05	−0.03	0.0009
F2.C2. S2 Street-Facing Entrances	21.93	8.85	78.3225
F2.C2. S3 Street Signage	20.13	7.05	49.7025
F2.C2. S4 Length of Segment	18.90	5.82	33.8724
F3.C1. S1 Well-locating of service utilities	25.88	12.8	163.84
F3.C1. S2 Amount of Street Furniture	29.75	16.67	277.8889
F3.C1. S3 Sidewalk Lighting	14.67	1.59	2.5281
F3.C1. S4 Number of Intermediary	14.67	1.59	2.5281
F3.C1. S5 Shelters	11.66	−1.42	2.0164
F3.C1. S6 Planting deciduous trees	14.94	1.86	3.4596
F3.C1. S7 Existence and width of medians	19.68	6.6	43.56
F3.C1. S8 Existence of On-street Parking	13.80	0.72	0.5184
F3.C1. S9 Human Ergonomic Scale Design	8.62	−4.46	19.8916
F3.C2. S1 Width of Walking Zones,	16.84	3.76	14.1376
F3.C2. S2 Types of Sidewalk Pavement,	13.39	0.31	0.0961
F3.C2. S3 Number of Street Trees,	10.96	−2.12	4.4944
F3.C2. S4 Sidewalk Steepness,	8.96	−4.12	2.5281
F3.C2. S5 Windy climate,	4.37	−8.71	75.8641
F3.C2. S6 Not-crowded Route,	13.54	0.46	0.2116
F3.C2. S7 Height and types of Fences,	11.68	−1.4	1.96
F3.C2. S8 Street reserve	9.07	−4.01	16.0801
F4.C1. S1 Number(s) of Traffic Lanes	13.36	0.28	0.0784
F4.C1. S2 Existence and width of medians	25.09	12.01	144.2401
F4.C1. S3 Length of Segment	11.31	−1.77	3.1329
F4.C1. S4 Width of Traffic Zones	4.43	−8.65	74.8225
F4.C1. S5 Widths of Buildings	7.05	−6.03	36.360
F4.C2. S1 Releasing visual Obstacles/Nuisances	13.6	0.2704	0.52
F4.C2. S2 Traffic Signals	13.84	0.5776	0.76
F4.C2. S3 Sidewalk Steepness	10.50	6.6564	−2.58
F4.C2. S4 Not-crowded Route,	10.74	5.4756	−2.34
F4.C2. S5 Existence of On-street Parking	6.65	5.4756	−6.43
F4.C2. S6 Mid-block crossing	14.08	1	1
F4.C2. S7 Height and types of Fences	13.36	0.0784	0.28
F4.C2. S8 Public parking next to street	7.53	30.8025	−5.55
F4.C2. S9 Slow Traffic speed	15.29	4.884	2.21
F5.C1. S1 Width of Curb-to-Curb Roadway	3.82	−9.26	85.7476
F5.C1. S2 Width of Utility Zones	4.13	−8.95	80.1025
F5.C1. S3 Building Setbacks	3.2	−9.88	97.6144
F5.C1. S4 Width of buffer zone	7.12	−5.96	35.5216
F5.C1. S5 Street reserve	7.53	−5.55	30.8025
F5.C1. S6 Diversity of buildings	15.29	2.21	4.8841
F5.C1. S7 Mixed functionality of Adjacent Buildings	14.78	1.7	2.89
F5.C1. S8 Enclosure ratio	11.40	−1.68	2.8224
F5.C2. S1 Planting diversity,	6.65	−6.43	41.3449
F5.C2. S2 Sidewalk Lighting,	2.72	−10.36	107.3296
F5.C2. S3 Width of Landscaping Strips,	4.03	−9.05	81.9025
F5.C2. S4 Types of Sidewalk Pavement,	4.43	−8.65	74.8225
F5.C2. S5 Intangible Senses,	7.05	−6.03	36.3609
F5.C2. S6 Planting deciduous trees,	9.57	−3.51	12.3201
F5.C2. S7 Length of Tree Canopies,	8.77	−4.31	18.5761
F5.C2. S8 Number of Street Trees,	14.85	1.77	3.1329
F5.C2. S9 Building a Vital Atmosphere in sidewalks,	10.94	−2.14	4.5796
F5.C2. S10 Street Interface,	13.98	0.9	0.81
F5.C2. S11 Heights of Buildings,	13.30	0.22	0.0484
F5.C2. S12 Upper-Floor Windows,	6.83	−6.25	39.0625
F5.C2. S13 Skyline height	11.03	−2.05	4.2025
	$\sum X = 1029.06$	**$\overline{X} = 11.18$**	**$\sum X (X - \overline{X})^2 = 3332.25$**

5. Results and Findings

As can be seen in Table 2, the participants had different judgement on walkability sub-criteria in respect to each destination. In Shopping Center A, the participants believed that the sub-criterion "F1.C1.S2 Existence of Pedestrian Crossing" has the most significant role (26.67%) in the neighborhood's walkability, which was the highest percentage for Shopping Center C (25.80%), as well. Hence, on the "overall" neighborhood's walkability, which is the average of values from all three destinations, the sub-criterion "Existence of Pedestrian Crossing" plays the significant role (24.25%). In Shopping Center B, the sub-criterion "F2.C2.S2 Street-Facing Entrances" has the significant impact (24.19%) to the neighborhood's walkability. In contrast, the DTM analysis resulted "F1.C3.S7 Street Surveillance" loads the least contributor (4.82%) to the neighborhood's overall walkability; which makes room for urban designers and planners to allocate much more finance for improving the surveillance system of the streets in this neighborhood. The PWA model has established the grading based on the score index (see Table 6). In Table 6, the grade of each walkability variable measured in the Taman Universiti neighborhood can be determined. For instance, the sub-criterion "Existence of Pedestrian Crossing" rated as "Superior" grade means the pedestrian crossings in this neighborhood are well-designed and the residents are satisfied with them. The sub-criterion "Street Surveillance" attained the "very poor" grade, meaning the surveillance system of this neighborhood is non-usable and below standards, and the residents do not feel even minimum level of satisfaction; hence, it needs extensive improvement and/or correction actions.

Table 6. Grading Index of the Path Walkability Assessment (PWA) Index Model.

Path Walkability Scores Rating		Description and Recommendations
■ Superior	25 to 30	■ Well-designed and pedestrian-friendly constructed sidewalk to which satisfies users; Minor improvements, if any, needed
■ Good	20 to <25	■ constructed sidewalk to which accommodates users; Minor improvements may improve to superior rating
■ Fair	10 to <20	■ Usable sidewalk to which some users do not feel high level of walkability; improvement, such as better facilities and amenities, almost needed
■ Poor	5 to <10	■ Usable sidewalk to which many users do not feel high level of walkability; significant improvement, such as lack of facilities and amenities, probably needed
■ Very Poor	0 to <5	■ Non-usable sidewalk to which users do not feel even medium level of walkability, and has sub-standard conditions combined with heavy traffic; Should be improved.

The following presents the results of regression analysis of the association between each shopping center (A, B, and C) and the overall neighborhood walkability. According to the result of regression analysis, the association between measured variables (i.e., shopping centers walkability) and the conceptual variable (i.e., overall neighborhood walkability) was approximated with a straight line; thus, the result identifies the "linear relationship" among the measured variables and the conceptual variable. The regression analysis shows different patterns of residents' DTM for walking towards each shopping destination, which were affected by different walkability characteristics of those destinations. According to the linear regression analysis results, the independent and dependent variables have a positive direct relationship. The research found that, although each shopping center meets specific portion of overall neighborhood's walkability indexing, Shopping Center A has the main portion since the Pearson regression coefficient is higher than the other two shopping centers (r = 0.6696).

Regression Equation $(\hat{Y}) = \overline{Y} + r\,\frac{S_Y}{S_X}\,(X - \overline{X}) = 10.80 + 0.52\,\frac{7.09}{8.78}\,(X - 13.41) = 0.66696X + 5.2211$ (see Figure 6).

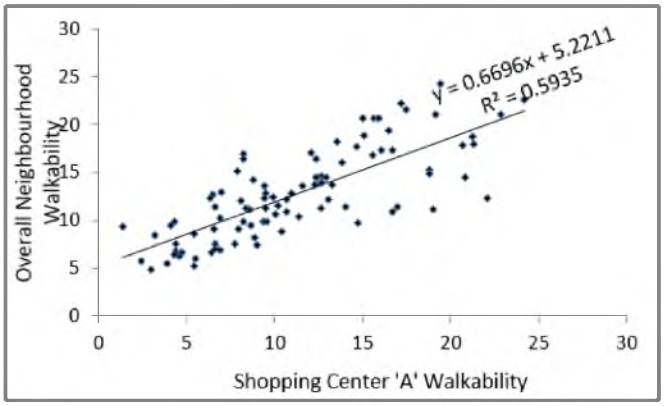

Figure 6. Scatter-plot diagram resulted from regression analysis of predicted overall neighborhood walkability based on Shopping Center A walkability.

Regression Equation $(\hat{Y}) = \overline{Y} + r\,\frac{S_Y}{S_X}\,(X - \overline{X}) = 10.80 + 0.48\,\frac{6.23}{8.78}\,(X - 13.41) = 0.5361X + 5.6938$ (see Figure 7).

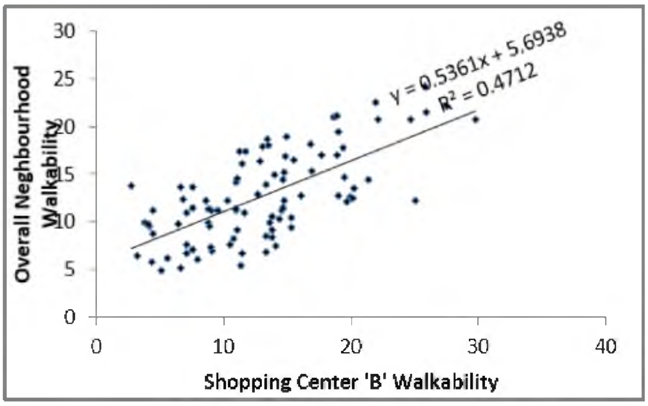

Figure 7. Scatter-plot diagram resulted from regression analysis of predicted overall neighborhood walkability based on Shopping Center B walkability.

Regression Equation $(\hat{Y}) = \overline{Y} + r\,\frac{S_Y}{S_X}\,(X - \overline{X}) = 10.80 + 0.52\,\frac{7.09}{8.78}\,(X - 13.41) = 0.5035X + 5.7131$ (see Figure 8).

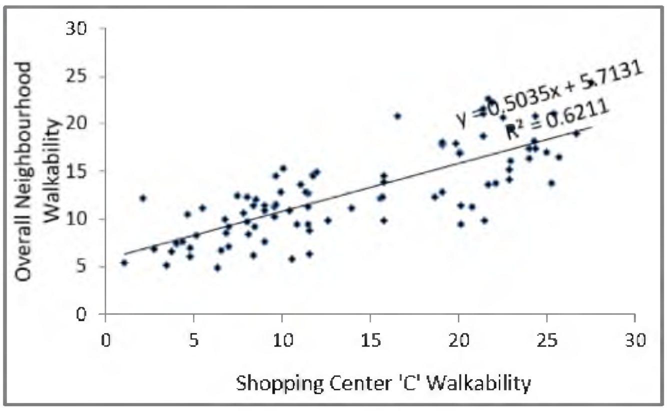

Figure 8. Scatter-plot diagram resulted from regression analysis of predicted overall neighborhood walkability based on Shopping Center C walkability.

6. Discussion

The study on walkability is a rapidly growing interest that integrates the expertise of several disciplines: transportation planning, urban design and planning, public health, and landscape architecture [69–71]. Indeed, urban walkability can safeguard the future performance of green and low-energy urban development by integrating the triple-bottom-line of sustainability [72–74]; environment protection (i.e., the environmental aspects of walkability), human well-being and livability (i.e., the social aspects of walkability), and economic sensitiveness (i.e., the economic aspects of walkability).

Previous researchers have mostly investigated the pedestrian's walking behavior in macro-scale (i.e., urban planning and transportation planning) quantitatively and physically. However, the pedestrian's walking behavior has been not been sufficiently explored in micro-scale (i.e., urban design) qualitatively. In this regard, this research has developed the Path Walkability Assessment (PWA) Index Model to quantify and measure the walkability of the built environment based on the individual's decision-tree-making (DTM) in their walking patterns and route selection. Using the PWA model aids urban and transportation professionals as a design decision support tool to facilitate neighborhoods towards a walkable and pedestrian-friendly environment, particularly for shopping activity. The PWA index model incorporates networking with walkability concepts, where networking refers to the integration of "urban transportation networks" with opportunities for "social networking".

(A) The focus on urban transportation networking promotes urban connectivity, accessibility, and degree of street interconnectedness for achieving a more compact city development. This approach reduces the amount of land needed for constructing road and street facilities, reduces pollution emissions and energy resource consumption, shortens walking distances, provides more route choices, and reduces the need for wide, difficult-to-cross streets, which simultaneously improves urban aesthetics and vitality, and preserves open space and parks.

(B) The focus on social networking identifies inconsistencies between the "perceptual qualities" of the urban built infrastructure and measures of "qualitative variables" that relate to people's needs and preferences for activity opportunities within the urban environment that encourage the selection of walking rather other modes of travel. Hence, the research will address the walkability qualities (both tangible and intangible) of the built environment in allowing social community networks to pursue and satisfy basic daily needs and preferences on foot.

This research has conducted a survey with the residents of the Taman Universit neighborhood, which has 2500 householders. The research needed a fast and simple method to collect data from that large population who mostly speak in local Malay language (and cannot speak English fluently). In addition, the researcher has looked for a method that does not require to be trained, and the public can easily digest. Hence, the DTM method was employed, while there is room to employ other decision-tree methods such as Random Forests. The research has dealt with only 92 variables which made it possible to use f the decision-tree method, while the Random Forests method needs higher numbers of variables. The Random Forests method is a predictive model, while the DTM method is also descriptive, which was properly fitted to the aim of this research. The DTM was built based on an entire dataset using all the variables, while the random forest randomly selects some of the variables for multiple decisions.

Although DTM method can involve many layers, this research has applied just three layers, as the optimal size of tree, to reduce the complexity and hence to improve predictive accuracy of analyses. In fact, a large tree may increase the risks of overfitting the data and poorly generalizing to new samples, while a small tree might not capture important structural information about the sample space. In this research, the three-layered tree has made the procedure of data collection much faster and manageable, and produced valuable and valid results. This strategy used little power to classify instances. This research applied the smallest optimized tree strategy, which reduced the computational load of the model.

7. Conclusions

The research developsd the Path walkability Assessment (PWA) model which incorporates the New Urbanism, Smart Growth, and Sustainability principles and strategies. The PWA index model is developed using Decision Tree Making (DTM) method. The application of DTM in path walkability assessment adds considerable value over conventional neighborhood urban-form analysis and conventional path-walkability analysis, especially in comparison to studies that focus only on mode-choice, trip chaining, and destination travel. The PWA model has a middle-out approach to enhance urban walkability. It considers both top-down and bottom-up approaches to boost urban walkability by engaging the participation of both government and private stakeholders in walkable urban growth and resilience. The PWA model as an urban design decision support tool is useful for urban designers and urban/transportation planners in deciding on future development/redevelopment and corrective actions.

The PWA model is a global-based tool that can be applied in any neighborhood in cities around the world. It determines the walkability score index and grade using environmental and physical qualities of a neighborhood with the aid of the residents' needs, perception, and preferences. Applying this tool guides the urban designers in prioritizing their financial investment based on the attained grades. Ultimately, using this model contributes to less energy consumption, less CO_2 and GHG emissions, and fewer street fatalities and accidents.

As future works, the tourist and tourist planners may use the output of this study. In addition, further studies may focus on:

- Descriptive study on walkability index as the Smartphone Application
- Formulating walkability index as a Smartphone Application
- Developing a framework to assess correlation of neighborhood walkability through Smartphone Application.

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Nomenclature

Symbol	Description
PWA	Path Walkability Assessment
DTM	Decision Tree Making
F_i	Features (1st layer of DTM)
C_j	Criteria (2nd Layer of DTM)
S_k	Sub-criteria (3rd Layer of DTM)
Rr	Respondent
$AvWVF_iC_jS_k$	Average Weight Value of the variable
$R_rRWVF_iC_jS_k$	The abbreviation of Rate Weight Value of the variable by rth Respondent (Rr)
n	Total number of respondents
RWV Max	The least possible Rate Value of the Variable by Respondent
$AcWVF_i$	Actual Weight Value of each variable in 1st Layer of DTM
$AcWVF_iC_j$	Actual Weight Value of each variable in 2nd Layer of DTM
$AcWVF_iC_jS_k$	Actual Weight Value of each variable in 3rd Layer of DTM
$\hat{Y}$	The predicted score of an individual on the dependent variable

$\overline{Y}$	The mean of independent variable
X	The scores of dependent variables
$\overline{X}$	The mean of dependent variable
S_X	The standard deviations of X
S_Y	The standard deviations of Y
r	Pearson correlation coefficient
N	Total number of the sample size
CSM	The Combined Scaling Method

Appendix A

Table A1. The Urban Path Walkability Index Assessment Model's Variables (Clustered to Three Levels of Features, Criteria, and Sub-Criteria).

Features (Layer 1)	Criteria (Layer 2)	Sub-Criteria (Layer 3)	Description	Citations
F1. Sense of Safety and Security	F1.C1. Safety facilities at sidewalks	… **[F1.C1. S1]** Driveway Curb-cuts,	The points along the sidewalk that interrupt pedestrian's continuous movement by automobiles entering driveways.	[16–18,24,32–34]
		… **[F1.C1. S2]** Existence of Pedestrian Crossing,	Pedestrian Crossing facilities in both segment and intersection exist in the different types, including marked crosswalk with pedestrian signal light, marked crosswalk with stop sign, marked crosswalk with hatching.	[17,18,34–37]
		… **[F1.C1. S3]** Width of Utility Zones,	The width of the sidewalk next to the curb allotted to street facilities.	[17,24,26,33,38]
		… **[F1.C1. S4]** Shelters,	For preservation against sun rain, and snow such as bus stations.	[26,39,40]
		… **[F1.C1. S5]** Length of Tree Canopies,	Total length of the center-line of the sidewalk walking zone covered by the tree canopies, including those planted on the private properties.	[17,24,33,37]
		… **[F1.C1. S6]** Releasing visual Obstacles/Nuisances,	Visual obstacles such as freeway overpass, utility poles and hanging wires make dissatisfaction on both street and sidewalk users.	[26,33,34,41]
		… **[F1.C1. S7]** Sidewalk Steepness,	The elevation difference between the end points of the segments divided by length of the segment.	[16,24,28,33,42]
		… **[F1.C1. S8]** Existence of Bike Lanes,	Bike Lanes would exist in both sides of the street.	[26,28,34,36,43,44]
		… **[F1.C1. S9]** Existence of On-street Parking,	On-street parking would exist on both sides of the street in the various forms: rectangular, diagonal, parallel, and non-parking.	[17,32,39,43]
		… **[F1.C1. S10]** Informing the intersection blindness,	It prevents continuous path of travel and cannot provide visual continuity of the streetscape. It requires additional signage which creates visual clutter	[18,25]
		… **[F1.C1. S11]** Mid-block crossing,	The element separates two parallel streets by solid obstacle such as grail, boulevard, or lighting.	[17,24,35,43,44]
		… **[F1.C1. S12]** Providing over-bridge	A way to get over water or a freeway for pedestrians.	[40]
	F1.C2. Slowing traffic speed	… **[F1.C2. S1]** Existence of Pedestrian Crossing,	Pedestrian Crossing facilities in both segment and intersection exist in different types, including marked crosswalk with pedestrian signal light, marked crosswalk with stop sign, and with hatching.	[18,25,35,36,43,44]
		… **[F1.C2. S2]** Number(s) of Traffic Lanes,	The number of traffic lanes design based on volume of street. The main and secondary street would have one or two traffic lanes.	[16,17,35,36,44,45]
		… **[F1.C2. S3]** Traffic Signals,	It is a pedestrian crossing facility located in the corner at the intersections or junctions.	[26,33,34,45,46]
		… **[F1.C2. S4]** Traffic Calming Devices,	Traffic Calming Devices are in different forms of speed bumps, chokers, bulb-out, chicanes, street closing with bollards, raised crosswalks, textured paving treatments, diverters, crossing islands, and mini-circles.	[7,24,28,34,35,43]
		… **[F1.C2. S5]** Drivers' respect to pedestrian,	The manner causes drivers to slow down the speed to let pedestrians pass, especially in junctions, intersections.	[7,27,45,47,48]
		… **[F1.C2. S6]** Slow Traffic speed	Making the mix of pedestrians, cyclists and vehicles slow and safe when lot frontages are wide.	[46]

Table A1. *Cont.*

Features (Layer 1)	Criteria (Layer 2)	Sub-Criteria (Layer 3)	Description	Citations
	F1.C3. Security in day and nights	. . . **[F1.C3. S1]** Sidewalk Lighting,	Lighting would be located in both sides of the streets, or in a middle along the street segment.	[24,26,35,43,44]
		. . . **[F1.C3. S2]** Number of Intermediary,	Similar to façade transparencies, intermediaries are objects that link public space on the sidewalk and indoor private space, such as small tables and chairs outside restaurants	[7,17,24,33,44]
		. . . **[F1.C3. S3]** Length of Tree Canopies,	Total length of the center-line of the sidewalk walking zone covered by the tree canopies, including those planted on the private properties.	[17,32,39,43]
		. . . **[F1.C3. S4]** Number of Street Trees,	The street trees are mostly planted between the traffic zones and sidewalk passages, excluding small trees, bushes, and private property.	[26,33,34,37,38]
		. . . **[F1.C3. S5]** Releasing visual Obstacles/Nuisances,	Visual obstacles, such as freeway overpass, utility poles and hanging wires, make dissatisfaction on both street and sidewalk users.	[7,24,26,28,41,45]
		. . . **[F1.C3. S6]** Not-crowded Route,	Public realm where became cluttered and have high traffic.	[7,24,40]
		. . . **[F1.C3. S7]** Street Surveillance,	It limits the opportunity for crime by increasing the perception designing transparent barriers (glass walls, picket fences).	[7,24,35,40,43]
		. . . **[F1.C3. S8]** Street-Facing Entrances,	Street-facing entrances are in relationship with the orientation of the doors, proximity to the sidewalk (not more than 70 feet).	[35,43,45,47,49–51]
		. . . **[F1.C3. S9]** Street-level Façade Transparency,	The degree of visual access of pedestrians into the inside of adjacent buildings. It is mainly indicated by proportion of glass windows on façade.	[28,34,42,49–51]
		. . . **[F1.C3. S10]** First Floor Use of Buildings,	The first floor use of buildings in the segment are different; commercial, residential, office, industrial, and institutional.	[7,16,22,24,45,50]
		. . . **[F1.C3. S11]** Upper-Floor Windows	The windows facing the street in the segment in the second and third floors.	[28,45,50,51]
F2. Connectivity	**F2.C1.** Sidewalk accessibility	. . . **[F2.C1. S1]** Sidewalks networking,	The linkages among the sidewalk routes which connects them tightly and systematically.	[49,50,52]
		. . . **[F2.C1. S2]** Length of Sidewalks,	A sidewalk is defined as a linear space for pedestrians separated from traffic zones by physical devices, such as vertical curb, bollards, or fences.	[26,28,33,34,40,44]
		. . . **[F2.C1. S3]** Width of Walking Zones,	The width of the clear passageway for pedestrians on the sidewalk excluding the utility zones.	[7,24,26,33,38]
		. . . **[F2.C1. S4]** Continuity to diverse activity,	Proper hierarchical understanding of places as physical, social and psychological dimensions of human experience.	[18,25,27,45,47]
		. . . **[F2.C1. S5]** Length of Segments,	The length between the center points of the two intersections along the street segment.	[17,28,40,44,45]
		. . . **[F2.C1. S6]** Informing the Intersection blindness,	It prevents continuous path of travel and cannot provide visual continuity of the streetscape. It requires additional signage which creates visual clutter	[17,38]
		. . . **[F2.C1. S8]** Street signage	Different sings to show the rule or functions of that specific place.	[7,16,22,53]

Table A1. *Cont.*

Features (Layer 1)	Criteria (Layer 2)	Sub-Criteria (Layer 3)	Description	Citations
	F2.C2. Physical connectivity	... **[F2.C2. S1]** Sidewalk steepness,	The elevation difference between the end points of the segments divided by length of the segment.	[7,16,17,24,42,44,45,54]
		... **[F2.C2. S2]** Street-Facing Entrances,	Street-facing entrances are in relationship with the orientation of the doors, proximity to the sidewalk.	[35,43,45,47,50,51]
		... **[F2.C2. S3]** Street Signage,	Different sings to show the rule or functions of that specific place.	[7,24,27,53]
		... **[F2.C2. S4]** Length of Segment	The length between the center points of the two intersections along the street segment.	[17,28,40,44,45]
F3. Comfort	F3.C1. Physical comfort	... **[F3.C1. S1]** Well-locating of service utilities,	The service facilities need to be arranged and located properly within the walkable area not to compromise the walking activity.	[35,43–45]
		... **[F3.C1. S2]** Amount of Street Furniture,	There are many types of street furniture, such as benches, seating facilities, lighting, trashes, and drinking fountains.	[17,26,33,34,37,38,45]
		... **[F3.C1. S3]** Sidewalk Lighting,	Lighting would be located in both sides of the streets, or in a middle along the street segment.	[17,18,24–26,44,45,55]
		... **[F3.C1. S4]** Number of Intermediary,	Similar to façade transparencies, intermediaries are objects that link public space on the sidewalk and indoor private space, such as small tables and chairs outside restaurants.	[17,26,33,34,37]
		... **[F3.C1. S5]** Shelters,	For preservation against sun, rain, and snow such as bus stations	[26,28,40]
		... **[F3.C1. S6]** Planting deciduous trees,	Planting deciduous trees in both sides of streets for providing shading during a year.	[45,54]
		... **[F3.C1. S7]** Existence and width of medians,	The elements along the street segments separate it into two sides.	[17,26,36,37,45,54]
		... **[F3.C1. S8]** Existence of On-street Parking,	The places are design in the edge of streets for vehicle parking.	[45,50]
		... **[F3.C1. S9]** Human Ergonomic Scale Design	It is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a street and urban system.	[5,6,31,33,34,41,48,52,56–58]
	F3.C2. Environmentally comfort	... **[F3.C2. S1]** Width of Walking Zones,	The width of the clear passageway for pedestrians on the sidewalk excluding the utility zones.	[17,26,33,34,38]
		... **[F3.C2. S2]** Types of Sidewalk Pavement,	The sidewalk pavements are various, such as colored/patterned concrete, bricks, cobblestones, asphalt, or dirt.	[26,33–45]
		... **[F3.C2. S3]** Number of Street Trees,	The street trees are mostly planted between the traffic zones and the sidewalk passages, excluding small trees, bushes, and private property.	[17,26,33,34,38]
		... **[F3.C2. S4]** Sidewalk Steepness,	The elevation difference between the end points of the segments divided by length of the segment.	[5,6,31,33,48,52,56]
		... **[F3.C2. S5]** Windy climate,	Places or routes cannot break the wind by design or planting which makes air circulation.	[26,39]
		... **[F3.C2. S6]** Not-crowded Route,	Public realm where became cluttered and have high traffic.	[28,40]

Table A1. *Cont.*

Features (Layer 1)	Criteria (Layer 2)	Sub-Criteria (Layer 3)	Description	Citations
		… **[F3.C2. S7]** Height and types of Fences,	There are different types of fences; chain-link, barbed wire, iron bars, and wood board.	[45,50,51,54]
		… **[F3.C2. S8]** Street reserve	The land set aside for a street carriageway and verge incorporating the full width from property line to opposite property line.	[7,27,48]
F4. Convenience	**F4.C1.** Functionality of diverse activities	… **[F4.C1. S1]** Number(s) of Traffic Lanes,	The number of traffic lanes design based on volume of street. The main and secondary street would have one or two traffic lanes.	[17,35–37,45]
		… **[F4.C1. S2]** Existence and width of medians,	The elements along the street segments separates it into two sides	[17,35,37,45]
		… **[F4.C1. S3]** Length of Segment,	The length between the center points of the two intersections along the street segment.	[17,28,33,40,45]
		… **[F4.C1. S4]** Width of Traffic Zones,	Width of the moving traffic excluding on-street parking, bike lanes, left/right turn lanes, and medians.	[16,33,34,38,43]
		… **[F4.C1. S5]** Widths of Buildings	Widths of buildings include garages and other structures with walls within each property. Normally, the buildings which are setback more than 70 feet from the property lines	[26,36,37,45,54]
	F4.C2. Easy access without obstacles	… **[F4.C2. S1]** Releasing visual Obstacles/Nuisances,	Visual obstacles such as freeway overpass, utility poles and hanging wires make dissatisfaction on both street and sidewalk users.	[7,16,22,41,53]
		… **[F4.C2. S2]** Traffic Signals,	It is a pedestrian crossing facility located in the corner at the intersections or junctions.	[18,22,46]
		… **[F4.C2. S3]** Sidewalk Steepness,	The elevation difference between the end points of the segments divided by length of the segment.	[7,19,22,53]
		… **[F4.C2. S4]** Not-crowded Route,	Public realm where became cluttered and have high traffic.	[28,40]
		… **[F4.C2. S5]** Existence of On-street Parking,	On-street parking would exist in both sides of the street in the various forms; rectangular, diagonal, parallel, and non-parking.	[28,35,40,44,45]
		… **[F4.C2. S6]** Mid-block crossing,	The element separates two parallel streets by solid obstacle such as grail, boulevard, or lighting.	[28,40,45]
		… **[F4.C2. S7]** Height and types of Fences,	There are different types of fences; chain-link, barbed wire, iron bars, and wood board.	[31,40,44,45,51]
		… **[F4.C2. S8]** Public parking next to street,	The places are design in the edge of streets for vehicle parking.	[45,54]
		… **[F4.C2. S9]** Slow Traffic speed	Making the mix of pedestrians, cyclists and vehicles slow and safe when lot frontages are wide.	[46]
F5. Attractiveness and Aesthetic	**F5.C1.** Street enclosure	… **[F5.C1. S1]** Width of Curb-to-Curb Roadway,	Pedestrian Crossing facilities in both segment and intersection exist in the different types, including marked crosswalk with pedestrian signal light, marked crosswalk with stop sign, marked crosswalk with hatching.	[7,16,22,53]
		… **[F5.C1. S2]** Width of Utility Zones,	The width of the sidewalk next to the curb allotted to street facilities.	[26,38,45]
		… **[F5.C1. S3]** Building Setbacks,	The building setback is the distance between the edge of sidewalk and the primary façade line of building or walls.	[28,34,50,51]
		… **[F5.C1. S4]** Width of buffer zone,	Width of buffers on the both sides of the street where is the space between edge of traffic lane and the clear passage of the sidewalk.	[28,34,50,54,59,60]

Table A1. *Cont.*

Features (Layer 1)	Criteria (Layer 2)	Sub-Criteria (Layer 3)	Description	Citations
		. . . **[F5.C1. S5]** Street reserve,	The land set aside for a street carriageway and verge incorporating the full width from property line to opposite property line.	[7,48,56]
		. . . **[F5.C1. S6]** Diversity of buildings,	The diversity in building functions and shapes make diverse destinations for pedestrian who can memorize them as the landmarks.	[17,33]
		. . . **[F5.C1. S7]** Mixed functionality of Adjacent Buildings,	It is one of the major determinants of travel behavior by resident. It is interaction between commercial and residential uses which is the combination of public uses, employment uses.	[17,28,33,40,45,50]
		. . . **[F5.C1. S8]** Enclosure ratio,	It the ratio of average building-to-building distance to average building height of the street segment	[7,24,28,34,51]
	F5.C2. Vibrancy and vitality	. . . **[F5.C2. S1]** Planting diversity,	The diversity in landscape and planting make diverse functions and roles through the paths and spaces for pedestrians.	[42,54]
		. . . **[F5.C2. S2]** Sidewalk Lighting,	Lighting would be located in both sides of the streets, or in a middle along the street segment.	[7,17,24,26,33,38]
		. . . **[F5.C2. S3]** Width of Landscaping Strips,	Width of the landscaping strips on both sides of the street.	[7,24,26,33,35,43]
		. . . **[F5.C2. S4]** Types of Sidewalk Pavement,	The sidewalk pavements are various, such as colored/patterned concrete, bricks, cobblestones, asphalt, or dirt.	[17,26,33,35]
		. . . **[F5.C2. S5]** Intangible Senses,	An asset that cannot be perceived by the senses, such as smelling of flowers	[7,27,31,57]
		. . . **[F5.C2. S6]** Planting deciduous trees,	Planting deciduous trees in both sides of streets for providing shading during a year.	[28,34]
		. . . **[F5.C2. S7]** Length of Tree Canopies,	Total length of center-line of the sidewalk zone covered by the tree canopies, including those planted on the private properties.	[28,34,40,44,45]
		. . . **[F5.C2. S8]** Number of Street Trees,	The street trees are mostly planted between the traffic zones and the sidewalk passages, excluding small trees less (less than five inches), bushes, and private property.	[17,28,40,44,45]
		. . . **[F5.C2. S9]** Vital Atmosphere in sidewalks,	Complex of intangible characteristics of place make it attractive to actual and potential residents and influences their behavior in observable ways.	[25,31,35,36,43,44,58]
		. . . **[F5.C2. S10]** Street Interface	Using streetscape treatments as transitional elements between commercial and residential areas.	[26,38,45]
		. . . **[F5.C2. S11]** Heights of Buildings,	Vertical measure of the building located in both sides of the street, which should balance with the street width and adjacent buildings.	[7,24,35,40,43]
		. . . **[F5.C2. S12]** Upper-Floor Windows,	The windows facing the street in the segment in the second and third floors.	[26,38,45,61]
		. . . **[F5.C2. S13]** Skyline height	The line along the surface of the earth and the sky appear to meet.	[26,38,45,51]

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