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The Influence of Built Environment and Perceived Walkability on Walking Behaviour in Taiwan

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Abstract

Walking is the most common and natural forms of transport mode and the most important transport mode for public transport to connect the first mile and last mile. This study aims to investigate the relationships between objective and subjective measures of the walking environment, walkability and walking behaviour in Taiwan. We assume perceptions of the walking environment mediate between objective measures of walking environment, and overall walkability and walking behaviour. A structural equation model was adopted to verify the hypotheses of this study. The results show that objective measures of population density, land-use mix, the percentage of 4-way intersections and the number of cul-de-sacs exert significant impact on the perceptions of distances to services, opportunities & street connectivity, aesthetics and on-street barriers. In addition, an individual's perceptions of the walking environment have a significant influence on overall walkability, and overall walkability affects travel mode choice towards walking.

1. Introduction

Walking is one of the most common and natural forms of physical activity and transport mode [1, 2]. It is also the most important transport mode for public transport, connecting the 'first and last mile' [3]. Most public transport journeys include an element of walking both to and from the bus stop or metro/railway station, and possibly at interchange points [4]. A walkable environment can boost walking accessibility and so encourage use of public transport [3]. Hence, it is important to understand the associations between the walking environment and walking behaviour.

Many walking travel behaviour studies have identified relationships between key built environment attributes such as services proximity, street connectivity, traffic safety and neighbouring aesthetics, and walking behaviours such as walking frequency and walking time [5-7]. People living in a walkable neighbourhood tend to walk more frequently and for longer walking distances [5-7]. However, only relatively few studies have included walking trips in travel mode choice behaviour models [8-10].

Several studies have found evidence that the walking environment – whether captured using objective or subjective measures – exerts some influence on walking behaviour [5, 7, 11, 12]. A number of studies have also examined the correlations between the two types of measures [13-15]. However, there is a lack of evidence which shows the relationships between objective measures and subjective measures of the walking environment and walking behaviour. Alfonzo [16] asserted that the objective walking environment is an important indirect determinant of

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walking behaviour, which operates via its impact on the cognition of walking environment [16]. Ewing and Handy [17] suggested that perceptions of the walking environment are influenced by physical features for walking, amongst other things, and determine overall perceived walkability and walking behaviour. Very few studies have incorporated both objective measures and subjective measures of walking environment to examine their relationships and impacts on walking behaviour [18] .

The aims of this study are to examine 1) to what extent objective walking environment factors influence perceived walking environment factors, and 2) to what extent perceived environmental factors influence overall perceived walkability and walking as a mode choice, using a cross-sectional approach.

There are six sections in this paper. The next section reviews previous studies about walking behaviour, and objective and subjective measures of the walking environment. The third section proposes a conceptual model for this study. The fourth section describes the data collected for this study and the data analysis methods used. The fifth section presents the model estimated results. The final section discusses some important findings and the limitations of this study.

2. Literature Review

Walking behaviour includes walking frequency, walking time and choice of walking over other modes of transport [16]. Most of the past studies have adopted walking frequency and walking time as dependent variables [16].. The relationships between (objective or subjective measures of) the walking environment, walking frequency and walking time have been a popular area for research over the last decade [5, 11, 12, 19-21] both within the fields of transport and health. Within transport studies, additional attention has been paid to the effects of the walking environment on the mode choice of walking. However, walking behaviour has been neglected in most travel mode choice studies [22-25]. Where walking is considered in mode choice studies, it is often treated as being an option for all trips [9, 10]. However there are many factors which make walking difficult, if not impossible, for many trips [16]. These include trip distance and individual characteristics such as health and disability. Rodríguez and Joo [8] assumed that walking is not an option for a traveller if his/her trip distance too long, and used a 6.45 km one-way distance as the cut off point for walking as an available mode.

A behaviour of choosing walking over other modes of transport represents the results of an interaction between the person and the walking environment [26] amongst other factors. According to the ecological model of walking [16, 26], an individual's interaction with the walking environment is through a cognition process [16, 26, 27]. An individual's perceptions of the walking environment may be influenced by his/her reaction to the physical (objective) walking environment [16]. People may differ with respect to the affordances they perceived within the environment. For example, within the same setting such as street block length, presence of sidewalks and sidewalks widths, one individual may perceive the physical walking environment has met his/her need for connectivity, whereas another person may not. An individual's perceived walking environment determines their perceived overall walkability and walking behaviour [16, 17, 27]. Alfonzo [16] and Ewing and Handy [17, 27] have asserted that perceived environmental factors are mediators between physical environment features, and overall walkability and walking behaviour. An individual's overall perception of walkability determines their walking behaviour [17, 27]. Kremers, De Bruijn [28] also argued that the impact of neighbourhood environmental attributes on physical activity may be mediated through environmental cognitions.

An individual's socio-demographic characteristics such age, gender, income, household motorised vehicle ownership have been found to affect their walking behaviour. [10, 29]. These factors may influence both the affordances an individual perceives within the environment, and how these combine into perceived overall walkability, but may also influence walking behaviour through other mechanisms relating to, for example, motivations and intentions [16,26] and the availability of alternatives to walking [16].

Objective walking environment measures attempt to capture urban form and urban design using data either collected in the field [30, 31] or from existing spatial and land use databases [11, 32, 33]. Proximity and connectivity are the most frequently captured built environmental features in studies of walking behaviours [11, 12, 19, 20, 33]. Proximity, which is similar to accessibility, refers to opportunities to access different activities by walking [11, 12, 20]. Proxy measures frequently used to represent proximity are density (population density or dwelling density) and the level of land use mixing [11, 12]. Connectivity measures the directness and convenience of the pathways between households and destinations [11, 12, 20]. Proxy measures of connectivity are often based on street layout measures such as the density of intersections, average length of road segments and the numbers of cul-de-sacs [11-13]. Comfort, safety, and neighbourhood aesthetics tend to be captured using measures such as sidewalk widths, percentage of sidewalks present, traffic volumes, traffic speeds, numbers of road traffic collisions, numbers of street lights, presence of graffiti and the numbers of trees along sidewalks [8, 13, 14, 16, 18].

Subjective measures of the walking environment are self-reported perceptions of the walking environment usually obtained from survey questionnaires [5, 13, 15, 21, 34-36]. The Neighborhood Environment Walkability Scale (NEWS) and its abbreviated forms, NEWS-A, is one of the frequently used survey instruments for capturing perceptions of the walking environment [5, 15, 21, 34, 35, 37, 38]. Participants are asked to rate their neighbourhood (local environment) for a number of different factors, including land use mix, street connectivity, infrastructure for walking, neighbourhood aesthetics, traffic hazards, and crime safety [5, 15, 21, 34, 35, 37, 38]. Chiang and Weng [7] used NEWS-A to examine the association between subjective measures of the walking environment, and walking duration and walking frequency in Taiwan and found statistically significant relationships between them.

Several studies have examined the correlations between objective measures of the walking environment and perceptions of walking environment and have found only low agreement between the objective measures and the perceived walking environment factors tested [13-15, 39, 40]. This is hardly surprising given subjective measures of walking environment capture individuals' reactions, which reflect their perceptions of an affordance for a particular need [16] and thus are varied from person to person, whilst objective measures do not. For example, under the same objective measures of walking environment, an individual who prefers walking may perceive a high level of walkability, whereas another person who is accustomed to using a private vehicle may perceive a low level of walkability. Cerin, Leslie [15], however, found associations between objective measures of dwelling density, intersection density, land use mix and net retail area with perceived measures of residential density, land use mix, access to services and walking infrastructure, traffic safety, traffic speed.

Although several recent studies have used both objective and perceived walking environmental factors in their analysis, most of them only examined the correspondence between objective measures and self-reported perceptions of walking environmental factors. Few studies have incorporated both objective measures of walking environmental features and perceived environmental factors with walkability and walking behaviour. This is required if we wish to test the ecological walking behaviour model proposed by Sallis and Cervero [26] and Alfonzo [16], that walking-decision making is a cognition process of individual interaction with objective walking environment. There is currently a lack of an evidence to verify this model. Past studies [RQ] have suggested that subjective measures of the walking environment seem to act as mediators between objective measures of the walking environment, and walkability and walking behaviour, however very few studies have tested this conceptual model.

3. Conceptual Model

The conceptual model underlying this study assumes that walking environmental perceptions and overall perceived walkability mediate between objective measures of the walking environment, and walking behaviour, as shown in Figure 1 [16, 17, 27]. Overall perceived walkability reflects an individual's overall assessment about the walking environment, which is determined by perceived environmental factors. Overall perceived walkability affects walking behaviour along with an individual's socio-demographic characteristics (Figure 1) and other factors which affect the mode choice set. Socio-demographic characteristics have been found to be important factors affecting travel mode choice [8, 10]. This study incorporates gender, age, income, household car ownership and household motorbike ownership in the model. An important constraint on walking as a mode choice is trip distance. In Taiwan, less than 5% of walk trips take more than 45 minutes to complete [41].

Walking can be considered to consist of two main kinds of travel behaviour: walking to a destination (i.e. where the entire trip is made on foot) and walking to access public transport. The walking to destination could be more related to accessible activities within walking distance. Walking to public transport could influenced by whether there is a suitable public transport stop/station within walking distance as well as the walkability of the environment. Thus, walking to the destination and walking to public transport need to be considered separately as they have different characteristics. The availability and relative attractiveness of alternatives to walking and walking to public transport also need to be considered.

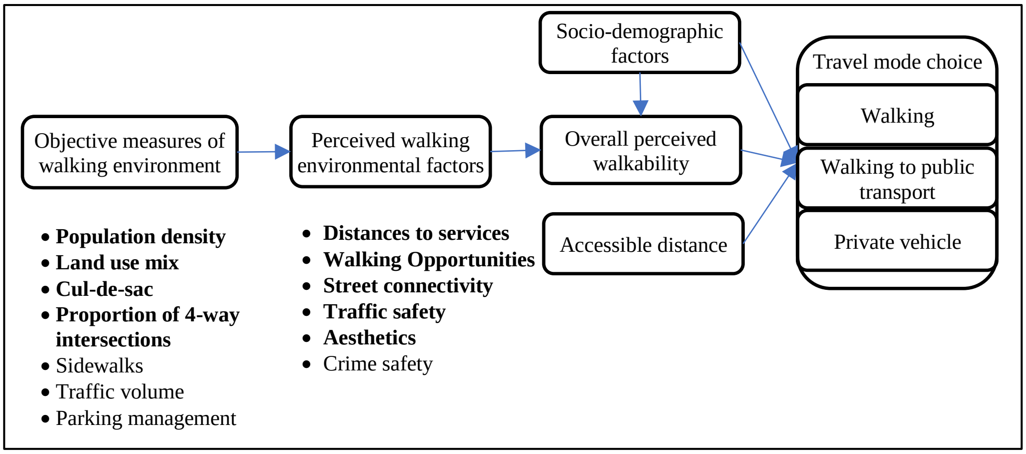

Figure 1 Conceptual model

4. Data and Analysis Method

This section presents the data used in this study, describes the measures and variables extracted from the data, gives some descriptive statistics of the subjective measures and objective measures data, and describes the method used in data analysis. The analysis focuses on home-based commuting trips in Taiwan.

4.1. Data sources

Data on perceptions of walking environment, attitudes toward public transport, mode choice for commuting trips, and socio-demographic characteristics was drawn from an online survey of travel behaviour. An unrestricted self-selection survey method was used, in other words the survey was open to the public to participate in. Participants could fill the questionnaire using any electronic device, including desktop computers, laptops, tablets and mobile phones, which can access the internet and open the web link. A snowball sampling method was used; the questionnaire web link was sent to contacts in Taiwan through email, Facebook and online chat apps; these contacts were asked both to complete the questionnaire and to forward the web link to their friends in Taiwan. The survey took place in July and August 2015. A total of 1,619 effective responses were collected. The responses covered all of the 19 cities and counties in Taiwan.

Of the 1,619 valid responses, 1,031 were used in this study. Among the excluded 588 responses, 381 respondents' residences were located in the places (villages) where the land use data are not available. These excluded responses were from villages including military facilities. The other 207 excluded responses included travel mode choices reported as using private vehicles to access public transport (107), bike and taxi (35) and no reported commuting trips (65). Responses from children under the age of 15 were also excluded. The sample covered urban, suburban and rural environments and areas with population densities ranging from 0.03 to 1185.05 persons/hectare (Table 3).

As can be seen in Table 1, the socio-demographic statistics show that the respondents include both genders, all age groups, all levels of education and all income groups in Taiwan. The proportion of males (57.3%) is somewhat greater than females (42.7%). About 85% of the respondents owned a car driver's license or motorbike driver's license. The monthly income of the sample ranged from less than US$333 to US$ 3,333 and over, and the proportion of respondents in the lowest income group is about the same as for the highest income group. Average household car ownership and motorbike ownership levels are 1.20 (standard deviation =0.80) and 1.65 (standard deviation=1.17) vehicles per household respectively (Table 1). Comparing the sample to the population of Taiwan, the percentage of males in the sample (57.3%) is higher than for the whole population (49.9%) [42]. In terms of age, the sample has a higher percentage of people aged between 25-54 (83%) as compared to the population (58.1%). The percentage of those aged 15-24 and aged 55 and over in the sample (11.2% and 5.8% respectively) are lower than for the whole population (16.1% and 25.5% respectively) [42]. This may be because senior people were less likely to use the Internet, required to fill in the online questionnaire. This means that males and those aged between 25-54 are over represented in the sample; females, and those aged 15-24 and aged 55 and over are underrepresented. However, as the focus of this study is on understanding individual behaviour rather than predicting behaviour for the population this is not of major concern.

Table 1 Descriptive statistics for socio-demographics characteristics

Items	Freq.	Percentage
Gender		
Male	591	57.3
Female	440	42.7
Age		
15-24	115	11.2
25-54	856	83.0
55 and Over	60	5.8
Education		
High school and under	72	7.0
Bachelor	547	53.0
Master or higher	406	9.4
Missing	6	0.6
Car driver's license		
Yes	881	85.4
No	150	14.6
Motorbike driver's license		
Yes	895	86.8
No	136	13.2
Monthly personal income		
Under US$ 666	105	10.2
US$ 667-2666	725	70.3
US$ 2667 and over	150	14.6
Missing	51	4.9
Household car ownership		
0	168	16.3
1	555	53.8
2	247	24.0
3	48	4.7
4 and more	12	1.1
Missing	1	0.1
Household motorbike ownership		

0	174	16.9
1	338	32.8
2	283	27.4
3	140	13.6
4 and more	96	9.3

The objective measures were drawn from the Taiwanese Socio-economic Database [43], the Taiwanese National Land Surveying Database [44], and the Taiwanese Traffic Network Digital Map [45] respectively. The GIS data was at a resolution of 1/25,000.

4.2. Objective measures

The objective built environment features were measured at the village scale. Village is the basic unit of Taiwanese administrative subdivision; under cities/counties and districts. The average area and population of a village in Taiwan are 4.7 km^2 and 3,017 persons respectively [43]. Suppose that villages are circular in shape, then the radius of the average village would be about 1.2 km, which suggests it is reasonable to use village as the scale of analysis for walking environment features [6, 33, 46]. Four objective measures of walking environment attributes were calculated for each of the villages where respondents were located: population density, land use mix entropy, the percentage of 4-way intersections and the numbers of cul-de-sacs.

Table 3 shows the descriptive statistics of these objective measures of walking environment features. Land use mix entropy, which is to measure the extent of land use diversity in a village, was calculated using Eq. (1) based on six land use categories: residential, commercial, industrial, government offices, education, and hospital and social care buildings. Land use entropy ranges from 0 to 1, with higher entropy value indicate in a more evenly distributed mix of land uses. In order to reduce the varied ranges among these objective measures of walking environment factors, all the four factors were standardised into z-scores in the analysis.

$$Land\ use\ mix\ entropy = -\sum_j P_j \times \frac{\ln(P_j)}{\ln(J)} \quad (1)$$

Where Pj is the proportion of land use type j in the area, and J is the total number of land use types, which equals to 6.

Table 3 Descriptive statistics of objective measures of built environment

	Obs.	Mean	Std. Dev.	Min	Max
Population density (persons/hectare)	1031	214.26	195.33	0.030	1185.05
Land use mix entropy	1031	0.41	0.19	0.004	0.88
Percentage of 4-way intersections	1031	0.25	0.13	0	0.75
Numbers of cul-de-sacs	1031	12.36	21.75	0	203.00

4.3. Subjective measures

The survey contained five categories of questions on perceptions of the walking environment, which were walking opportunities, street connectivity, aesthetics, traffic safety and distances to services. In total 21 questions were asked to measure perceptions of walking environment factors (Table 2). Except for distances to services, the questions used a 5-likert scale from strongly agree to strongly disagree to assess the walking environment attributes of a respondent's neighbourhood. For questions where strongly agree and agree mean a positive walking environment, the 5-likert scale was coded as strongly agree: 5, agree: 4, neutral: 3, disagree: 2, strongly disagree: 1. For questions where strongly agree and agree mean a negative walking environment, such as SC4, SC5, TS2, TS4 in Table 2, the 5-likert scale was coded as strongly agree: 1, agree: 2, neutral: 3, disagree:4, strongly disagree:5. As for distances to services, the respondents reported estimated walking time (choices from less than 5 mins, 6-10 mins, 11-15 mins, 16-20 mins, 21-30 mins, and 30 mins and over) to their nearest facilities including convenient stores, bus stops, supermarkets, primary schools, post offices and banks, breakfast restaurants, and parks. The descriptive statistics for the perceptions of walking environmental indicators are shown in Table 2.

Among the likert-scale indicators in Table 2, the indicator WO2 had the highest average score, which indicates that the respondents were most satisfied with this indicator – convenient stores are within easy walking distance. This is consistent with WT1 indicator –walking time to the nearest convenient store – in distance to services, which had the shortest average walking time (Table 2).

Table 2 Descriptive statistics of perceived walking environmental indicators

Category	Code	Indicators	Ave.	Std. Dev.
Walking opportunities	WO1	There are many places to go within easy walking distance	3.87	1.10
	WO2	Convenient stores are within easy walking distance	4.29	0.91
	WO3	It is easy to walk to a public transport stop (bus, metro or train)	3.60	1.30
Street connectivity	SC1	The distance between intersections is usually short (150 meters or less)	3.84	1.00
	SC2	There are many alternative routes for getting from place to place	3.67	1.02
	SC3	There are sidewalks on most of the streets in my neighbourhood	3.22	1.27
	SC4	**There are motorbike parking on the streets and sidewalks blocking the way**	2.58	1.21
	SC5	**There are 'hawkers' and shops on the streets and sidewalks blocking the way**	3.03	1.19
Traffic safety	TS1	There are crosswalks and pedestrian signals on intersections	3.67	1.04
	TS2	**So much traffic along nearby streets that it makes difficult or unpleasant to walk in my neighbourhood.**	3.05	1.00
	TS3	The speed of traffic on most nearby streets is usually slow (40 km/hr or less)	2.98	1.03
	TS4	**Most drivers exceed the speed limits while driving in my neighbourhood**	2.78	1.01
Aesthetics	AE1	There are many trees along the streets in my neighbourhood	3.26	1.06
	AE2	There are many attractive natural sights in my neighbourhood	3.01	1.17
Distances to services	WT1	Walking time to the nearest convenient store is	5.80*	5.73
	WT2	Walking time to the nearest bus stop is	7.50*	6.97
	WT3	Walking time to the nearest supermarket is	12.04*	9.30
	WT4	Walking time to the nearest primary school is	11.71*	8.20
	WT5	Walking time to the nearest post office/ bank is	13.07*	9.64
	WT6	Walking time to the nearest breakfast restaurant is	6.53*	6.44
	WT7	Walking time to the nearest park is	9.39*	8.84

'*': the average walking time to nearest services estimated by the respondents.

4.4. Dependent variables

There are two dependent variables in this study. One is overall perceived walkability, another is travel mode choice. Overall perceived walkability plays roles as both a dependent variable and an independent variable. Overall perceived walkability acts as a dependent variable for the perceptions of walking environment factors; and it acts as an independent variable for travel mode choice (Figure 1).

4.4.1. Perceived overall walkability

The perceived overall walkability was self-reported using a 7-likert scale: extremely satisfied, satisfied, somewhat satisfied, neutral, somewhat dissatisfied, dissatisfied, and extremely dissatisfied, which were coded from 7 to 1 respectively. The average score and standard deviation of the sample for overall perceived walkability were 4.95 and 1.48 respectively.

4.4.2. Travel mode choice

The travel mode choice set includes walking, walking to access public transport and private vehicle (car and motorbike) for home-based commute journeys. Of the 1,031 responses, 6.1% chose walking to their destination; 22.2% chose walking to access public transport; and 71.8% chose private vehicle (Table 4).

Table 4 Travel mode choice

Transport modes	Freq.	Percentage
Walking to destinations	63	6.1
Walking access to public transport	228	22.2
Private vehicle	740	71.8
Total	1,031	100

4.5. Structural model

Based on the conceptual model (see figure 1), Figure 2 presents the structural model of this study. Subjective walking environmental factors and socio-demographic characteristics are assumed to influence overall perceived walkability; overall perceived walkability and socio-demographic characteristics are assumed to influence travel mode choice between walking (to destination), walking access to public transport and private vehicles.

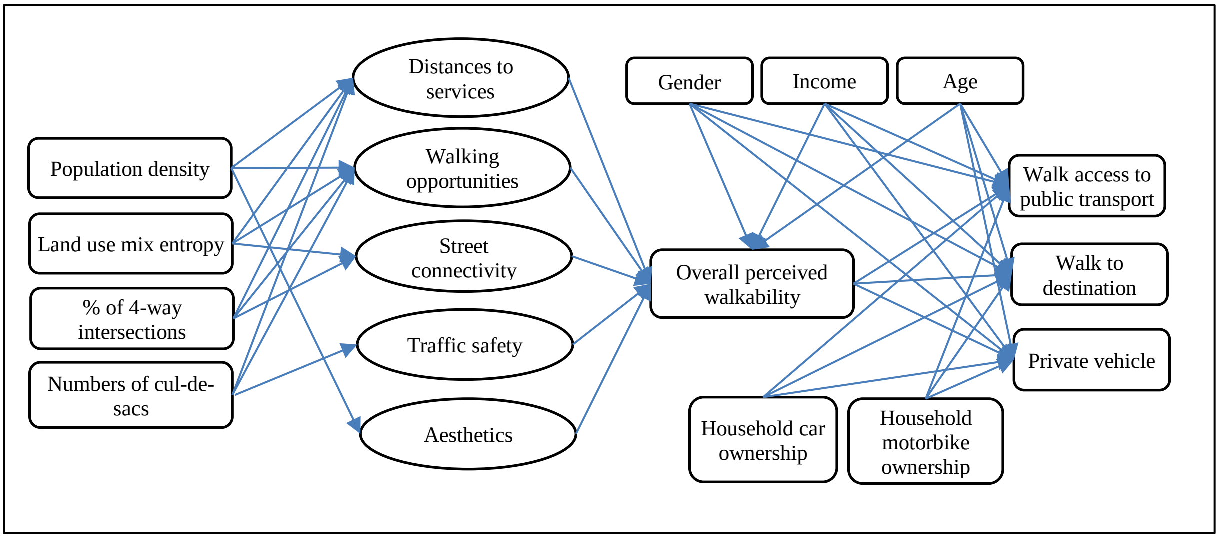

Figure 2 Model structure

4.6. Data analysis method

Data analysis was divided into two stages. The first stage used factor analysis to extract a set of perceptions of walking environment factors from the 21 indicators. The second stage used a generalized structural equation model

(GSEM) to verify the hypothesis that objective measures of the walking environment influence subjective measures of the walking environment, and then subjective measures of the walking environment influence walkability and walking behaviour.

5. Results

5.1. Factor analysis for subjective measures of walking environmental indicators

Two different factor analyses were used to extract the perceived walking environmental factors due to the different measurement scales in use. The first factor analysis focused on the 14 indicators which use a 5-likert scale, and the second factor analysis focused on the 7 indicators indicating distances to service.

The Cronbach's Alpha for the 14 5-likert scale indicators is 0.746, which indicates that the dataset has adequate internal consistency [47]. The index of Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO-MSA) is 0.79 and Bartlett's Test of Sphericity is significant at $p<0.000$, which indicates that the 5-likert scales indicators dataset is suitable for factor analysis [48]. Principal axing factoring method along with varimax rotation was used to extract four perceived walking environmental factors [48]. As can be seen in Table 5, the four perceived-walking-environmental factors are named, using the features of their indicators, as opportunities & street connectivity, on-street barriers, aesthetics and traffic safety. These accounted for 64.9% of total variance. Table 5 shows the factor loadings, with loadings less than 0.30 supressed [48].

Table 5 Rotated factor loading matrix

		Factor loading			
		Opportunities & connectivity	On-street barriers	Aesthetics	Traffic safety
WO1	There are many places to go within easy walking distance of my home.	.783			
WO2	Convenient stores are within easy walking distance of my home.	.687			
WO3	It is easy to walk to a public transport stop (bus, metro or train) from my home.	.695			
SC1	Distance between intersections in my neighbourhood is usually short (150 meters or less).	.659			
SC2	There are many alternative routes for getting from place to place in my neighbourhood.	.611			
SC3	There are sidewalks on most of the streets in my neighbourhood.	.615		.336	
TS1	There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighbourhood.	.589			
SC4	**There is motorbike parking on the streets and sidewalks blocking the way.**		.813		
SC5	**There are 'hawkers' and shops on the streets and sidewalks blocking the way.**		.788		
TS2	**So much traffic along nearby streets that it makes difficult or unpleasant to walk in my neighbourhood.**		.465		
AE2	There are many attractive natural sights in my neighbourhood			.782	
AE1	There are trees along the streets in my neighbourhood.			.790	
TS4	**Most drivers exceed the speed limits while driving in my neighbourhood.**		.302		.838
TS3	Speed of traffic on most nearby streets is usually slow (40 km/hr or less).				.541

A single Distances to services factor was extracted from the second factor analysis. The values of Cronbach's Alpha (0.87), KMO-MSA (0.88) and Bartlett's Test of Sphericity (significant at $p<0.000$) showed the dataset has internal consistency and is suitable for factor analysis. About 58% of total variance was extracted from the 7 indicators by principal axing factoring method. The factor loadings are shown in Table 6.

Table 6 Factor loadings of distances to services factor

Code	Indicators	Loading
WT1	Walking time to the nearest convenient store	0.742
WT2	Walking time to the nearest bus stop	0.622

WT3	Walking time to the nearest supermarket	0.782
WT4	Walking time to the nearest primary school	0.700
WT5	Walking time to the nearest post office/ bank	0.796
WT6	Walking time to the nearest breakfast restaurant	0.760
WT7	Walking time to the nearest park	0.580

5.2. Correlation between objective and subjective measures of walking environment factors

The correlations in Table 7 show that overall perceived walkability tends to have higher correlations with subjective measures of walking environmental factors than objective measures of the walking environment. With the exception of Traffic safety, all the subjective measures of walking environment factors were significantly correlated to at least one objective measure of the walking environment.

Table 7 Correlations

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Objective measures	Population density (1)	1.00									
	Land use mix (2)	**-0.49**	1.00								
	Percentage of 4-way intersection (3)	**0.22**	-0.06	1.00							
	Numbers of cul-de-sacs (4)	**-0.42**	**0.18**	**-0.23**	1.00						
	Overall perceived walkability (5)	**0.16**	-0.06	0.07	**-0.22**	1.00					
Subjective measures	Opportunities & street connectivity (6)	**0.34**	**-0.11**	**0.19**	**-0.35**	**0.47**	1.00				
	On-street barriers (7)	-0.06	**0.10**	**-0.10**	0.05	**0.13**	-0.03	1.00			
	Aesthetics (8)	**-0.16**	0.09	-0.03	0.04	**0.27**	0.04	0.05	1.00		
	Traffic safety (9)	0.05	-0.06	0.02	-0.04	**0.14**	-0.03	**0.09**	0.06	1.00	
	Distances to services (10)	**-0.39**	**0.11**	**-0.20**	**0.38**	**-0.38**	**-0.65**	**0.13**	0.07	-0.08	1.00

Bold number denote correlation is significant at the 0.01 level (2-tailed)

5.3. Model results

Structural equation modelling (SEM) and generalized structural equation modelling (GSEM) with Stata 13.1 were used to estimate the path coefficients of the relationships between the constructs in the research model in Figure 2.

The estimation was divided into two stages. The first stage used SEM to estimate the paths in Figure 2 from objective measures of walking environmental factors to subjective measures of walking environmental factors and to overall walkability. The goodness-of-fit indices of the structural model were as follows: CFI = 0.98, TLI = 0.94, and RMSEA = 0.04. SRMR=0.02. The data shows a good fit with the hypothesized model structure. The second stage used GSEM to further include discrete choice between walking, walking access to public transport and private vehicle. The McFadden's pseudo R-squared for multinomial logit model is equal to 0.142.

The results of the structural equation model in Table 8 reveal that the path coefficients from population density, land use mix entropy, percentage of 4-way intersections and cul-de-sacs to the perceptions of distances to services and opportunities & street connectivity are all statistically significant and in the expected directions. Likewise, the path coefficients from land use mix entropy and percentage of 4-way intersections to on-street barriers are statistically significant and in the expected direction. The path coefficient from population density to aesthetics are statistically significant and in the expected direction.

The path coefficients from the subjective factors – distances to services, opportunities & street connectivity, aesthetics, on-street barriers and traffic safety – to overall walkability are all statistically significant and in the expected directions (Table 8). These results indicate that an individual's perceived overall walkability is determined by his/her perceptions of distances to services, opportunities & street connectivity, on-street barriers and traffic safety. Opportunities and street connectivity (0.381) exerts the highest impact on overall walkability followed distances to services (-0.272), by aesthetics (0.264), on-street barriers (0.197) and then traffic safety (0.176).

The coefficients' directions in Table 8 explain the relationships between objective and subjective measures of walking environment. People perceived shorter distances to services and greater walking opportunities and street connectivity if the environment has a higher population density, land use mix and percentage of 4-way intersections, and lower numbers of cul-de-sacs. People living in low population density neighbourhoods, which represent more rural places, tend to perceive better neighbouring aesthetics. Perceptions of on-street barriers are positively related to land use mix and negatively to the percentage of four-way intersections. This may be because higher land use mix in the neighbourhood means that many activities can be reached by walking. This potentially reduces the use of private vehicles and, hence reduces difficulties crossing roads and the amount of obstructive parking. On the other hand, a greater percentage of 4-way intersections represents a more grid-like street pattern which may be easier for motorbikes to access. Greater motorbike use may cause more severe on-street barriers, particularly with motorbikes being parked on sidewalks.

These results support the study's hypothesis that the objective measures of the walking environment are indirect determinants of walkability and walking behaviour, which operate via their impact on perceptions of the walking environment.

None of the socio-demographic characteristics used in this study showed significant influence on overall perceived walkability. This indicates that overall perceived walkability did not vary for these different socio-demographic groups.

Table 8 Structure model for objective and subjective walking environmental factors and walkability

	Coefficient	Std. dev.	t-value	Sig.
Distances to services <-				
Population density	**-0.373**	**0.034**	**-11.140**	**0.000**
Land use mix entropy	**-0.106**	**0.031**	**-3.460**	**0.001**
Percentage of 4-way intersections	**-0.103**	**0.027**	**-3.810**	**0.000**
Numbers of cul-de-sacs	**0.187**	**0.026**	**7.320**	**0.000**
Constant	-0.002	0.026	-0.090	0.927
Opportunities & street connectivity <-				
Population density	**0.358**	**0.035**	**10.380**	**0.000**
Land use mix entropy	**0.083**	**0.031**	**2.630**	**0.009**
Percentage of 4-way intersections	**0.107**	**0.028**	**3.860**	**0.000**
Numbers of cul-de-sacs	**-0.120**	**0.026**	**-4.550**	**0.000**
Constant	-0.031	0.027	-1.140	0.254
Aesthetics				
Population density	**-0.167**	**0.032**	**-5.280**	**0.000**
Land use mix entropy	0.003	0.032	0.090	0.931
Constant	0.016	0.027	0.580	0.559
On-street barriers <-				
Land use mix entropy	**0.074**	**0.028**	**2.690**	**0.007**
Percentage of 4-way intersections	**-0.074**	**0.026**	**-2.850**	**0.004**
Constant	0.011	0.026	0.430	0.671
Traffic safety<-				
Numbers of cul-de-sacs	-0.026	0.022	-1.150	0.249
Constant	-0.004	0.025	-0.150	0.879
Perceived overall walkability <-				
Distances to services	**-0.272**	**0.054**	**-4.990**	**0.000**
Opportunities & street connectivity	**0.381**	**0.047**	**8.170**	**0.000**
Aesthetics	**0.264**	**0.035**	**7.600**	**0.000**
On-street barriers	**0.197**	**0.036**	**5.510**	**0.000**

Traffic safety	**0.176**	**0.038**	**4.660**	**0.000**
Gender (female=0)	-0.094	0.061	-1.550	0.121
Aged 55 and over	0.169	0.128	1.320	0.186
Monthly income >= US$ 2,667	0.161	0.087	1.860	0.063
Constant	-0.051	0.048	-1.050	0.295

Table 9 shows the impacts on travel mode choice. Overall perceived walkability and most of the socio-demographic characteristics have statistically significant influence on the choices between walking to access public transport and private vehicles, and walking to the destination and private vehicles (Table 9). The impacts of overall walkability on walking to access public transport and walking to destination are similar (Table 9). In terms of socio-demographic characteristics, the aged 55 and over group are more likely to walk either to access public transport or to destinations than other age groups. The higher income group (monthly income >US$ 2,667) has a higher perception of the walkability of their neighbourhood compared to other income groups (Table 8), while they have a lower probability of walking to access public transport (Table 9). High household car and motorbike ownership are related a low probability of walking in Taiwan. The more motorbikes in a household, the less likely household members are to walk either to their destination or to access public transport (Table 9). Several studies have found that motorbike trip features are short distances and multi-trips [49]. Hence, they possibly offer more of an alternative to walking than the car.

Table 9 Walkability and -demographic characteristics influence walking behaviour

		Coefficient	Std. dev.	t-value	Sig.
Walking to access public transport	Overall walkability	**0.414**	**0.098**	**4.210**	**0.000**
	Gender (female =0)	**-0.372**	**0.182**	**-2.050**	**0.041**
	Aged 55 and over	**0.937**	**0.371**	**2.530**	**0.012**
	Monthly income >= 2,667	-0.368	0.264	-1.400	0.163
	Household car ownership	**-0.716**	**0.140**	**-5.100**	**0.000**
	Household motorbike ownership	**-0.707**	**0.096**	**-7.390**	**0.000**
	Constant	**0.985**	**0.223**	**4.430**	**0.000**
Walking to destinations	Overall walkability	**0.401**	**0.179**	**2.240**	**0.025**
	Gender (female =0)	-0.370	0.327	-1.130	0.257
	Aged 55 and over	**1.623**	**0.555**	**2.920**	**0.003**
	Monthly income >= 2,667	**-1.341**	**0.598**	**-2.240**	**0.025**
	Household car ownership	**-0.720**	**0.254**	**-2.830**	**0.005**
	Household motorbike ownership	**-0.642**	**0.173**	**-3.720**	**0.000**
	Constant	-0.619	0.371	-1.670	0.095

Table 10 shows the total effects - calculated from the significant relationships - that the objective measures and subjective measures of walking environment factors exert on overall walkability and travel mode choice. By and large, perceived walking environment factors exert greater effects on overall walkability and walking behaviour (Table 10). Population density has the greatest total effects on overall walkability and walking behaviour among the objective measures of walking environmental factors, following by numbers of cul-de-sacs (with negative effects), land use mix entropy and percentage of 4-way intersections. In terms of the effects of perceived walking environmental factors on overall walkability and walking behaviour, opportunities and street connectivity has the greatest total effect on overall walkability and walking behaviour, aesthetics, follow by distances to services, on-street barriers and traffic safety.

Table 10 Total effects of objective measures on walkability

Factors	Effects on walkability	Effects to mode choice: walking v private vehicle	Effects to mode choice: walking to access public transport v private vehicle
Population density	0.19	0.08	0.08
Land use mix entropy	0.08	0.03	0.03
Percentage of 4-way intersections	0.05	0.02	0.02
Numbers of cul-de-sacs	-0.10	-0.04	-0.04
Distances to services	-0.27	-0.11	-0.11
Opportunities and street connectivity	0.38	0.15	0.16

Aesthetics	0.26	0.11	0.11
On-street barriers	0.19	0.08	0.08
Traffic safety	0.14	0.07	0.07

6. Discussion and Conclusion

The results of this study provide evidence to support the conceptual model that objective measures of the walking environment exert indirect impacts on walkability and walking behaviour via perceptions of the walking environment.

This study provides insight into walking environments, walkability and walking behaviour. The results show that an individual's perceptions of distances to services, and opportunities & street connectivity are determined in part by population density, land use mix, percentage of 4-way intersections and numbers of cul-de-sacs. Moreover, perceptions of on-street barriers are partly determined by land use mix and percentage of 4-way intersections. In addition, an individual's perceptions of distances to services, opportunities & street connectivity, on-street barriers and traffic safety are significant determinants for overall walkability.

There are some limitations in this study. Firstly, more aspects of the walking environment need to be incorporated. The four objective measures used cannot cover all the aspects of the built environment which influence people's subjective evaluation of the walkability of an area. Future study may include more detailed objective measurements such as the number of facilities within walking distance, sidewalks widths, presence of sidewalks, average street block length, traffic volume, traffic speed, street lighting and street trees. This will help to provide more information on how individuals react to the physical walking environment. Secondly, subjective measures of walking environment factors may not be the only mediators between objective measures of the walking environment, walkability and walking behaviour. People's attitudes and intention towards walking may be also associated with their perceptions of the walking environment and affect perceived walkability and walking behaviour [50]. Finally, similar to some previous studies [9, 10], this study assumed that walking is an available choice for all travellers. Some studies, however, have argued that including an unavailable choice in the traveller's choice set may cause biased results [8]. This raises the question: under what circumstances is walking considered not an option?

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