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Exploring the Walkability of Senior Citizens in a Densely Populated Neighborhood of Chennai, India—A Structural Equation Modeling Approach

Dharmambigai Prithviraj [1,*] and Lakshmi Sundaram [2]

[1] School of Architecture and Planning, Anna University, Chennai 600025, India
[2] Division of Transportation Engineering, Department of Civil Engineering, Anna University, Chennai 600025, India; lakshmi_sundaram@yahoo.com
* Correspondence: dharmambigaik@gmail.com

Abstract: Walking is the most sustainable, safe, and active mode of transportation among the elderly. There is growing evidence that the built environment influences walkability. However, little research has been conducted to assess the perceived built environment correlates for senior citizens walking in low- and middle-income countries. This paper explores the relationship between built environment characteristics and the walkability of senior citizens in Triplicane, Chennai, India. Seniors aged 60 years and above, both men and women, living in Triplicane, Chennai, were interviewed (n = 221). Personal characteristics and perceived built environment factors were assessed using the Neighborhood Environment Walkability Scale for India (NEWS India). Data were analyzed using SPSS 26 and AMOS 21 software. Structural equation modeling (SEM) was conducted to examine the association between the built environment characteristics and the walkability of senior citizens. The results show that built environment attributes, namely pedestrian safety infrastructure, physical barriers of the neighborhood, and aesthetics, have a high impact on walkability among senior citizens.

Keywords: walking; senior citizens; built environment; structural equation modeling

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1. Introduction

The dynamics of rapid urbanization and an aging population are two global trends that shape the future development of cities. It is expected that, by 2050, the proportion of seniors aged 65 and older will be double that of children aged below 5 [1]. Hence, accommodating the growing needs of a fast-graying population has become one of the key challenges faced by cities. Seniors are more vulnerable and hence confined to their homes and the immediate neighborhood. Outdoor spaces, specifically built environments, when planned and well designed, provide better opportunities for healthy and active aging, ensuring autonomy, dignity, and self-confidence in senior citizens [2]. The socio-ecological model [3] and the person–environment fit model [4] emphasize the vital role of built environment attributes on individual physical activity levels. It has been well documented in previous studies that regular physical activity has a profound beneficial impact on health in old age [5,6].

Walking is the most appropriate mode of physical activity in this cohort, as it is safe, sustainable, economical, and can be easily incorporated into daily life [7–9]. The UN has adopted Sustainable Development Goals (SDG), of which SDG 3 aims to ensure health and well-being across all age groups with special emphasis on the senior citizens (vulnerable population). Walking is considered a vital component in achieving this goal. SDG 11 is directly linked to walking as it targets to ensure universal access to "safe, affordable, accessible and sustainable transport for all" [10]. The World Health Organization (WHO) recommends that senior citizens should engage in moderate-intensity physical activity for a minimum of 150 min every week [11].

Walking, an active mode of transportation can help mitigate the health outcomes of climate change (SDG 13), chronic diseases, and air pollution levels. Research shows that people who take up active transportation modes enjoy good health and an increased life span [12,13]. This is further emphasized by a recent review that walking, running, and swimming are the only active and sustainable modes of transportation that produce nil or negligible carbon footprint and no addition to the atmospheric greenhouse gases [14]. Overall, walkability contributes to the three pillars of sustainability—Economic, Social, and Environmental. The reduced expenses on travel, health, and access to amenities contribute to the economic component in a big way. It adds to the social aspect of sustainability by providing better opportunities for social interaction and autonomy of movement. Reduced emissions and carbon footprint helps to ensure the environmental quality of the neighborhood [15].

In order to improve the walking levels of the elderly, the built environment should be planned such that it is age-friendly. Furthermore, Jeff Speck has proposed the General Theory of Walkability, which explains four essential elements for evaluating the level of walkability in an urban environment, namely usefulness, comfort condition, safety, and attractiveness of the built environment [16].

Walkability studies in the Indian context typically tend to focus on the entire population rather than the senior citizens. These published studies have sufficiently examined the potential impact of the built environment on pedestrian travel behavior [17], pedestrian accessibility [18], pedestrian level of service of sidewalks [19], and tourist walkability experience [20]. However, little research has been conducted on the walkability of the elderly in India. Prior studies have assessed the mobility of the elderly in urban public spaces using pedestrian audit [21] and the neighborhood characteristics that support active aging [22]. Impelled by these chief concerns, this study aimed to evaluate the possible extent to which each of the perceived micro-scale built environment constructs impacts the overall walkability of elderly people. This study further attempts to explore the same in the densely populated neighborhood of Triplicane, Chennai, India, using structural equation modeling (SEM).

2. Literature Review

Walkability refers to how friendly a built environment is for walking. It comprises the urban design elements that assure the accessibility, comfort, safety, and enjoyable walking experience for its pedestrians [23]. According to Southworth, walkability is "the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network" [24].

2.1. Walkability and Senior Citizens

A study by Yang Cao et al. shows that the walking radius of elderly people ranges between 800 m and 1500 m from their home [25]. This constriction of mobility radius is observed in senior citizens as they experience a gradual decline in their inherent capacity, reduced personal resources, and difficulty in handling environmental challenges, leading to adverse health outcomes [26]. Some of the common health issues faced by the elderly are chronic conditions like diabetes, obesity, cardiovascular diseases, stroke, and cancer [27]. Routine physical activity, mainly walking, undoubtedly has a significant beneficial impact on health and well-being in old age [28–30]. Several studies have adequately demonstrated the direct correlation between specific built environment attributes and walking in the elderly [31–33]. However, Indian cities are designed to accommodate the needs of a younger cohort, posing mobility restrictions for the vulnerable elderly [22]. Quantitative studies sufficiently explain the vital role of built environment characteristics like street connectivity, land-use mix, destination accessibility, and population density [31,34,35].

2.2. Destination Accessibility

Wachs and Kumagai (1973) defined accessibility as the comparative ease with which individuals may reach specific destinations within a certain distance [36]. Another notable source refers to accessibility as the extent to which senior citizens regardless of any impairment can access, enter, use, and stroll about places they need to frequent. Studies have shown that the presence of useful destinations and their corresponding densities were associated with more significant levels of neighborhood walking [37,38]. Highly accessible destinations tend to attract more pedestrians. Several previous studies have also explained the positive correlation between street connectivity and pedestrian volume [39,40]. It is also observed that higher residential density and proper access to destinations were positively associated with physical activity levels [41,42]. However, extremely high levels of residential density discourage walking. The planning of age-friendly neighborhoods must carefully consider these contrasting impacts [43].

2.3. Level of Safety

Safety from the perspective of elderly people encompasses safety from traffic, fall injury, and crime. Elderly pedestrians are the most vulnerable on the streets and are prone to injury and at times end up fatal. This is attributed to their physical and cognitive levels, reduced reaction speed, and poor confidence level. Thus, the safety of elderly pedestrians is of growing concern [44]. Do Hyung Kim suggests that raised medians, three-way intersections, and avenue trees have a positive impact on the safety of elderly pedestrians. The current road structure is planned for the younger demographic and healthy users. It is vital to refurbish the road system for older and vulnerable pedestrians [45]. A study by Lee et al. found that reduced traffic speeds were associated with lesser fear of falling in elderly residents [46]. Sidewalk condition has a vital role to play in the walking levels of senior citizens. It includes sidewalk presence, continuity, and maintenance [47,48]. Burton and Mitchell suggest that a safe pavement should be simple, even, non-slippery, and non-reflective. Furthermore, they explain that the sewer grates and drains should be flush with the paving [49]. From the purview of crime, it is vital to how the seniors feel less vulnerable to crime. The presence of physical vulgarities like graffiti, litter, abandoned buildings, and vandalism adds to the fear of crime and hence reduces outdoor mobility in the elderly. The presence of street lighting, natural surveillance, and a reduced crime rate ensures a safe neighborhood from the pretext of seniors [47,50].

2.4. Comfort Conditions

Environmental support positively impacts the senior citizen's comfort level and, in turn, their willingness to walk outdoors [51]. Overall, the key attributes that present a good comfort condition while walking are traffic calming elements [47], micro-scale built environment attributes like tree-lined walkways, public seating [22], quiet and undaunting streets, public toilets [49], landmarks, and distinctive buildings [52]. Another study elaborates on the sensory overload of the elderly posed by potential barriers such as poor signage, confusing street networks, and noise [52]. High noise levels, poor street lighting, and heavy traffic were reported as highly uncomfortable in neighborhood environments. Older people in such neighborhoods typically experienced a more significant risk of functional decline of over one year in comparison with those living in better-built environments [53].

2.5. Aesthetic Environment

The aesthetic appeal of a neighborhood has a positive impact on the pleasure levels and walkability of senior citizens. This is attributed to factors like avenue trees, land-use mix, public spaces brimming with activity, attractive architectural features, historic buildings, colorful elements, and outdoor dining spaces [47]. Some studies have explicitly tied the perceived level of environmental aesthetics to increased walking levels [54]. Another study in Britain revealed precisely that the lack of nuisance, attractive surroundings, and presence of public amenities encouraged walking [55].

3. Methodology

3.1. Study Area

The study is based in the Chennai Metropolitan Area (CMA) which comprises 15 zones and is further subdivided into 200 wards. Ward Number 116 (Triplicane), located in Zone 9 (Teynampet), was selected for the study (Figure 1). Triplicane, also known as Thiruvellikeni, is one of the oldest neighborhoods in the Southern part of Chennai.

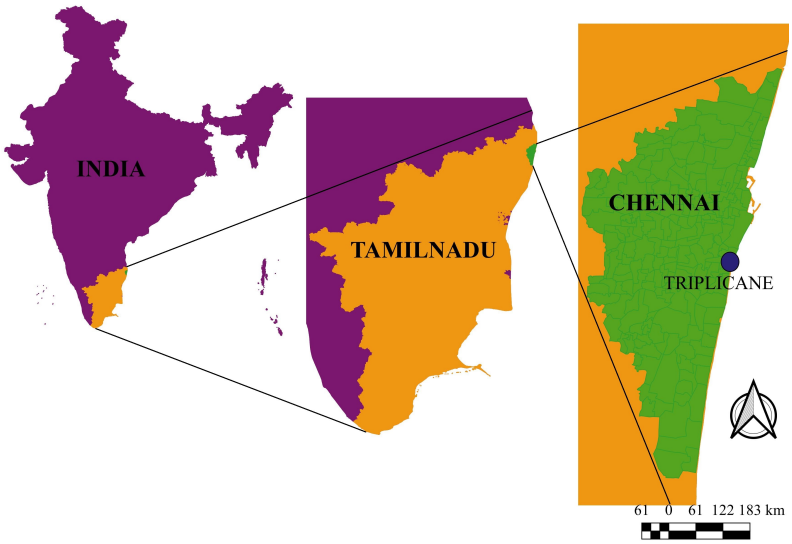


Figure 1. Map showing location of Triplicane in Chennai, Tamil Nadu, India.

It is located on the banks of the Buckingham Canal. The canal bisects the neighborhood in the north-south direction. The Triplicane ward is bounded by Chepauk in the north, Mylapore in the south and south-west, Marina Beach in the east, and Royapettah in the west and north-west (Figure 2).

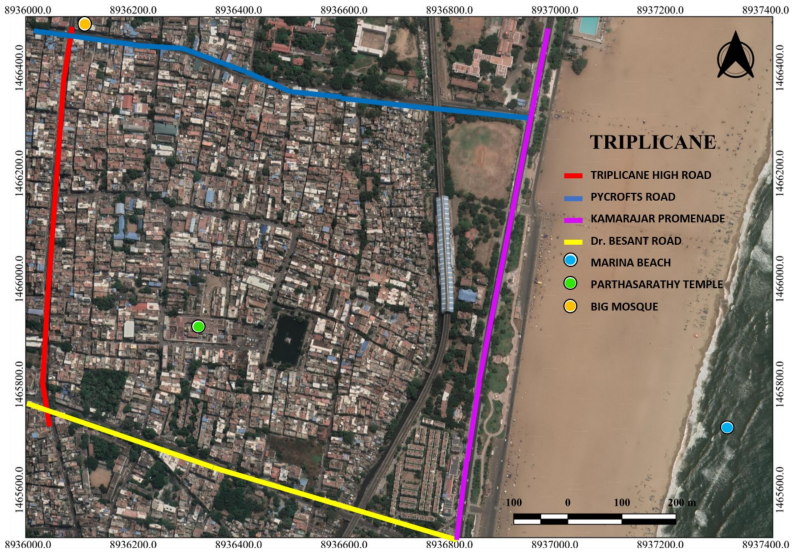


Figure 2. Map of Triplicane (Source: Google Earth Software, modified by authors).

Ward No. 116 has the highest density of elderly people (8519 seniors per sq. km). This is an old settlement with an organic form developed around potential focal points/attraction poles for the elderly population like places of worship (Parthasarathy Temple and Big Mosque) and recreational spaces (Marina Beach). Visiting religious places contributes positively to the subjective well-being of elderly people. It serves as a "coping mechanism" that dwells on matters of "ultimate concern" [56]. Additionally, studies have scientifically

proven that exposure to the natural environment, especially blue spaces like coastal waters, produces a beneficial impact on the elderly mental health [57].

3.2. Study Design and Respondents

The cross-sectional study was conducted on individuals aged 60 and above. Interviews were conducted during April and May 2022. Data were collected by trained volunteers through face-to-face semi-structured interviews at the respondent's homes. A random sampling approach was used to select senior citizens (both men and women) to participate in the interview. The inclusion criteria for screening the participants were as follows: the senior citizens should (a) be residents of the ward, (b) have resided in the ward for at least one year, (c) be physically active and independent in walking outdoors, (d) be mentally healthy, (e) exhibit no visible signs of cognitive impairment, and (f) be willing to participate. Finally, 257 senior citizens participated in the interview. This constitutes 4.3% of the elderly population in Triplicane (Ward 116). A total of 46 incomplete questionnaires were rejected, and 221 completed questionnaires amounting to a response rate of 86% were used for the study. Verbal informed consent was obtained from the respondents before each interview.

A semi-structured questionnaire on the potential impact of neighborhood walkability and elderly walking behavior was administered to the respondents in the interview process. The questionnaire comprised two main components: (i) socio-demographic characteristics and (ii) perceptions of the neighborhood environment based on the original version of the Neighborhood Environment Walkability Scale (NEWS) adapted to the Indian context [58].

3.3. Analytical Strategy

Structural equation modeling (SEM) is a multivariate analytical technique that measures the relationship among the latent constructs and their indicators (measurement model) and measures the relationship among the latent constructs as well (structural model) simultaneously [59]. It combines the role of factor analysis and multiple regression analysis and is therefore regarded as an ideal statistical tool for research purposes. Previous literature shows the use of SEM across a broad spectrum of study areas, including transportation [60,61] and land-use studies [62,63]. The measurement model includes observed indicators, which can be grouped into exogenous and endogenous constructs. The exogenous constructs are predetermined by factors outside of the model, and endogenous constructs are determined by factors within the model. The SEM is denoted by the following matrix algebra notation [64]:

$$\eta = \beta \cdot \eta + \tau \cdot \xi + \zeta \quad (1)$$

where η = vector of unobserved endogenous variables; ξ = vector of unobserved exogenous variables; ζ = vector of unobserved errors; β and τ = matrices of structural parameters to be estimated. The measurement model is explained by two equations:

$$x = \Lambda x \cdot \xi + \delta \quad (2)$$

$$y = \Lambda y \cdot \eta + \epsilon \quad (3)$$

x, y = vectors of the observed endogenous and exogenous indicators; Λ = parameter matrices (explain the link between the observed indicators and unobserved constructs); δ, ϵ = vectors that contain the error terms of the indicators.

To assess the elderly walkability of the study area, several built environment factors or indicators must be considered. These built environment factors or indicators are associated with different unobserved variables or latent constructs like accessibility, pedestrian safety infrastructure, safety from crime, personal safety, comfort, aesthetics, etc. These latent constructs cannot be measured directly, so they are linked to a set of indicators, say built environment factors, which can be measured. SEM utilizes two statistical techniques, namely exploratory factor analysis (EFA) and confirmatory factor analysis (CFA).

EFA is used to identify the smallest number of latent constructs that can best explain the correlation among the indicators. The principal component analysis method is employed in EFA to estimate the factor loadings of indicators under each construct. Cronbach's alpha, Kaiser–Meyer–Olkin (KMO), and Bartlett's test of sphericity were used to measure the overall sampling adequacy and the effectiveness of the model for EFA. Respondent's scores on a 5-point Likert-type scale were used as the input for the analysis. CFA estimates the parameters and determines the fitness of the hypothesized exploratory factor model [65]. On confirming the fitness of the measurement model, the study proceeded to the structural model. The model is deemed fit if it satisfies the criteria of the goodness of fit indices. The structural model is formulated to test the hypothesis framed based on the structural theory.

4. Results

4.1. Descriptive Statistics

Respondents (n = 221) had a mean age of 69.1 ± 5.8 years and 48.4% of them were female. Of the respondents, 66.5% were aged between 60 and 70, 20.8% of them were aged between 71 and 75, 8.1% of them were aged between 76 and 80, and 4.5% of them were aged between 81 and 90. With respect to employment status, 30.8% were retired, 26.2% were employed, and 43% were unemployed. Almost 65.2% of them belonged to the Economically Weaker Section (EWS), 30.3% belonged to the Low-Income Group (LIG), and 4.5% belonged to the Middle-Income Group (MIG). The survey responses were analyzed (Table 1) to arrive at the satisfaction level of seniors regarding various walkability attributes. Very few attributes were rated high, while most of them were rated moderate to poor. Familiarity of the ward and the presence of alternate routes to destinations received the maximum mean of 4.26 and 4.24, respectively, while sidewalk condition was rated the least at 1.77.

Table 1. Descriptive statistics of perceived built environment indicators of walkability (n = 221).

Category	Code	Indicators	Mean	Standard Deviation	Skewness	Kurtosis
Accessibility	WA1	Familiarity of the ward	4.24	0.744	−0.945	1.056
	WA2	Alternative routes to reach a destination	4.26	0.690	−0.900	1.393
	WA3	Short distance between intersections	3.90	0.750	−0.682	1.348
	WA4	Streets have no dead ends	3.93	0.847	−0.820	1.027
	WA5	Good mix of residential and commercial areas	4.21	0.789	−1.069	1.184
Pedestrian Safety	PS1	Less traffic along my walking route	3.44	1.192	−0.805	−0.532
	PS2	Speed of traffic is usually under safe limits	3.23	1.205	−0.500	−1.053
	PS3	The streets used by motorists to bypass signals	3.57	1.083	−0.680	−0.704
	PS4	Drivers ride on the footpaths	2.79	1.166	0.301	−1.181
	PS5	Crosswalks and pedestrian signals	2.69	1.142	0.109	−1.410
	PS6	Pedestrian crossing time is adequate for elderly	2.57	1.160	0.073	−1.489
Sidewalk Condition	SW1	There are sidewalks on most of the streets	2.14	1.107	0.644	−0.917
	SW2	The sidewalks are well maintained	1.77	0.887	1.298	1.385
	SW3	The sidewalks are continuous without breaks	1.85	0.910	1.178	1.310
	SW4	Bollards are present in the sidewalks	2.24	1.134	0.697	−0.697
	SW5	Grade changes (varying heights) in sidewalks	3.84	1.317	−0.982	−0.251
	SW6	The parking lot abutting the sidewalk	4.14	1.093	−1.147	0.180
	SW7	Stray animals	3.97	1.074	−0.923	−0.228
Safety from Crime	CS 1	Activity level in the street (vibrance levels)	3.93	0.889	1.312	
	CS 2	There are hawkers and street vendors in my ward	3.88	0.863	−1.005	1.410
	CS 3	Surveillance cameras	4.08	0.981	−1.292	1.496
	CS 4	High theft rate in my ward	3.84	0.944	−1.042	1.179
	CS 5	The streets in my ward are well lit at night	3.94	1.038	−1.274	1.485

Table 1. *Cont.*

Category	Code	Indicators	Mean	Standard Deviation	Skewness	Kurtosis
Comfort Condition	CC 1	The noise level from the traffic is very high	3.81	1.221	−0.855	−0.380
	CC 2	There are trees in my walking route	2.59	1.224	0.304	−1.248
	CC 3	Seating facilities	2.49	1.397	0.302	−1.459
	CC 4	Legible signboards	3.98	1.193	−1.222	0.467
	CC 5	Toilets present in my walking route	3.44	1.113	−0.884	−0.444
Aesthetics	AS 1	Interesting things to look at while walking	2.22	1.168	0.820	−0.498
	AS 2	Garbage bins	3.46	1.281	−0.604	−0.862
	AS 3	There is natural scenery to look at while walking	2.06	1.071	0.891	−0.271
	AS 4	Dirty scribblings/posters on blank walls	3.19	1.267	0.286	−1.242
	AS 5	The streets in my ward are unclean and dirty	2.40	0.994	0.946	−0.116

4.2. Exploratory Factor Analysis

Factor analysis was conducted for the 33 selected indicators (Table 1) using Statistical Package for Social Sciences (SPSS) software version 26. The Kaiser–Meyer–Olkin value was 0.682, which suggests that the correlation matrix is suitable for factoring. Bartlett's test statistic for this study was observed to be highly significant as $p < 0.05$. This implies that the matrix is not orthogonal as the variables are correlating among themselves and hence suitable for factoring [65].

To determine the number of factors to be extracted to explain the correlation among the variables, the Kaiser criterion [66] was applied. A scree plot (Figure 3) was mapped between the eigenvalues (latent roots) and the number of factors based on the order of extraction.

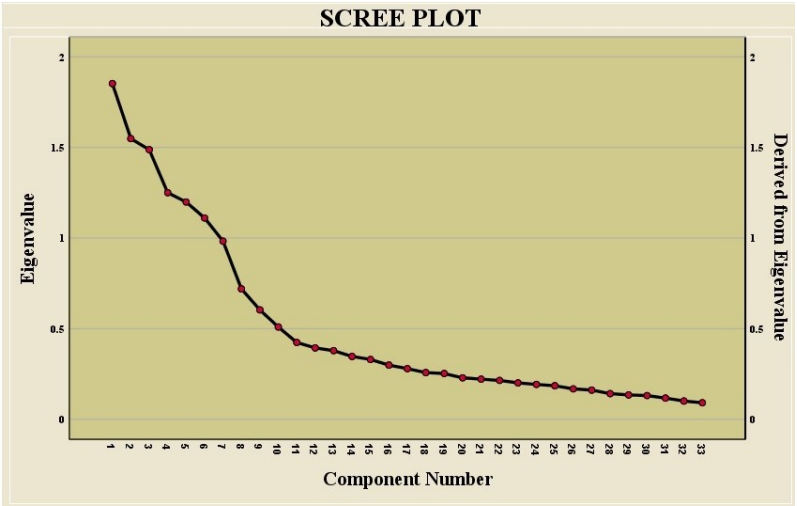


Figure 3. Scree plot showing the number of components to be retained for factor analysis.

This decides the number of latent roots to be retained for EFA. When EFA was performed, using the principal component analysis method and varimax rotation with Kaiser normalization, it yielded a clear factor structure with ten factors (Table 2), which accounted for 68.260% of the total variance. The rotation converged in six iterations. After each iteration, the factors with low communalities, with factor loadings less than 0.50, and factors that were cross-loaded were eliminated. The results show that all communalities were over 0.397, and the extracted ten factors strongly reflect the built environment attributes of elderly walkability. Furthermore, the Cronbach alpha value obtained for each latent variable is greater than 0.7. This vividly explains the reliability of the questionnaire [67]. Cronbach's alpha is the measure of internal consistency reliability, and it ranges from zero to one.

Table 2. Exploratory factor analysis.

Code	Indicators	Communalities	Factor Loading	Explained Variance	Cumulative Variance	Cronbach's Alpha
	Component 1—Safety from Crime					
CS 1	Activity level in the street (vibrance levels)	0.614	0.767			
CS 2	Hawkers and street vendors in my ward	0.545	0.704			
CS 3	Surveillance cameras	0.734	0.832	11.228	11.228	0.834
CS 4	High theft rate in my ward	0.634	0.771			
CS 5	The streets in my ward are well lit at night	0.632	0.766			
	Component 2—Accessibility					
WA1	Familiarity of the ward	0.619	0.747			
WA2	Alternative routes to reach a destination	0.652	0.758			
WA3	Short distance between intersections	0.397	0.565	9.385	20.613	0.735
WA4	Streets have no dead ends	0.505	0.668			
WA5	Good mix of residential and commercial areas	0.576	0.728			
	Component 3—Sidewalk Condition					
SW1	There are sidewalks on most of the streets	0.664	0.762			
SW2	The sidewalks are well maintained	0.699	0.801			
SW3	The sidewalks are continuous without breaks	0.724	0.828	9.016	29.630	0.747
SW4	Presence of Bollards in Sidewalks	0.557	0.607			
	Component 4—Barriers to Walking					
SW5	Grade changes (varying heights) in sidewalks	0.765	0.838	7.577	37.207	0.817
SW6	The parking lot abutting the sidewalk	0.77	0.856			
SW7	Stray animals	0.733	0.839			
	Component 5—Aesthetics					
AS 1	Interesting things to look at while walking	0.752	0.817			
AS 3	Natural scenery to look at while walking	0.736	0.834	7.266	44.473	0.800
AS 5	The streets in my ward are unclean and dirty	0.709	0.790			
	Component 6—Pedestrian Safety					
PS4	Drivers ride on footpaths	0.563	0.644			
PS5	Crosswalks and pedestrian signals	0.732	0.814	6.732	51.205	0.726
PS6	Pedestrian crossing time is adequate for elderly	0.724	0.827			
	Component 7—Comfort Condition					
CC1	The noise level from the traffic is very high	0.752	0.843			
CC4	Legible signboards	0.765	0.851	5.957	57.162	0.790
CC5	Toilets present in my walking route	0.663	0.721			
	Component 8—Traffic condition					
PS1	Less traffic along my walking route	0.81	0.887	4.358	61.519	0.831
PS2	Speed of traffic is usually under safe limits	0.815	0.875			
	Component 9—Pedestrian resting areas					
CC 2	There are trees in my walking route	0.822	0.890	3.656	65.176	0.806
CC 3	Seating facilities	0.812	0.867			
	Component 10—Cleanliness					
AS2	Garbage bins	0.743	0.785	3.084	68.260	0.743
AS4	Dirty scribblings/posters on blank walls	0.790	0.851			

$$\alpha = \frac{N \cdot \bar{c}}{\bar{v} + (N-1)\bar{c}} \quad (4)$$

where N is the number of items, $\bar{c}$ is the average inter-item covariance among the items, and $\bar{v}$ is the average variance [68].

4.3. Confirmatory Factor Analysis (CFA) and the Measurement Model

The initial measurement model did not provide a satisfactory fit; therefore, the model was modified. The measurement model was respecified after reviewing the factor loadings, error terms, and modification indices to decide on the items to be dropped from or included in each factor. Some of the items were excluded to achieve a satisfactory fit. Hair et al. have emphasized that the latent constructs should be indicated by at least three measured variables to avoid estimation problems in the later stages of the modeling process [69]. So, three constructs, namely traffic condition, pedestrian resting areas, and cleanliness, were dropped as they contained only two variables each. The final measurement model had seven constructs that explain the built environment attributes of walkability in the elderly population (Figure 4). The measurement theory model graphically represents the measured variables associated with each latent construct, their error variance, and the correlation between the constructs.

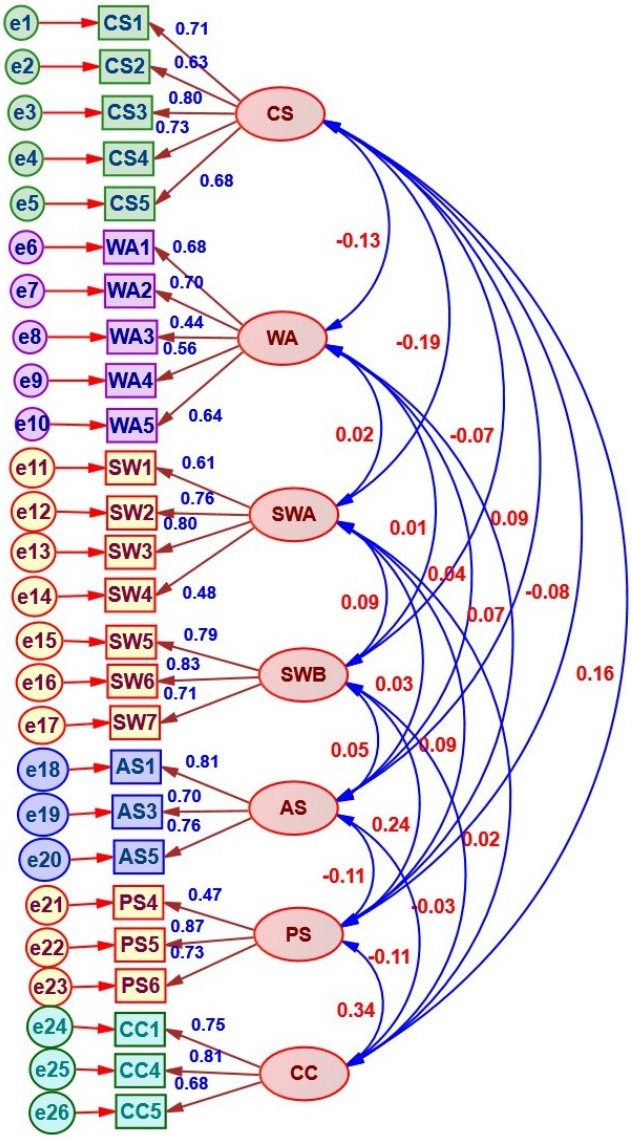


Figure 4. Measurement theory (CFA) model.

Table 3 explains the statistical relationship between the latent exogenous construct, measured exogenous variable, and the latent endogenous construct. Standard regression weights or beta weights explain the degree to which the measured variable is related to the construct. Most of the beta weight values are greater than 0.5 except for WA3 (0.437),

SW4 (0.470), and PS4 (0.484). Standard errors (SE) in the measurement model reflect the accuracy with which an indicator is estimated; the smaller the values, the more accurate the estimation. Critical ratio (CR) is a test statistic that is the ratio of the parameter estimate and standard error. At a probability level of 0.05, the critical ratio needs to be >±1.96 for the hypothesis to be rejected [59]. Further, the measurement model was checked for goodness of fit (GoF), which explains how well a model replicates the observed covariance matrix among the measured variables [69]. The measurement model with seven constructs satisfied the test criteria set by the fit indices (CFI, GFI, SRMR, RMSEA, TLI, and PClose). Hence, the model is considered good for a sample size of 221.

Table 3. Factor estimation for measurement model.

Latent Exogenous Construct		**Measured Exogenous Variable**		**Std RW**	**Estimate**	**SE**	**CR**	***p***
CS	Crime Safety	CS1	Activity level	0.711	0.892	0.099	8.992	***
		CS2	Hawkers and street vendors	0.624	0.759	0.094	8.044	***
		CS3	Surveillance cameras	0.801	1.108	0.113	9.801	***
		CS4	High theft rate in my ward	0.727	0.968	0.106	9.158	***
		CS5	Street lighting	0.683	1			
WA	Accessibility	WA1	Familiarity of the ward	0.681	1.005	0.138	7.264	***
		WA2	Alternative routes	0.703	0.963	0.131	7.367	***
		WA3	Distance between intersections	0.437	0.65	0.124	5.236	***
		WA4	Streets have no dead ends	0.556	0.935	0.147	6.362	***
		WA5	Land-use mix	0.639	1			
SWA	Sidewalk Condition	SW1	Sidewalk presence	0.608	1.262	0.222	5.687	***
		SW2	Sidewalk maintenance	0.763	1.271	0.205	6.192	***
		SW3	Sidewalk continuity	0.807	1.379	0.222	6.219	***
		SW4	Bollards in sidewalk	0.470	1			
SWB	Barriers to Walking	SW5	Grade changes	0.783	1.33	0.134	9.903	***
		SW6	Parking lot abutting the sidewalk	0.830	1.17	0.118	9.936	***
		SW7	Stray animals	0.722	1			
AS	Aesthetics	AS1	Interesting things	0.812	1.251	0.134	9.333	***
		AS3	Natural scenery	0.699	0.986	0.109	9.065	***
		AS5	Street cleanliness level	0.763	1			
PS	Pedestrian Safety	PS4	Drivers ride on footpaths	0.484	0.632	0.101	6.285	***
		PS5	Crosswalks and pedestrian signals	0.829	1.06	0.140	5.592	***
		PS6	Pedestrian crossing time	0.770	1			
CC	Comfort Condition	CC1	Noise level	0.762	1.235	0.142	5.937	***
		CC4	Legible signboards	0.803	1.27	0.145	7.555	***
		CC5	Toilets	0.677	1			
Latent endogenous construct		Latent exogenous variable		Std RW	Estimate	SE	CR	*p*
Walkability		CS	Crime Safety	0.352	1			
		WA	Accessibility	0.250	1			
		SWA	Sidewalk Condition	0.264	1			
		SWB	Barriers to Walking	0.385	1			
		AS	Aesthetics	0.376	1			
		PS	Pedestrian Safety	0.443	1			
		CC	Comfort Condition	0.374	1			

*** implies that significance is lesser than 0.001.

4.4. The Structural Model

When the measurement model fulfilled the fitness requirements, the study progressed to the formulation of the structural model. In a structural model, the structural theory is applied to examine how the constructs are related to one another and the nature of the relationship. Table 4 explains the model fit measures of the measurement and structural model. The hypothesized structural model was adequately fit, with the model fit indices having achieved a threshold with the structural model illustrated in Figure 5. The model fit indices of the structural model were calculated following the same methodology as explained for the measurement model. The standard regression equation of the model

was formulated based on the standard regression weights derived for the latent exogenous variables (Table 4).

$$\hat{y} = 0.443(PS) + 0.374(CC) + 0.352(CS) + 0.264(SWA) + 0.250(WA) + 0.385(SWB) + 0.376(AS) \quad (5)$$

Table 4. Model fit measures.

Measure		Threshold	Measurement Model	Structural Model
CMIN	Chi-Square	——	350.033	381.674
df	Degrees of freedom	——	279	298
CMIN/df	Normed Chi-Square value	Between 1 and 3	1.255	1.281
CFI	Comparative Fit Index	≥ 0.9	0.958	0.951
GFI	Goodness-of-Fit-Index	≥0.9	0.893	0.882
SRMR	Standardized Root Mean Square Residual	<0.08	0.062	0.078
RMSEA	Root Mean Square Error of Approximation	<0.06	0.034	0.036
TLI	Tucker–Lewis Index	≥0.9	0.951	0.946
PClose	P of Close Fit	>0.05	0.994	0.991

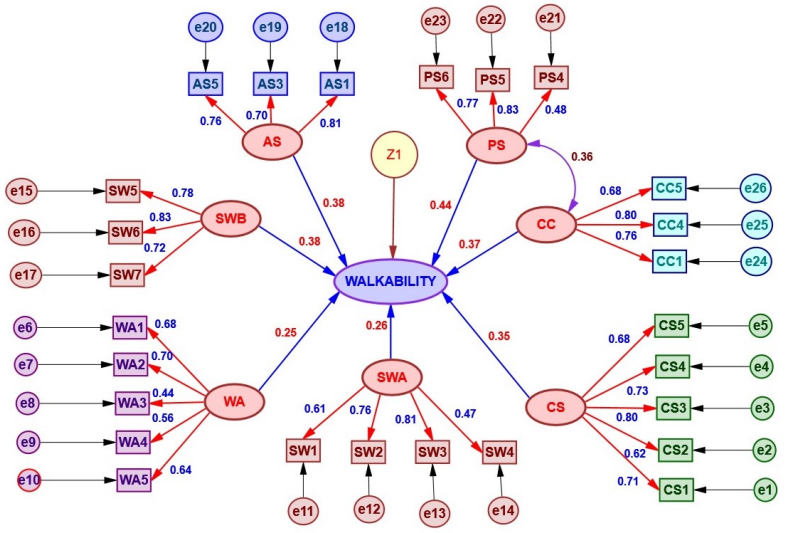


Figure 5. Structural equation model for walkability in elderly population.

5. Discussion

The current study examined the extent to which each of the perceived micro-scale built environment constructs impacts the overall walkability of elderly people in a densely populated neighborhood in Chennai. The overall structural model reflects Jeff Speck's General Theory of Walkability [16] and is consistent with the socio-ecological model [3].

Factors related to pedestrian safety (PS) had the maximum impact (0.44) on the walkability of senior citizens. Crossing a road is the most critical moment in the walking episode of pedestrians as they have to confront vehicles and other road users. Furthermore, this issue was more distinct in the case of older pedestrians. This study also highlighted that pedestrian crossings with uneven surfaces or poor markings discouraged walking among senior pedestrians as it added to their inherent problems of pedestrian–vehicle conflict [70,71]. The seniors usually have a slower gait speed [72], and they reported that the pedestrian crossing time at traffic signals must be adequate for them to cross the road.

The barriers to walking (SWB) and aesthetics (AS) had the next highest level of impact (0.38) on elderly walkability. The seniors were apprehensive of the barriers in their walkways, and hence this construct received the next maximum coefficient value. This included barriers caused by parked vehicles, uneven walkways, and stray animals. The streets in Triplicane were highly narrow (Figure 6) and did not have dedicated sidewalks. Hence, people are compelled to walk on the streets. The streets have several grade changes like projecting manholes and broken speed breakers, which hinder their barrier-free movement.

Moreover, the vehicles of residents and pilgrims are parked on narrow roads, and hence walking is hindered. Stray animals (cows and oxen) create a huge menace in this neighborhood. Cattle are reported to be the cause of several fall incidents and sometimes have been fatal too (Figure 7). Many seniors commented that they were frightened to walk outdoors for fear of falling. The association between the built environment conditions and fear of falls among the elderly is consistent with the findings of Distefano et al. [73] and Angela Curl et al. [74].



Figure 6. The narrow lanes of Triplicane.



Figure 7. Cattle as a barrier to elderly walking in Triplicane.

Factors related to aesthetics (AS) also have a vital role to play in walkability. The seniors had an affinity for walking as their walking route had interesting things to watch like the temple tank, religious processions, and colorful rangoli patterns drawn on the streets in the procession pathway. But there was no scope for natural scenic views, which made the walk an interesting experience. However, the streets were unclean and dirty due to the cattle defecating on the roads and spilled garbage. This created a setback for the elderly walking in the neighborhood. The study by Malambo et al. and Zandieh et al. arrived at a similar conclusion that "good-quality aesthetics" in the neighborhood had a positive impact on the physical activity levels [75,76].

The comfort condition construct (CC) had an equivalent impact (0.37) on walkability as the previous constructs. Most of the streets lacked shelter from trees and did not have seating facilities. The seniors had no resting place or seating on their walking route, and very few streets had trees to provide shade. The seniors emphasized the need for such infrastructure amenities to increase their footfall in the neighborhood. Sugiyama et al. and Herrmann-Lunecke et al. suggested that tree-lined walkways and the presence of seats en route to a destination provide a supportive environment for many older people. This makes the walk easy and enjoyable [55,77].

The safety from crime (CS) construct had an equal contribution (0.35) to neighborhood walkability. Previous literature shows that lack of safety from crime leads to diminishing levels of walking among the elderly and makes them more sedentary [78]. The respondents of the present study reported higher activity levels in the streets during the morning and evening hours of the day. The pilgrims and the street vendors further enhance the activity levels. This created a conducive environment for the seniors to walk during the day. Surveillance cameras present at vital points improved the neighborhood safety levels. Street lighting was present on most streets; however, few remained dark, thereby increasing the possibility of crime and unsafe walking conditions for the seniors during the night.

The sidewalk construct (SWA) has been ranked low (0.26). The factors relate to sidewalk presence, continuity, and maintenance. The traditional settlement has an organic plan and is mainly planned for pedestrian movement. The lanes are very narrow (Figure 6)

except for the lanes in the religious precincts and the main roads on the periphery of the ward. Hence most of them do not have sidewalks. If sidewalks are present, they are blocked by parked vehicles, abstaining access to pedestrians. This result was in contrast to van Cauwenberg's findings, which state that the sidewalk evenness was considered as a high priority by seniors for transportation walking [79].

The accessibility construct (WA) received the least coefficient value (0.25). Most of the seniors were familiar with the neighborhood as they had been residing there for many years. But a vast majority of them do not attempt to travel long distances by walking. They restrain themselves to the neighboring streets due to age factors, health conditions, and fear of fall.

6. Conclusions

The elderly population is growing at an alarming rate, and hence it is essential to address the needs of this cohort. They are prone to physical, mental, and cognitive decline as they age. Empty nesters are left lonely and are burdened to satisfy their access to basic amenity needs by themselves. Furthermore, they prefer to vent their loneliness by walking outdoors, which serves as a form of physical activity, relaxation, and an avenue to socialize with fellow citizens. These restrictions constrict their movement radius and are generally confined to the neighborhood where they reside. In order to cater to the walkability needs of senior citizens, the neighborhood environment must provide conducive walking conditions.

With an aim to address the above scenario, the study focuses on assessing the level of impact of the various micro-scale built environment attributes that influence elderly walkability in Triplicane, Chennai. This is a traditional neighborhood settlement that is densely populated and occupied by a higher proportion of senior citizens. This is attributed to their familiarity with the neighborhood and the presence of a number of easily accessible focal points (religious places, recreation areas) attracting the elderly population. In this study, 221 elderly people were interviewed about the walkability conditions and the barriers they face while walking in the neighborhood.

Data were collected on 33 indicators. The exploratory factor analysis was performed, which grouped the 33 indicators into 10 constructs or factors. Then, the 10 constructs were subjected to confirmatory factor analysis, and the final measurement model had only 7 constructs, as certain constructs had to be deleted to obtain a satisfactory fit. Then, the structural model was formulated to examine the relationship between the seven constructs, namely crime safety, accessibility, sidewalk condition, barriers to walking, aesthetics, pedestrian safety, and comfort conditions.

The structural equation model revealed that the walking characteristics of the elderly were highly impacted by the prevailing pedestrian safety infrastructure, the presence of barriers to walking (grade changes, stray animals), and the aesthetics of the built environment. The study further identified the indicators, which had a strong bearing on elderly walking behavior. The presence of crosswalks and pedestrian signals, crossing time at signals, interesting views, and street cleanliness level had a positive impact, while barriers such as parking lots abutting the sidewalks, grade changes, and stray animals had a negative impact on elderly walkability.

The senior citizens have a slow gait, which is further accentuated by a fear of falls in many of them. Hence, they prefer to cross safely at locations where crosswalks and safe waiting areas were present, further, they expressed their need for a comparatively higher pedestrian crossing time at signalized intersections. Barriers to walking play a big role in elderly outdoor walking. Parking lots abutting the sidewalk serve as a hindrance to walking. The sidewalks are generally avoided as they are either not continuous or uneven or blocked by street vendors. Hence elderly pedestrians are compelled to walk on the road behind parked vehicles. This poses a threat to walking as pedestrians are compelled to walk between the parked vehicles and the busy traffic on the roads. This situation must be rectified by allotting parking lots on wider roads only and ensuring proper maintenance of

sidewalks. This would ensure that pedestrians walk only on the sidewalks and do not opt to walk on busy roads.

In Triplicane, Chennai, stray animals are a big menace to senior citizens. The cattle are left to wander astray and are reported to cause several trip and fall incidents, which at times end up fatal too. This has instilled a fear of psychosis amongst the elderly residing there. The uncontrolled wandering of cattle on streets should be restricted. Interesting scenic views and clean streets encourage walking among the elderly population. This tends to enhance the walkability levels.

Furthermore, longitudinal and experimental studies should be conducted to test the above-mentioned interventions. Another possible area of future research would be to assess the potential of the methodology for integrated evaluations of sustainable mobility, pedestrian mobility and soft mobility by public transport in the research trends. The study methodology can be applied to similar geographic locations and green field developments with higher elderly population density, to arrive at suitable location-specific recommendations. More work needs to be conducted to enhance walkability and soft mobility for elderly and physically challenged people in all possible modes of transportation.

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