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Article

The Built Environment and Walking Activity of the Elderly: An Empirical Analysis in the Zhongshan Metropolitan Area, China

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Abstract: Policies and interventions involving the built environment have become a promising opportunity for the promotion of walking as a sustainable transportation mode. Among voluminous literature, few studies were found that examined the association between the built environment and walking among the elderly in China. This study investigated the relationship between the built environment and the walking activity of the elderly based on data collected in Zhongshan Metropolitan Area, China. The results suggest that abundant sidewalks, dense bus stops, easily accessible commercial establishments, and ample green land space are potentially effective to enhance walking among the elderly, albeit to varied degrees. The compact urban form, which is considered as walkability in the western context, may not necessarily play a positive role in Zhongshan's context. The findings provide insights into the policy-making to promote sustainable transportation modes and the design of interventions on health promotion of the elderly in China.

Keywords: built environment; walking activity; the elderly; probability; frequency and duration; Zero-inflated Poisson Regression; sustainable transportation

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1. Introduction and Background

There is strong evidence that regular physical activity provides substantial health benefits to the elderly [1]. Physical activity is positively associated with prevention of chronic diseases, disability, and bone fractures among the elderly [2]. As an important form of physical activity and a sustainable transportation mode, walking is safe, accessible and easy to incorporate into daily life [3,4]. In addition, walking has a low risk of injury and does not require special facilities or equipment [5,6]. Promoting walking among the elderly is a crucial component of the efforts to improve the overall physical activity levels of the elderly [7].

Up to the year 2012, the population of the elderly (aged 60 and over) in China was 194 million, accounting for 14.3% of the China's overall population [8]. China has stepped into an aging society. Since 2007, the National Health and Family Planning Commission of China (NHFPC) has launched an initiative of promoting healthy lifestyle in the Chinese population [9]. One of the key actions is to promote "ten thousand steps a day" among the general population, including the elderly, aiming to promote all kinds of walking and enhance the health level. However, the fact is that little is known about the factors that may influence the walking activity of the elderly in the non-western populations [10]. To provide practical implications for environmental interventions to promote walking activity of the elderly in China and policies to enhance the modal split of walking as a sustainable travel mode, it is imperative to investigate how the built environment is correlated with the walking activity.

After several decades of study on the connections between the built environment and travel behavior, researchers from the transportation-planning field have considered the effect of the built environment on walking as a mode of transportation [11–13]. Meanwhile, treating walking as a form of physical activity, researchers from the public health field has increasingly focused on the connection between the built environment and walking in the past decade or two [14,15]. Currently, researchers from these two fields have worked together to mutually contribute to the proliferation of research on the built environment correlates of walking by the elderly in the western context [16]. The research findings from the two fields have facilitated our understanding of the connection between the built environment and walking by the elderly and provided important policy implications for the planning of interventions.

The built environment measures employed in physical activity-related studies typically fell into two categories: the objective and the subjective. The objective built environment measures were generated from: (1) calculating built environment attributes at neighborhood level from secondary data such as Traffic Analysis Zone or Census [17,18]; (2) measuring the built environment attributes within a certain buffer radius of the respondents' residences [17,19]; or (3) quantifying the built environment attributes at high resolution or used cluster analysis to identify different urban forms [20,21]. The subjective measures were generally derived by surveying respondents' perceptions of the built environment [12,22]. Over the past decade, the volume of literature on the influence of the built environment on physical activity and health promotion among different age groups in the western context has exploded.

Elderly are found to be especially susceptible to the built environment as compared to the younger population [23,24]. Therefore, interventions involving the built environment have become a promising opportunity for the promotion of walking activity among the elderly [25,26]. In a recent systematic review mainly focusing on the western context, Van Cauwenberg *et al.* [14] concluded that the following built environment features would impact the walking activity of the elderly, albeit to varied degrees: (1) walkability, e.g., residential density, land use mix diversity, and street connectivity [27,28]; (2) access to services, e.g., access to public transportation and recreational facilities [29,30]; (3) walking facilities, e.g., sidewalks and walking trails [29]; (4) safety, e.g., presence of heavy traffic and neighborhood crime-related safety [29]; (5) esthetics, e.g., greenery and scenery[31]; and (6) urbanization, e.g., the difference between urban and rural residents [32]. In terms of transportation (or utilitarian) walking, researchers [16,33] found that neighborhoods with higher density, greater connectivity, proximity of nonresidential destinations, and more land use mix reported higher rates of transportation walking than low-density, poorly connected, and single land use neighborhood. The recreational walking seemed more closely related to walking facilities, esthetics, crime safety, and access to commercial and recreational destinations [28,29,34].

What is worth mentioning is that the majority of "built environment–physical activity" studies have predominantly been conducted in the western context and their findings are not necessarily translatable to the Chinese context [14]. In recent years, supported by the validation and reliability of the physical activity scale in the Chinese context [35,36], scholars from the public health field have begun to examine the effects of physical activity on health outcomes in the elderly, e.g., obesity, inflammation, diabetes, metabolic syndrome, mortality, and subjective well-being [37–39]. However, in China's transportation planning field, only a few studies have examined the built environment representations in the Chinese context [40,41], let alone the association between the built environment and walking activity among the elderly [10,34], as the present paper does. Since the walking activity of the elderly is an indispensable starting point to facilitate the understandings and design effective interventions on health promotion, the present paper will serve as an extended body of literature.

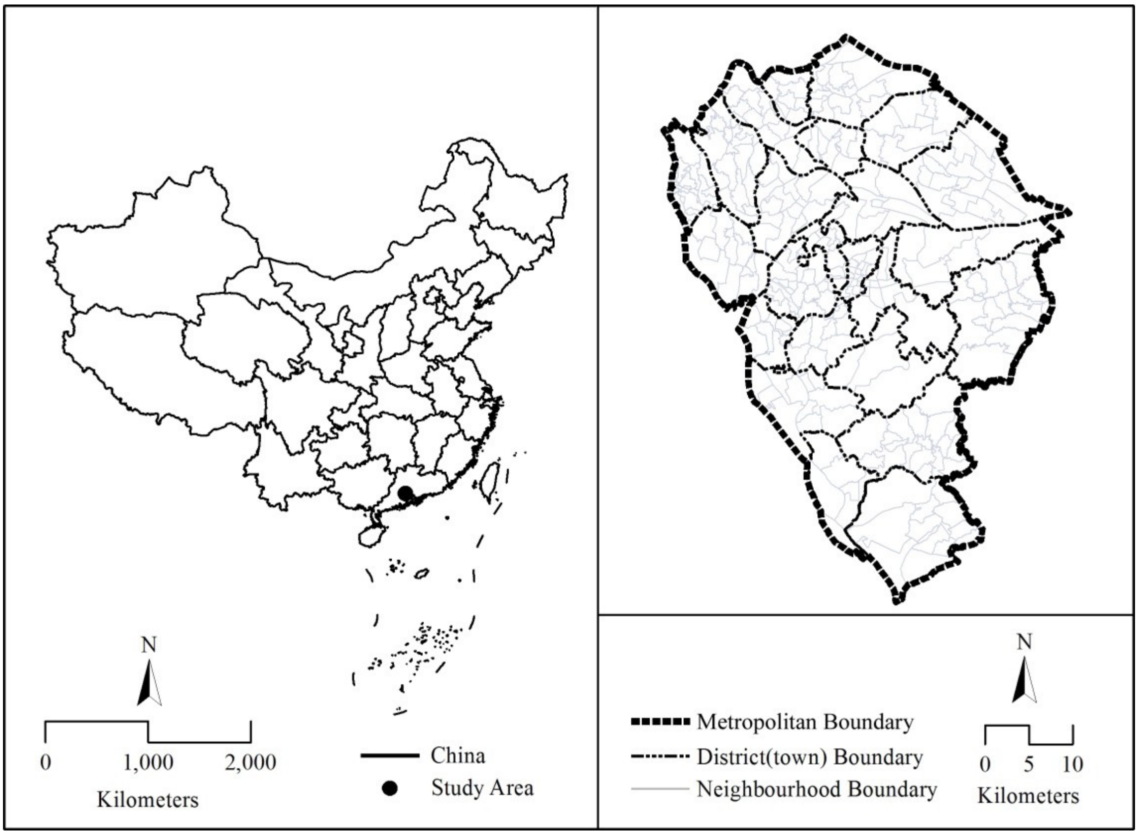
This paper will present research results from a study aimed at investigating the relationship of the built environment on the walking activity of the elderly in the Chinese context with data collected from 274 neighborhoods in the Zhongshan Metropolitan Area. The study first generated built environment attributes featuring walkability, walking facility, access to services and destinations, and esthetics. Then, zero-inflated Poisson models were used to examine specifically how the probability, frequency and duration of self-reported walking trips of the elderly were related to the built environment attributes, together with personal and household attributes. The walking activity in the present study includes the daily trip frequency and duration of total walking, *i.e.*, both transportation and recreational walking. The elderly population in this study focuses on adults aged 60 and over. This study is among the rare efforts to incorporate the built environment into a walking activity-related study in the Chinese context. The findings will provide insights for transportation and public health agencies, practitioners, and researchers into the effective design of interventions on health promotion for the elderly and policy-making to boost the sustainable transportation mode.

2. Data and Methods

2.1. Study Area

We choose the Zhongshan Metropolitan Area as our study area to examine the walking behaviors of the elderly in the Chinese context. Located in one of the three largest coastal urban agglomerations with the most competitive economies in China (Figure 1), Zhongshan is a medium-sized prefecture-level city with an area of 1800 km^2 and a population of 3.1 million [42]. In the three agglomerations, there are about 20 medium-sized cities with similar urbanization and motorization levels and urban transport characteristics to Zhongshan [42]. Thus the research findings in Zhongshan might be typical and informative of the type of cities. In Zhongshan, the elderly make 2.55 trips per day on average, among which 52.5% are walking trips. The average frequency and duration of walking trips of the elderly is 1.38 trips and 19.56 minutes.

Figure 1. Study area. The figure on the left shows the location of the Zhongshan Metropolitan Area in China and the figure on the right shows the boundary of the Zhongshan Metropolitan Area.



2.2. Data Collection

2.2.1. The Built Environment Data

The following data for the characterization of built environment attributes come from the Zhongshan Municipal Bureau of Urban Planning: (1) Traffic analysis zone (TAZ) boundaries—proxy for neighborhood boundaries; (2) land use in 2010 with five major types of land use (residential land, commercial and service facilities, industrial and manufacturing, green space, and other types of land uses); (3) population, dwelling units and employment in 2010; (4) road networks; (5) bus stops, and (6) political boundaries such as city and zone boundaries. All the data were then integrated into ArcGIS for further analysis.

2.2.2. The Walking Activity Data

The cross-sectional walking activity data were derived from Zhongshan Household Travel Survey (ZHTS) in 2010 [43]. Selected by stratified random sampling covering the whole Zhongshan Metropolitan Area, the sample size of the elderly over 60 was 4308 (excluding invalid data) with a sample rate of 2.0%. The ZHTS 2010 provided the self-reported one-day walking activity, e.g., frequency, duration, purpose of walking trips, together with the personal and household data of the elderly.

2.3. Characterization of Built Environment Attributes

The built environment data were collected on the basis of neighborhoods, which are defined to be spatially equivalent to TAZs. As designed to be homogeneous with respect to socio-demographic characteristics and living conditions [44], TAZs share boundaries with administrative divisions in most cases. A total of 274 TAZs in Zhongshan were included in this study. From the raw data, six built environment measures were identified on the neighborhood level: population density, sidewalk density, percentage of green space land use, bus-stop density, commercial accessibility and land-use diversity. According to the previous literature [14], the population density and land-use diversity demonstrates the features of walkability, the sidewalk density embodies the feature of walking facility, the bus stop density and commercial accessibility represent the features of access to services and destinations, and the percentage of green space land use reflect the feature of esthetics.

The population density, sidewalk density, percentage of green space land use and bus stop density are self-explanatory. The commercial accessibility and land-use diversity were calculated with respect to the context of Zhongshan or China, as applicable.

The commercial accessibility is measured by the area coverage of commercial facilities within fourteen minutes' walking distance from the center of a neighborhood. According to ZHTS, the duration of fourteen minutes was the average duration of a single walking trip of the elderly and was considered acceptable by the elderly [43].

The land-use diversity represents the degree to which different land uses in a neighborhood are mixed. We calculated the land-use diversity by the Entropy Index (EI) [45], wherein 0 indicates single-use environments and 1 stands for the equalization of different land uses in area coverage. EI is defined by:

$$EI=\sum_{i=1}^{n} P_i \log(1/P_i) \tag{1}$$

where n = number of unique land uses, $n \geq 1$; P_i = percentage of land use i's coverage over total land use coverage. In China, the officially recommended proportion of residential land, industrial manufacturing land, commercial facilities land, green space land and other land is close to 2:2:1:1:1 [46], which is applied in the land use planning practice in Chinese cities including Zhongshan. This proportion generates an entropy index of 0.67. Thus each of the original entropy indices of a TAZ in this study is transformed into a criterion that is 0.67 of the standard 1, and all other indices are ranged between 0 and 1 based on the standard 1 [41].

2.4. Model Specification

The percentage of the elderly making zero walking trips is 43.4%. Thus the count of frequency or duration of walking trips has more zero observations than predicted by a Poisson process, which assumes that the conditional variance of the distributions of frequency and duration of walking trips are equal to the expected values [47]. The Vuong model selection test indicates insignificant over-dispersion, strongly favoring a zero-inflated Poisson (ZIP) regression approach to analyzing the data. Compared to a standard Poisson regression model, a ZIP model can capture both the excess zero group and the nonzero group by estimating two separate models and connecting them [48]. First, a binary logit model is estimated for the certain-zero cases, predicting whether or not an elderly person would make walking trips. Then, a Poisson model is estimated for the elderly that make at least one walking trip per day.

This study chose a ZIP model to analyze the relationship between the built environment and the walking activity. The ZIP model assumes that the dependent variable (in this case, the frequency and duration of walking trips of the elderly) for a sample size k, $N = (n_1, n_2, ..., n_k)$, is independent. The model is [49]:

$$\begin{cases} n_i=0 \text{ with probability } p_i+(1-p_i)^{\exp(-\lambda_i)} \\ n_i=n \text{ with probability } \dfrac{(1-p_i)^{\exp(-\lambda_i)\lambda_i^n}}{n!} \end{cases} \quad (2)$$

where p_i is the probability of an elderly person having zero frequency and duration of walking trips and n ($n > 0$) is the frequency and duration of walking trips.

To calibrate the coefficient of the ZIP model with Stata 12.0, we rewrote the ZIP model with natural log transformation in both Poisson and binary logit models. We employed the same independent variable sets in the binary logit and Poisson models, as we assumed that those variables were significantly associated with the walking activity of the elderly. The ZIP model specifications were expressed as follows in the order of the Poisson model and binary logit model:

$$\begin{aligned} Pr_{\text{frequency}}(Pr_{\text{duration}}) = \beta_0 + \beta_1 * \text{GENDER} + \beta_2 * \text{AGE} + \beta_3 * \text{EMPLOYED} \\ + \beta_4 * \text{PROWALK} + \beta_5 * \text{HHSIZE\_1} + \beta_6 * \text{HHSIZE\_2} + \beta_7 * \text{HIGHINC} \\ + \beta_8 * \text{MEDINC} + \beta_9 * \text{BIKES} + \beta_{10} * \text{EBIKES} + \beta_{11} * \text{MOTORS} + \beta_{12} * \text{CARS} \end{aligned} \quad (3)$$

$$\begin{aligned} Nr_{\text{frequency}}(Nr_{\text{duration}}) = \beta_0' + \beta_1' * \text{GENDER} + \beta_2' * \text{AGE} + \beta_3' * \text{EMPLOYED} \\ + \beta_4' * \text{PROWALK} + \beta_5' * \text{HHSIZE\_1} + \beta_6' * \text{HHSIZE\_2} + \beta_7' * \text{HIGHINC} + \\ \beta_8' * \text{MEDINC} + \beta_9' * \text{BIKES} + \beta_{10}' * \text{EBIKES} + \beta_{11}' * \text{MOTORS} + \beta_{12}' * \text{CARS} \end{aligned} \quad (4)$$

where $Pr_{\text{frequency}}$ and Pr_{duration} in the binary logit mode is the probability of having zero frequency and duration of walking trips; $Nr_{\text{frequency}}$ and Nr_{duration} in the Poisson model is the frequency (trips) and duration (minutes) of walking trips; GENDER denotes whether the respondent is male or female; AGE represents the respondent's age in years; EMPLOYED stands for employment status of the respondent; PROWALK describes whether the respondents favor walking over other travel modes in daily travel; HHSIZE_1 and HHSIZE_2 are dummies for the household size of one and two persons (with a reference category of more than two); HIGHINC and MEDINC_M are dummies for the household total annual income ranges of above 60000 Chinese Yuan Renminbi (RMB, 6.2 Renminbi ≈

1 US Dollar in 2010) and 20000–60000 RMB (with a reference category of 0–20000 RMB); BIKES, EBIKES, MOTORS and CARS represent the number of bicycles, electric bikes, motorcycles and private cars in a household, respectively.

Along with the basic model presented above, regression of the dependent variables proceeded in an expanded model. The expanded model adds six built environment attributes as independent variables, where POP, MIXTURE, SIDEWALK, BUSSTOP, COMACC, and GREEN demonstrate the population density, land-use mixture of the neighborhood, sidewalk density, commercial destination accessibility, bus-stop density, and percentage of green space land use where the respondents lives.

3. Results

3.1. Descriptive Statistics

Descriptive statistics provide a general view of the dependent and independent variables (Table 1), broken down based on whether or not the elderly would make walking trips. There is a higher percentage of male and employed elders in Group One (having no walking trips) than in Group Two (having at least one walking trip). Group two is generally older and has a more positive attitude towards walking than Group One. At the household level, Group one has a larger household size with nearly half of them (48%) living in a household with three persons or more, compared to 41% of Group Two. The households of Group One are more affluent and own more vehicles than that of Group two. The standard deviation values of the built environment attributes were larger than or close to their mean values (all but MIXTURE, land-use mixture), implying the substantial variations of built environment features among neighborhoods in Zhongshan (Table 1).

Table 1. Descriptive statistics for dependent and independent variables.

Description	*Group One*		*Group Two*		*Group One & Two*	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Frequency of walking trips of the elderly, trips per day, count	0	0	2.43	1.04	$0^{*}/1^{**}$	$0^{*}/10^{**}$
Duration of walking trips of the elderly, minutes per day, count	0	0	34.57	24.06	$0^{*}/1^{**}$	$0^{*}/290^{**}$
1 = Male, 0 = Female, binary	0.71	0.46	0.52	0.50	0	1
Age of the respondent in years, count	65.30	5.59	68.45	7.09	60	$94^{*}/95^{**}$
The respondent is employed, binary, 1 = yes	0.33	0.47	0.18	0.38	0	1
The respondent favors walking over other modes, binary,1 = yes	0.07	0.25	0.42	0.49	0	1
Household size is one person, binary, 1 = yes	0.17	0.38	0.22	0.42	0	1
Household size is two persons, binary, 1 = yes	0.35	0.48	0.36	0.48	0	1
Household size is three or more persons, binary, 1 = yes	0.48	0.50	0.41	0.49	0	1
High household income(>60000 RMB/yr), binary, 1 = yes	0.14	0.35	0.16	0.36	0	1
Medium household income (20000–60000 RMB/yr), binary, 1 = yes	0.52	0.50	0.44	0.50	0	1
Low household income (<20000 RMB/yr), binary, 1 = yes	0.34	0.47	0.40	0.49	0	1
Number of bikes in a household, count	0.74	0.74	0.53	0.67	0	5
Number of electric bikes in a household, count	0.29	0.50	0.16	0.41	0	3*/4**
Number of electric bikes in a household, count	0.29	0.50	0.16	0.41	0	$3^{*}/4^{**}$
Number of motorcycles in a household, count	0.88	0.89	0.65	0.80	0	$5^{*}/4^{**}$

Table 1. *Cont.*

Description	*Group One*		*Group Two*		*Group One & Two*	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Number of private cars in a household, count	0.17	0.38	0.15	0.41	0	4
Population density, 1000 persons/km^2, continuous	5.09	7.46	9.76	11.27	0.048	43.934
Land-use mixture	0.71	0.18	0.69	0.18	0	0.99
Sidewalk density, km/km^2, continuous	3.79	2.84	5.08	3.47	0.10	12.14
Bus stop density, number of bus stops per km^2, continuous	1.08	1.66	2.13	2.80	0	10.38
Area coverage of commercial establishments within 14 minutes' walk, in ha, continuous	5.41	6.13	7.48	6.87	0	203.46
Percentage of green space land use in all land uses, continuous	0.06	0.07	0.07	0.09	0.005	0.654

Note: *Group One* denotes the elderly who have zero frequency and duration of walking trips per day (sample=1870); *Group Two* denotes the elderly who have at least one walking trips per day (sample = 2438); Std. Dev. denotes Standard Deviation. * belongs to *Group One* and ** belongs to *Group Two.*

3.2. Logit Regression Analysis of Probability of Zero Frequency and Duration of the Walking Trips of the Elderly

The results of the logit regression of the ZIP model revealed how different attributes were associated with the probability of the elderly having zero frequency and duration of walking trips. We took the results of the probability of zero walking frequency as an example, as showed in column two of Table 2. At the personal level, all of the attributes displayed significant associations (Table 2). To be specific, being male or employed was associated with a higher probability of having zero walking trips. On the contrary, having a positive attitude towards walking (pro-walking), *i.e.*, preferring walking to other modes, would substantially decrease the probability of having zero walking trips.

At the household level, living arrangement and vehicle ownership showed significant associations. Living alone or with a spouse/partner, compared to living with two or more other members, was associated with a 61.54% to 61.79% higher probability of having zero walking trips. Having an additional bike, electric bike, motorcycle or private car in the household was related to a significant increase of zero probability of walking frequency.

Among the six neighborhood built environment attributes, four displayed significantly negative associations. One unit increase of population density, sidewalk density or bus stop density is related to a 6.3% to 14.6% decrease of probability of having zero walking trips. Compared to the elderly residing in the neighborhood with the lowest percentage of green space land use, the elderly who live in the neighborhood with the highest would have 39.8% less probability to make zero walking trips.

The significance and signs for the household variables persisted across all models and the relative risk ratios (RRRs) showed only slight variation. The increase of LR chi2 and Log likelihood (Table 2) in expanded models compared to the basic model demonstrated the improvement of goodness of fit. That implied that the built environment contributed to strengthening the explanatory power.

3.3. Poisson Regression Analysis of Frequency of Walking Trips by the Elderly

The results indicated the connections between different attributes and the walking frequency of the elderly who made at least one walking trip in a day (Table 2). At the personal and household level, only two attributes, *i.e.*, the attitude of pro-walking and household bike ownership, displayed significant associations. The elderly who were pro-walking would make 32.7% more walking trips than the counterpart. Having an additional bike in a household was related to a 4.6% decrease in the walking frequency of the elderly.

All the six built environment attributes were statistically significant at a 95% confidence interval, of which the sidewalk density, bus stop density, commercial accessibility and percentage of green space land use were positive, and the population density and land-use mixture were negative. Given the range of 12.04 (km/km^2) of sidewalk density (Table 2) and an incident rate ratio (IRR) of 3.5% (= exp(0.034)−1), the elderly who live in the neighborhood with the densest sidewalks would make 41.3% more walking trips than those living in the neighborhood with the sparsest sidewalks. Similarly, with abundant and easily accessible commercial establishments within walking distance, the elderly would at most walk 85.0% more. All else being equal, in the neighborhood with the highest percentage of green space land use or densest bus stops, the elderly would make 12.2% to 23.2% more walking trips. Compared to the elderly living in the neighborhood with the lowest population density or land-use mixture, the elderly living in the neighborhood with the highest would make 38.3% or 30.3% less walking trips, respectively.

The signs for the household variables persisted across all models and the IRRs showed only slight variation. The LR chi2 and Log likelihood of each model represent the overall goodness of fit. Adding built environment variables to the model enhanced the predictability as shown in the change of LR chi2 and Log likelihood (Table 2).

Table 2. Zero-inflated Poisson regressions of frequency and duration of walking trips of the elderly.

Variable	Basic Model				Expanded Model			
	Frequency of walking (trips/day)		Duration of walking (minutes/day)		Frequency of walking (trips/day)		Duration of walking (minutes/day)	
	Coefficient		Coefficient		Coefficient		Coefficient	
	Logit	Poisson	Logit	Poisson	Logit	Poisson	Logit	Poisson
Personal attributes								
CONSTANT	2.809	0.777	2.373	3.282	3.801	0.778	2.984	3.009
GENDER	0.761	0.034	0.618	0.032	0.717	0.039	0.578	0.041
AGE	−0.066	0.001	–0.052	0.004	–0.064	0.001	–0.049	0.005
EMPLOYED	0.559	–0.050	0.523	–0.173	0.326	–0.011	0.324	–0.120
PROWALK	–3.706	0.270	–2.053	0.053	–3.617	0.283	–2.021	0.360

Table 2. *Cont.*

Variable	Basic Model				Expanded Model			
	Frequency of walking (trips/day)		Duration of walking (minutes/day)		Frequency of walking (trips/day)		Duration of walking (minutes/day)	
	Coefficient		Coefficient		Coefficient		Coefficient	
	Logit	Poisson	Logit	Poisson	Logit	Poisson	Logit	Poisson
Household attributes (HHSIZE>2 and LOWINC are reference categories)								
HHSIZE_1	0.385	–0.012	0.302	0.040	0.480	0.001	0.315	0.019
HHSIZE_2	0.374	–0.015	0.303	–0.016	0.481	–0.001	0.349	–0.030
HIGHINC	–0.402	0.138	–0.377	0.004	–0.108	0.076	–0.098	–0.081
MEDINC	–0.025	0.059	–0.011	–0.043	0.171	0.025	0.164	–0.086
BIKES	0.340	–0.061	0.345	–0.019	0.296	–0.047	0.292	–0.068
EBIKES	0.612	–0.058	0.542	–0.067	0.507	–0.036	0.431	–0.054
MOTORS	0.376	–0.006	0.292	0.030	0.330	0.008	0.236	0.040
CARS	0.343	0.012	0.287	0.040	0.336	0.026	0.248	0.040
Built environment attributes								
POPDEN					–0.065	–0.008	–0.038	–0.005
MIXTURE					–0.360	–0.360	0.244	–0.041
SIDEWALK					–0.106	0.034	–0.045	0.016
BUSSTOP					–0.157	0.012	–0.124	0.012
COMACC					–0.007	0.004	–0.009	0.002
GREEN					–0.952	0.305	–0.858	0.224
Summary statistics								
Number of obs	4308							
Nonzero obs	2438							
Zero obs	1870							
LR chi2	46.27		856.52		99.66		1588.32	
Prob > chi2	0.0000		0.0000		0.0000		0.0000	
Log likelihood	–5892.74		–25757.78		–5777.46		–25300.95	

Note: Bold face denotes significance at $p < 0.05$.

3.4. Poisson Regression Analysis of Duration of the Walking Trips of the Elderly

All of the personal attributes displayed significant associations with the duration of walking of the elderly, except for the age (Table 2). All else being equal, being pro-walking or employed was related to a 43.33% increase or a 11.3% decrease, respectively, with regard to the duration of walking trips. Being male was associated with a slight (4.14%) increase of walking duration.

At the household level, five of the eight attributes showed negative significance. Having an additional bike or electric bike was related to a 6.6% or 5.3% decrease of duration of walking trips, respectively. Compared to the elderly living in low-income households, the elderly who lived in households with high-to-medium income would walk 8% less in terms of duration.

The entire built environment attributes displayed significant correlations. The sidewalk density and the percentage of green space land use in a neighborhood were related to a 21.2% and 16.3% increase of the walking duration at most, respectively. The elderly tended to walk 12.9% or 38.5% more in duration if living in a neighborhood with the densest bus stops or most commercial destinations, respectively, and 21.4% or 4.0% less if living in a neighborhood with the densest population or most commercial destinations, respectively.

The signs for the household variables persisted across all models and the IRRs showed only a slight variation. The LR chi2 and Log likelihood of each model represent the overall goodness of fit. Adding built environment variables to the model enhanced the predictability as shown in the change of LR chi2 and Log likelihood (Table 2).

4. Discussion and Policy Implications

This paper presented findings from a study aimed at investigating the relationship of the built environment on the walking activity of the elderly in the Chinese context. With data collected from 274 neighborhoods in the Zhongshan Metropolitan Area, we first generated six built environment attributes featuring walkability, walking facility, access to services and destinations, and esthetics. Then, we employed zero-inflated Poisson models to examine specifically how the probability, frequency and duration of self-reported walking trips of the elderly were related to the built environment attributes, together with personal and household attributes.

Personal and household attributes related to the gender, the employment status, the attitude towards travel modes, the living arrangement and the availability of vehicles are significantly correlated with the walking activity of the elderly. To be specific, being male or employed, favoring other modes than walking, living alone or with a spouse/partner, or owning vehicles like bikes, electric bikes, motorcycles or private cars, are highly related to the increase of probability of zero walking trips. A positive attitude towards walking is also found to substantially promote the frequency and duration of the walking trips. The findings on the correlation of a pro-walking attitude imply the potential effects of the broad dissemination of a healthy life style involving walking activity among the elderly.

The correlations of the built environment attributes on the walking activity of the elderly yield some interesting findings. To examine the magnitude of the built environments, we computed the weighted average elasticities of built environment attributes (Table 3) with the methods used by Ewing and Cervero [11]. For the probability of making zero walking trips, four attributes played a significantly negative role, albeit to varying degrees. The population density and the sidewalk density had large elasticities, while the bus stop density had a medium elasticity and the percentage of green space land use had a small elasticity. These findings indicate that the walkability (population density) and the walking facility (sidewalk density) would have stronger effects on promoting the elderly to choose walking, compared to the access to the public transportation services (the bus stop density) and the esthetics (percentage of green space land use).

In terms of the frequency and duration of walking trips, more available sidewalks, denser bus stops, easily accessible commercial establishments, and abundant green space land use near the residence would promote the elderly to walk more, which is consistent with previous findings [14]. Among the four attributes, the sidewalk density and commercial accessibility would have stronger effects than the bus stop density and percentage of green space land use for both the frequency and duration, as the elastisities have revealed. For example, for the elderly who make at least one walking trip per day, if the sidewalk density near their residence doubled from the average value of 5.08 (Table 1) to

10.16 (km/km^2), their walking frequency and duration would, all else being equal, increase by 0.38 trips and 2.73 minutes.

Table 3. Elasticities of the walking activity of the elderly with respect to built environment variables.

Category	Variables	Type One	Type Two	Type Three
Walkability	Population density	–0.219	–0.068	–0.038
	Land-use mixture	/	–0.253	–0.029
Walking facility	Sidewalk density	–0.209	0.155	0.079
Access to services and destinations	Bus stop density	–0.114	0.020	0.021
	Commercial accessibility	/	0.137	0.062
Esthetics	Percentage of green space land use	–0.028	0.021	0.015

Note: Type One represents the elasticities of the probability of having zero walking trips among all the respondents; Types Two and Three represent the elasticities of the frequency and duration of walking trips of the elderly who had at least one walking trip; / demonstrates that the variable is not significant at 95% confidence.

With regard to population density and land use mixture, which represent walkabilty in the western, especially the US, context, we, however, found inconsistent associations [11]. In populated and mixed-developed neighborhoods in Zhongshan, the elderly tend to walk less in terms of the frequency and duration. The land use mixture has the strongest effect (the largest absolute value of elasticity) of the six attributes of the walking frequency of the elderly. The average population densities are 3596 persons/km^2 in the Zhongshan Metropolitan Area and 15018 persons/km^2 in the Zhongshan's urban core. The population density may largely exceed those of the cases studied in the western context. The highly compact urban form, closely related to the dense population and mixed land use, is very likely to increase the possibility of trip-chaining instead of independent trips and to reduce the walking distance. Consequently, the frequency and duration of walking trips may decrease at the same time. Nonetheless, this was our preliminary speculation, and the underlying mechanism of the role that the compact urban form plays in Zhongshan remains unclear and is worthy of further study.

Based on the discussions above, we could recommend policies and interventions involving the built environment, e.g., building more and connective sidewalks, facilitating access to bus stops and commercial establishments, and increasing the proportion of green space land use, that are potentially effective to promote the sustainable transportation mode of walking among the elderly in Zhongshan. However, the compact urban form related to high density and mixed development, which is one of the main themes of urbanization in Chinese cities, may not necessarily facilitate the walking activity of the elderly. Therefore, in the context of rapid urbanization and evolving built environment features, the question of how to incorporate health interventions into the policy-making and practice of urban and transportation planning and promote the walking activity among the elderly, would be a great challenge in China.

5. Strengths and Limitations

This study has a number of strengths and limitations. In terms of the strengths, firstly, the study investigated the objective built environment in the Chinese context with a quantitative approach and with the aim to facilitate the emerging built environment-travel behavior research in China. Secondly, the study focused on the elderly population and provided informative policy implications for the aging society. Finally, the study revealed the effects of various built environments on travel behaviors in a developing country with rapid urbanization and motorization, which might further promote the comparative research between different contexts. In terms of the limitations, firstly, the study was restricted to the Zhongshan Metropolitan Area, which is a single geographical area in the Pearl River Delta. Therefore, the findings may only be generalized to the geographical characteristics that are similar to Zhongshan. Secondly, the dependent outcomes, walking frequency and duration, are derived from self reports, which may lead to self report bias that does not capture all domains of this activity. However, self reports in physical activity remain the primary source for assessing walking activity in large scale studies like this [28]. Finally, cross sectional data were used in this study. The full evaluation of causal effects of built environment on walking activity will require longitudinal and multilevel analyses over time.

6. Conclusions

This study adds to the existing literature by exploring the relationship between built environment and the walking activity of the elderly in the Chinese context with data collected in the Zhongshan Metropolitan Area. The study generated six built environment attributes featuring walkability, walking facility, access to services and destinations, and esthetics. In a next step, zero-inflated Poisson models were used to examine specifically how the probability, frequency and duration of walking trips of the elderly were related to the built environment attributes and personal and household attributes.

Among the six built environment attributes, five (population density, sidewalk density, percentage of green space land use, bus stop density, commercial accessibility) displayed substantial variations across neighborhoods in Zhongshan. The descriptive analysis showed some remarkable differences between the socio-demographic characteristics of the elderly who had zero or at least one walking trip per day. The zero-inflated regression models suggested that, all else being equal, abundant sidewalks, dense bus stops, easily accessible commercial establishments, and ample green land space were related to the increase of probability, frequency, and duration of the walking activity of the elderly. The findings were consistent with the positive associations of walking facility, accessibility to transit and destinations, and esthetic features of the walking activity, which had previously been found in the western context. However, the walkability, which features the compact urban form in the western context, may not play a positive role in promoting walking activity among Zhongshan's elderly, as revealed by the present paper. The models also detected that the attitude towards walking and the availability of household vehicles were strongly related to the elderly's walking activity in Zhongshan. The findings provide insights for transportation and public health agencies, practitioners, and researchers into the policy-making of boosting the sustainable transportation mode and the design of interventions on health promotion for the elderly in China. Among the possible interventions, we suggested the first priority for the government should be to build sidewalks, considering the elasticity of the measures (Table 3) and cost-efficiency of the interventions. During the reconstruction of urban road networks in the past decade or two, some of the sidewalks in Zhongshan were transformed to driveways to facilitate motorized travel demands. To enhance walking, the government could restore the original sidewalks to promote walking activity without much investment.

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Conflicts of Interest

The authors declare no conflict of interest.

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