

Article

Built Environment Correlates of the Propensity of Walking and Cycling

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Abstract: Walking and cycling are not only frequently-used modes of transport but also popular physical activities. They are beneficial to traffic congestion mitigation, air pollution reduction, and public health promotion. Hence, examining and comparing the built environment correlates of the propensity of walking and cycling is of great interest to urban practitioners and decision-makers and has attracted extensive research attention. However, existing studies mainly look into the two modes separately or consider them as an integral (i.e., active travel), and few compare built environment correlates of their propensity in a single study, especially in the developing world context. Thus, this study, taking Xiamen, China, as a case, examines the built environment correlates of the propensity of walking and cycling simultaneously and compares the results wherever feasible. It found (1) built environment correlates of the propensity of walking and cycling differ with each other largely in direction and magnitude; (2) land use mix, intersection density, and bus stop density are positively associated with walking propensity, while the distance to the CBD (Central Business District) is a negative correlate; (3) as for cycling propensity, only distance to CBD is a positive correlate, and job density, intersection density, and bus stop density are all negative correlates. The findings of this study have rich policy implications for walking and cycling promotion interventions.

Keywords: built environment; walking; cycling; propensity; comparative study; China

1. Introduction

Walking and cycling are not only frequently-utilized modes of transport but also a popular component of people's daily physical activity. As two alternatives to motorized travel modes such as private driving, walking and cycling can effectively reduce transport costs and, at the same time, mitigate traffic congestion induced by the explosion of motorized transport [1]. Meanwhile, as environmentally friendly travel modes, walking and cycling are conducive to decreasing energy consumption and transportation-related air pollutants [2] and greenhouse gases [3]. In addition, walking and cycling involve moderate activity of skeletal muscles and can act as an efficient remedy for the sedentary lifestyle that is widespread in modern society, preventing a wide variety of non-communicable diseases such as obesity [4], cardiovascular diseases [5,6], hypertension [7], diabetes [8], and mental disorders [9,10]. Moreover, walking and cycling are related to a higher level of social integration and interaction, thereby bringing about various social benefits [11]. In summary, walking and cycling have great potential for promoting economic, environmental, and social sustainability and public health.

However, despite the aforementioned multi-aspect benefits, walking and cycling are faced with marginalized or marginalizing status. The developed world has been witnessing a steadily low share of walking and cycling for decades. For example, in the USA, despite a mild rise from 9.6% in 2001, the combined mode share of walking and cycling was still as low as 12.9% in 2017 [12]. In the developing world, walking and cycling play a much more important role in people's daily life than it does in the West. However, they are experiencing a rapid decline because of the ever-increasing prevalence of private motor vehicles. In Beijing, China, the mode share of cycling dropped to 15% in 2014 from 62.7% in 1986 [13]. The latest travel survey of Shenzhen revealed that walking and cycling have steadily declined in Shenzhen in the last few years; and that walking has decreased from 50.0% in 2010 to 46.0% in 2019, while cycling dropped from 6.2% to 4.0% [14,15].

Against this backdrop, to promote walking and cycling or retard their decline, researchers from a variety of domains such as geography, urban planning, and public health have devoted themselves to examining the characteristics and built environment correlates/determinants of walking and cycling. The key to identifying the built environment correlates of walking and cycling is to accurately measure the built environment. The "3Ds" model proposed by Cervero and Kockelman [16], which delineates the built environment with the density of objects of interest (e.g., population, dwelling, and employment), diversity (i.e., land use mix), and design (often measured by street connectivity), is among the most influential and frequently-used methods of quantifying key elements of the built environment. Later, the "3Ds" model was expanded to "5Ds" by Ewing and Cervero [17], with "distance to transit" and "destination accessibility" added. Afterward, the "5Ds" model was further advanced to the "7Ds" model, with "demographic characteristics" and "demand management" involved.

However, despite the enormous research findings based on the application of the above-discussed "Ds" models, there are three critical issues correlated with walking and cycling studies. First, more often than not, the existing studies consider walking and cycling as similar or as an integral (i.e., active travel), and limited studies examine and compare the impacts of the built environment on walking and cycling simultaneously. As revealed by increasing studies, walking and cycling are essentially distinguished transport modes [18–20]. Hence, distinguishing between the built environment correlates of walking and cycling can enlighten the practitioners and policy-makers and help provide targeted interventions. Second, the existing findings of the effects of the built environment on walking and cycling are mixed, and inconsistencies and discrepancies exist, especially between different contexts (which we will further elaborate on in the literature review section). Third, most of the studies are in the western context. The transferability or generalizability of experiences and findings derived from developed countries in the West remains highly questionable, given the major contextual differences between developed and developing countries. For example, in the western context, especially North America, walking and cycling are more frequently considered physical activity and only take up marginal share rates of transportation modes. However, in the developing world such as China, despite the ever-increasing prevalence of private motor vehicles, walking and cycling are still dominant travel modes. The differences between the roles that walking and cycling play in people's daily lives in developed and developing contexts may lead to people's different elasticity and response to the built environment and thus distinct associations between the built environment and walking and cycling.

Therefore, taking Xiamen, China, as a case and employing its large-scale travel behavior survey, this study examines the associations between the built environment and the propensity of walking and cycling (defined as using walking/cycling as the principal travel mode at least once during the survey day, and cycling includes the use of both man-powered and electric bicycles), respectively, and compares the associations wherever feasible. It contributes to existing literature by providing a typical and representative case in the developing context and by revealing the differences in the effects of the built environment on these two travel modes/physical activities.

The remainder of the article is organized as follows. Section 2 reviews the relevant literature. Section 3 describes the study area, data source, and statistical method. The modeling results are

presented, analyzed, and discussed in Section 4. Section 5 concludes the article with contributions and limitations.

2. Literature Review

2.1. Socioeconomic Correlates

Individual- and household-level socioeconomic and demographic characteristics such as age, education, and household income can influence people's walking and cycling propensity through affecting his/her transportation resources, time and money budget, physical fitness, etc. Arguably, there are generally two ways of dealing with socioeconomic variables in travel behavior studies [21]. First, researchers have divided the general population into different subgroups based on certain socioeconomic features (e.g., children and elderly, local and migrant, and female and male) and focused on one or more subgroup(s). The aim of doing so is to disclose the characteristics and correlates of a certain population subgroup or compare those between different subgroups. Such studies often derive diverse subgroup-specific findings on built environment-travel behavior associations, due to different travel demands, preferences, attitudes, and constraints of different population subgroups [22], which can usually moderate (exacerbate or attenuate) the effects of the built environment on travel behaviors. For example, through reviewing 17 academic articles, Adkins et al. [22] revealed that the impacts of the built environment on walking, cycling, and physical activity were stronger for the advantaged population groups (e.g., high-income and whites) than the socioeconomically disadvantaged. Similarly, Liu et al. [21] compared the trip frequency of four major transport modes of migrants and that of local residents and identified their built environment correlates. They corroborated that the built environment had less pronounced impacts on travel behaviors of migrants (who are socially and economically disadvantaged) and attributed the result to the process of "transportation assimilation" of migrants. A study conducted in the USA [23] found that the built environment surrounding both home and school (e.g., residential density) can significantly influence the probability of walking and cycling of adolescents. Whereas, also in the USA, the study by Nagel et al. [24] revealed that as for the elderly, the built environment had no effects on their propensity of walking whatsoever.

Second, more frequently, socioeconomic variables are incorporated in travel behavior studies and considered as control variables. In such studies, there are no specific population subgroups identified. More often than not, the incorporation of socioeconomic variables is for adjusting for confounders and singling out the effects of the built environment. Table 1 lists some representative studies belonging to this category.

2.2. Built Environment Correlates

Basically, studies on the associations between the built environment and walking and/or cycling can be divided into three categories, according to whether the study examines built environment correlates/determinants of walking and cycling separately or simultaneously, or considers them as an integral.

The first category examines the effects of the built environment on walking and cycling separately. There are numerous such studies in the last few decades. Handy et al. [25] confirmed that after controlling for attitudes and residential preferences, the built environment still had a significant impact on walking. Saelens and Handy [26] reviewed and summarized 13 reviews and 29 original empirical studies and pointed out that density, land use mix, and non-residential destination proximity had significantly positive effects on walking; and that such effects were more pronounced for transportation walking than recreational walking. A recent empirical study [27] corroborated such findings. As for cycling, Fraser and Lock [28] conducted a comprehensive review and identified the positive environmental factors such as population density and proximity of amenities, and negative factors such as long trip distance. Despite the fruitful research findings, such studies focusing on

walking and cycling separately failed to inform us whether and how the same built environment affects walking and cycling differently.

The second category combines walking and cycling into one as active travel, in consideration of the fact that the two modes share a variety of similarities, such as both being non-motorized transport modes and both involving moderate physical activity [29]. Freeman et al. [30] found that higher walkability (measured by density, land use mix, etc.) was significantly associated with a higher probability of active travel in New York. Similarly, the built environment was also found to be significantly associated with active travel in the UK, especially for obligatory/mandatory purposes [31], and in China, especially for the elderly [32]. However, it may be problematic to combine walking and cycling as one, which ignores the distinctions between features and correlates/determinants of the two transport modes. For example, in their international comparative study on the effects of the built environment on walking and cycling based on 17 cities in 12 countries, Kerr et al. [18] concluded that a highly walkable environment may not be suitable for transport cycling. Applying the stage-of-change approach, Biehl et al. [19] identified both shared and disparate determinants of walking and cycling. Moreover, based on the empirical study in the Netherlands, Ton et al. [20] identified different determinants for walking and cycling and stressed that walking and cycling should be considered two distinguished transport modes.

The third category examines the effects of the built environment on walking and cycling simultaneously and conducts comparisons wherever possible. Such studies are relatively limited in quantity. Table 1 presents a summarization of representatives of such studies, including their study areas, control variables (mainly socioeconomic characteristics), measurements they employed for “5Ds” variables, and most importantly, the associations between the “5Ds” variables and walking and cycling they revealed. Such studies are predominantly conducted in the developed world context, particularly the United States and Europe. Empirical examinations from the developing context are limited, for which the representatives include studies by Cervero et al. [33] in Colombia, Hino et al. [34] in Brazil, Munshi [35] in India, and Biehl et al. [19] and Liu et al. [21] in China. Moreover, inconsistencies exist between developed and developing contexts and between built environment correlates/determinants of walking and cycling. For example, most studies in the developed context found that density (typically measured by residential or employment density) has significant positive effects on walking and cycling [36–38], while a study in Colombia found no effects of density on either walking or cycling [33]. Hino et al. [34] found that land use mix had no significant impacts on walking but significant negative impacts on cycling, while Munshi [35] revealed that it was positively associated with walking and had no effects on cycling. Both studies derived different results from studies in the developed context (e.g., [39–41]). Discrepancies of associations between the built environment and walking and cycling exist in both developed and developing contexts. For instance, a Netherlands study [42] confirmed significant positive effects of density on walking but its negative effects on cycling. Liu et al. [21] found that in Xiamen, China, distance to the closest commercial center was significantly negatively related to walking and yet positively related with cycling. Such discrepancies between the built environment correlates of walking and cycling corroborate that walking and cycling are essentially distinguished transport modes.

All in all, researchers have predominantly identified the built environment correlates/determinants of walking and cycling separately or considered the two modes as one, and studies elucidating and comparing the impacts of the built environment on walking and cycling are relatively limited. On the other hand, among the studies focusing on walking and cycling simultaneously, inconsistencies still exist, both between developed and developing contexts and between the two modes themselves.

Table 1. Connections between the built environment and walking and cycling.

5Ds	Reference	Measurement	Associations ¹		Study Area	Control Variables
			W	C		
Density	Christiansen et al. [38]	Residential density	+ ²	+	14 cities in 10 countries	SES ³ , safety
	Boulangue et al. [36]	Dwelling density	+	+	Melbourne	SES
	Chen et al. [37]	Employment and population density	+	+	New York, USA	SES
	Kemperman and Timmermans [42]	Urbanization density	+	-	The Netherlands	SES, car ownership, driving license
	Cervero et al. [33]	Dwelling density	0	0	Bogota, Colombia	SES, car ownership, slope of land
Diversity	Van Dyck et al. [40]	Destinations within 20 min and accessibility	+	+	Baltimore and Seattle in the USA, Adelaide in Australia, and Ghent in Belgium	SES, body mass index
	Appleyard [39]	Land use mix	+	+	San Francisco Bay Area	SES
	Yu [41]	Entropy	+	0	Austin, USA	Poverty rate
	Lee et al. [43]	Entropy	+	0	Los Angeles	SES, travel purpose
	Hino et al. [34]	Entropy	0	-	Curitiba, Brazil	SES
	Munshi [35]	Dissimilarity index	+	0	Rajkot, India	SES
Design	Khan et al. [44]	3-or-4-way intersection density	+	+	Washington State	SES, travel purpose
	Adams et al. [45]	Street connectivity	0	+	Cardiff, Kenilworth and Southampton, UK	SES, traffic safety
	Kaplan et al. [46]	Intersection density	0	-	Denmark	SES
	Marshall and Garrick [47]	Street connectivity	+	+	Los Angeles, USA	SES, health
	Cervero et al. [33]	Connectivity index	+	0	Bogota, Colombia	SES, car ownership, slope of land
Distance to transit	Boulangue et al. [36]	Distance to train station/bus stop	+	0	Melbourne, Australia	SES
	Yu [41]	Transit stop density	0	+	Austin, USA	Poverty rate
	Bueno et al. [48]	Transit accessibility	+	0	New York & New Jersey, USA	SES
	Kaplan et al. [46]	Transit stop within 1 km	+	-	Denmark	SES
	Biehl et al. [19]	Bus stops within 300 m buffer	0	0	Beijing, China	SES, travel purpose
Destination accessibility	Charreire et al. [49]	Proximity to destinations	+	+	Paris, France	SES
	Kärmeniemi et al. [50]	Accessibility to destinations	+	+	Multiple study areas (review)	
	Adams et al. [45]	Availability of local amenities	+	0	Cardiff, Kenilworth, and Southampton, UK	SES, traffic safety
	Ewing et al. [51]	Employment accessibility	+	+	15 USA regions	SES
	Liu et al. [21]	Distance to the closest commercial center	-	+	Xiamen, China	SES

Note: ¹: W indicates walking, C indicates cycling; ²: “+” represents the significant positive association, “-” represents the significant negative association, “0” means no significant associations found; ³: SES is short for socioeconomic status characteristics, often including some or all of the following variables: age, gender, education, occupation, personal or household income, family structure, residence tenure, etc. Except for the title, contexts in bold show the studies from the developing world context.

3. Data and Methodology

3.1. Study Area

Enticingly known as the “Garden on the Sea (haishang huayuan),” Xiamen is a famous tourism city situated in Southeast China. As of 2018, the city covered an area of 1700.61 km² and accommodated a population of 4.11 million. The Kinmen Islands lie less than 10 km away. Xiamen is a representative second-tier city in China and has undergone rapid economic development and urban expansion in the last four decades [52,53]. The city consists of six administrative districts: Siming, Huli, Tong’an, Xiang’an, Jimei, and Haicang. Among them, Siming and Huli districts constitute Xiamen Island, which is the most developed and urbanized area of the city. The other four districts are situated on the mainland. Xiamen is renowned not only for its outstanding livability, rapid economic development, and advanced tourism industry but also for its high walkability. Hence, Xiamen is appropriate to act as our study area.

3.2. Data

We employed three kinds of data in this study, including travel behavior data, individual- and household-level socio-demographic data, and built environment data.

The travel behavior data and socio-demographic data were extracted from the 2015 Xiamen Travel Survey (XTS2015). The Xiamen Travel Survey is a long-run survey, which is carried out every five years. The XTS2015 is the latest large-scale survey on travel behaviors of Xiamen residents. In total, there were 96,010 respondents from 40,201 families that were randomly selected. The sampling rate was as high as 3.05%, which exceeded most of the surveys completed in other Chinese cities, including Hong Kong (1.5%, see [54]), Beijing (<1%, see [55]), Nanjing (<0.1%, see [56]), and Zhongshan (2%, see [57]). The XTS2015 collects the residents’ socio-demographic characteristics (e.g., age, education, and automobile availability) and details of all the trips they made during the 24 h survey period (e.g., trip duration, origin, destination, and the main travel mode), etc.

The built environment data incorporated land use, urban design, and transportation infrastructures of Xiamen and were obtained from the Xiamen Institute of Urban Planning and Design and Xiamen University. We further processed the built environment data with ArcGIS 10.6 based on the “5Ds” model.

3.3. Methodology

3.3.1. Variables

We built two groups of models in this study for walking and cycling, respectively. For each group of models, the dependent variable was a dummy variable indicating the respondent taking at least one ($Y = 1$) walking/cycling trip or not ($Y = 0$).

The independent variables comprised individual- and household-level socioeconomic variables and built environment variables. At the individual level, age, gender, hukou (i.e., household registration system in China) status, education background, and occupation category were included, while household-level variables incorporated residence size and type, household size, and motor vehicle availability. We selected built environment variables based on the “5Ds” model [58], including population/job density, land use mix, intersection density, distance to the closest commercial center, and bus stop density. The details of calculating the built environment variables are presented in Table 2.

Table 2. “5Ds” built environment variables selected and their formulas.

Variable	Description	Formula
Population density	The variable represents the amount of all residents within a unit of area.	$\frac{\text{Count of all residents within a community}}{\text{Area of the community (ha)}}$
Job density	The variable represents the amount of all jobs within a unit of area.	$\frac{\text{Count of job positions within a community}}{\text{Area of the community (ha)}}$
Land use mix	The variable represents the diversity of the urban function. We identified nine major types of urban functions: leisure and entertainment, accommodation, medical service, government office, traveling, education and research, commerce, financial service, and restaurant.	$LUM = \frac{(-1)(\sum_{i=1}^n p_i \ln(p_i))}{\ln(n)};$ $n=9, p_i = \frac{\text{Count of } i\text{th kind of POI}}{\text{Count of all 9 kinds of POI}}$
Intersection density	The variable represents the amount of 3-or-more-way intersections within a unit of area.	$\frac{\text{Count of all intersections within a community}}{\text{Area of the community (ha)}}$
Distance to commercial center	The three most important commercial centers were selected (including Zhongshan Road, Lianban, and SM Plaza). Distances from the centroids of the communities to these centers were then measured in ArcGIS, and the shortest distance was assigned to this variable.	Formula: null; Unit: km.
Bus stop density	The variable represents the number of bus stops within a unit of area.	$\frac{\text{Count of all bus stops within a community}}{\text{Area of the community (ha)}}$

Table 3 presents a descriptive summarization of the socio-demographic variables of the respondents and some variables characterizing the built environment of the communities those respondents reside in. As can be seen, most of the respondents are relatively young, with a mean age of 38.8 and more than two-thirds of them are below 45 years old, and they are evenly distributed in gender. More than two-thirds of the respondents are local residents with a Xiamen hukou, and those owning residences by themselves are in almost the same proportion. Additionally, they have a relatively low education level, with only 18.6% having an undergraduate degree or above, and most of them (85%) having blue- or white-collar jobs. Additionally, 43 percent of the respondents own at least one motor vehicle.

Table 3. Statistical descriptions of socio-demographic and built environment variables.

Variable	Percentage/Mean (Std. Dev.)
Age (%)	
Below 17	10
18–44	57
45–64	24.7
Above 65	8.3
Gender (%)	
Male	49.7
Female	50.3
Hukou	
Migrant	32.4
Native resident	67.6
Education (%)	
Middle School and below	40.1
High School to Junior College	41.2
Undergraduate and above	18.6
Occupation (%)	
Blue-collar	63.0
Student	10.9
White-collar	22.5
Official	3.6
Residence type (%)	
Self-owned	63.3
<i>Danwei</i> residence	1.5
Rental residence	35.2
Household size (%)	
1 to 3	34.8
4 to 7	63.1
8 to 10	2.0
Motor vehicle ownership (%)	
No	57.0
Yes	43.0
Age	38.82 (16.50)
Residence size (m²)	84.52 (45.28)
Population density (per ha)	232.16 (156.90)
Job density (per ha)	5.77 (7.00)
Land use mix (Entropy)	0.70 (0.08)
Intersection density (per ha)	0.25 (0.25)
Distance to commercial center (km)	3.16 (1.88)
Bus stop density (per ha)	0.82 (0.76)

Note: Percentage for categorical variables and mean value (standard deviation) for continuous variables.

3.3.2. Probit Model

The binomial (or dichotomous) nature of the dependent variable enables the application of the probit model, which is used to identify the associations between walking/cycling propensity and

the socio-demographic and built environment variables in this study. The probit model has been extensively used in a voluminous body of literature to analyze the condition where the dependent variable has only two outcomes and to measure the relationship between a binomial dependent variable and various independent variables by estimating probabilities using a probit link function. Compared to the logit model, an inherent advantage of the probit model is that it can handle random taste variation and allows any pattern of substitutions. The model takes the following form:

$$P_i = F\left(\sum_k \beta^k X_i^k\right) \quad (1)$$

where $P_i(Y = 1)$ is the probability of respondent i taking at least one walking or cycling trip during the survey day, X_i^k is the k th variable of respondent i , and $F(\cdot)$ is the cumulative distribution function of the standard normal distribution.

4. Results and Discussions

A total of four probit models were estimated using the maximum likelihood method. Models 1 and 2 examined walking propensity, while Models 3 and 4 investigated the cycling propensity. Models 1 and 3 were basic models with only individual-level (e.g., age and gender) and family-level socio-demographic variables (e.g., residence size), while Models 2 and 4 were enhanced by adding the built environment variables. Fitting basic and enhanced models can highlight the role played by built environment variables. The enhanced models outperform the basic models, as indicated by AIC (i.e., Akaike information criterion) and log-likelihood values. By comparing the basic and enhanced models, we can clearly observe the effects of built environment variables on walking and cycling. Table 4 displays the modeling outcomes.

We found that associations between socio-demographic variables and walking propensity remained steady in the aspects of direction and magnitude by comparing Models 1 and 2. This finding provides some evidence for the robustness of our models. Specifically, age, being female, and being a student (with blue-collars as the reference) are significantly positively associated with walking propensity, while being natives (with migrant as the reference), high education level, being white-collars and officials, and motor vehicle availability have adverse effects. In other words, elders, female, migrants, students, residents with a lower education level, and those without motor vehicles are more likely to walk. Moreover, after controlling for the abovementioned socio-demographic variables, there are statistically significant associations between walk propensity and land use mix, intersection density, bus stop density, and distance to commercial center. This meets our expectations and indicates that residents in communities with high functional diversity, street connectivity, and decent public transport and commercial center accessibility are more likely to walk. However, population and job densities are not significant at the 10% level.

Results of Models 3 and 4 imply that rental residences and household size are positively associated with cycling propensity, while age, being female, being natives, education level, being white-collars and officials (with blue-collars as the reference), and owning at least one motor vehicle are negatively correlated with cycling propensity. Furthermore, after controlling for the individual-level and family-level socioeconomic variables, cycling propensity is positively connected to distance to the closest commercial center but negatively related to job density, intersection density, and bus stop density. This result implies that residents living in communities with good job accessibility, high street connectivity, and decent accessibility to public transport and commercial centers are less likely to cycle. Additionally, population density and land use mix turn out to be not significant at the 10% level, and they seem too weak to affect the cycling propensity in the context.

Table 4. Results of basic and enhanced probit models.

Variables	Walking		Cycling	
	Model 1	Model 2	Model 3	Model 4
	Coef. (<i>t</i> -Statistic)	Coef. (<i>t</i> -Statistic)	Coef. (<i>t</i> -Statistic)	Coef. (<i>t</i> -Statistic)
Age	0.016 ***(31.87)	0.015 ***(30.51)	−0.008 ***(−11.03)	−0.007 ***(−9.08)
Gender				
Male	Ref.	Ref.	Ref.	Ref.
Female	0.367 ***(29.69)	0.363 ***(29.32)	−0.238 ***(−14.11)	−0.231 ***(−13.59)
Hukou				
Migrant	Ref.	Ref.	Ref.	Ref.
Native resident	−0.062 ***(−3.37)	−0.086 ***(−4.60)	−0.122 ***(−4.88)	−0.084 ***(−3.30)
Education				
Middle School and below	Ref.	Ref.	Ref.	Ref.
High School to Junior College	−0.327 ***(−22.91)	−0.342 ***(−23.77)	−0.200 ***(−10.36)	−0.170 ***(−8.72)
Undergraduate and above	−0.482 ***(−23.18)	−0.505 ***(−24.13)	−0.547 ***(−17.59)	−0.494 ***(−15.73)
Occupation				
Blue-collar	Ref.	Ref.	Ref.	Ref.
Student	0.610 ***(23.13)	0.583 ***(22.00)	−0.376 ***(−10.20)	−0.314 ***(−8.47)
White-collar	−0.267 ***(−15.22)	−0.268 ***(−15.24)	−0.067 *(−2.90)	−0.066 *(−2.80)
Official	−0.289 ***(−7.54)	−0.300 *(−7.82)	−0.243 ***(−4.24)	−0.218 ***(−3.78)
Residence size (m²)	−0.000(−0.92)	−0.000(0.11)	0.001 *(3.06)	0.001(1.51)
Residence type				
Self-owned	Ref.	Ref.	Ref.	Ref.
Danwei residence	0.051(1.01)	0.035(0.70)	0.034(0.48)	0.061(0.86)
Rental residence	−0.027(−1.43)	−0.028(−1.45)	0.087 *(3.40)	0.081 *(3.09)
Household size				
1 to 3	Ref.	Ref.	Ref.	Ref.
4 to 7	−0.002(−0.19)	−0.006(−0.50)	0.123 ***(6.53)	0.131 ***(6.91)
8 to 10	−0.001(−0.02)	−0.008(−0.19)	0.199 ***(3.29)	0.216 ***(3.55)
Motor vehicle availability				
No motor vehicle	Ref.	Ref.	Ref.	Ref.
At least one motor vehicle	−0.173 ***(−12.48)	−0.168 ***(−12.04)	−0.321 ***(−16.41)	−0.334 ***(−16.99)
Population density (per km²)		0.002(0.40)		−0.007(−1.07)
Job density (per ha)		0.001(1.00)		−0.004 *(−2.20)
Land use mix (Entropy)		0.137 *(1.83)		0.035(0.34)
Intersection density (per ha)		0.082 *(3.08)		−0.096 *(−2.30)
Distance to commercial center (km)		−0.023 ***(−5.94)		0.052 ***(10.11)
Bus stop density (per ha)		0.027 *(3.02)		−0.046 ***(−13.59)
AIC	57214.6	57109.68	27615.43	27341.2
Log-likelihood	−28592.3	−28533.839	−13792.716	−13649.602

Note: Coef. = coefficient; Ref. = Reference. * for $p < 0.1$, ** for $p < 0.05$, *** for $p < 0.001$.

Results of Model 2 reveal the significant positive impacts of land use mix (diversity), intersection density (design), and bus stop density (distance to transit) as well as negative impacts of distance to the closest commercial center (destination accessibility) on residents' walking in Xiamen, which coincides with findings of a wide variety of previous studies (e.g., [17,59–61]). This implies that even in China, of which the cities are well-known for high walkability, some measures can still be undertaken to intervene in the development of the built environment to enhance residents' walking propensity. However, population density and job density are found to have no significant effects on residents' walking. That is, they appear to be too weak to impact residents' walking behaviors. This outcome substantially differs from the results of other studies, especially those carried out in the West (e.g., [37,62]). Our finding evidently echoes varying effects of the built environment on travel behavior, as pointed out by certain recent studies (e.g., [63]). This may be because Xiamen Island is a highly developed area with an enormous population and abundant employment opportunities, and its population and job densities are much higher than those of western cities with decentralization.

As revealed by Model 4, in Xiamen, residents' cycling propensity is negatively impacted by job density, intersection density, bus stop density, and commercial center accessibility, but it is not significantly related to population density or land use mix. While the negative effects of bus stop density on cycling propensity agrees with what some studies reveal (e.g., [64]), others obtained correlations that largely differ from the findings of a few previous studies. For example, Winters et al. [65] found that the cycling behavior of North Americans is positively associated with population density, intersection density, and greater land use mix. In North America, cycling is an alternative travel mode to driving, and most people choose cycling as a way to escape from sedentary behavior, physical inactivity, and other health-harming factors associated with driving [66]. In other words, cyclists in western contexts (e.g., North America) tend to be "choice cyclists" (with a similar definition to choice rider [67]). However, in China, those cyclists who choose cycling as the principal travel mode are usually "captive cyclists" (with a similar definition to captive rider [67]). They choose cycling because, on the one hand, they are suffering from poor job accessibility (lower job density and longer distance to commercial centers) and poor transit accessibility (lower bus stop density), and on the other hand, they cannot afford a private motor vehicle. Hence, cycling, which is much cheaper than private driving but more efficient than walking, is chosen. Additionally, in Xiamen, suburban areas have undergone a massive development of infrastructure in recent years. Thus, bicycle lanes, which can influence the safety and comfort of cycling, may be denser in suburban areas than in central areas. These can explain the unusual associations between the built environment and Xiamen residents' cycling.

Comparing Models 2 and 4, we can easily find that the built environment has distinct influences on walking and cycling. Specifically, job density has negative impacts on cycling but no impacts on walking, while land use mix has positive effects on walking but no effects on cycling. Influences of intersection density, distance to commercial center, and transit stop density on walking have opposite effects to those on cycling. Such results indicate that walking and cycling, at least in our context, are distinguished transport modes, coinciding with what Kerr et al. [18] and Ton et al. [20] concluded.

The confirmed differentiations between built environment effects on walking and cycling have rich implications for practices and policy-making. The conventional and ongoing interventions, informed by, to a certain extent, misleading previous findings, have considered walking and cycling as similar activities/modes. As ample evidence implies, practitioners and policy-makers should not take it for granted that providing a built environment that facilitates or encourages walking will promote cycling at the same time. Instead, they should reconsider their intervention measures and provide tailored policies for such essentially distinguished transport modes.

5. Conclusions

Bearing in mind that walking and cycling have multiple social, environmental, and health-related benefits and they may be essentially distinguished, we elaborated on the built environment correlates of walking and cycling. Employing Xiamen, China, as the case study and utilizing its large-scale travel

behavior survey in 2015, we scrutinized the effects of the built environment on the two transport modes simultaneously and conducted comparisons wherever feasible. We obtained the following empirical findings: (1) built environment effects on walking differ with those on cycling in terms of direction and magnitude, implying that walking and cycling are indeed essentially distinguished modes; (2) positive built environment factors for walking propensity include land use mix, intersection density, and transit stop density, while the distance to the closest commercial center is the negative factor; (3) job density, intersection density, and transit stop density are negatively associated with cycling propensity, while the distance to commercial center is positively correlated with it.

This study has multiple strengths. First, by setting basic and enhanced models simultaneously and comparing their gaps in goodness-of-fit, we corroborated the significant effects of the built environment on walking and cycling in Xiamen, a second-tier middle-sized city, which can represent a large number of cities in the developing world lacking academic attention. Second, we identified the positive and negative factors of walking and cycling, respectively, and highlighted the pronounced differences between them. Third, by stressing that walking and cycling are essentially distinguished transport modes, we call for practitioners and policy-makers to re-contemplate their decision process and put forward tailored interventions.

This study was limited in the following aspects. First, some frequently utilized variables, such as personal or household income, are not incorporated in the analysis because of data unavailability. Fortunately, variables such as occupation category and residence size can to some extent imply the socioeconomic status of respondents and thus can partly substitute for the missing variables (e.g., income). In addition, future research should try to quantify the availability or quality of bicycle lanes and include this variable in the analysis, which may influence the comfort and safety of cycling. Second, attitudinal and preferential characteristics of residents are missing from the data source. Although certain studies disclosed the significant role of the built environment on walking and/or cycling after controlling for self-selection [25], future studies are still needed to control for residents' attitudes and preferences to avoid under- or over-estimation and/or delve into the residential self-selection issue. Third, the data this study utilized are cross-sectional, and hence this study can only derive correlation instead of causality. Future studies can employ longitudinal or quasi-experimental research designs to explore the causal effects of the built environment on walking and cycling, which would offer more persuasive conclusions. Last, in line with many "saint" studies (e.g., [16,17,25]), this study jointly used trip data and built environment data and found some associations between the built environment and travel behavior (more specifically, walking and cycling propensity). However, hybrid methods that combine both quantitative (e.g., questionnaire survey) and qualitative methods (e.g., structured or semi-structured interview) (see [68]) are needed to better clarify or delve deeper into the mechanism through which the built environment impacts travel behavior. In the same way, more sophisticated statistical methods are indispensable to scrutinize the complex relationship between the two.

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