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Built-environment determinants of active travel behavior of older adults in Xiamen, China

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Abstract: Arguably, active travel (AT) is important for active aging. Using data from the Travel Survey of Xiamen Residents 2015 and geodata, this study develops a set of multilevel regression models to scrutinize the effect of the neighborhood-level built environment on three AT outcomes (daily AT propensity, frequency, and time) of older adults aged 60 years or above in Xiamen, China. Its results show that the built environment truly shapes the AT behavior of older adults. Land use mix, intersection density, and bus route density have a positive association with AT, whereas the distance to the commercial center has a negative association. Population density has no significant association with the AT behavior of older adults. Land use mix is the most significant built-environment variable. Various robustness checks confirm the plausibility of the key findings. This study provides practical implications for China's national strategy of "actively addressing population aging."

1. INTRODUCTION

Population aging has become a global issue (Prettner, 2013). China, as the largest developing country, is also confronted with this issue. According to the Seventh National Census of China, in 2020, the number of Chinese individuals aged 60 years or above was 264 million, accounting for 18.7% of the total population; and the number of individuals aged 65 years or above was 191 million, constituting 13.5% of the total, meaning that China is approaching the international threshold of deep aging (⩾ 14%). The number of Chinese individuals aged 60 years or above is predicted to increase by approximately 10 million per year in the following five years. Inevitably, population aging triggers considerable urban development challenges in most, if not all, aspects of society (Jing, Zhi et al., 2021; Yang, L., Ao et

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al., 2021). Taking effective measures to cope with population aging actively is urgent for the Chinese government. In October 2020, the Fifth Plenary Session of the 19th Communist Party of China Central Committee proposed the national strategy of "actively addressing population aging" (*jijiyingduirenkoulaolinghua*). "Actively addressing population aging" was also pointed out in the Outline of the Fourteenth Five-year Plan of China.

Being physically active and "full of go" in old age has numerous benefits for keeping the body in good health, such as decreasing the incidence of hypertension, obesity, strokes, and certain types of cancers (Jackson, Pialoux et al., 2016; Rudnicka, Napierała et al., 2020). For example, walking or cycling can improve the health of older adults (Mendes de Leon, Cagney et al., 2009; Van Holle, Van Cauwenberg et al., 2014).

Active aging, which is conceptualized as "the process ofoptimizing opportunities for health,participation and security in orderto enhance quality of life as peopleage" by the World Health Organization, has long been widely advocated. Active travel (AT), which is defined as travel by non-motorized means (e.g., walking, cycling, and non-electric or human-powered scooters), is closely connected and of considerable importance to activity participation and independence of older adults and thus indispensable for active aging (Cheng, Chen et al., 2019).In addition, AT is a kind of physical activity and thus can enhance the health of older adults (Pucher, Buehler et al., 2010).Furthermore, compared with physical activity participation such as tai chi (*taijiquan*), square dancing, and mountaineering, AT is rarely impeded by people's emotional-level barriers (e.g., lack of self-confidence, social fear, and lack of interest) (Franco, Tong et al., 2015). Therefore, AT seems to be a practical and feasible method for promoting the physical activity and health of older adults (Vancampfort, Smith et al., 2018).

In addition to its widely recognized and highly regarded health benefits, AT has various social and economic advantages (Heath, Parra et al., 2012). For instance, AT can decrease the use of automobiles and thus help reduce motor exhaust/greenhouse gas emissions and noise pollution, curtail traffic congestion and automobile accidents, and improve air quality (Jarrett, Woodcock et al., 2012; Sallis, Spoon et al., 2015), thereby leading to green, clean, and quiet urban living environments. Notably, compared with motorized travel, AT-induced physical activity gives travelers a higher sense of comfort and satisfaction (De Vos, Mokhtarian et al., 2016). The wonderful feelings obtained from AT can improve quality of life and well-being ·(Lättman, Olsson et al., 2018). Additionally, walking and cycling, as the most popular AT modes, offer positive dividends to society (Hellberg, Guaralda et al., 2021; Liu, Q., Homma et al., 2020). They are estimated to save the National Health Service roughly UK £17 billion (2010 price) by reducing the incidence of type 2 diabetes, dementia, and cancers attributed to increased physical activity (Jarrett, Woodcock et al., 2012). Urbanwalkability and bikeability are commonly selected as indicators of a healthy, sustainable, and economically viable city.

Although AT has a positive and significant relationship with healthy and active aging and plays an imperative role in promoting the physical and mental health of older adults, the AT activity of older adults in most countries remains low (Berkemeyer, Wijndaele et al., 2016). Hence, analyzing the determinants of the AT behavior of older adults is necessary. Such determinants are mainly categorized as socio-demographic characteristics and the built environment (Chen, S., Bao et al., 2022a; Chen, S., Wang et al., 2022b; Lee, 2020; Yang, H., Zhang et al., 2020). The "3Ds"/"5Ds"/"7Ds" model is the most popular assessment method for the built environment, which categorizes built environment attributes into three/five/seven dimensions (Cervero and Kockelman, 1997; Ewing and Cervero, 2010). Therefore, identifying the built-environment determinants of the AT behavior of older adults is the primary step in community planning to prompt the AT behavior of older adults and should be our focus. This act is crucial in the era of increasing societal attention to population aging. Fortunately, this issue recently caught the attention of scholars and professionals in urban and transport planning, geography, public health, and so on.

Older adults with adequate AT activities can actively participate in social, economic, and cultural activities, which play an extraordinary role in the establishment of harmonious social relations and the advancement of the quality of life and well-being. Therefore, based on the identification of the built-environment factors affecting older adults' AT behavior, we aim to enlighten decision-makers on how to build walking-/cycling-friendly communities or cities and respond to the national strategy of "actively addressing population aging." In light of the above discussion, we use a sample of 11,732 individuals aged ≥ 60 years from the Travel Survey of Xiamen Residents 2015 (TSXR 2015, *2015 nianjuminchuxingdiaocha*) and establish a multilevel binary logit model, multilevel negative binomial model, and multilevel linear model to identify the correlates of the AT behavior (daily AT propensity, frequency, and time) of older adults in Xiamen, China. To our knowledge, very few studies simultaneously explored the correlation between the AT propensity, frequency, and time of older adults and the built environment in China and beyond. This study serves as a reference for relevant research, especially studies in similar contexts. It can help urban planners/designers, policymakers, and government officials make effective plans, policies, and decisions. The contributions of this study are threefold: (1) modeling various AT outcomes of older adults in a Chinese city; (2) comparing the effects of the built environment on correlated AT outcomes; and (3) unraveling that most built-environment attributes have similar, but not identical, relationships with correlated AT outcomes.

The remainder of this study proceeds as follows. Section 2 introduces the data and the methodology of the multilevel binary logit model, multilevel negative binomial model, and multilevel linear model. Section 3 presents the modeling results and reveals the key built-environment determinants. Section 4 discusses the results. Section 5 concludes the paper.

2. DATA AND METHODOLOGY

2.1 Data

We choose Xiamen, China, as the study area. Xiamen is a bustling city on the southeast coast of China. It covered an area of 1700.61 km^2 and was home to 5.16 million permanent residents in 2020. Commonly known as the "garden on the sea," this city is one of the most livable cities in China. Moreover, Xiamen is a famous and attractive tourism city not only because of its scenery (e.g., tree-lined beaches and Victorian-style buildings) but also its culture (e.g., former treaty port enclave and frontline in the Chinese Civil War). Xiamen Island is the city's most developed and urbanized area.

We extracted travel behavior and socio-demographic data from a large-scale officially administered survey, namely TSXR 2015. TSXR 2015 is cooperatively organized by Xiamen Transport Bureau, Xiamen Urban Planning and Design Institute, and China Academy of Urban Planning & Design. TSXR 2015 provides comprehensive information about the trips taken by randomly sampled Xiamen respondents on the last day, including trip origin and destination, departure and arrival time, and trip mode.The data has been used in plenty of transport research (Liu, J., Wang et al., 2021; Liu, J., Xiao et al., 2021a).

A total of 120,603 questionnaires were distributed, and 96,010 questionnaires were retrieved. The effective response was 93,861, with a recovery rate of 97.8%. The sampling rate was 3.1%, indicating that TSXR 2015 data well represented the residents of Xiamen. In this study, we extracted the individuals aged 60 years and over from TSXR 2015 data for the following analysis. Furthermore, the built environment data is mainly collected from OpenStreetMap.

2.2 Variables

The summary of the dependent and independent variables is shown in *Table 1*. In this study, we focused on three dimensions of older adults' AT, namely ATpropensity, frequency, and time. In line with a large body of travel research, we used individual or household socio-demographic variables and built-environment variables as the two types of independent variables. Among them, individual or household socio-demographic variables served as the control variables because our interest is pointing out the built-environment variables affecting the AT behavior of older adults. Notably, the selection of individual or household socio-demographic variables followed the existing literature (Cheng, Chen et al., 2019), and only the variables in TSXR 2015 that are commonly thought to relate to AT outcomes were extracted. Moreover, the selection of built-environment variables followed the "5Ds" model (Ewing and Cervero, 2010).

As revealed in*Table 1*, the mean of the AT propensity, frequency, and time of older adults was 0.51, 1.29 (SD = 1.52), and 25.11 min (SD = 40.13 min), respectively. The gender distribution was balanced (50% for men and 50% for women). On average, the older people lived with two other family members. Additionally, few older respondents had a driver's license or family automobile. Moreover, we analyzed the older adults' AT destination distributions and found that older adults make very few non-discretionary trips, which agrees with our expectations. It is widely recognized in the literature that older adults make many optional (discretionary) trips (e.g., leisure and recreation) and few mandatory trips (e.g., commuting and going to school).

We took the AT propensity, frequency, and time of older adults in Xiamen as the dependent variables and singled out the effect of the built environment while controlling for the socio-demographic differences. After discarding the observations with incomplete information, we used the left 11,732 older adults living in 316 communities for multilevel modelling (Yang, L., Tang et al., 2022).

Table 1. Summary of the dependent and independent variables

Variable	**Description**	**Mean/ Percentage**	**SD**	**Level**
Dependent variables				
AT propensity	Indicator variable, which equals 1 for a person who has traveled by active modes in the past 24 hours and 0 otherwise	0.51	0.50	
AT frequency	Count variable	1.29	1.52	
AT time	Continuous variable (unit: min)	25.11	40.13	
Control variables: socio-demographics				
Male	Indicator variable, which equals 1 for males and 0 for females	0.50	0.50	Level 1
Age	(unit: year)	67.61	6.94	Level 1
Education	Ordered variable, which equals 1 for middle school and below, 2 for high school or vocational college, and 3 for undergraduate or above	2.06	1.17	Level 1
Household size	Number of family numbers	3.17	1.34	Level 1
Driver's license	Indicator variable, which equals 1 for a person with a driver's license and 0 otherwise	0.10	0.30	Level 1
Automobile	Indicator variable, which equals 1 for a person with an automobile and 0 otherwise	0.32	0.47	Level 1
Explanatory variables: built environment				
Population density	Population density within the neighborhood (unit: 100 people/ km^2)	186.80	167.99	Level 2
Land use mix	Entropy for land uses within the neighborhood.	0.68	0.15	Level 2
Intersection density	Density of street intersections within the neighborhood (unit: 1/ km^2)	0.22	0.25	Level 2
Distance to the commercial center	Distance to the nearest commercial center (unit: km)	9.06	9.31	Level 2
Bus route density	Density of bus routes within the neighborhood (unit: 1/ km^2)	0.68	0.74	Level 2
Sample size	11,732			

2.3 Method

Because older adult observations are nested in a community, the multilevel modeling approach, whichaccounts for the lack of independence within nests (groups) of observations, should be used (Yang, L., Liang et al., 2022). AT propensity is an indicator (binary, dichotomous) variable, so it is predicted by a multilevel binary logit model. AT frequency is a count variable, so it is predicted by a multilevel negative binomial model. AT time is a continuous variable, so it is predicted by a multilevel linear model. Establishing separate models for different dimensions of AT can help discern the socio-demographic and built-environment attributes that promote/hinder the AT of older adults and unveil sufficient details. Furthermore, socio-demographic variables are Level 1 variables, whereas built-environment attributes are Level 2 variables.

The multilevel binary logit model is used to relate the probability of engaging in AT on the last day to some independent variables. Its formula is as follows.

$$Pr\left(y_{ij} = 1|\boldsymbol{x}_{ij}, \boldsymbol{u}_j\right) = \frac{exp(\,\boldsymbol{x}_{ij}\boldsymbol{\beta} + \boldsymbol{u}_j)}{exp(\,\boldsymbol{x}_{ij}\boldsymbol{\beta} + \boldsymbol{u}_j) + 1} \quad (1)$$

where y_{ij} is the AT propensity of older adult *i* living in community *j* (binary variable); $\boldsymbol{u}_j$ captures the random effect of community *j*; $\boldsymbol{x}_{ij}$ is the independent variable of older adult *i* living in community *j*; $\boldsymbol{\beta}$ is the coefficient;$Pr\left(y_{ij} = 1|\boldsymbol{x}_{ij}, \boldsymbol{u}_j\right)$ is the probability of $y_{ij} = 1$ conditional on $\boldsymbol{x}_{ij}$ and $\boldsymbol{u}_j$.

The formula of the multilevel negative binomial model is as follows.

$$y_{ij}|\zeta_{ij} \sim \text{Poisson}(\zeta_{ij}) \quad (2)$$

$$\zeta_{ij}|\boldsymbol{u}_j \sim Gamma(\frac{1}{\alpha}, \frac{1}{1 + \alpha\mu_{ij}}) \quad (3)$$

$$\mu_{ij} = E(y_{ij}|\boldsymbol{x}_{ij}, \boldsymbol{u}_j) = exp(\,\boldsymbol{x}_{ij}\boldsymbol{\beta} + \boldsymbol{u}_j) \quad (4)$$

$$\boldsymbol{u}_j \sim N(\boldsymbol{0}, \boldsymbol{\Sigma}) \quad (5)$$

$$Pr\left(y_{ij} = y|\boldsymbol{u}_j\right) = \frac{\Gamma(y + \frac{1}{\alpha})}{\Gamma(y + 1)\Gamma(\frac{1}{\alpha})} \left(\frac{1}{1 + \alpha\mu_{ij}}\right)^{\frac{1}{\alpha}} \left(\frac{\alpha\mu_{ij}}{1 + \alpha\mu_{ij}}\right)^{y} \quad (6)$$

where y_{ij} is the AT frequency of older adult *i* living in community *j* (count variable); ζ_{ij} is the latent variable; $\boldsymbol{u}_j$ captures the random effect of community *j*; $\alpha$is a constant; $\boldsymbol{x}_{ij}$ is the independent variable of older adult *i* living in community *j*; $\boldsymbol{\beta}$ is the coefficient; $\boldsymbol{\Sigma}$ is the variance matrix; and$Pr\left(y_{ij} = y|\boldsymbol{u}_j\right)$is the probability of $y_{ij} = y$ conditional on $\boldsymbol{u}_j$.

The formula of the multilevel linear model is as follows.

$$y_{ij} = \alpha + \boldsymbol{x}_{ij}\boldsymbol{\beta} + \boldsymbol{u}_j \quad (7)$$

where y_{ij} is the AT time of older adult *i* living in community *j* (continuous variable); $\boldsymbol{u}_j$ captures the random effect of community *j*; $\alpha$is a constant; $\boldsymbol{x}_{ij}$ is the independent variable of older adult *i* living in community *j*; and$\boldsymbol{\beta}$ is the coefficient.

We tried to extend the two-level models to three-level models (Level 1: individual. Level 2: family. Level 3: community). The modeling estimates are more than similar to those from two-level models. Therefore, we only present two-level modeling results in this paper for brevity.

3. RESULTS

First, we determine the multicollinearity of the independent variables to prevent any flawed and misguided estimation before interpreting the regression models. The test results are revealed in *Figure 1*, which demonstrates the absence of multicollinearity.

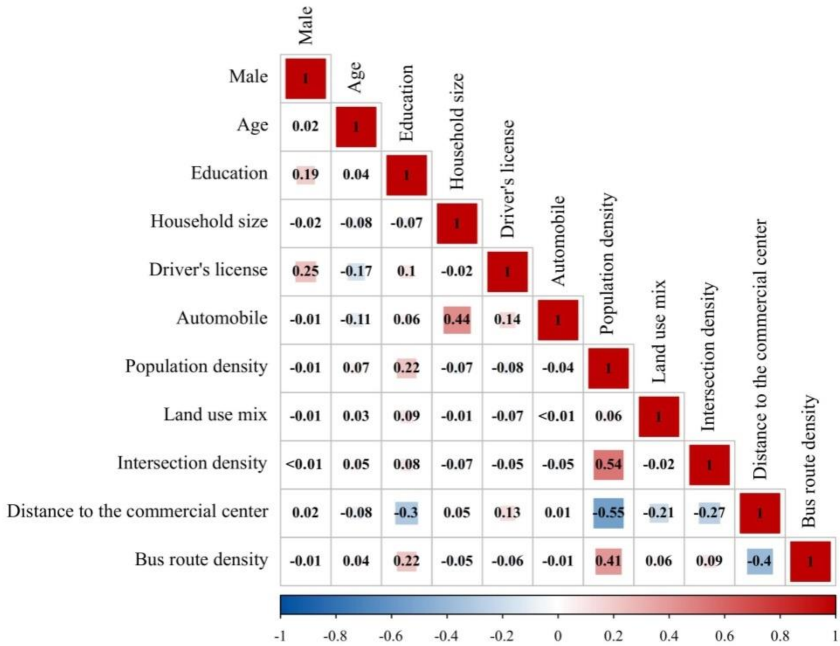

Figure 1. The correlation test results of the independent variables

As mentioned previously, we adopt three multilevel regression models, namely the multilevel binary logit model, multilevel negative binomial model, and multilevel linear model, to identify the effect of built environment attributes on three AT outcomes of older adults.We establish three equations separately. Specifically, Model 1 estimates the AT propensity, Model 2 estimates the AT frequency, and Model 3 estimates the AT time. We model the dependent variable as a function of socio-demographic variables and the built environment.

Table 2 reports the regression model results, which are provided by the popular statistical software package STATA (*version 16.0*).We compared the performance of the multilevel models and their corresponding one-level models and found that the multilevel models perform better. In addition, the AT behavior of older people is influenced by the built environment factors (neighborhood level) and individual-/family-level socio-demographic attributes.Older adults' socio-demographic characteristics perform consistently in the three models.

Many of the socio-demographic variables are crucial determinants of the three AT outcomes.Being young, living with few family members, and having no driver's license have positive correlations with the three AT outcomes of older adults. As expected, age is negatively related to AT outcomes because, inevitably, mobility declines with advancing age, resulting in a reduction in daily travel. Moreover, household size is adversely associated with AT outcomes. A possible explanation is that family members can share the housework (e.g., shopping and buying medicine) of older adults (Feng, Dijst et al., 2013), thereby decreasing their need to take utilitarian AT trips. Another explanation is that older people who live with others may be responsible for certain domestic activities, such as caring for their grandchildren. Such domestic activities bind them at home and impose considerable spatio-temporal constraints, thereby decreasing their chances of AT. Furthermore, having a driver's license can significantly decrease the AT outcomes, which corresponds to reality. Older adults possessing a driver's license prefer to travel by automobile over on foot or by bicycle.

Being female and owning an automobile are significantly related to AT propensity but not to AT frequency and time.Older women are more likely to engage in behavior than older men. This finding can be explained by the different family responsibilities between men and women in China (Feng, Dijst et al., 2013). Traditionally, women undertake more family maintenance tasks (e.g., daily shopping) and take more short-distance AT trips than men.Moreover, automobile availability plays a very weak role in determining older adults' AT behavior (insignificant in most of the models). This finding is congruent with the outcomes of existing studies in transit-dependent cities (Liu, J., Xiao et al., 2021a) but contradicts observations in numerous automobile-dominant cities (Rosenbloom, 2001).

This study focuses on scrutinizing the determinants of the built environment on the AT of older adults. Our results show that land use mix is significant at the 1% level in the three models, indicating that it is a crucial determinant of the AT outcomes. Moreover, land use mix has the highest *t*-statistic among the five built-environment variables, suggesting that it is the most significant built-environment variable. Areas with highly diverse land use are typically equipped with abundant urban services and supporting facilities (Cerin, Nathan et al., 2017; Winters, Brauer et al., 2010) and thus can easily satisfy people's travel demands (e.g., shopping, fitness, and social networking). Moreover, distance to the commercial center has a negative impact on the AT outcomes in the three models, which indicates that commercial facility accessibility plays an imperative role in determining older adults' AT, which is highly sensitive to trip distance. Long travel distances may pose considerable challenges to older adults' physical capacity (especially for older adults) and thus weaken the appeal and perception of commercial facilities. Moreover, bus accessibility is positively associated with the three AT outcomes, revealing that access to transit stimulates older people's active trips (Giles-Corti, Vernez-Moudon et al., 2016). This finding is in line with those of prior studies (Sugiyama and Thompson, 2008).

Intersection density is significantly connected to the AT propensity of older adults but not to the other two outcomes. Areas with a high intersection density are generally characterized by high street connectivity(Cerin, Nathan et al., 2017), which shortens travel distances and enhances destination accessibility. Therefore, older people in such areas are inclined to engage in AT behavior, which meets our expectations.

However, we do not observe a significant impact of population density on the AT, which differs from the evidence presented in the majority of previous studies (Cao, X. and Fan, 2012; Chen, C., Gong et al., 2008). A possible explanation is the non-linear impact of population density.

To confirm the plausibility of our key findings, we decided to conduct a few robustness checks and see how "core" coefficient estimates behave if modifying the regression specifications and re-estimate the regression models in the following four ways: (1) randomly taking 70%, 80%, or 90% out of the 11,732 observations (i.e., randomly dropping 30%, 20%, and 10%), (2) dropping observation falling outside three standard deviations of the average, (3) adjusting the age threshold from 60 to 65 years (redefining older adults) (Yang, L., Tang et al., 2022), and (4) testing alternative model specifications (multilevel Tobit model) because onemay argue that there are a large number of zero-valued observations for AT frequency and time (Lachapelle, Tanguay et al., 2018; Liu, J., Xiao et al., 2021a; Stewart, 2013).

Table 3 shows the robustness check outcomes, in which onlythe coefficient estimates of built-environment variables are reported and those of socio-demographic variables are omitted for brevity.The outcomes are congruent with those revealed in *Table 2*. This congruency provides strong evidence of structural validity and ensures the credibility of our key findings.

Table 2. Multilevel modeling results

Variable	**Model 1: AT propensity**		**Model 2: AT frequency**		**Model 3: AT time**	
	Coefficient	***z*-value**	**Coefficient**	***z*-value**	**Coefficient**	***z*-value**
Control variables: socio-demographics						
Male	-0.144**	-3.41	-0.037	-1.56	0.976	1.28
Age	-0.034**	-10.95	-0.021**	-11.39	-0.330**	-6.06
Education	-0.018	-0.89	-0.008	-0.69	0.102	0.28
Household size	-0.126**	-7.16	-0.028**	-2.79	-1.569**	-5.00
Driver's license	-0.845**	-11.26	-0.408**	-9.23	-11.137**	-8.55
Automobile	-0.124*	-2.47	-0.038	-1.33	0.371	0.41
Explanatory variables: built environment						
Population density	-0.001	-1.05	-0.001	-0.53	-0.009	-1.55
Land use mix	1.205**	4.67	0.759**	5.00	12.445**	3.53
Intersection density	0.504*	2.12	0.218	1.64	4.607	1.52
Distance to the commercial center	-0.018**	-2.78	-0.007*	-1.93	-0.272**	-3.25
Bus route density	0.171*	2.03	0.096*	2.01	1.788*	1.67
Constant	2.126	6.66	1.176	6.32	46.071	9.16
Random effects						
	Estimate	95% C.I.	Estimate	95% C.I.	Estimate	95% C.I.
Variance of level-2 errors	0.514	[0.427, 0.686]	0.173	[0.135, 0.222]	71.113	[53.740, 94.102]
Performance statistics						
Log-likelihood	-7,508.7		-18,014.5		-59,724.6	
AIC	15,043.3		36,057.0		119,476.7	
BIC	15,139.1		36,160.2		119,579.9	
Sample size	11,732					

Note: ** Significant at the 1% level. * Significant at the 10% level.C.I. means confidence interval.

Table 3. Robustness check results

Variable	**AT propensity**		**AT frequency**		**AT time**	
	Coefficient	***z*-value**	**Coefficient**	***z*-value**	**Coefficient**	***z*-value**
Robustness check 1: keeping 70% of the observations (N=8,212)						
Population density	0.000	-0.95	0.000	-0.39	-0.008	-1.31
Land use mix	1.044**	3.87	0.637**	4.00	11.725**	3.02
Intersection density	0.499*	2.09	0.234*	1.76	5.060	1.58
Distance to the commercial center	-0.016*	-2.54	-0.006*	-1.72	-0.246**	-2.76

Variable	AT propensity		AT frequency		AT time	
	Coefficient	***z*-value**	**Coefficient**	***z*-value**	**Coefficient**	***z*-value**
Bus route density	0.168*	2.01	0.094*	2.01	1.505	1.35
Robustness check 2: keeping 80% of the observations (N=9,386)						
Population density	0.000	-0.70	0.000	-0.46	-0.006	-0.98
Land use mix	1.298**	4.81	0.788**	5.02	12.832**	3.34
Intersection density	0.414*	1.73	0.178	1.34	3.873	1.21
Distance to the commercial center	-0.017*	-2.57	-0.007*	-1.99	-0.244**	-2.73
Bus route density	0.142*	1.67	0.083*	1.77	1.382	1.23
Robustness check 3: keeping 90% of the observations (N=10,559)						
Population density	0.000	-0.92	0.000	-0.49	-0.008	-1.36
Land use mix	1.292**	4.87	0.834**	5.32	13.374**	3.65
Intersection density	0.534*	2.22	0.253*	1.88	4.878	1.56
Distance to the commercial center	-0.016*	-2.46	-0.006	-1.58	-0.265**	-3.07
Bus route density	0.191*	2.26	0.112*	2.33	1.908*	1.74
Robustness check 4: dropping observations falling outside three standard deviations of the average (N=11,574)						
Population density	0.000	-1.03	0.000	-0.63	-0.007	-1.37
Land use mix	1.182**	4.56	0.737**	4.83	9.961**	3.55
Intersection density	0.514*	2.15	0.235*	1.75	4.922*	1.93
Distance to the commercial center	-0.017**	-2.69	-0.007*	-1.80	-0.222**	-3.22
Bus route density	0.173*	2.04	0.100*	2.08	1.966*	2.18
Robustness check 5: adjusting the age threshold (N=6,974)						
Population density	0.000	-0.51	0.000	0.07	-0.006	-0.88
Land use mix	1.087**	3.54	0.776**	4.25	12.387**	2.82
Intersection density	0.517*	1.98	0.222	1.51	4.254	1.18
Distance to the commercial center	-0.014*	-1.95	-0.004	-0.92	-0.197*	-1.94
Bus route density	0.165*	1.79	0.086	1.64	1.347	1.06
Robustness check 6: applying alternative model specifications, namely multilevel Tobit models, for AT frequency and time (N=11,732)						
Population density			0.000	-0.73	-0.019	-1.33
Land use mix			1.673**	4.97	39.163**	4.89
Intersection density			0.543*	1.76	13.525*	1.94
Distance to the commercial center			-0.019*	-2.29	-0.640**	-3.36
Bus route density			0.228*	2.07	5.019*	2.02

Note: ** Significant at the 1% level. * Significant at the 10% level. Full modeling results can be obtained from the corresponding author upon reasonable request.

4. DISCUSSION

We find that the built environment plays a vital role in promoting the AT of older adults, which aligns with our subjective judgment and the existing literature. Such a relationship survives a host of robustness checks. On the one hand, this outcome indicates that urban and transport planners can encourage older adults' AT behavior through built-environment interventions. On the other hand, it can remind urban planners of their obligation to use their professional skills carefully and correctly and consider the behavioral impact of the built environment before making or implementing urban/transport planning and policy(Yang, L., Liu et al., 2020; Yang, Y., Sasaki et al., 2022a; Yang, Y., Sasaki et al., 2022b). Meanwhile, as land use mix, intersection density, and bus route density reveal great importance for older adults' AT outcomes, urban planners should prioritize the improvement of the three built-environment attributes in their future planning. Among the three attributes, land use mix and bus route density are most significant (with the highest *z*-values). We believe that they should be paid substantial attention to in future age-friendly built-environment planning.

We observe that the farther the commercial facilities are, the more reluctant older adults are to engage in AT behavior. This outcome is confirmed by the finding that travel distance is an essential determinant of the AT behavior of older adults (Somenahalli and Shipton, 2013). Older people typically refrain from engaging in long-distance travel owing to their declining physical function. Hence, travel distance to essential destinations should be shortened to satisfy the travel needs and facilitate the AT of older adults. For example, urban planners, policymakers, and government officials should pay special attention to making age-friendly arrangements in combination with the spatial distribution of older adults in the blueprint planning of public service facilities, especially those strongly relevant to older adults (e.g., chess & card room, vegetable market, and fitness facility) (Feng, 2017).

Population density appears too weak to affect the AT of older adults in Xiamen. Nonetheless, we do not decisively deny the impact of population density on the AT of older adults. On the contrary, an optimal population density value range may exist to support older people's AT, which deserves further exploration in future research. Urban planners and policymakers should fully grasp the local situation and have keen insights into the complex relationship between the built environment and older adults' AT to clarify the range within which planning interventions can exert an influential role.

Enhancing the AT-related built environment can effectively promote physical activity. Older adults' quality of life can be improved by creating an age-friendly built environment (e.g., an enjoyable and pleasant street environment and convenient daily service facilities) to promote their physical activity and enrich their spiritual life (Cao, J. and Zhang, 2016). In other words, a high-quality built environment is necessary to promote physical activities and AT behaviour (Wu, Qin et al., 2018). In addition, walkable or cyclable communities can be developed for older adults. Walkable communities are of decisive importance because they not only fulfill residents' demand for reaching desired opportunities easily but also promote social interaction, foster weak social ties, and improve social trust, social capital, and community engagement (Leyden, 2003). For example, social interactions can be stimulated when older adults pick up their grandchildren after school. Hence, urban planners, policymakers, and government officials should address the declining physical function of older adults and improve accessibility to essential facilities (e.g., public service facilities, commercial facilities, and bus/metro stations). Notably, accessibility to essential facilities, which reflects the ease of reaching the facilities, is crucial for enhancing older adults' quality of life.

5. CONCLUSIONS

Population aging is currently a prominent social issue in China (Fang, Scheibye-Knudsen et al., 2015). Older adults' declining physical functions can lead to a reduction in their daily mobility (Cao, J. and Zhang, 2016), which can posegreat challenges to mobility and health. Given that the AT of older adults plays a critical role in promoting healthy and active aging, the AT of older adults should receive considerable attention, and an AT-supportive built environment should be constructed to help cities adapt to the aging society. Therefore, delving into the optimization of the neighborhood-level built environment is essential, of which the first step is to scrutinize the determinants of older adults' AT behavior.

In light of the above discussion, we integrate TSXR 2015 data and built environment data and establish three multilevel regression models to analyze the impact of built-environment factors on the AT behavior of older adults aged 60 years or above in Xiamen, China. The results of our study are as follows: (1) the built environment truly shapes the AT propensity, frequency, and time of older adults; (2) land use mix, intersection density, bus route density, and distance to the commercial center are determinants of the AT behavior; (3) population density has no significant association with AT behavior; and (4) land use mix is the most significant built-environment variable.

Our study is not without limitations. First, we used cross-sectional data for analysis, so we explored only the correlation between the built environment and AT of older adults. Therefore, time-series data or panel data should be adopted to examine the causal relationship and provide more substantial evidence to support the studied problem. Second, limited by TSXR 2015 data, we could not include other potential predictors of AT behavior. Hence, rigorous research design and investigation are necessary for future research to gather first-hand data on other aspects (e.g., attitude, weather/climate, and urban streetscape) (He, Zhao et al., 2021; Santosa, Nur et al., 2021; Yang, H., Zhang et al., 2020). Third, we did not consider non-linear relationships or the existence of the "threshold-value" effect (or threshold effect). The non-linear mechanism through which the built environment influences older adults' AT behavior can be attributed to the "peer effect" (one person's travel behavior can be influenced by that of the other) and "positive utility of travel" (travel may be desired for its own sake and thus cannot completely replaced because of its benefits). However, we overlooked this mechanism. Therefore, machine learning techniques, which were recently applied to travel behavior research, should be employed extensivelyin future research to scrutinize the non-linear relationship and threshold effect.

AUTHOR CONTRIBUTIONS

Conceptualization, Z.Z., Z.S. and L.Y.; methodology, L.Y.; software, Z.Z. and X.T.; investigation, Z.Z. and X.T.; resources, Z.S. and L.Y.; data curation, Z.Z. and X.T.; writing—original draft preparation, Z.Z., X.T. and L.Y.; writing—review and editing, Z.Z., Z.S., Z.S. and L.Y.; supervision, Z.S. and L.Y. All authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors declare that they have no conflicts of interest regarding the publication of the paper.

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