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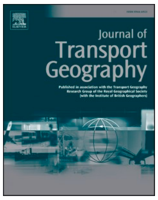

Associations between the streetscape built environment and walking to school among primary schoolchildren in Beijing, China

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ABSTRACT

Active travel to school is considered one of the channels for improving schoolchildren's daily physical activity level. The built environment is increasingly recognized as a factor likely to influence travel behavior. However, previous studies have primarily captured the macro-level built environment, usually assumed to be linearly associated with active travel to school. Using travel data from Beijing (China) enriched with street view imagery, this study employs generalized additive mixed models to examine non-linear associations between the odds of children's walking to school and streetscape built environmental attributes. Results show that schoolchildren, especially from higher-income families, are more likely to walk to school when they live in neighborhoods with lower street walkability, while higher street enclosure was associated with higher odds of walking for all respondents. A non-linear but overall negative relationship was observed between the odds of walking and street safety facilities. Stratified analyses showed that schoolchildren's household car ownership, educational attainment of parent(s), and household annual income modify the built environment-walking to school association. These findings contribute to a growing evidence base for child-friendly cities promoting active travel.

1. Introduction

Physical inactivity and a sedentary lifestyle are major health-risk factors for schoolchildren, causing overweight, obesity, and some chronic diseases. The World Health Organization (WHO) recommended that children and adolescents should engage in $\geq$60 min of moderate to vigorous physical activity daily to maintain good health (WHO, 2020). Globally, however, about 81% of adolescents did not meet this recommendation (WHO, 2018). In China, only 22.7% of primary schoolchildren met the recommendation in 2010 (Zhang et al., 2012).

Active travel (i.e., walking and cycling) to school (AST) is considered an important channel to increase energy expenditure (Fulton et al., 2005; Schoeppe et al., 2013). Previous studies have found that children and adolescents who reported a higher level of AST had higher physical activity levels (Pizarro et al., 2016; Chillón et al., 2010). Consequently, there is a great need to promote children's physical activity by encouraging them to travel to school actively.

The built environment (i.e., man-made places and spaces including buildings, parks and transportation systems) has increasingly been recognized as a contributor to children's AST with evidence primarily from western countries (Helbich et al., 2016; Vanwolleghem et al., 2016; Kaplan et al., 2016; Dias et al., 2019). The level of AST varies worldwide (Hallal et al., 2012). In China, 56.3% of schoolchildren and adolescents walk or cycle to school, while only 15% in Chile and 86% in Japan do so (Alliance, 2018). At present, only a few studies have focused on the built environment – AST relationship in Chinese cities (Sun et al., 2018; Lu et al., 2019a; Yang et al., 2020b). However, most of these studies have captured the built environment from a bird's eye view, such as the 5Ds (i.e., density, diversity, design, destination accessibility, and distance to transit), thereby failing to capture how people perceive their

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surroundings on the ground. Some have applied machine learning and street view data to measure the levels of street greenery within children's residential neighborhoods (Yang et al., 2020b; Łaszkiewicz and Sikorska, 2020), but other street environmental features, such as street safety and walkability, which have been proven to have significant effects on schoolchildren's travel behavior, have rarely been included (Sun et al., 2018; Christiansen et al., 2014; Buttazzoni et al., 2019).

Most existing studies assume that each built environment attribute has a linear relationship with AST (Christiansen et al., 2014, Buttazzoni et al., 2019). Nevertheless, this may not always be the case. Previous studies have suggested that there were different non-linear and threshold effects of different built environment attributes on physical activity (PA) for children. For example, low or excessive land-use mix, population density, and destination accessibility may have no effect on children's PA, and intersection density may have optimal value in the relationship with children's PA (Huang et al., 2021). However, little attention has been paid to possible non-linear relationships between the built environment and AST.

Previous studies have focused on the built environment in the vicinity of a child's residential address (Lu et al., 2019a; Sun et al., 2018). However, scant attention has been paid to the effects of built environment attributes on active travel within the school neighborhood which may be fundamentally different than the residential environment (Su et al., 2013).

To address these research gaps, this paper aims to investigate the non-linear relationship between the streetscape built environment and the odds of walking to school among primary schoolchildren in Beijing. This paper enriches the knowledge on the relationship between the built environment and transport-related walking for schoolchildren in three ways: (1) it makes a first attempt to assess associations between the streetscape environment and AST, (2) it makes a methodological contribution by unraveling possible non-linear relationships, and (3) it further examines how the streetscape built environment within the residential and the school context jointly related to AST.

2. Literature review

2.1. Built environment and travel behaviors for schoolchildren

The urban environment seems to play a role in how children travel (McMillan, 2016; Panter et al., 2008) as suggested in the behavioral model of school transportation (Mitra, 2013). Essential built environmental determinants for adults include population density (Dias et al., 2019; Dalton et al., 2011), design (Kaplan et al., 2016; Maki-Opas et al., 2014), distance to transit (Yang et al., 2020b; Page et al., 2010), land use mix diversity (Vanwolleghem et al., 2016; Rothman et al., 2015; Zang et al., 2019), and destination accessibility (Evenson et al., 2006; Moran et al., 2015), while it is less well understood how these factors are associated with children's AST.

Many previous studies have used the intersection density and street connectivity as measures to represent urban design (Ewing and Cervero, 2010; Cervero and Kockelman, 1997). For example, a Danish study used road connectivity as a part of walkability index and found that higher walkability of the school site was related with higher odds of AST (Christiansen et al., 2014). Similarly, a study in Perth (Australia) also found a positive relationship between street connectivity and walking to school (Giles-Corti et al., 2011). In contrast, a study in California reported a negative association between the street connectivity and walking to school among children (Su et al., 2013). However, pedestrians' activities may vary significantly due to the changes in the streetscape environments, indicating that the current widely used street design indicators may not capture fine-grained aspects of streetscape design (Yin and Wang, 2016). Therefore, alternative street design indicators have been proposed, who found children's active travel behavior was positively (though not always significantly) related to (the perception of) route safety (Christiansen et al., 2014), the presence and quality of sidewalk (Kim and Heinrich, 2016; Ghekiere et al., 2015; Verhoeven et al., 2017) and the presence of a window facing the street (McMillan, 2007), while higher traffic and a hilly terrain along the route were negatively related (Kaplan et al., 2016; Timperio et al., 2006). There were mixed results for the points of interest along the street, like on-street retail and snack shops (Kaplan et al., 2016; Yu and Zhu, 2013), and the presence of traffic lights and pedestrian crossings (Hume et al., 2009; Timperio et al., 2006).

Three methods are commonly used for measuring the above built-environment factors. First, questionnaires and audits from photographs are time-consuming and labor-intensive. Second, GIS data are widely available but are not suitable to represent what residents perceive on the ground. To overcome these issues, third, machine learning techniques are occasionally used to extract streetscape environmental features from street view images. A few studies conducted in Hong Kong showed that street greenery has a positive effect on an individual's travel propensity (Yang et al., 2020a) and odds of active traveling (Yang et al., 2020b; Lu et al., 2019b).

2.2. Non-linear relationship between the built environment and active travel behaviors

Most previous studies reassumed a linear relationship between the built environment and travel behaviors (Buttazzoni et al., 2019; Chillón et al., 2014), which may lead to estimation bias (van Wee and Handy, 2014). Recently, some machine learning methods (e.g., random forest, gradient boosting, decision trees), were used to examine non-linear relationships and threshold effects of the built environment and residents' travel behaviors, such as travel mode choice (Zhao et al., 2020; Hagenauer and Helbich, 2017), driving distance (Ding et al., 2018), and active travel behaviors (Liu et al., 2021a, 2021b; Tao et al., 2020). These studies have highlighted the importance of considering the non-linear shape of the relationship between the built environment and travel behaviors.

Although the machine learning approach provides a better understanding of the relationships between the travel behaviors and built environment effects, the disadvantages of using machine learning approaches to measure the built environment effects should not be overlooked. First, different from traditional regression methods, machine learning methods fail to report whether the variable was significant or not (Ding et al., 2021; Ding et al., 2018), which may challenge model interpretation. Second, some machine learning approaches have been recognized as a "black box" model whereby the underlying rationale behind the function is not understandable by humans, and the outcome cannot provide indications for its choice (Guidotti et al., 2018). Third, most studies with machine learning methods have not considered the spatial heterogeneity of different neighborhoods or traffic analysis zones and correlation structures caused by nested respondents' data, which may bias statistical inference (Chen et al., 2021). To overcome the above issues, studies have used generalized additive mixed models (GAMMs) to examine non-linear relationships between the built environment and travel behaviors (Kerr et al., 2016; Christiansen et al., 2016). Using GAMMs, one can not only explore threshold effect of built environment characteristics on travel behaviors but also provided a better understanding of variable significance. For 17 cities across 12 countries, it was found that perceived residential density had a non-linear relationship with the likelihood of transport-related walking more than 150 min per week and the odds of transport cycling (Kerr et al., 2016). In addition, a curvilinear relationship between the net resident density and odds of transport-related walking with an inversed U-shape with a threshold of 12,000 dwellings/km^2 was reported in a multi-country investigation (Christiansen et al., 2016).

Little attention has been paid to exploring the non-linear relationship between the built environment and AST (Panter et al., 2008). A study conducted in Hong Kong, a high-density and developed city, found that population density within 30,000–60,000 persons/km^2 was positively related to transport-related walking for youth (Lu et al., 2019a). This study, however, ignored the built environment around children's schools and did not consider the different effects of the built environment on the travel behavior of respondents with different socioeconomic statuses.

2.3. *Role of socioeconomic status on schoolchildren's travel behavior*

According to the social ecological model, besides the physical built environment, intrapersonal and interpersonal factors as well as organizational and policy factors play a role for children's physical activities and travel behaviors (Sallis and Owen, 2001; Lee and Moudon, 2004). In addition, the social ecological model also emphasized the exploration of the reciprocal interaction between factors at different levels, which was an effective way to understand and change people's behaviors (Sallis et al., 2006; Vanwolleghem et al., 2016; Mitra, 2013).

Some studies found that children and adolescents with a lower socioeconomic status (SES) were more likely to travel actively to school (Bringolf-Isler et al., 2008; Siiba, 2020; McDonald, 2008). One possible explanation might be that the families of children with a lower SES were more likely to face financial problems, which were barriers for schoolchildren to choose passive travel modes, such as the car and public transport (Dias et al., 2019; McDonald, 2008). A Swiss study found that the likelihood of commuting passively was 3.1 times higher among families with $\geq$2 cars than that of families without cars (Bringolf-Isler et al., 2008). A study in Ghana found that the odds of AST for primary children living in an owner-occupied residence was only about 57.46% of the active travel probability of other children (Siiba, 2020). Another study found that households with an annual income of more than $60,000 in the U.S. had a lower ratio of active transportation, which was only about 68% of those with an annual income of less than $30,000 (McDonald, 2008). Besides, children would have higher odds of AST if their parents believed in their ability to be independently mobile or to travel alone (Veitch et al., 2017).

In summary, most previous studies considered the built environment from a macro-level perspective and/or either focused on the built environment at home or at the school site. Both approaches likely lead to a bias in assessing the built environment–AST relationship. Finally, most earlier studies focused on developed countries, whereas evidence from developing countries is limited. However, there are differences not only in the built environment between developed and developing countries, but also in polices regarding schoolchildren. For example, the "attending nearby school" policy in China restricts primary school admission to schoolchildren living within a defined distance, which may lead to particularities of the schooling patterns of Chinese schoolchildren.

3. Materials and methods

3.1. *Study area and data*

This study focused on Beijing, the capital of China. The travel data were obtained from the Fourth Beijing Official Household Travel Survey (BOHTS) carried out by the Beijing Municipal Commission of Transport in 2010 (http://jtw.beijing.gov.cn/). Since 1986, five rounds of cross-sectional BOHTS (i.e., 1986, 2000, 2005, 2010, and 2015) were conducted to support the improvement of transportation strategies. Beijing conducted the BOHTS based on Traffic Analysis Zones (TAZ) as the areal unit. In 2010, the Beijing area comprised 1,912 TAZs. We used only those 676 TAZs within the Fifth Ring Road of Beijing (with an area less than 3.14 km^2) or that intersected with it, as TAZs beyond the Fifth Ring Road were usually large in size and sparsely populated (Fig. S1). The average size of the included TAZs was 1.034 km^2.

3.2. *Travel survey data*

The household travel survey was based on a 24-h travel diary comprising in total 253,583 trips conducted by 115,920 participants within 46,900 households, which accounted for 0.6% of the total population of Beijing. The participants reported all their trips within 24-h in chronological order when they were interviewed. Each trip record included some travel attributes, such as transport modes, the TAZ code of trip origin and destination, start time per trip and arrival time, and travel purpose (e.g., working, schooling, personal affairs, visiting friends). Fig. 1 shows the sample selection. We selected trips conducted by schoolchildren in primary education located within the study area. In total, our final sample included 1,758 schoolchildren, who provided 3,347 trips.

Characteristics of travel-to-school records and vice versa were based on self-reported data. Subjects could choose from 14 response items including walking, car, motorbike, cycling, bus, metro etc. We considered walking trips (dichotomized into 'walking: yes or no') as the dependent variable. Whether or not the trip origin and destination were in the same TAZ was coded as 'yes or no'. We also calculated the Euclidean distance between the central point of the origin TAZ and destination TAZ to capture travel distance (in kilometers), which was defined as 0 if the trip's origin and destination were within the same TAZ. We also collected data on parental companionship during schoolchildren's walking trips to school. The variable was grouped into travel alone vs. travel with parent(s) vs. travel with grandparent(s).

In addition to the trip-record data, the survey also recorded the participants' socio-demographic information. We included the following covariates: gender (female vs. male), age (in years), hukou status (local hukou vs. non-local hukou), household car ownership (no car vs. have car), household bicycle ownership (no bicycle vs. have bicycles), annual family income (<50,000 yuan vs. 50,000–100,000 yuan vs. >100,000 yuan), and the highest educational level of the schoolchildren's parent(s) (junior high school or below vs. senior high school vs. college or above).

3.3. *Tencent street imagery data*

We obtained street view images taken in 2013 from Tencent Map (https://map.qq.com/). Sampling points were created every 50 m along

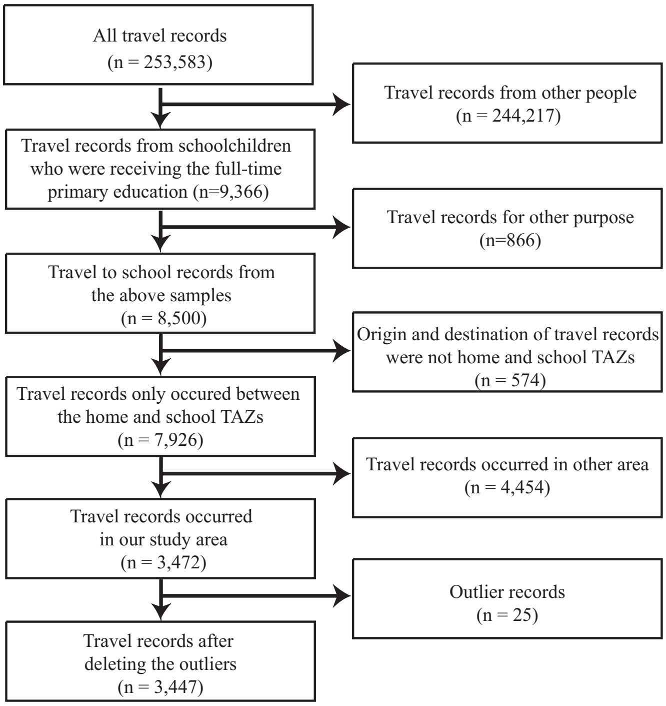

Fig. 1. Sample selection.

the street network, which was retrieved from OpenStreetMap (https://www.openstreetmap.org). For each sample point, we selected four street view images from 0°, 90°, 180°, and 270°. In total, there were 32,148 sample points with 128,592 street view images. We implemented a machine learning approach to extract objects from those downloaded street view images. We used a fully convolutional neural network (i.e., the FCN-8s) to conduct semantic image segmentation, thereby identifying 151 street different objects (Yao et al., 2019). To train the FCN-8s, we used the ADE20K scene parsing and segmentation database (Zhou et al., 2018; Zhou et al., 2017). Thereafter, the proportion of each street object's pixel per image was calculated by feeding the images into the trained model. Each object's pixel proportion of the four street view images per sample point were averaged. The segmentation accuracy of the FCN-8s reached 81.44% and 66.83% in the training and test set (Yao et al., 2019), ranking within the top 10% worldwide (leaderboard: http://sceneparsing.csail.mit.edu). A similar model has been widely applied elsewhere (Helbich et al., 2019; Liu et al., 2021a, 2021b; Wang et al., 2019a, 2019b, 2019c; Yao et al., 2019).

Based on the segmented street view images, four detailed built environmental features have been determined which were found to affect residents' travel behavior (Ewing and Handy, 2009; Christiansen et al., 2014; Ross et al., 2017). Streetscape greenery and walkability were used to represent the physical features along the street (Yang et al., 2020b; Dessing et al., 2016; Dalton et al., 2011; Kim and Heinrich, 2016), while enclosure and street safety facilities may reflect the walking and cycling experience of pedestrians and their perception of the street environment (Ewing and Handy, 2009). Streetscape greenery is represented by the average value of greenery of all sampling points within a TAZ. Walkability is given as the ratio of the pavement's pixels to the sum of the pavement and the driveway's pixels of the sample points within a TAZ. Our measure to capture enclosure was defined as the average height-to-width ratio of vertical objects (i.e., buildings and trees) and the horizontal objects (i.e., pavements and roads) of the sample points within a TAZ (Ma et al., 2021). Finally, we defined street safety facilities as the average value of the sum of pixels in the proportion of street furniture objects (i.e., fences, streetlamps, traffic lights, cameras, and windows) of the sample points within a TAZ. Formulas for each streetscape measure are given in the supplementary materials (Table S1).

3.4. TAZ data

We used several measures of the built environment per TAZ. We computed these variables within each residential TAZ and within each school TAZ. Population density was measured by using the Beijing Census Data for townships and sub-districts for 2010. We calculated the number of intersections, bus stops, and metro stations from point of interest (POI) data. Besides, we obtained land use data extracted from the Landsat-5 remote sensing imagery with a spatial resolution of 30 m to compute the proportion of greenspace per TAZ. Finally, regarding the public security level of the TAZs, we extracted the number of criminal cases for 2013 per 10,000 people from the court of Beijing (https://www.bjcourt.gov.cn/cpws/index.htm). The crime data included seven crime types: theft, intentional homicide, intentional injury, affray, larceny, robbery and being disorderly. Further details are given in the supplementary materials (Table S1).

3.5. Statistical analyses

Descriptive analyses were used to summarize the sample characteristics. The relationship between the streetscape built environmental variables and walking to school was estimated using generalized additive mixed models (GAMMs). GAMMs can model data based on a variety of distribution assumptions, and they account for dependency in the data due to clustering (i.e., trips nested in individuals nested in TAZs), and make it possible to estimate non-linear relationships (Wood, 2006; Hinckson et al., 2017). We fitted fully adjusted GAMMs with logit link functions to model the likelihood of walking (versus not walking). The odds ratio (OR) and 95% confidence intervals (95% CI) were reported. Non-linear effects were modeled with thin-plate splines. The criterion to determine whether a variable had a curvilinear relationship was based on the estimated degrees of freedom (EDF) (i.e., the higher the value, the more complex is a smooth function) and through Akaike information criterion (AIC)-based comparisons with a linear term. A >10-unit AIC decrease provides strong evidence for a non-linear association (Sallis et al., 2020; Lu et al., 2019a). Multi-collinearity was tested with variance inflation factors (VIF).

Model 1 examined the non-linear relationship between the odds of walking and the built environment at the residential TAZs only. After that, for considering the possible effect of built environments around school jointly, we multiplied the value of built environmental indicators of residential and school TAZ by 0.5, respectively, and added them together and explored their non-linear effects on odds of walking (Model 2). Stratified analyses were conducted to explore the heterogenous effect of schoolchildren and their households' socioeconomic and demographic characteristics on built environments - walking behaviors associations. We conducted stratified analyses based on respondents' household annual income, highest educational level of parent(s), and car ownership (Models 3–5). GAMMs were estimated in R using the "mgcv" package (Wood, 2006).

4. Results

4.1. Descriptive statistics

Walking accounts for 51.58% of the total trips. Cross-TAZ traveling to school accounted for a relatively large proportion (61.33%), while the average travel distance was 1.51 km, which was shorter than the 3 km specified by the Chinese government for ensuring that schoolchildren live within the stipulated distance of a compulsory school (http://www.moe.gov.cn/). Only 35.92% of the school trips were children accompanied by their guardians, of which 28.63% and 7.29% were accompanied by parent(s) and grandparent(s). Other summary statistics of the sample and the covariates are summarized in Table 1, while the spatial distribution of the streetscape variables is shown Fig. S2.

4.2. Association between built environment characteristics and active travel to school

There was no evidence of multi-collinearity among the variables. Table 2 shows the results of associations between the odds of walking to school and the built environmental characteristics after full covariate adjustments. Higher odds of walking to school were significantly associated with lower walkability and higher enclosure value within residential TAZs (Model 1). A curvilinear relationship was observed between the odds of walking to school and the street safety facilities of residential TAZs. The likelihood of walking was negatively associated with street safety facilities in residential TAZs to the value of 0.010, and then remained relatively stable up to 0.017; thereafter a decline was noticeable (Model 1) (Fig. 2). We found no further evidence that other variables had a non-linear association. In addition, there was a negative linear relationship between the odds of walking and street safety facilities when simultaneously considering the built environments of residential and school TAZs (Model 2). Population density and intersection density were both positively related to odds of walking to school in both the models, while respondents with a higher density of metro stations showed a negative relationship with odds of walking (Model 1).

An increase in age was significantly positively correlated with the higher odds of walking to school. Respondents that had local Beijing hukou and owned bicycles had a lower likelihood of walking, and car-owners had lower odds of walking when considering only the built environments of residential TAZs.

Table 1
Descriptive statistics of the sample ($N = 3{,}447$).

Characteristics	Proportion / mean (SD)
Outcomes	
Walking	51.58
Other modes of travel	48.42
Trip characteristics	
Whether residential address and school address are located in the same TAZ (%)	
No	61.33
Yes	38.67
Euclidean distance between the residential TAZ and school TAZ (km)	1.51 (2.30)
Companionship information (%)	
Travel alone	64.08
Travel with parent(s)	28.63
Travel with grandparent(s)	7.29
TAZ characteristics (in each TAZ)	
Streetscape greenery	0.14 (0.07)
Walkability	0.10 (0.05)
Enclosure	1.24 (0.50)
Street safety facilities	0.02 (0.01)
Crime rate per 10,000 people (%)	1.72 (1.64)
Population density (persons/km^2)	18,119.22 (31,424.54)
Density of street intersections	65.95 (57.14)
Density of bus stops	17.52 (13.42)
Density of metro stations	1.70 (5.08)
Proportion of green space (%)	31.32 (6.17)
Individual socio-demographic characteristics	
Gender (%)	
Male	52.79
Female	47.21
Age	9.04 (1.83)
Hukou status (%)	
Local hukou	77.42
Non-local hukou	22.58
Car ownership (%)	45.16
Bicycle ownership (%)	72.50
Education level of the head of household (%)	
Junior high school or below	13.54
Senior high school	25.54
College or above	60.92
Annual family income (%)	
Less than 50,000	50.06
50,000–100,000	37.32
More than 100,000	12.62

There was a higher likelihood of walking when the addresses of residence and school were in the same TAZ, and travel distance from residence to school had a negative association with the odds of walking. Besides, traveling with parent(s) was significantly related to the reduction in the odds of walking.

4.3. *Stratified analyses by socioeconomic characteristics*

Comparing the AIC score of Model 1 and Model 2 indicated that the model based on the built environment of residential and school TAZs had a better goodness-of-fit (AIC: 2,860.744 vs. 2,672.898). Therefore, we conducted stratified analyses only for Model 2. Results from the stratification are given in Table 3.

For car ownership, a higher walkability index was related only to lower odds of walking to school for car owners, and we found a negative effect of street safety facilities on odds of walking, which was stronger for car owners. For the educational attainment analyses of the parent(s), higher streetscape greenery was related to lower odds of walking among those children whose parents had a senior high education or below, while higher street safety facilities were associated with lower odds of walking only for the more highly educated group. Stratifying by income, we found that walkability and street safety facilities were related only to lower odds of walking for the higher-income group.

Table 2
Results of generalized additive mixed models of walking to school.

	Model 1		Model 2	
	Built environment in residential TAZ		Built environment in residential and school TAZ	
	OR (95% CI)		OR (95% CI)	
Built environments				
Streetscape greenery	0.839	(0.635,1.108)	0.916	(0.588,1.427)
Walkability	0.728*	(0.507,1.045)	0.688	(0.401,1.179)
Enclosure	2.038***	(1.233,3.369)	1.544	(0.729,3.269)
Street safety facilities	NA		0.542**	(0.332,0.886)
Crime ratio	1.165	(0.870,1.560)	1.143	(0.770,1.698)
Population density	1.235*	(0.978,1.561)	1.370*	(0.997,1.882)
Intersection density	1.268**	(1.052,1.528)	1.268*	(0.959,1.675)
Bus station	1.090	(0.894,1.329)	0.975	(0.687,1.384)
Metro	0.892*	(0.790,1.008)	0.975	(0.826,1.150)
Greenspace	0.995	(0.335,2.958)	0.718	(0.157,3.288)
Gender (Reference: Female)				
Male	1.160	(0.938,1.435)	1.182	(0.930,1.503)
Age	1.158***	(1.091,1.230)	1.175***	(1.097,1.258)
Hukou (Reference: non-local hukou)				
Local hukou	0.603***	(0.455,0.798)	0.635***	(0.459,0.876)
Car ownership	0.796*	(0.629,1.008)	0.816	(0.626,1.065)
Bicycle ownership	0.511***	(0.398,0.656)	0.478***	(0.359,0.637)
Annual family income (Reference: less than 50,000 yuan)				
50,000–100,000 yuan	0.926	(0.722,1.187)	0.936	(0.704,1.244)
More than 100,000 yuan	0.865	(0.598,1.253)	0.799	(0.520,1.225)
Household educational level (Reference: Junior high school)				
Senior high school	1.146	(0.795,1.650)	1.093	(0.727,1.643)
College or above	1.002	(0.702,1.430)	0.878	(0.592,1.303)
Travel in the same TAZ	1.794***	(1.274,2.527)	2.429***	(1.524,3.871)
Travel distance	0.307***	(0.256,0.368)	0.319***	(0.260,0.392)
Companionship				
Companion with parent(s)	0.768**	(0.611,0.965)	0.805*	(0.627,1.033)
Companion with grandparent(s)	1.119	(0.756,1.657)	1.068	(0.699,1.631)
Intercept	0.010	(0.001,0.173)	0.000***	(0,0.031)
Curvilinearity variable	EDF	*P*-value		
Street safety in residential TAZ	3.629***	0.002		
Observations	3,447		3,447	
Adjusted R^2	0.599		0.682	
AIC	2,860.744		2,672.898	

OR = odds ratio, 95% confidence intervals (CI) in parentheses.

[*] $p < 0.10$.

[**] $p < 0.05$.

[***] $p < 0.01$.

5. Discussion

This study enhances our understanding of the relationship between built environments and the odds of schoolchildren walking to school. Besides considering traditional built environmental variables, we explored the role of the streetscape built environment by unraveling possible non-linear relationships. The results indicated that odds of walking to school were associated with a street's walkability, a street's enclosure, and safety facilities, as well as the population density, intersection density, and metro density of the residential and school TAZs. Furthermore, a pronounced travel distance and travel with parent(s) were associated with lower odds of walking to school. Evidence concerning non-linear associations was limited to street safety facilities. We also found that the relationship between the built environment and odds of walking was moderated by car ownership, educational level of parent

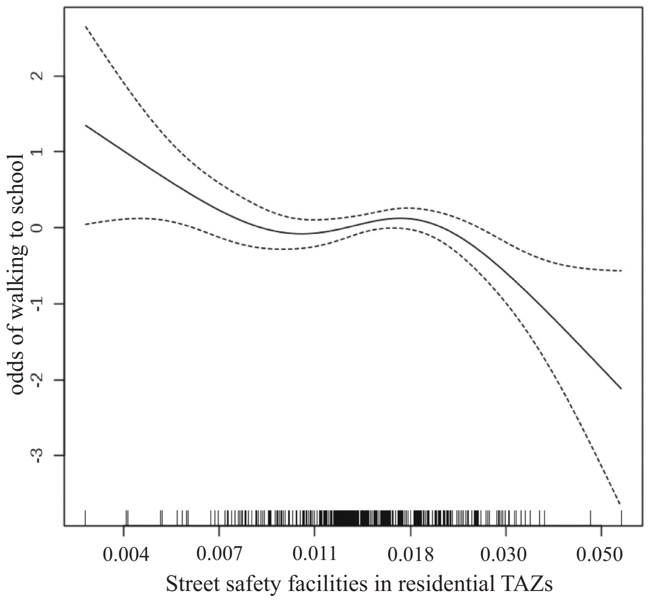

Fig. 2. Non-linear association between the street safety facilities of residential TAZs and odds of walking. Dashed lines represent the 95% confidence interval.

(s), and annual household income.

5.1. *Streetscape built environments*

We found no significant relationship between the streetscape greenery and the odds of walking. Previous evidence concerning the AST-green space association was mixed. Some were conducted in developed countries or regions, and found a positive relationship, such as in the US and Hong Kong (Kim and Heinrich, 2016; Evenson et al., 2006). In contrast, a study from New Hampshire (US) and one in four Dutch cities reported that a higher likelihood of walking to school was negatively related to the neighborhood green space (Dalton et al., 2011; Aarts et al., 2013). In line with our results, there were some studies that also found an insignificant relationship (Helbich et al., 2016; Veitch et al., 2017). One possible explanation for insignificant correlations was that streetscape greenery might not be important enough to schoolchildren to promote walking to school, especially when schoolchildren face time constraints while traveling to school. Characteristics such as walking friendliness, distance to destination, and street safety likely play a more important role to enhance the odds of children walking to school (Mitra, 2013).

We found that a street's walkability of the residential TAZs was significantly and negatively related to the odds of children walking to school. Our study site was central Beijing, which had a more compact urban form than newly developed areas. Streets in this area are relatively narrow, and the sidewalks may be blocked by illegal parking and street vendors, which may cause incidents and inconvenience to active travelers (Oranratmanee and Sachakul, 2014; Feng, 2016). Furthermore, parents possibly also rate such an urban environment as unsafe and less pedestrian friendly. For example, in a study in Vietnam, an increased number of street vendors occupying the sidewalks or roads was related to a lower likelihood of there being active travelers (Leung and Le, 2019).

The enclosure of streets of the residential TAZs was positively related to the odds of children walking to school. The pattern of the correlation between the enclosure and people's travel behavior has been mixed in the literature. Some thought that an appropriate proportion of vertical elements' height to street width would maintain a comfortable feeling of the streets for pedestrians, which would provide a sense of security for pedestrians and encourage people to walk (Ewing and Handy, 2009). For

Table 3
Stratified analyses results by socioeconomic status.

	Model3				Model4				Model5			
	Car ownership				Parent(s)' educational level				Family income			
	No car		Have car		senior high education or below		college or above		Less than 50,000 yuan		More than 50,000 yuan	
	OR (95% CI)		OR (95% CI)		OR (95% CI)		OR (95% CI)		OR (95% CI)		OR (95% CI)	
Streetscape greenery	0.920	(0.510,1.658)	0.891	(0.468,1.696)	0.522*	(0.252,1.081)	1.333	(0.772,2.303)	0.881	(0.483,1.607)	0.976	(0.520,1.834)
Walkability	0.963	(0.457,2.030)	0.450*	(0.200,1.013)	0.705	(0.316,1.571)	0.700	(0.332,1.475)	0.998	(0.505,1.972)	0.440**	(0.196,0.987)
Enclosure	1.651	(0.597,4.567)	1.450	(0.491,4.283)	2.207	(0.665,7.325)	1.331	(0.532,3.333)	0.966	(0.354,2.638)	2.057	(0.724,5.847)
Street safety facilities	0.538*	(0.277,1.048)	0.519*	(0.260,1.035)	0.658	(0.284,1.520)	0.485**	(0.272,0.864)	0.575	(0.290,1.139)	0.512**	(0.263,1.000)
Observations	1,886		1,561		1,369		2,078		1,742		1,705	
Adjusted R^2	0.695		0.711		0.747		0.657		0.713		0.679	
AIC	1,482.501		1,167.853		989.113		1,676.528		1,317.236		1,354.476	

OR = odds ratio, 95% confidence intervals (CI) in parentheses.
All travel-level, individual-level and TAZ-level covariates have been adjusted for.

* $p < 0.10$.
** $p < 0.05$.

example, results from a high-density community in India showed that the increasing feeling of enclosure by pedestrians increased their feeling of perceived safety when walking (Singh, 2016). However, others argued that a higher degree of enclosure may create opportunities for offenders and generate possible threats, which may evoke fearful feelings, and thus people are increasingly unwilling to travel actively (Nasar et al., 1993; Stamps, 2013). Evidence from the US showed that high enclosure environments formed by vegetation were related to a lower level of perceived safety compared to medium or low enclosure environments (Baran et al., 2018).

Somewhat unexpected was the negative relationship between the street safety facilities and the odds of walking, regardless of whether the built environments of school TAZs were considered. However, our finding echoes the results of two other studies. The first, conducted in the U.S., found that primary children's AST was negatively related to their parents' perception of safety (Chillón et al., 2014). The second, carried out in 17 cities across 12 countries, indicated that perceived traffic safety was negatively associated with total minutes of walking among those who walked and the likelihood of transport-related walking for more than 150 mins per week (Kerr et al., 2016). Possible explanations include, first, our innovative calculation method of street safety facilities based on street static objects, such as traffic lights, streetlights, monitors etc. extracted from street view images. Second, compared with people who rarely walk on a daily basis, those who walk regularly may be more familiar with street security. Previous studies also proved that schoolchildren's travel was greatly affected by their parents' perception of street safety (Hume et al., 2009; Pont et al., 2013; Buttazzoni et al., 2019).

5.2. Other built environmental factors

Besides streetscape built environmental variables, several of the typical built environmental factors were related to walking. Population density had a stronger positive relationship with odds of walking when considered within both the residential and school TAZs. A study in Hong Kong suggested that the odds of transport-related walking for youths was positively related to a population density of up to 60,000 persons/km^2 (Lu et al., 2019a). In our case, 90% of TAZs had a population density of fewer than 30,000 persons/km^2.

Intersection density was positively related to walking. This association suggests that improving street connectivity around residential and school sites may promote AST. This finding is in line with results from developed countries (e.g., Kerr et al., 2007; Giles-Corti et al., 2011).

Our results also indicated that the metro density of the residential TAZs was negatively related to the odds of walking, which was consistent with prior evidence. For example, a higher accessibility of a transit station may lead to more traffic flow, which in turn, may increase schoolchildren's and parents' concerns about traffic safety (Lu et al., 2019a; Yu and Zhu, 2013; Yang et al., 2020b).

5.3. Stratified analyses by socioeconomic status

Consistent with previous studies (Chillón et al., 2014; Bringolf-Isler et al., 2008; McDonald, 2008), our stratified analyses showed that the relationship between streetscape built environments and the likelihood of schoolchildren walking to school varied depending on demographic and socioeconomic characteristics. The streetscape greenery of the residential and school TAZs was only negatively related to odds of walking for the lower-educated group. This is probably because lower-educated families tend to have lower incomes and often live in old communities, low-rent houses, and other places with poor environmental quality, which may be more sensitive to green space exposure (Rodriguez-Loureiro et al., 2021). The walkability of the residential TAZs was only negatively related to the odds of walking for car owners and higher-income groups. Car ownership often means a better household income. Previous studies found that those with a higher income more often reside between the suburbs of the third to the fifth ring of Beijing, which have a better environmental quality (Feng and Zhong, 2018). Based on this, an improvement in walkability may not only promote walking but may also enhance the comfort of passive travel (i.e., driving and public transport). Finally, the negative association of street safety facilities and walking was stronger for car owners and was observed in higher educated and higher-income groups. It could be that people with a lower socioeconomic status (i.e., people without a car, lower educated, and lower-income group) are limited in their travel choices.

5.4. Limitations

This study had some limitations. First, due to our cross-sectional data, we were not able to assess the causal relationship between built environments and walking behaviors. Second, constrained by data availability, we considered only objective built environmental factors and neglected children's and parents' perceptions that were found to be of relevance to how children travel (Yu and Zhu, 2013; Sun et al., 2018; Vanwolleghem et al., 2016). Third, the measurements of the street environment were based on the extraction of static street view image data, which is probably not able to fully reflect the real situation on the streets. Dynamic indicators, such as real-time traffic volume, may circumvent this shortcoming in the future (Giles-Corti et al., 2011). Lastly, we considered only the transport-related walking of schoolchildren and did not consider their walking for other purposes (e.g., leisure). As suggested elsewhere (Moran et al., 2015), the relationship between the built environment and other purposes among children may be different. However, whether this also applies to high-density cities in China remains unexplored.

6. Conclusions

We examined the non-linear relationships between the streetscape built environment and schoolchildren's odds of walking to school in Beijing. We found that higher odds of walking were related to the lower walkability and higher enclosure of the residential TAZs. A curvilinear relationship was observed between the odds of walking and the street safety facilities of residential TAZs, but the shape showed a negative correlation as a whole. Similar was the street safety facilities-odds of walking association for the school TAZs. Higher population density and intersection density were linked to higher odds of walking, while the metro density of residential TAZs had an inhibitory effect on odds of walking. Besides, those children living further away from school or going to school with their parent(s) had a lower likelihood of walking. Finally, the relationships between the streetscape built environment and odds of walking to school for schoolchildren were stronger for car owners, parents with higher level of education, and those with a higher income.

Our results have some implications for planning practices. First, territorial planning of China should emphasize the spatial governance at streetscape of cities, such as the street quality of walking/cycling environment. Policymakers and urban planners are advised to identify the quality of street environments to reach a comprehensive understanding of the urban form by combining emerging data sources (i.e. street view data) with the traditional survey data. Second, our results suggest a significant association between street furniture and schoolchildren's walking behavior. Hence, policymakers are advised to increase the provisions of child-friendly street facilities, like barrier-free pedestrian spaces, signs for children, appropriate lighting, and a non-motorized lane of the proper width. Finally, the government and schools are instructed to organize some activities to raise the awareness of schoolchildren and their parents of the benefits of active travel, such as "walking school bus" and "car-free days".

Consent for publication

Consent forms are available upon reasonable request.

Availability of data and materials

The datasets used and/or analysis during the current study are available from the corresponding author on reasonable request.

Authors' contributions

Xiaoge Wang: Methodology, Software, Formal analysis, Writing-original draft. Ye Liu: Conceptualization, Writing - review & editing, Funding acquisition. Chunwu Zhu: Data curation. Yao Yao: Data curation, Writing - review & editing. Marco Helbith: Writing - review & editing. All authors read and approved the final manuscript.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtrangeo.2022.103303.

References

Aarts, M.J., Mathijssen, J.J., van Oers, J.A., Schuit, A.J., 2013. Associations between environmental characteristics and active commuting to school among children: a cross-sectional study. Int. J. Behav. Med. 20, 538–555.

Alliance, A.H.K.G., 2018. *The Global Matrix 3.0 On Physical Activity For Children And Youth* [Online]. Available: https://www.activehealthykids.org/3-0/.

Baran, P.K., Tabrizian, P., Zhai, Y., Smith, J.W., Floyd, M.F., 2018. An exploratory study of perceived safety in a neighborhood park using immersive virtual environments. Urban For. Urban Green. 35, 72–81.

Bringolf-Isler, B., Grize, L., Mader, U., Ruch, N., Sennhauser, F.H., Braun-Fahrlander, C., Team, S, 2008. Personal and environmental factors associated with active commuting to school in Switzerland. Prev. Med. 46, 67–73.

Buttazzoni, A.N., Clark, A.F., Seabrook, J.A., Gilliland, J.A., 2019. Promoting active school travel in elementary schools: a regional case study of the school travel planning intervention. J. Transp. Health 12, 206–219.

Cervero, R., Kockelman, K., 1997. Travel demand and the 3Ds: density, diversity, and design. Transp. Res. Part D 2, 199–219.

Chen, E., Ye, Z., Wu, H., 2021. Nonlinear effects of built environment on intermodal transit trips considering spatial heterogeneity. Transp. Res. Part D 90, 102677.

Chillón, P., Ortega, F.B., Ruiz, J.R., Veidebaum, T., Oja, L., Mäestu, J., Sjöström, M., 2010. Active commuting to school in children and adolescents: an opportunity to increase physical activity and fitness. Scand. J. Public Health 38, 873–879.

Chillón, P., Hales, D., Vaughn, A., Gizlice, Z., Ni, A., Ward, D.S., 2014. A cross-sectional study of demographic, environmental and parental barriers to active school travel among children in the United States. Int. J. Behav. Nutr. Phys. Act. 11, 61.

Christiansen, L.B., Toftager, M., Schipperijn, J., Ersbøll, A.K., Giles-Corti, B., Troelsen, J., 2014. School site walkability and active school transport – association, mediation and moderation. J. Transp. Geogr. 34, 7–15.

Christiansen, L.B., Cerin, E., Badland, H., Kerr, J., Davey, R., Troelsen, J., van Dyck, D., Mitas, J., Schofield, G., Sugiyama, T., Salvo, D., Sarmiento, O.L., Reis, R., Adams, M., Frank, L., Sallis, J.F., 2016. International comparisons of the associations between objective measures of the built environment and transport-related walking and cycling: IPEN Adult Study. J. Transp. Health 3, 467–478.

Dalton, M.A., Longacre, M.R., Drake, K.M., Gibson, L., Adachi-Mejia, A.M., Swain, K., Xie, H., Owens, P.M., 2011. Built environment predictors of active travel to school among rural adolescents. Am. J. Prev. Med. 40, 312–319.

Dessing, D., de Vries, S., Hegeman, G., Verhagen, E., Mechelen, W., Pierik, F., 2016. Children's route choice during active transportation to school: difference between shortest and actual route. Int. J. Behav. Nutr. Phys. Act. 13.

Dias, A.F., Gaya, A.R., Pizarro, A.N., Brand, C., Mendes, T.M., Mota, J., Santos, M.P., Araujo Gaya, A.C., 2019. Perceived and objective measures of neighborhood environment: association with active commuting to school by socioeconomic status in Brazilian adolescents. J. Transp. Health 14, 100612.

Ding, C., Cao, X., Næss, P., 2018. Applying gradient boosting decision trees to examine non-linear effects of the built environment on driving distance in Oslo. Transp. Res. A Policy Pract. 110, 107–117.

Ding, C., Cao, X., Yu, B., Ju, Y., 2021. Non-linear associations between zonal built environment attributes and transit commuting mode choice accounting for spatial heterogeneity. Transp. Res. A Policy Pract. 148, 22–35.

Evenson, K.R., Birnbaum, A.S., Bedimo-Rung, A.L., Sallis, J.F., Voorhees, C.C., Ring, K., Elder, J.P., 2006. Girls' perception of physical environmental factors and transportation: reliability and association with physical activity and active transport to school. Int. J. Behav. Nutr. Phys. Act. 3, 28.

Ewing, R., Cervero, R., 2010. Travel and the built environment. J. Am. Plan. Assoc. 76, 265–294.

Ewing, R., Handy, S., 2009. Measuring the unmeasurable: urban design qualities related to walkability. J. Urban Des. 14, 65–84.

Feng, J., 2016. The built environment and active travel: evidence from Nanjing, China. Int. J. Environ. Res. Public Health 13.

Feng, J., Zhong, Y., 2018. Restructuring of social space in Beijing from 2000 to 2010. Dili Xuebao/Acta Geogr. Sin. 73, 711–737.

Fulton, J.E., Shisler, J.L., Yore, M.M., Caspersen, C.J., 2005. Active transportation to school: findings from a national survey. Res. Q. Exerc. Sport 76, 352–357.

Ghekiere, A., van Cauwenberg, J., Mertens, L., Clarys, P., DE Geus, B., Cardon, G., Nasar, J., Salmon, J., de Bourdeaudhuij, I., Deforche, B., 2015. Assessing cycling-friendly environments for children: are micro-environmental factors equally important across different street settings? Int. J. Behav. Nutr. Phys. Act. 12, 54.

Giles-Corti, B., Wood, G., Pikora, T., Learnihan, V., Bulsara, M., van Niel, K., Timperio, A., Mccormack, G., Villanueva, K., 2011. School site and the potential to walk to school: the impact of street connectivity and traffic exposure in school neighborhoods. Health Place 17, 545–550.

Guidotti, R., Monreale, A., Ruggieri, S., Turini, F., Giannotti, F., Pedreschi, D., 2018. A survey of methods for explaining black box models. ACM Comput. Surv. 51, 1–42.

Hagenauer, J., Helbich, M., 2017. A comparative study of machine learning classifiers for modeling travel mode choice. Expert Syst. Appl. 78, 273–282.

Hallal, P.C., Andersen, L.B., Bull, F.C., Guthold, R., Haskell, W., Ekelund, U., 2012. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet 380, 247–257.

Helbich, M., Emmichoven, M.J., Dijst, M.J., Kwan, M.P., Pierik, F.H., Vries, S.I., 2016. Natural and built environmental exposures on children's active school travel: a Dutch global positioning system-based cross-sectional study. Health Place 39, 101–109.

Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P., Wang, R., 2019. Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. Environ. Int. 126, 107–117.

Hinckson, E., Cerin, E., Mavoa, S., Smith, M., Badland, H., Stewart, T., Duncan, S., Schofield, G., 2017. Associations of the perceived and objective neighborhood environment with physical activity and sedentary time in New Zealand adolescents. Int. J. Behav. Nutr. Phys. Act. 14, 145.

Huang, X., Lu, G., Yin, J., Tan, W., 2021. Non-linear associations between the built environment and the physical activity of children. Transp. Res. Part D: Transp. Environ. 98, 102968.

Hume, C., Timperio, A., Salmon, J., Carver, A., Giles-Corti, B., Crawford, D., 2009. Walking and cycling to school: predictors of increases among children and adolescents. Am. J. Prev. Med. 36, 195–200.

Kaplan, S., Nielsen, T.A.S., Prato, C.G., 2016. Walking, cycling and the urban form: a Heckman selection model of active travel mode and distance by young adolescents. Transp. Res. Part D: Transp. Environ. 44, 55–65.

Kerr, J., Frank, L., Sallis, J.F., Chapman, J., 2007. Urban form correlates of pedestrian travel in youth: differences by gender, race-ethnicity and household attributes. Transp. Res. Part D 12, 177–182.

Kerr, J., Emond, J.A., Badland, H., Reis, R., Sarmiento, O., Carlson, J., Sallis, J.F., Cerin, E., Cain, K., Conway, T., Schofield, G., MacFarlane, D.J., Christiansen, L.B., van Dyck, D., Davey, R., Aguinaga-Ontoso, I., Salvo, D., Sugiyama, T., Owen, N., Mitas, J., Natarajan, L., 2016. Perceived neighborhood environmental attributes associated with walking and cycling for transport among adult residents of 17 cities in 12 countries: the IPEN study. Environ. Health Perspect. 124, 290–298.

Kim, H.J., Heinrich, K.M., 2016. Built environment factors influencing walking to school behaviors: a comparison between a small and large US City. Front. Public Health 4, 77.

Łaszkiewicz, E., Sikorska, D., 2020. Children's green walk to school: an evaluation of welfare-related disparities in the visibility of greenery among children. Environ. Sci. Pol. 110, 1–13.

Lee, C., Moudon, A.V., 2004. Physical activity and environment research in the health field: implications for urban and transportation planning practice and research. J. Plan. Lit. 19, 147–181.

Leung, A., Le, T.P.L., 2019. Factors associated with adolescent active travel: a perceptive and mobility culture approach – insights from Ho Chi Minh City, Vietnam. Transp. Res. A 123, 54–67.

Liu, J., Wang, B., Xiao, L., 2021a. Non-linear associations between built environment and active travel for working and shopping: an extreme gradient boosting approach. J. Transp. Geogr. 92, 103034.

Liu, Y., Xiao, T., Liu, Y., Yao, Y., Wang, R., 2021b. Natural outdoor environments and subjective well-being in Guangzhou, China: comparing different measures of access. Urban For. Urban Green. 59, 127027.

Lu, Y., Sun, G., Gou, Z., Liu, Y., Zhang, X., 2019a. A dose–response effect between built environment characteristics and transport walking for youths. J. Transp. Health 14, 100616.

Lu, Y., Yang, Y., Sun, G., Gou, Z., 2019b. Associations between overhead-view and eye-level urban greenness and cycling behaviors. Cities 88, 10–18.

Ma, X., Ma, C., Wu, C., Xi, Y., Yang, R., Peng, N., Zhang, C., Ren, F., 2021. Measuring human perceptions of streetscapes to better inform urban renewal: a perspective of scene semantic parsing. Cities 110, 103086.

Maki-Opas, T.E., de Munter, J., Maas, J., den Hertog, F., Kunst, A.E., 2014. The association between physical environment and cycling to school among Turkish and Moroccan adolescents in Amsterdam. Int. J. Public Health 59, 629–636.

McDonald, N.C., 2008. Critical factors for active transportation to school among low-income and minority students. Evidence from the 2001 National Household Travel Survey. Am. J. Prev. Med. 34, 341–344.

Mcmillan, T.E., 2007. The relative influence of urban form on a child's travel mode to school. Transp. Res. A Policy Pract. 41, 69–79.

Mcmillan, T.E., 2016. Urban form and a child's trip to school: the current literature and a framework for future research. J. Plan. Lit. 19, 440–456.

Mitra, R., 2013. Independent mobility and mode choice for school transportation: a review and framework for future research. Transp. Rev. 33, 21–43.

Moran, M.R., Plaut, P., Baron Epel, O., 2015. Do children walk where they bike? Exploring built environment correlates of children's walking and bicycling. J. Transp. Land Use 9 (2), 43–65.

Nasar, J.L., Fisher, B., Grannis, M., 1993. Proximate physical cues to fear of crime. Landsc. Urban Plan. 26, 161–178.

Oranratmanee, R., Sachakul, V., 2014. Streets as public spaces in Southeast Asia: case studies of Thai pedestrian streets. J. Urban Des. 19, 211–229.

Page, A.S., Cooper, A.R., Griew, P., Jago, R., 2010. Independent mobility, perceptions of the built environment and children's participation in play, active travel and structured exercise and sport: the PEACH project. Int. J. Behav. Nutr. Phys. Act. 7, 17.

Panter, J.R., Jones, A.P., van Sluijs, E.M., 2008. Environmental determinants of active travel in youth: a review and framework for future research. Int. J. Behav. Nutr. Phys. Act. 5, 34.

Pizarro, A.N., Schipperijn, J., Andersen, H.B., Ribeiro, J.C., Mota, J., Santos, M.P., 2016. Active commuting to school in Portuguese adolescents: using PALMS to detect trips. J. Transp. Health 3, 297–304.

Pont, K., Wadley, D., Ziviani, J., Khan, A., 2013. The influence of urban form and family decision making on children's travel to school. J. Urban Des. 18, 363–382.

Rodriguez-Loureiro, L., Casas, L., Bauwelinck, M., Lefebvre, W., Vanpoucke, C., Vanroelen, C., Gadeyne, S., 2021. Social inequalities in the associations between urban green spaces, self-perceived health and mortality in Brussels: results from a census-based cohort study. Health Place 70, 102603.

Ross, A., Rodríguez, A., Searle, M., 2017. Associations between the physical, sociocultural, and safety environments and active transportation to school. Am. J. Health Educ. 48, 198–209.

Rothman, L., Buliung, R., To, T., Macarthur, C., Macpherson, A., Howard, A., 2015. Associations between parents' perception of traffic danger, the built environment and walking to school. J. Transp. Health 2, 327–335.

Sallis, J., Owen, N., 2001. Ecological models of health behavior. In: Health Behaviour and Health Education: Theory, Research and Practice.

Sallis, J.F., Cervero, R.B., Ascher, W., Henderson, K., 2006. An ecological approach to creating active living communities. Annu. Rev. Public Health 27.

Sallis, J.F., Cerin, E., Kerr, J., Adams, M.A., Sugiyama, T., Christiansen, L.B., Schipperijn, J., Davey, R., Salvo, D., Frank, L.D., de Bourdeaudhuij, I., Owen, N., 2020. Built environment, physical activity, and obesity: findings from the international physical activity and environment network (IPEN) adult study. Annu. Rev. Public Health 41, 119–139.

Schoeppe, S., Duncan, M.J., Badland, H., Oliver, M., Curtis, C., 2013. Associations of children's independent mobility and active travel with physical activity, sedentary behaviour and weight status: a systematic review. J. Sci. Med. Sport 16, 312–319.

Siiba, A., 2020. Active travel to school: understanding the Ghanaian context of the underlying driving factors and the implications for transport planning. J. Transp. Health 18, 100869.

Singh, R., 2016. Factors affecting walkability of neighborhoods. Proc. Soc. Behav. Sci. 216, 643–654.

Stamps, A., 2013. Effects of multiple boundaries on perceived spaciousness and enclosure. Environ. Behav. 45, 851–875.

Su, J.G., Jerrett, M., Mcconnell, R., Berhane, K., Dunton, G., Shankardass, K., Reynolds, K., Chang, R., Wolch, J., 2013. Factors influencing whether children walk to school. Health Place 22, 153–161.

Sun, G., Han, X., Sun, S., Oreskovic, N., 2018. Living in school catchment neighborhoods: perceived built environments and active commuting behaviors of children in China. J. Transp. Health 8, 251–261.

Tao, T., Wu, X., Cao, J., Fan, Y., Das, K., Ramaswami, A., 2020. Exploring the nonlinear relationship between the built environment and active travel in the twin cities. J. Plan. Educ. Res. 00 (0), 1–16 (0739456X2091576).

Timperio, A., Ball, K., Salmon, J., Roberts, R., Giles-Corti, B., Simmons, D., Baur, L.A., Crawford, D., 2006. Personal, family, social, and environmental correlates of active commuting to school. Am. J. Prev. Med. 30, 45–51.

van Wee, B., Handy, S., 2014. Key research themes on urban space, scale, and sustainable urban mobility. Int. J. Sustain. Transp. 10, 18–24.

Vanwolleghem, G., van Dyck, D., de Meester, F., de Bourdeaudhuij, I., Cardon, G., Gheysen, F., 2016. Which socio-ecological factors associate with a switch to or maintenance of active and passive transport during the transition from primary to secondary school? PLoS One 11, e0156531.

Veitch, J., Carver, A., Salmon, J., Abbott, G., Ball, K., Crawford, D., Cleland, V., Timperio, A., 2017. What predicts children's active transport and independent mobility in disadvantaged neighborhoods? Health Place 44, 103–109.

Verhoeven, H., Ghekiere, A., van Cauwenberg, J., van Dyck, D., de Bourdeaudhuij, I., Clarys, P., Deforche, B., 2017. Which physical and social environmental factors are most important for adolescents' cycling for transport? An experimental study using manipulated photographs. Int. J. Behav. Nutr. Phys. Act. 14, 108.

Wang, R., Liu, Y., Lu, Y., Yuan, Y., Zhang, J., Liu, P., Yao, Y., 2019a. The linkage between the perception of neighbourhood and physical activity in Guangzhou, China: using street view imagery with deep learning techniques. Int. J. Health Geogr. 18, 18.

Wang, R., Lu, Y., Zhang, J., Liu, P., Yao, Y., Liu, Y., 2019b. The relationship between visual enclosure for neighbourhood street walkability and elders' mental health in China: using street view images. J. Transp. Health 13, 90–102.

Wang, R., Yuan, Y., Liu, Y., Zhang, J., Liu, P., Lu, Y., Yao, Y., 2019c. Using street view data and machine learning to assess how perception of neighborhood safety influences urban residents' mental health. Health Place 59, 102186.

WHO, 2018. Global Action Plan on Physical Activity 2018–2030.

WHO, 2020. WHO Guidelines on PA and Sedentary Behavior.

Wood, S.N., 2006. Generalized Additive Models:An Introduction With R.

Yang, L., Liu, J., Lu, Y., Ao, Y., Guo, Y., Huang, W., Zhao, R., Wang, R., 2020a. Global and local associations between urban greenery and travel propensity of older adults in Hong Kong. Sustain. Cities Soc. 63, 102442.

Yang, Y., Lu, Y., Yang, L., Gou, Z., Zhang, X., 2020b. Urban greenery, active school transport, and body weight among Hong Kong children. Travel Behav. Soc. 20, 104–113.

Yao, Y., Liang, Z., Yuan, Z., Liu, P., Bie, Y., Zhang, J., Wang, R., Wang, J., Guan, Q., 2019. A human-machine adversarial scoring framework for urban perception assessment using street view images. Int. J. Geogr. Inf. Sci. 33, 2363–2384.

Yin, L., Wang, Z., 2016. Measuring visual enclosure for street walkability: using machine learning algorithms and Google Street View imagery. Appl. Geogr. 76, 147–153.

Yu, C.-Y., Zhu, X., 2013. Impacts of residential self-selection and built environments on children's walking-to-school behaviors. Environ. Behav. 47, 268–287.

Zang, P., Lu, Y., Ma, J., Xie, B., Wang, R., Liu, Y., 2019. Disentangling residential self-selection from impacts of built environment characteristics on travel behaviors for older adults. Soc. Sci. Med. 238, 112515.

Zhang, X., Song, Y., Yang, T.B., Zhang, B., Dong, B., Ma, J., 2012. Analysis of current situation of physical activity and influencing factors in Chinese primary and middle school students in 2010. Zhonghua yu fang yi xue za zhi [Chin. J. Prevent. Med.] 46, 781–788.

Zhao, X., Yan, X., Yu, A., van Hentenryck, P., 2020. Prediction and behavioral analysis of travel mode choice: a comparison of machine learning and logit models. Travel Behav. Soc. 20, 22–35.

Zhou, B., Zhao, H., Puig, X., Fidler, S., Barriuso, A., Torralba, A., 2017. Scene parsing through ADE20K dataset. In: 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 21–26 July 2017, pp. 5122–5130.

Zhou, B., Zhao, H., Puig, X., Xiao, T., Fidler, S., Barriuso, A., Torralba, A., 2018. Semantic understanding of scenes through the ADE20K dataset. Int. J. Comput. Vis. 127, 302–321.