Social Science & Medicine 238 (2019) 112515

Contents lists available at ScienceDirect

Social Science & Medicine

journal homepage: www.elsevier.com/locate/socscimed

# Disentangling residential self-selection from impacts of built environment characteristics on travel behaviors for older adults

Peng Zang[a], Yi Lu[b,c,*], Jing Ma[d], Bo Xie[e], Ruoyu Wang[f], Ye Liu[f,g]

[a] Department of Architecture and Urban Planning, Guangdong University of Technology, Guangzhou, China
[b] Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong
[c] City University of Hong Kong Shenzhen Research Institute, Shenzhen, China
[d] Beijing Key Laboratory for Remote Sensing of Environment and Digital Cities, Faculty of Geographical Science, Beijing Normal University, Beijing, China
[e] School of Urban Design, Wuhan University, Wuhan, China
[f] School of Geography and Planning, Sun Yat-Sen University, Guangzhou, China
[g] Guangdong Key Laboratory for Urbanization and Geo-Simulation, Sun Yat-Sen University, Guangzhou, China

ARTICLE INFO

*Keywords:*
Travel behaviors
Residential self-selection
Older adults
Built environment

ABSTRACT

In the context of population ageing in many developed and developing countries, encouraging active transport behaviors of older adults, is a key public health priority. However, many cross-sectional studies assessing the impact of built environment characteristics on travel behavior fail to address residential self-selection bias, and hence the causal relationship is uncertain. A large-scale public housing scheme provided this study with a unique research opportunity to distinguish residential self-selection from the effects of built environment characteristics on the travel behaviors of older adults ($N$ = 13,468 and 3,961 in two analyses respectively) in Hong Kong, because public housing residents have little freedom to choose their residential locations. The results showed that the elderly living in public housing estates generally have fewer trips, shorter overall travel times and distances, and fewer motorized trips including those by rail or private car than those living in private housing estates. In addition, the results for walking, walking times, numbers of trips, and travel distance for elderly people in public and private housing all exhibited markedly different associations with built environment characteristics. Strength of built environment-travel behavior associations dropped by approximately 30–50% after controlling for the effect of residential self-selection. The results indicate that both built environment characteristics and residential self-selection affect travel behaviors.

## 1. Introduction

The travel behaviors of urban residents worldwide have changed dramatically in recent years from favoring active transport modes such as walking or cycling to private vehicle use. The change in travel behavior also leads to more physical inactivity among older adults, who are the most sedentary segment of the population (King et al., 2013). There is compelling evidence that active transport has many benefits for older adults, such as preventing and treating chronic illnesses and improving physiological and psychological health (Sener et al., 2016). Walking constitutes the most popular habitual physical activity because it requires no special equipment or clothing, and can be done alone or in the company of others and at any time, so it can easily be incorporated into daily personal routines (Hamdorf et al., 2002; Tudor-Locke et al., 2002). Therefore, in the context of developing sustainable and healthy cities, encouraging active transport behaviors for older adults should be a key public policy priority (Sun et al., 2017).

To tackle the problem of shifting travel behavior, researchers in the fields of public health, urban planning, and transportation have taken an ecological approach by examining the influence of various individual, social, and built environment factors on travel behavior (Handy et al., 2002). Built environment characteristics have been increasingly recognized as key factors affecting travel behaviors. The interaction between socioeconomics and urban form is central to the understanding of the decision-making concerning travel behavior (Badoe and Miller, 2000).

### 1.1. Built environment-travel behavior associations

The built environments of neighborhoods are particularly relevant

* Corresponding author. Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong.
*E-mail addresses:* pzang89@gdut.edu.cn (P. Zang), yilu24@cityu.edu.hk (Y. Lu), jing.ma@bnu.edu.cn (J. Ma), xiebo317@whu.edu.cn (B. Xie), wangry6@mail2.sysu.edu.cn (R. Wang), liuye25@mail.sysu.edu.cn (Y. Liu).

https://doi.org/10.1016/j.socscimed.2019.112515
Received 24 April 2019; Received in revised form 8 July 2019; Accepted 21 August 2019
Available online 24 August 2019
0277-9536/

for older adults, who have increased functional limitations and may be reluctant to go outdoors. Physical barriers such as distance, slopes, and other obstacles may hinder the active travel behavior of older adults (Cauwenberg et al., 2011). In general, empirical studies of built environment-travel behavior associations find that the inhabitants of dense, compact neighborhoods with mixed land use undertake shorter trips and use public transport or active transport modes more often (Barnett et al., 2017; Cerin et al., 2017; Chaudhury et al., 2016). High population densities, the presence of many pedestrian destinations, and well-connected street networks result in shorter trip distances, and hence higher rates of walking, cycling, or public transport trips, with less dependence on private vehicles. However, the availability of parks and open greenspaces may be limited, and personal safety may be an issue (Saelens and Handy, 2008). A recent review of longitudinal studies showed that changes in the built environment lead to changes in physical activity. New infrastructures for walking, cycling, and public transportation were associated with increased overall and transportation-related physical activity (Karmeniemi et al., 2018). In terms of specific active transport behavior, the built environment was more likely to be associated with transportation walking compared with other types of active transport behaviors, such as recreational walking (McCormack and Shiell, 2011).

### 1.2. Residential self-selection bias

However, many of the abovementioned studies that estimate the impact of built environment characteristics on travel behavior fail to address residential self-selection bias and hence the causal relationship is uncertain (van de Coevering et al., 2015). Residential self-selection refers to when people choose their residential locations because of their travel attitudes and preferences or social inequity (Cao et al., 2009; Diez Roux, 2004). In other words, personal preferences and attitudes towards travel behaviors may affect residential location selection. For example, people preferring walking may consciously choose to live in neighborhoods that encourage walking. Therefore, the observed built environment-travel behavior associations may be spurious. Empirical studies confirm that residential location choice is endogenous to the relations between travel behavior and urban form (Boarnet and Crane, 2001; Krizek, 2003; Sermons and Seredich, 2001). Social inequity, particularly in terms of household income and vehicle ownership, also contributes to residential self-selection. Low-income families may choose residential locations solely because of housing affordability, which may not have urban design features that support walking. Built environment-travel behavior associations have been found to be divergent from community socioeconomic status (Su et al., 2017). People in households without access to a car make 42% more walking journeys than the population average (Boone-Heinonen et al., 2010). Socioeconomically disadvantaged communities are found to have fewer design features supporting active transport for children. These results illustrate the significant social inequalities in both built environment and travel behavior.

The two main research approaches taken to mitigate residential self-selection bias are first to distinguish residential preferences, often via a questionnaire, from built environment-travel behavior relationships (Boone-Heinonen et al., 2011; Cao, 2015b; Ding et al., 2018; Sallis, 2009; Van Dyck et al., 2011), and second, to use a longitudinal research design to explore the influence of changes in urban form on travel behavior (due to residential movement or built environment intervention), with the individual as his or her own control (Aditjandra et al., 2016; Braun et al., 2016; Collins et al., 2018; Giles-Corti et al., 2013; Hirsch et al., 2016; Hirsch et al., 2014; Karmeniemi et al., 2018; Knuiman et al., 2014; McCormack et al., 2017). Both built environment and self-selection have been found to affect the variations in travel behavior across different neighborhoods, and that residential self-selection typically weakens the effects of the built environment on travel behavior (Cao et al., 2009). For example, a recent review of longitudinal studies found that the effects of environmental change/relocation on various travel behaviors were weak, unlike the findings in cross-sectional studies (Ding et al., 2018). Some studies also reported attenuated associations between built environment characteristics and physical activity after accounting for residential self-selection (McCormack and Shiell, 2011).

### 1.3. Opportunity arising from large-scale public housing programs

Hong Kong is a densely populated city on the southeast coast of China and is internationally renowned for its large-scale public housing program, which provides inexpensive accommodation for low-income families. As of 2018, the total stock of public rental housing flats was 818,903, which provided accommodation for nearly 30 percent of the total population (Census & Statistics Department of Hong Kong, 2018). Each public house estate has on average 3975 housing flats and a site area of 60,000 $m^2$, accommodating 10,832 residents. Public housing estates are located throughout the Hong Kong territories, and generally consist of multiple 30- to 40-story residential towers and surrounding public spaces built for physical and leisure activities. Importantly, the assignment of public flats is largely based on availability and family size, but not on personal preferences for residential location. Public housing residents had little freedom to choose residential location according to their travel preferences. Hence, the residential self-selection bias is significantly reduced for public housing residents (Fig. 1).

Previous studies have established that exploring built environment-travel behavior associations for public housing residents is a viable option to address self-selection bias, because those residents cannot realize their travel preferences and the differences in travel behaviors of public housing residents are largely caused by built environment characteristics (Lin et al., 2017). For example, one study explored the changes in travel behaviors for low-income women moving to either a neo-traditional community or a suburban neighborhood with the help from a public housing program (Wells and Yang, 2008). In another

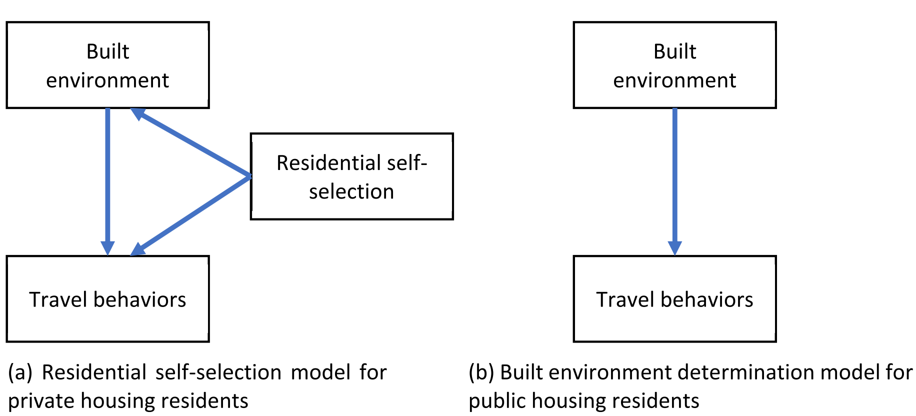


**Fig. 1.** The conceptual framework. (a) Private housing residents can choose their residential locations based on their travel abilities and preferences. The built environment-travel behavior associations may be overestimated because of residential self-selection. (b) Public housing residents have little freedom to choose residential locations; their travel behaviors are largely determined by built environment characteristics. By comparing the strength of built environment-travel behavior associations for the two groups, we can identify whether residential location choice is endogenous to the associations between travel behavior and built environment characteristics.


**Fig. 2.** Eye-level street greenness assessment with PSPNet, a computer deep learning technique. (a) Sampling points with 50 m spacing were generated in the street centerlines. (b) Four streetscape images were retrieved for each point from Google Street View, in the north, east, south, and west directions, respectively. (c) All street vegetation in the images was segmented with PSPNet.

study, the built environment-travel behaviors associations were compared for two groups of residents related to whether they have freedom to choose residential locations in Beijing, China (Lin et al., 2017). As suggested by that study, built environment and travel preferences reciprocally affect each other for the group with freedom to choose residential location; built environment determines travel preferences for the group without freedom (Lin et al., 2017). Therefore, in the context of China and other societies with large-scale public housing programs, it is critical to identify whether residents have freedom to choose where they live (Lin et al., 2017).

### 1.4. Our study

Objectively estimating residents' daily exposure to the built environment is another challenge facing researchers. Urban big data have been recently exploited to measure fine-grained urban greenness exposure and other urban environment characteristics (Adlakha, 2017; Nguyen et al., 2018; Su et al., 2017). For example, most health studies used one of three methods to assess street greenery: questionnaires, field audits, and geographic information systems (GIS) (Lu et al., 2018). Some recent studies have demonstrated the big data of urban streetscape images, such as Google Street View (GSV), can be a cost-effective and time-saving method of assessing greenness exposure, because these images bear a close resemblance to what pedestrian see on the streets. Emerging evidence supports that fine-grained urban greenness exposure accessed by GSV is significantly correlated with active transport, overall physical activity behaviors and mental health (Lu, 2018; Lu et al., 2018; Rzotkiewicz et al., 2018; Wang et al., 2019a, 2019b).

We address these issues in the present study. First, we exploit the research opportunity of a citywide public housing scheme in Hong Kong to address the issue of residential self-selection bias. We can confidently control for residential self-selection by comparing the built environment-travel behavior associations of elderly people who can satisfy their residential preferences (e.g., those in private housing estates) with those who cannot (e.g., the elderly in public housing estates) (Fig. 1) (Smith et al., 2016). Second, we estimate residents' exposure to urban greenness using GSV images combined with a machine learning technique. In brief, the current study examines whether the elderly in private and public housing estates have different travel behaviors, and whether the built environment has different effects on these two groups of elderly people.

## 2. Methods

### 2.1. Travel data

We obtained travel behavior data from the 2011 Hong Kong Travel Characteristics Survey (HKTCS). The HKTCS was commissioned by the Transportation Department to identify the general travel behavior of the whole Hong Kong population, and thus has a large sample size. The main survey includes a total of 13,468 elderly people ($\geq$65 years old), 4,680 of whom live in public housing estates and 8,788 in private housing estates. Trained interviewers conducted the face-to-face interviews, and individual information including age, gender, dwelling location, and household income were obtained. The travel behavior of the participants was examined in this round of the main survey by asking them whether they had decided to walk or not during the previous 24 h (their willingness to walk). The survey response rate was 71%. Thus, from this survey we can identify whether the participants had recently walked or not. It was worth noting, only participants making at least one travel trip were included in our analysis, because personal factors, such as physical function limitations, may prevent some elderly people from conducting travel behaviors independently.

The interviewers conducted an additional survey for a subset of 3,961 elderly people to obtain detailed travel trip data including the number of trips taken and the total travel distance, travel time, walking time, and the number of trips with different types of motorized transport. We thus obtain detailed travel data for the 3,961 elderly people. Ethical approval for the study was obtained from the Research Committee of City University of Hong Kong (H000691).

### 2.2. Urban greenness

The level of urban greenness exposure was obtained from the GSV images in conjunction with a machine learning technique, PSPNet (Zhao et al., 2017). Using the reported addresses, the locations of the participants were geocoded on a digital map with ArcGIS 10.5 (Esri, USA). A neighborhood was defined as a 500 m street network buffer around a participant's dwelling location. The sampling points are generated on the street centerline, with a spacing of 50 m as the buffer. Using the Python script we developed, we retrieved four street view images facing north, east, south, and west (Fig. 2). We trained the PSPNet model with the cityscape dataset, a repository of 5,000 streetscape images with pixel-level annotations from 50 cities. The trained PSPNet model can extract vegetation in any new streetscape images (Fig. 2c). The greenness value for each point can be measured by the green view index (the proportion of green pixels in the four images), using the following formula:

$$\text{Green view index} = \sum_{i=1}^{4} \textit{Greenery pixels}_i / \sum_{i=1}^{4} \textit{Total pixels}_i$$

The green view index values range from 0.0 to 1.0, with a higher value indicating more eye-level greenness. The average green vision index of all points in the buffer zone is used to assess the communities around the place of residence. The reliability of the PSPNet greenness extraction has been confirmed in other studies by comparing it with the level extracted through expert judgement ($r = 0.89$; $p < 0.01$).

### 2.3. Other factors

Other built environment characteristics that may potentially influence travel behavior were included: population density, street connectivity, and land-use mix (Barnett et al., 2017; Cerin et al., 2017). The population density data were obtained from the Census & Statistics Department of the Hong Kong government. The density was measured by the residential population per km$^2$ (people/km$^2$). Land-use mix was measured by the land-use entropy score, indicating the level of land-use diversity. Four land-use types were included in this score: residential, retail, office, and recreational. Street connectivity was calculated as the number of three-way or four-way street intersections per km$^2$. The data were obtained from the Planning Department of Hong Kong. We also measured distance to transit and destination accessibility, which may also affect travel behaviors for elderly people (Barnett et al., 2017; Cerin et al., 2017; Tan and Xue, 2016). These were assessed by the distance to the closest Mass Transit Rail (MTR) station and the number of retail shops, respectively. The individuals' information, e.g., age, gender, private vehicle ownership, and household income, were also included in the study.

### 2.4. Data analysis

A two-step analysis structure was applied to measure travel behavior: the likelihood of walking or not for 13,468 elderly people, and the detailed travel behavior (including number of trips, total travel distance, total travel time, total walking time, and number of motorized trips) of a subset of 3,961 participants. Separate multilevel models were conducted to account for the clustering structure of elderly people (level 1) nested within neighborhoods (level 2). In Analysis 1, a logistic regression model was used to test the associations between various built environment factors and the odds of walking for 13,468 elderly people. In Analysis 2, linear regression models were used to test the associations of predictors with various travel behaviors for the subset of participants. The travel behavior of elderly people in public housing was compared with those in private housing, using the mean, standard deviation (SD), *t*-test, and corresponding p-values. In all analyses, data were divided into public and private housing to identify how built environment-travel behavior associations vary across these two groups of participants. Built environment variables were selected based on variance inflation factor (VIF), ensuring there was no multicollinearity between those variables, similar to selection criterion in previous studies (Ma and Dill, 2015; Mertens et al., 2017). All variables (VIF ≤ 2) were kept in regression models except street intersection density. The intra-class correlation coefficient (ICC) was reported to estimate the proportion of variation in outcomes attributed to clustering structure, i.e. the degree of fitness of multilevel models. The monthly household income data were converted to a four-band categorical variable: low (< 10 k HKD/month), medium-low (10 k-20 k), medium-high (20 k-30 k) and high (> 30 k). The multilevel modeling was conducted in R with the lme4 package. Odds ratios (ORs), 95% confidence intervals (CIs), and standardized β were reported for the model fitting.

## 3. Results

### 3.1. Descriptive results

The descriptive statistics of the 13,468 elderly in Analysis 1 are shown in Table 1. Overall, 53.9% of participants walked at least once. The average age was 74.5 years. Female participants slightly outnumbered male (52.2% vs. 47.8%), and a large proportion had low household incomes (42.1%). Most participants had no private vehicles (92.6%). Roughly one third (34.7%) lived in public housing estates with the remainder in private housing estates (65.3%).

**Table 1**
Characteristics of study participants in Analysis 1. ($N = 13{,}468$; Hong Kong SAR, China, in 2011).

| Individual characteristics | Number of participants (number of neighborhoods) | Percentage (%) | Do some walking (%) |
|---|---|---|---|
| Gender | | | |
| Male | 6443 | 47.8 | 52.8 |
| Female | 7025 | 52.2 | 54.8 |
| Household income (HKD/month) | | | |
| Low (< 10 k) | 5673 | 42.1 | 57.9 |
| Medium-low (10–20 k) | 3198 | 23.7 | 53.6 |
| Medium-high (20–30 k) | 2171 | 16.1 | 52.8 |
| High (> 30 k) | 2426 | 18 | 45.8 |
| Vehicle ownership | | | |
| No | 12477 | 92.6 | 54.8 |
| Yes | 991 | 7.4 | 41.8 |
| Housing type | | | |
| Public housing | 4680 (238) | 34.7 | 55.1 |
| Private housing | 8788 (1529) | 65.3 | 53.2 |
| All participants | 13468 | 100 | 53.9 |

**Table 2**
Characteristics of study participants in Analysis 2. (*N* = 3,961; Hong Kong SAR, China in 2011).

| Individual characteristics | Number of participants (number of neighborhoods) | Percentage (%) |
|---|---|---|
| Gender | | |
| Male | 2148 | 54.2 |
| Female | 1813 | 45.8 |
| Household income (HKD/month) | | |
| Low (< 10 k) | 1568 | 39.6 |
| Medium-low (10–20 k) | 903 | 22.8 |
| Medium-high (20–30 k) | 648 | 16.4 |
| High (> 30 k) | 842 | 21.3 |
| Vehicle ownership | | |
| No | 3548 | 89.6 |
| Yes | 413 | 10.4 |
| Housing type | | |
| Public housing | 1203 (197) | 30.4 |
| Private housing | 2758 (929) | 69.6 |
| All participants | 3961 | 100 |

The descriptive statistics of the 3,961 participants in Analysis 2 are shown in Table 2. The average age was 72.4 years, and there were fewer female participants than male (45.8% vs. 54.2%). A large proportion of participants had low household incomes (39.6%). Vehicle ownership was 10.4%. The participants in private housing estates still outnumbered those in public housing estates (69.6% vs. 30.4%).

The detailed travel behavior outcomes in Analysis 2 were summarized by the residential type (public vs. private estates). The mean, standard deviation (SD), *t*-test, and corresponding p-value are given in Table 3. The elderly in public housing had fewer trips (2.13 vs. 2.25), shorter overall travel times (72.29 min vs. 75.43 min), and travel distances (9974.01 m vs. 11745.48 m), and fewer trips in motorized transport, including rail (0.53 vs. 0.66) and private cars (0.01 vs. 0.13), than those in private housing.

### 3.2. The associations between built environment attributes and the likelihood of walking (elderly people in public vs. private housing)

The results of the model predicting the odds of walking from Analysis 1 are given in Table 4. As hypothesized, the odds of walking for those in both public and private housing had markedly different associations with built environment characteristics and individual factors. The model of all built environment factors accounts for 9% of variance in the likelihood of walking for elderly people in public housing, and 17% for those in private housing. By controlling for residential self-selection, the built environment-likelihood of walking association reduces from 17% (elderly people in private housing) to 9% (those in public housing). We assume residential self-selection is only applicable for elderly people in private housing but not those in public housing. Hence, we can estimate residential self-selection may account for 47% of observed built environment-likelihood of walking association for elderly people in private housing, by calculating the percentage change of strengths of two associations ($R^2$) with formula: (17%–9%)/17% = 47%. The intra-class correlation coefficient (ICC) for elderly people in public housing was 0.13, indicating that 13% of variance in walking propensity can be explained by the clustering structure. The ICC for the multilevel model of elderly people in private housing was 0.21.

The number of retail shops was significantly related to the likelihood of walking for both groups. Land-use mix was significantly associated with the likelihood of walking for those in public housing but not in private housing. Urban greenness and population density were significantly associated with the likelihood of walking for those in private but not in public housing.

In terms of individual factors and neighborhood SES, vehicle ownership was negatively associated with the likelihood of walking for both groups. Neighborhood medium household income, household income, gender, and age were negatively associated with the likelihood of walking only for elderly people in private housing. Females in private housing had a higher likelihood to walk than males.

### 3.3. The associations between built environment attributes and total numbers of trips (elderly people in public vs. private housing)

The associations between built environment attributes and the total number of trips in Analysis 2 are shown in Table 5. The model of all built environment factors accounts for 17% of variance in the number of trips taken by elderly people in public housing, and for 39% of those in private housing. We can estimate residential self-selection may account for 56% of the observed associations between built environment factors and total number of trips for elderly people in private housing.

The number of trips taken by those in public and private housing exhibited markedly different associations with built environment characteristics and individual factors. The number of retail shops was negatively related to the number of trips for elderly people in both public and private housing. Distance to MTR was negatively associated with the number of trips of those in public housing only, while population density was negatively associated with the number of trips only for those in private housing.

In terms of neighborhood SES and individual factors, a neighborhood medium household income was positively associated with the number of trips only for those in private housing. Gender and age were negatively associated with the number of trips of elderly people in both public and private housing. Vehicle ownership was positively associated with trips only for those in private housing.

### 3.4. The associations between built environment attributes and total travel distance (elderly people in public vs. private housing)

The associations between built environment attributes and total travel distance in Analysis 2 are shown in Table 6. The model of all built environment factors accounts for 30% of variance in the total travel distance of elderly people in public housing, and for 43% of those in

**Table 3**
Travel behaviors by different residential types (public vs. private housing) in Analysis 2; N = 3,961.

| Travel behavior | Elderly in public estates mean (SD) | Elderly in private estates mean (SD) | *t*-test | p-value |
|---|---|---|---|---|
| Number of trips | 2.13 (0.54) | 2.25 (0.73) | −5.99 | < 0.01* |
| Number of walking trips | 0.15 (0.47) | 0.18 (0.52) | −1.74 | 0.08 |
| Total travel distance (m) | 9974.01 (10791.18) | 11745.48 (12356.19) | −4.54 | < 0.01* |
| Total travel time (min) | 72.29 (39.5) | 75.43 (41.9) | −2.26 | 0.02* |
| Total walking time (min) | 20.81 (12.61) | 21.46 (13.24) | −1.49 | 0.14 |
| Number of motorized trips | 1.97 (0.43) | 2.06 (0.54) | −5.48 | < 0.01* |
| Number of trips by rail | 0.53 (0.87) | 0.66 (0.94) | −4.21 | < 0.01* |
| Number of trips by car | 0.01 (0.12) | 0.13 (0.55) | −11.17 | < 0.01* |
| Number of trips by bus | 1.42 (0.91) | 1.24 (1) | 5.48 | < 0.01* |

**Table 4**
Multilevel logistic regression analysis to predict the odds of walking in Analysis 1; N = 13,468.

| Model predictors | Elderly in public housing | | Elderly in private housing | |
|---|---|---|---|---|
| | OR (95% CI) | p-value | OR (95% CI) | p-value |
| Built environment | | | | |
| Urban greenness | 1.01, (0.87, 1.18) | 0.91 | 1.14, (1.02, 1.27) | 0.02* |
| Population density | 1.07, (0.94, 1.22) | 0.32 | 1.14, (1.04, 1.24) | < 0.01* |
| Land-use mix | 1.17, (1.04, 1.32) | 0.01* | 1.01, (0.93, 1.11) | 0.77 |
| Number of retail shops | 1.18, (1.04, 1.35) | 0.01* | 1.28, (1.15, 1.43) | < 0.01* |
| Distance to MTR | 1.12, (1.00, 1.26) | 0.06 | 1.06, (0.96, 1.17) | 0.22 |
| Neighborhood SES | | | | |
| Medium household income | 0.93, (0.84, 1.03) | 0.16 | 0.90, (0.83, 0.96) | < 0.01* |
| Individual factors | | | | |
| Gender (Male as ref.) | | | | |
| Female | 1.05, (0.93, 1.19) | 0.43 | 1.14, (1.04, 1.26) | < 0.01 |
| Household income (Low as ref.) | | | | |
| Medium-low (10–20 k) | 0.85, (0.73, 1.03) | 0.06 | 0.91, (0.80, 1.04) | 0.17 |
| Medium-high (20–30 k) | 0.91, (0.75, 1.11) | 0.36 | 0.82, (0.71, 0.95) | 0.01* |
| High (> 30 k) | 0.83, (0.62, 1.13) | 0.24 | 0.70, (0.61, 0.81) | < 0.01* |
| Vehicle ownership (No as ref.) | | | | |
| Yes | 0.57, (0.36, 0.89) | 0.01* | 0.83, (0.69, 0.99) | 0.03* |
| Age | 0.94, (0.88, 1.00) | 0.06 | 0.95, (0.91, 1.00) | 0.04* |
| R-squared values (Tjur's D) | 0.09 | | 0.17 | |
| Intra-class correlation coefficient (ICC) | 0.13 | | 0.21 | |

private housing. Residential self-selection may account for 30% of the observed associations between built environment factors and total travel distance for elderly people in private housing.

The travel distances for elderly people in public and private housing also exhibited markedly different associations with built environment characteristics and individual factors. Population density, number of retail shops, and distance to MTR were significantly related to total travel distance only for those in private housing. None of the built environment factors were related to total travel distance for those in public housing.

In terms of individual factors, gender and age were negatively associated with total travel distance for the elderly in both public and private housing. High household income was positively associated with travel distance only for those in private housing.

### 3.5. The associations between built environment attributes and walking times (elderly people in public vs. private housing)

The associations between built environment attributes and total walking time in Analysis 2 are shown in Table 7. The pattern of results for this analysis was similar to those previously found. The overall model accounts for 22% of variance in the walking time of elderly people in public housing, and for 35% of those in private housing. Residential self-selection may account for 37% of the observed associations between built environment factors and walking times for elderly people in private housing.

The total walking time of those in public housing was also weakly related to predictors, unlike those in private housing. For those in both public and private housing, the number of retail shops was positively associated with walking time, and distance to the closest MTR station was negatively associated with walking time. However, urban greenness was positively associated with walking time for those in private but not in public housing. Neighborhood medium household income,

**Table 5**
Multilevel linear regression analysis to predict total number of trips in Analysis 2; N = 3,961.

| Model predictors | Elderly in public housing | | Elderly in private housing | |
|---|---|---|---|---|
| | β (95% CI) | p-value | β (95% CI) | p-value |
| Built environment | | | | |
| Urban greenness | 0.02, (−0.07,0.11) | 0.68 | 0.03, (−0.03, 0.08) | 0.33 |
| Population density | −0.04, (−0.09, 0.02) | 0.20 | −0.03, (−0.07, 0.00) | 0.05* |
| Land-use mix | −0.02, (−0.07, 0.03) | 0.40 | 0.00, (−0.03, 0.04) | 0.88 |
| Number of retail shops | −0.07, (−0.12,-0.01) | 0.01* | −0.11, (−0.16,-0.07) | < 0.01* |
| Distance to MTR | −0.06, (−0.11,-0.01) | 0.01* | 0.00, (−0.04, 0.03) | 0.82 |
| Neighborhood SES | | | | |
| Medium household income | 0.02, (−0.02,0.07) | 0.31 | 0.08, (0.05, 0.11) | < 0.01* |
| **Individual factors** | | | | |
| Gender (Male as ref.) | | | | |
| Female | −0.08, (−0.13,-0.02) | 0.01* | −0.17, (−0.21,-0.13) | < 0.01* |
| Household income (Low as ref.) | | | | |
| Medium-low (10–20 k) | −0.07, (−0.14, 0.00) | 0.04 | −0.04, (−0.09, 0.02) | 0.18 |
| Medium-high (20–30 k) | −0.04, (−0.13, 0.05) | 0.40 | −0.05, (−0.11, 0.01) | 0.09 |
| High (> 30 k) | −0.16, (−0.30,-0.02) | 0.02 | −0.05, (−0.10, 0.01) | 0.11 |
| Vehicle ownership (No as ref.) | | | | |
| Yes | 0.12, (−0.08,0.32) | 0.24 | 0.15, (0.08, 0.23) | < 0.01* |
| Age | −0.02, (−0.03,-0.02) | < 0.01* | −0.03, (−0.03,-0.02) | < 0.01* |
| R-squared values | 0.17 | | 0.39 | |
| Intra-class correlation coefficient (ICC) | 0.09 | | 0.21 | |

**Table 6**
Multilevel linear regression analysis to predict total travel distance in Analysis 2; N = 3,961.

| Model predictors | Elderly in public housing | | Elderly in private housing | |
|---|---|---|---|---|
| | β (95% CI) | p-value | β (95% CI) | p-value |
| Built environment | | | | |
| Urban greenness | 0.03, (−0.15, 0.22) | 0.71 | −0.07, (−0.16, 0.02) | 0.10 |
| Population density | 0.03, (−0.09, 0.16) | 0.57 | −0.09, (−0.14, −0.03) | < 0.01* |
| Land-use mix | 0.11, (0.00, 0.21) | 0.05 | −0.05, (−0.10, 0.01) | 0.11 |
| Number of retail shops | 0.09, (−0.02, 0.19) | 0.10 | 0.09, (0.02, 0.16) | 0.01* |
| Distance to MTR | −0.03, (−0.13, 0.07) | 0.58 | 0.06, (0.01, 0.12) | 0.03* |
| Neighborhood SES | | | | |
| Medium household income | 0.07, (−0.02, 0.16) | 0.14 | −0.05, (−0.10, 0.00) | 0.06 |
| Individual factors | | | | |
| Gender (Male as ref.) | | | | |
| Female | −0.18, (−0.29, −0.08) | < 0.01* | −0.15, (−0.22, −0.08) | < 0.01* |
| Household income (Low as ref.) | | | | |
| Medium-low (10–20 k) | 0.02, (−0.11, 0.14) | 0.81 | 0.02, (−0.08, 0.12) | 0.69 |
| Medium-high (20–30 k) | 0.03, (−0.14, 0.20) | 0.73 | 0.03, (−0.08, 0.14) | 0.64 |
| High (> 30 k) | 0.55, (0.28, 0.82) | < 0.01* | 0.01, (−0.09, 0.12) | 0.80 |
| Vehicle ownership (No as ref.) | | | | |
| Yes | −0.03, (−0.38, 0.32) | 0.87 | 0.20, (0.08, 0.31) | < 0.01* |
| Age | −0.01, (−0.02, −0.01) | < 0.01* | −0.01, (−0.02, −0.01) | < 0.01* |
| R-squared values | 0.30 | | 0.43 | |
| Intra-class correlation coefficient (ICC) | 0.20 | | 0.27 | |

**Table 7**
Multilevel linear regression analysis to predict total walking time in Analysis 2; N = 3,961.

| Model predictors | Elderly in public housing | | Elderly in private housing | |
|---|---|---|---|---|
| | β (95% CI) | p-value | β (95% CI) | p-value |
| Built environment | | | | |
| Urban greenness | −0.13, (−0.36, 0.10) | 0.26 | 0.23, (0.06, 0.39) | 0.01* |
| Population density | 0.04, (−0.04,0.13) | 0.30 | 0.01, (−0.05, 0.07) | 0.71 |
| Land-use mix | 0.08, (−0.01, 0.17) | 0.07 | −0.02, (−0.07, 0.04) | 0.56 |
| Number of retail shops | 0.08, (0.01, 0.17) | 0.05* | 0.11, (0.04, 0.17) | < 0.01* |
| Distance to MTR | −0.10, (−0.19,-0.01) | 0.02* | −0.07, (−0.12,-0.01) | 0.02* |
| Neighborhood SES | | | | |
| Medium household income | 0.04, (−0.04, 0.12) | 0.38 | −0.06, (−0.11,-0.01) | 0.02* |
| Individual factors | | | | |
| Gender (Male as ref.) | | | | |
| Female | −0.11, (−0.22, 0.00) | 0.06 | 0.02, (−0.05, 0.09) | 0.59 |
| Household income (Low as ref.) | | | | |
| Medium-low (10–20 k) | 0.00, (−0.13, 0.13) | 0.97 | 0.03, (−0.08, 0.13) | 0.63 |
| Medium-high (20–30 k) | −0.12, (−0.29, 0.06) | 0.19 | −0.09, (−0.20, 0.02) | 0.12 |
| High (> 30 k) | 0.04, (−0.23, 0.32) | 0.76 | −0.07, (−0.18, 0.03) | 0.17 |
| Vehicle ownership (No as ref.) | | | | |
| Yes | −0.16, (−0.52, 0.19) | 0.37 | −0.18, (−0.30, −0.05) | < 0.01* |
| Age | 0.00, (−0.01, 0.01) | 0.84 | −0.01, (−0.01, 0.00) | 0.02* |
| R-squared values | 0.22 | | 0.35 | |
| Intra-class correlation coefficient (ICC) | 0.17 | | 0.20 | |

vehicle ownership, and age were negatively associated with the walking time of those in private but not public housing.

## 4. Discussion

The present study compared the differences in travel behavior and the environment-travel associations of elderly people living in private and public housing estates. Those in public housing have far less freedom to choose their residential locations and are often unable to realize their preferences when assigned housing, so we can rule out the residential self-selection bias when estimating built environment-travel behavior associations. By comparing the strength of built environment-travel behavior associations for the two groups of elderly people, we can identify whether residential location choice is endogenous to the associations between travel behavior and built environment characteristics.

### 4.1. Major findings

As shown in Table 3, elderly people in public and in private housing estates exhibit notably different travel behaviors. Those in public housing estates had fewer trips, shorter total travel distances and times, and fewer trips by rail or by car but more trips by bus than their counterparts in private housing estates. Socioeconomic status may account for these differences. The elderly in private housing estates may make more trips because they have more potential destinations which they regularly visit. However, the number of walking trips and total walking time were similar for both groups. This finding differs from that in a previous study (Boone-Heinonen et al., 2010), which suggested that people of low-income households walk more than those in high-income households. The low prevalence of private vehicles and the well-established public transport system in Hong Kong may explain the contrasting finding in Hong Kong. Elderly people in both private and public housing estates rely heavily on walking and public transport, although those in the former use rail services more often, which are more expensive but more comfortable than the bus service.

Marked differences were found in the built environment-travel associations for the two groups of elderly people, regarding the likelihood of walking, the total number of trips, trip distance, and the decision to walk. The number of retail shops was negatively associated with the number of trips for elderly people in both public and private housing. The distance to the MTR was positive for those in public housing, while population density was negative for those in private housing. The number of retail shops was positively associated with the decision to take walking trips for elderly people in both public and private housing. Urban greenness and population density were positive only for those in private housing. Land-use mix was positive for those in public housing. In terms of total travel distance, population density was negative while the number of retail shops and the distance to MTR were positive for those in private housing. No built-environment characteristics had significant effects for those in public housing. The number of retail shops was positively associated with total walking time, while distance to MTR was negative for both groups. Urban greenness was only positive for those in private housing.

Our results suggest that built environment characteristics have greater effects on elderly people in private housing than on those in public housing. As implied by the difference in the strength of built environment-travel behavior associations ($R^2$ values) between the two groups, residential self-selection substantially reduces the associations by 30–50%. The reported built environment-travel behavior associations may be overestimated in other cross-sectional studies. Hence, future health studies should control for residential self-selection in their research designs. The findings support that both built environment and residential self-section affect travel behaviors (Boone-Heinonen et al., 2011; Cao, 2015a; Ettema and Nieuwenhuis, 2017; Ewing and Cervero, 2010; Feuillet et al., 2016; Howell et al., 2018). For example, different sociodemographic characteristics, attitudes, and preferences will influence which communities' residents choose to live in, and will therefore experience different built environment characteristics (Howell et al., 2018). The decision to use public transport is influenced the most by whether residents deliberately choose to live in an environment conducive to using this mode (Ettema and Nieuwenhuis, 2017). Residential preferences also confounded the associations between built environment characteristics and the time spent walking (Howell et al., 2018).

The discrepancy in built environment-travel associations among the two groups is manifested in the effect of urban greenness. Urban greenness was related to the decision to walk, and to the total walking time for elderly people in private but not for those in public housing. Elderly people with higher family incomes can choose to live in private housing estates within greener neighborhoods, while those with lower incomes do not have this choice. This is consistent with previous findings. For example, in Shanghai, residents with higher incomes can enjoy private, club-like green spaces within their housing estates, while lower income residents only have access to public green spaces (Xiao et al., 2017). A 25% difference was found in the weekly total leisure-time physical activity, in terms of minutes, between individuals with and without the self-reported availability of outdoor greenspaces or recreational facilities (Mackenbach et al., 2018).

Among all built environment characteristics, the number of retail shops is most consistently related to almost every aspect of travel behaviors for both elderly groups in Hong Kong. The results are consistent with previous evidence that the availability of pedestrian destinations is important for active travel behaviors such as walking. The presence of a mall has been positively associated with neighborhood walking in both objective and perceived models (Michael et al., 2006). The walking time per week has been significantly associated with the number of commercial establishments in local neighborhoods (Nagel et al., 2008). Retail shops, such as grocery shops, market places, and shopping malls, are essential to the daily life of the elderly in Hong Kong, possibly because they lack other types of leisure space (Zang et al., 2018). However, urban density and land-use mix have insignificant effects on most outcomes of travel behavior. The findings differ from those of previous studies, which are often conducted in Western cities with low urban density (Sallis, 2009). The different urban density may cause the different findings. The urban density of Hong Kong is much higher than in Western cities (Xue and Sun, 2018), and so in relative terms Hong Kong's low density may be equivalent to high density in other Western cities, or even higher, and thus urban density has a marginal impact on travel behavior (Lu et al., 2016). The same may apply to land-use mix, as mixed-used multilevel buildings are the norm in Hong Kong. The insignificant effects of urban density and land-use mix on travel behavior have also been found in other dense urban areas in Asia and South America (Lu et al., 2016, 2019; Salvo et al., 2014; Xu et al., 2010). For example, walkability, a composite measure of urban density, land-use mix, and street intersection density, was inversely associated with the moderate-to-vigorous physical activity time of adults in Cuernavaca, Mexico (Salvo et al., 2014).

### 4.2. Policy implications

The findings of the current study have several policy implications. The travel behaviors of different groups of elderly people have different associations with built environment characteristics. Hence, targeted policy interventions or urban planning strategies are needed to stimulate active travel behaviors of the specific demographic groups. Furthermore, our results suggest that pedestrian destination availability in neighborhoods outperforms 3D's variables (density, diversity and design) in predicting travel behaviors of elderly people in Hong Kong. Hence, local governments should be cautious when interpreting the findings of studies conducted in cities with different urban and social contexts, because they may be inapplicable. Our suggestion is, by collecting localized evidence, we can propose proper solutions to address important issues like population ageing and declined active transport rate.

### 4.3. Strengths and limitations

This study has several strengths. First, we exploited a unique research opportunity from a large-scale public housing scheme to distinguish residential self-selection from the effects of built environment characteristics on travel behavior. Second, this study features a large sample size, representative of the whole elderly population in Hong Kong. In addition, the travel behavior was scrutinized in depth and various aspects were considered, such as the number of trips, the likelihood of walking, total walking time, total travel distance and time, and the number of trips by rail, private car, or bus. The travel data were collected by trained interviewers using face-to-face interviews, to maintain high data quality. Third, urban big data of streetscape images were used to objectively assess eye-level urban greenness. The images more closely resemble what residents can see and perceive on the ground than overhead-view satellite images, so this is a quick and efficient method of estimating residents' daily exposure to urban greenness. This study also has some limitations. We still cannot establish a causal relationship between built environment characteristics and travel behavior, but we did address the residential self-selection bias. A more rigorous research design, such as a natural experiment, is warranted. The travel behaviors were self-reported and thus prone to recall-bias or social desirability bias. These could be objectively collected via portable devices, such as GPS systems and accelerometers, in future studies.

## 5. Conclusion

This present study compared the difference in the effect of the built environment on the travel behavior of two groups of elderly people: those living in private housing estates and those in public housing.

Those in public housing cannot realize their personal residential preferences because public housing allocation is largely based on random assignment and flat availability. Hence, we can control for residential self-selection when estimating built environment-travel associations. The results reveal a complex relationship among built environment, residential self-selection, and travel behavior. Thus, the elderly people in public housing have fewer trips, shorter overall travel times and distances, and fewer trips in motorized transport such as rail or private cars than those in private housing. The built environment has a stronger effect on the travel behavior of elderly people in private housing than in public housing. The results indicate residential self-selection and built environment simultaneously affect travel behavior. Hence, as suggested in other studies, it is important to control for residential self-selection when estimating built environment-travel associations.

## Acknowledgements

The work described in this paper was fully supported by grants from the National Natural Science Foundation of China (No.51578474, 51778552, 41871140), the Research Grants Council of the Hong Kong Special Administrative Region, China (No. CityU11666716) and the Innovative Research and Development Team Introduction Program of Guangdong Province (No. 2017ZT07X355).

## References

Aditjandra, P.T., Cao, X.Y., Mulley, C., 2016. Exploring changes in public transport use and walking following residential relocation: a British case study. J. Transport Land Use 9 (3), 77–95. https://doi.org/10.5198/jtlu.2015.588.

Adlakha, D., 2017. Quantifying the modern city: emerging technologies and big data for active living research. Front. Publ. Health 5, 7. https://doi.org/10.3389/fpubh.2017.00105.

Badoe, D.A., Miller, E.J., 2000. Transportation-land-use interaction: empirical findings in North America, and their implications for modeling. Transp. Res. D Transp. Environ. 5 (4), 235–263. https://doi.org/10.1016/s1361-9209(99)00036-x.

Barnett, D.W., Barnett, A., Nathan, A., Van Cauwenberg, J., Cerin, E., 2017. Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. Int. J. Behav. Nutr. Phys. Act. 14 (1). https://doi.org/10.1186/s12966-017-0558-z.

Boarnet, M., Crane, R., 2001. The influence of land use on travel behavior: specification and estimation strategies. Transp. Res. A Policy Pract. 35 (9), 823–845. https://doi.org/10.1016/s0965-8564(00)00019-7.

Boone-Heinonen, J., Gordon-Larsen, P., Guilkey, D.K., Jacobs, D.R., Popkin, B.M., 2011. Environment and physical activity dynamics: the role of residential self-selection. Psychol. Sport Exerc. 12 (1), 54–60. https://doi.org/10.1016/j.psychsport.2009.09.003.

Boone-Heinonen, J., Guilkey, D.K., Evenson, K.R., Gordon-Larsen, P., 2010. Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood. Int. J. Behav. Nutr. Phys. Act. 7. https://doi.org/10.1186/1479-5868-7-70.

Braun, L.M., Rodriguez, D.A., Song, Y., Meyer, K.A., Lewis, C.E., Reis, J.P., Gordon-Larsen, P., 2016. Changes in walking, body mass index, and cardiometabolic risk factors following residential relocation: longitudinal results from the CARDIA study. J. Transport Health 3 (4), 426–439. https://doi.org/10.1016/j.jth.2016.08.006.

Cao, X., 2015a. Examining the impacts of neighborhood design and residential self-selection on active travel: a methodological assessment. Urban Geogr. 36 (2), 236–255. https://doi.org/10.1080/02723638.2014.956420.

Cao, X., 2015b. Heterogeneous effects of neighborhood type on commute mode choice: an exploration of residential dissonance in the Twin Cities. J. Transp. Geogr. 48, 188–196. https://doi.org/10.1016/j.jtrangeo.2015.09.010.

Cao, X., Mokhtarian, P.L., Handy, S.L., 2009. Examining the impacts of residential self-selection on travel behaviour: a focus on empirical findings. Transp. Rev. 29 (3), 359–395.

Cauwenberg, J.V., De Bourdeaudhuij, I., De Meester, F., Van Dyck, D., Salmon, J., Clarys, P., Deforche, B., 2011. Relationship between the physical environment and physical activity in older adults: a systematic review. Health Place 17 (2), 458–469. https://doi.org/10.1016/j.healthplace.2010.11.010.

Census & Statistics Department of Hong Kong, 2018. Population Estimates. Retrieved from. http://www.censtatd.gov.hk/hkstat/sub/so150.jsp.

Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D.W., Barnett, A., 2017. The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. Int. J. Behav. Nutr. Phys. Act. 14 (1). https://doi.org/10.1186/s12966-017-0471-5.

Chaudhury, H., Campo, M., Michael, Y., Mahmood, A., 2016. Neighbourhood environment and physical activity in older adults. Soc. Sci. Med. 149, 104–113. https://doi.org/10.1016/j.socscimed.2015.12.011.

Collins, P.A., Tait, J., Fein, A., Dunn, J.R., 2018. Residential moves, neighbourhood walkability, and physical activity: a longitudinal pilot study in Ontario Canada. BMC Public Health 18. https://doi.org/10.1186/s12889-018-5858-y.

Diez Roux, A.V., 2004. Estimating neighborhood health effects: the challenges of causal inference in a complex world. Soc. Sci. Med. 58 (10), 1953–1960.

Ding, D., Nguyen, B., Learnihan, V., Bauman, A.E., Davey, R., Jalaludin, B., Gebel, K., 2018. Moving to an active lifestyle? A systematic review of the effects of residential relocation on walking, physical activity and travel behaviour. Br. J. Sports Med. 52 (12), 789. https://doi.org/10.1136/bjsports-2017-098833.

Ettema, D., Nieuwenhuis, R., 2017. Residential self-selection and travel behaviour: what are the effects of attitudes, reasons for location choice and the built environment? J. Transp. Geogr. 59, 146–155. https://doi.org/10.1016/j.jtrangeo.2017.01.009.

Ewing, R., Cervero, R., 2010. Travel and the built environment. J. Am. Plan. Assoc. 76 (3), 265–294. https://doi.org/10.1080/01944361003766766.

Feuillet, T., Salze, P., Charreire, H., Menai, M., Enaux, C., Perchoux, C., Oppert, J.M., 2016. Built environment in local relation with walking: why here and not there? J. Transport Health 3 (4), 500–512. https://doi.org/10.1016/j.jth.2015.12.004.

Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., Van Niel, K., Timperio, A., Boruff, B., 2013. The influence of urban design on neighbourhood walking following residential relocation: longitudinal results from the RESIDE study. Soc. Sci. Med. 77, 20–30. https://doi.org/10.1016/j.socscimed.2012.10.016.

Hamdorf, P., Starr, G., Williams, M., 2002. A survey of physical-activity levels and functional capacity in older adults in South Australia. J. Aging Phys. Act. 10 (3), 281–289.

Handy, S.L., Boarnet, M.G., Ewing, R., Killingsworth, R.E., 2002. How the built environment affects physical activity - views from urban planning. Am. J. Prev. Med. 23 (2), 64–73. https://doi.org/10.1016/s0749-3797(02)00475-0.

Hirsch, J.A., Meyer, K.A., Peterson, M., Rodriguez, D.A., Song, Y., Peng, K., Gordon-Larsen, P., 2016. Obtaining longitudinal built environment data retrospectively across 25 years in four US cities. Front. Publ. Health 4. https://doi.org/10.3389/fpubh.2016.00065.

Hirsch, J.A., Roux, A.V.D., Moore, K.A., Evenson, K.R., Rodriguez, D.A., 2014. Change in walking and body mass index following residential relocation: the multi-ethnic study of atherosclerosis. Am. J. Public Health 104 (3), E49–E56. https://doi.org/10.2105/ajph.2013.301773.

Howell, N.A., Farber, S., Widener, M.J., Allen, J., Booth, G.L., 2018. Association between residential self-selection and non-residential built environment exposures. Health Place 54, 149–154. https://doi.org/10.1016/j.healthplace.2018.08.009.

Karmeniemi, M., Lankila, T., Ikaheimo, T., Koivumaa-Honkanen, H., Korpelainen, R., 2018. The built environment as a determinant of physical activity: a systematic review of longitudinal studies and natural experiments. Ann. Behav. Med. 52 (3), 239–251. https://doi.org/10.1093/abm/kax043.

King, A.C., Hekler, E.B., Grieco, L.A., Winter, S.J., Sheats, J.L., Buman, M.P., Cirimele, J., 2013. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. PLoS One 8 (4). https://doi.org/10.1371/journal.pone.0062613.

Knuiman, M.W., Christian, H.E., Divitini, M.L., Foster, S.A., Bull, F.C., Badland, H.M., Giles-Corti, B., 2014. A longitudinal analysis of the influence of the neighborhood built environment on walking for transportation. Am. J. Epidemiol. 180 (5), 453–461. https://doi.org/10.1093/aje/kwu171.

Krizek, K.J., 2003. Residential relocation and changes in urban travel - does neighborhood-scale urban form matter? J. Am. Plan. Assoc. 69 (3), 265–281. https://doi.org/10.1080/01944360308978019.

Lin, T., Wang, D.G., Guan, X.D., 2017. The built environment, travel attitude, and travel behavior: residential self-selection or residential determination? J. Transp. Geogr. 65, 111–122. https://doi.org/10.1016/j.jtrangeo.2017.10.004.

Lu, Y., 2018. Using Google Street View to investigate the association between street greenery and physical activity. Landscape Urban Plan., 103435. https://doi.org/10.1016/j.landurbplan.2018.08.029.

Lu, Y., Sarkar, C., Xiao, Y., 2018. The effect of street-level greenery on walking behavior: evidence from Hong Kong. Soc. Sci. Med. 208, 41–49. https://doi.org/10.1016/j.socscimed.2018.05.022.

Lu, Y., Xiao, Y., Ye, Y., 2016. Urban density, diversity and design: is more always better for walking? A study from Hong Kong. Prev. Med. https://doi.org/10.1016/j.ypmed.2016.08.042.

Lu, Y., Yang, Y., Sun, G., Gou, Z., 2019. Associations between overhead-view and eye-level urban greenness and cycling behaviors. Cities 88, 10–18. https://doi.org/10.1016/j.cities.2019.01.003.

Ma, L., Dill, J., 2015. Associations between the objective and perceived built environment and bicycling for transportation. J. Transport Health 2 (2), 248–255. https://doi.org/10.1016/j.jth.2015.03.002.

Mackenbach, J.D., de Pinho, M.G.M., Faber, E., den Braver, N., de Groot, R., Charreire, H., Lakerveld, J., 2018. Exploring the cross-sectional association between outdoor recreational facilities and leisure-time physical activity: the role of usage and residential self-selection. Int. J. Behav. Nutr. Phys. Act. 15. https://doi.org/10.1186/s12966-018-0689-x.

McCormack, G.R., McLaren, L., Salvo, G., Blackstaffe, A., 2017. Changes in objectively-determined walkability and physical activity in adults: a quasi-longitudinal residential relocation study. Int. J. Environ. Res. Public Health 14 (5). https://doi.org/10.3390/ijerph14050551.

McCormack, G.R., Shiell, A., 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int. J. Behav. Nutr. Phys. Act. 8, 11. https://doi.org/10.1186/1479-5868-8-125.

Mertens, L., Compernolle, S., Deforche, B., Mackenbach, J.D., Lakerveld, J., Brug, J., Van Dyck, D., 2017. Built environmental correlates of cycling for transport across Europe. Health Place 44, 35–42. https://doi.org/10.1016/j.healthplace.2017.01.007.

Michael, Y., Beard, T., Choi, D., Farquhar, S., Carlson, N., 2006. Measuring the influence of built neighborhood environments on walking in older adults. J. Aging Phys. Act.

14 (3), 302–312. https://doi.org/10.1123/japa.14.3.302.

Nagel, C.L., Carlson, N.E., Bosworth, M., Michael, Y.L., 2008. The relation between neighborhood built environment and walking activity among older adults. Am. J. Epidemiol. 168 (4), 461–468. https://doi.org/10.1093/aje/kwn158.

Nguyen, Q.C., Sajjadi, M., McCullough, M., Pham, M., Nguyen, T.T., Yu, W.J., Tasdizen, T., 2018. Neighbourhood looking glass: 360 degrees automated characterisation of the built environment for neighbourhood effects research. J. Epidemiol. Community Health 72 (3), 260–266. https://doi.org/10.1136/jech-2017-209456.

Rzotkiewicz, A., Pearson, A.L., Dougherty, B.V., Shortridge, A., Wilson, N., 2018. Systematic review of the use of Google Street View in health research: major themes, strengths, weaknesses and possibilities for future research. Health Place 52, 240–246. https://doi.org/10.1016/j.healthplace.2018.07.001.

Saelens, B.E., Handy, S.L., 2008. Built environment correlates of walking: a review. Med. Sci. Sport. Exerc. 40 (7), S550–S566. https://doi.org/10.1249/MSS.0b013e31817e67a4.

Sallis, J.F., 2009. Measuring physical activity environments: a brief history. Am. J. Prev. Med. 36 (4), S86–S92. https://doi.org/10.1016/j.amepre.2009.01.002.

Salvo, D., Reis, R.S., Stein, A.D., Rivera, J., Martorell, R., Pratt, M., 2014. Characteristics of the built environment in relation to objectively measured physical activity among Mexican adults. Prev. Chronic Dis. 2011 (11), E147. https://doi.org/10.5888/pcd11.140047.

Sener, I.N., Lee, R.J., Elgart, Z., 2016. Potential health implications and health cost reductions of transit-induced physical activity. J. Transport Health 3 (2), 133–140. https://doi.org/10.1016/j.jth.2016.02.002.

Sermons, M.W., Seredich, N., 2001. Assessing traveler responsiveness to land and location based accessibility and mobility solutions. Transp. Res. D Transp. Environ. 6 (6), 417–428. https://doi.org/10.1016/s1361-9209(01)00006-2.

Smith, K.R., Hanson, H.A., Brown, B.B., Zick, C.D., Kowaleski-Jones, L., Fan, J.X., 2016. Movers and stayers: how residential selection contributes to the association between female body mass index and neighborhood characteristics. Int. J. Obes. 40 (9), 1384–1391. https://doi.org/10.1038/ijo.2016.78.

Su, S.L., Li, Z.K., Xu, M.Y., Cai, Z.L., Weng, M., 2017. A geo-big data approach to intra-urban food deserts: transit-varying accessibility, social inequalities, and implications for urban planning. Habitat Int. 64, 22–40. https://doi.org/10.1016/j.habitatint.2017.04.007.

Sun, Y.R., Du, Y.Y., Wang, Y., Zhuang, L.Y., 2017. Examining associations of environmental characteristics with recreational cycling behaviour by street-level strava data. Int. J. Environ. Res. Public Health 14 (6), 12. https://doi.org/10.3390/ijerph14060644.

Tan, Z., Xue, C.Q.L., 2016. The evolution of an urban vision: the multilevel pedestrian networks in Hong Kong, 1965-1997. J. Urban Hist. 42 (4), 688–708. https://doi.org/10.1177/0096144214566962.

Tudor-Locke, C., Jones, G., Myers, A., Paterson, D., Ecclestone, N., 2002. Contribution of structured exercise class participation and informal walking for exercise to daily physical activity in community-dwelling older adults. Res. Q. Exerc. Sport 73 (3), 350–356.

van de Coevering, P., Maat, K., van Wee, B., 2015. Multi-period research designs for identifying causal effects of built environment characteristics on travel behaviour. Transp. Rev. 35 (4), 512–532. https://doi.org/10.1080/01441647.2015.1025455.

Van Dyck, D., Cardon, G., Deforche, B., Owen, N., De Bourdeaudhuij, I., 2011. Relationships between neighborhood walkability and adults' physical activity: how important is residential self-selection? Health Place 17 (4), 1011–1014. https://doi.org/10.1016/j.healthplace.2011.05.005.

Wang, R., Lu, Y., Zhang, J., Liu, P., Yao, Y., Liu, Y., 2019. The relationship between visual enclosure for neighbourhood street walkability and elders' mental health in China: using street view images. J. Transport Health 13, 90–102. https://doi.org/10.1016/j.jth.2019.02.009.

Wang, R., Yuan, Y., Liu, Y., Zhang, J., Liu, P., Lu, Y., Yao, Y., 2019. Using street view data and machine learning to assess how perception of neighborhood safety influences urban residents' mental health. Health & Place 59, 102186. https://doi.org/10.1016/j.healthplace.2019.102186.

Wells, N.M., Yang, Y.Z., 2008. Neighborhood design and walking - a quasi-experimental longitudinal study. Am. J. Prev. Med. 34 (4), 313–319. https://doi.org/10.1016/j.amepre.2008.01.019.

Xiao, Y., Lu, Y., Guo, Y., Yuan, Y., 2017. Estimating the willingness to pay for green space services in Shanghai: implications for social equity in urban China. Urban For. Urban Green. 26, 95–103. https://doi.org/10.1016/j.ufug.2017.06.007.

Xu, F., Li, J., Liang, Y., Wang, Z., Hong, X., Ware, R.S., Owen, N., 2010. Associations of residential density with adolescents' physical activity in a rapidly urbanizing area of mainland China. J. Urban Health : Bull. N. Y. Acad. Med. 87 (1), 44–53. https://doi.org/10.1007/s11524-009-9409-9.

Xue, C.Q., Sun, C., 2018. How much development can a rail station lead? A case study of Hong Kong. Int. J. High-Rise Build. 7 (2), 95–109. https://doi.org/10.21022/IJHRB.2018.7.2.95.

Zang, P., Xue, C.Q.L., Lu, Y., Tu, K., 2018. Neighbourhood adaptability for Hong Kong's ageing population. Urban Des. Int. https://doi.org/10.1057/s41289-018-0074-z.

Zhao, H., Shi, J., Qi, X., Wang, X., Jia, J., 2017. Pyramid scene parsing network. In: Paper Presented at the Proceedings - 30th IEEE Conference on Computer Vision and Pattern Recognition, vol. 2017 CVPR.