Transportation Research Part D 50 (2017) 269–279

Contents lists available at ScienceDirect

Transportation Research Part D

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

Does improving the physical street environment create satisfactory and active streets? Evidence from Seoul's Design Street Project

Hyejin Jung [a], Sae-young Lee [b], Hwan Sung Kim [c], Jae Seung Lee [d,*]

[a] Department of Architecture, Graduate school of Engineering, Hanyang University, 222 Wangsimri-ro, Seongdonggu, Seoul 04763, Republic of Korea
[b] Department of Architecture, Chung-Ang University, Heuksukdong-ro 84, Dongjak-gu, Seoul 06974, Republic of Korea
[c] Department of Urban Design and Planning, Hongik University, K501, 94 Wausan-ro, Mapo-gu, Seoul 121-791, Republic of Korea
[d] Department of Urban Design and Planning, Hongik University, K520, 94 Wausan-ro, Mapo-gu, Seoul 121-791, Republic of Korea

ARTICLE INFO

Article history:

Keywords:
Pedestrian satisfaction
Pedestrian volume
Street improvement
Difference-in-difference analysis
Multilevel modeling

ABSTRACT

As the overall interest regarding pedestrian-friendly environments grows, street-improvement projects are continually implemented. These projects aim to encourage walking activities and promote street-based social activities through the improvement of pedestrian environments; however, only a few studies have empirically evaluated the impact of street improvement on pedestrian satisfaction and pedestrian volume. The present research study examines the influence of the Design Street Project of Seoul, Korea, for which sidewalks, public spaces, and the other physical elements of streets were improved. For a difference-in-difference analysis, the pedestrian-satisfaction levels and the pedestrian volumes of the Design Streets and the matching areas from before and after the implementation of the Design Street Project are compared. Multilevel models indicate that the improvement of the street environment positively influences pedestrian-satisfaction levels, but is not effective for increasing the pedestrian volume. The results imply that the physical improvement of street environments can be effective for the elevation of pedestrian-satisfaction levels, as well as quality of life.

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1. Introduction

Many researchers and planners argue that a low-carbon and low-energy city can be achieved by encouraging walking as a sustainable transportation option and by promoting healthy physical activity (e.g., Haines et al., 2010; Pucher and Buehler, 2010; Soltani and Hoseini, 2014). Walking is thus presented as a viable alternative to the use of private vehicles that produce harmful emissions. Urban planning approaches such as transit-oriented development and new urbanism focus on the promotion of walking with the aim of reducing air pollution and energy consumption (Calthorpe, 1993). Thus, streetscape qualities that encourage walking have emerged as an important factor in urban and transportation planning (Ha et al., 2011).

Streets are symbolic, ceremonial, social, and political urban spaces, with capacities beyond the spatial functions of access and movement (Jacobs, 1993:4). Key urban theorists and researchers such as Jane Jacobs, William Whyte, and Donald Appleyard have opposed the modernist perspective that regards walking space as merely an organ of an urban-transportation

* Corresponding author.
E-mail addresses: mcarey7878@gmail.com (H. Jung), syl@cau.ac.kr (S.-y. Lee), zkparliament@naver.com (H.S. Kim), jaeseung74@gmail.com (J.S. Lee).

http://dx.doi.org/10.1016/j.trd.2016.11.013
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system and argued that walking should recover its multi-dimensional functions. Streets, as places and social activity, should be equipped with adequate spatial structures and qualities for comfortable and pleasant walking (Whyte, 1988:56). When a street is ''markedly superior in character or quality,'' it can be considered a ''great street'' (Jacobs, 1993:2). Empirical studies also found that micro-scale streetscape features such as crowdedness, air quality, the presence of trees, and pavement condition are related to pedestrian satisfaction and activity levels (e.g., Ewing and Clemente, 2013; Kim et al., 2014; Park et al., 2013; Stradling et al., 2007). A variety of projects have thus been undertaken for the construction and improvement of walking environments.

The City of Seoul considers walking to be an important element in urban-space and social-culture policies. Initiated in 2007 by the former mayor of Seoul, Se-hoon Oh, the Design Street Project is leading an urban-policy project called ''Design Seoul'' that seeks to make Seoul a ''Clean and Attractive Global City.'' The aim of Design Seoul is to create a ''pleasant Seoul urban life environment'' through four basic strategies: ''clearing,'' ''integration,'' ''cooperation,'' and ''sustainability,'' whereby the focus is the improvement of public design and the cityscape. In considering the impression of disorganization projected by existing streets—a result of the separate construction of street elements for their respective functions—the project attempted to create an integrated design. The Seoul Metropolitan Government subsequently initiated three periods of the Design Street Project in 30 target areas from 2007 with the aim of creating pedestrian-friendly streets.

While a few studies have assessed street-environment improvement projects such as the Design Street Project, empirical studies regarding the actual post-completion influence of such projects are still insufficient. This study therefore comprises an analysis of how design integration, repairing a dispersed public-street facility, and improving signage and other façade design elements on neighboring buildings influence quality of life in the corresponding urban area.

Moreover, most walkability studies primarily focus on travelers' walking choices based on the satisfaction (utility) that can be observed from their chosen mode, treating travel as an instrument to meet travelers' mobility needs (McFadden, 2001). However, pedestrian satisfaction can also be understood as the degree of subjective well-being that pedestrians experience during travel (Axhausen and Garling, 1992; Friman et al., 2013). From this perspective, travel is regarded as an objective in itself, which can improve quality of life. Hence, the present study aims to investigate pedestrians' mode choice and experience by assessing the influence of physical street improvement on pedestrian volume and satisfaction.

To achieve this objective, we undertook difference-in-difference analyses of unique, repeated cross-sectional survey data from pedestrians in Seoul. We attempted to examine the Design Street Project's effect on pedestrian satisfaction and the volume of actual pedestrians, recorded before and after Design Street Project completion. Through a series of analyses, our ultimate goal is to attain insight into effective street strategies for achieving walkable environments that improve the quality of life of Seoul's citizens.

This paper is structured as follows: Section 2 discusses theoretical and empirical studies on the relationship between built environments and pedestrian satisfaction and volume; Section 3 introduces the present study's context, survey data, and methods; Section 4 presents the results of our pedestrian satisfaction and volume models; and the paper culminates with a discussion of the implications and limitations of the present study and suggestions for future research directions.

2. Theoretical and empirical background

2.1. Satisfaction and the built environment

In the field of urban planning, satisfaction regarding environmental quality has been primarily studied in the context of residential environments. Most relevant empirical studies have therefore investigated residential satisfaction in relation to residents' characteristics, attributes of physical environments, and social aspects of living environments. Amerigo and Aragones (1997) defined residential satisfaction as a ''positive affective'' psychological state experienced by individual residents living in residential environments; within their framework, the level of residential satisfaction is influenced by objective and subjective environmental attributes and the residents' characteristics (Amerigo and Aragones, 1997).

In the field of transportation, utility theory explains the ways that individual travelers choose activities, destinations, and travel modes based on the satisfaction levels (utility) that they derive from observed choices (McFadden, 2001); however, derived utility-based satisfaction can significantly differ from actual experience because travelers are likely to underestimate the intensity of their experiences (Ettema et al., 2010; Wilson and Gilbert, 2003). An alternative concept of experienced utility is the satisfaction derived from the outcomes of travelers' choices (Kahneman et al., 1997). Abou-Zeid and Ben-Akiva (2011), Abou-Zeid et al. (2012) developed tools that measure experienced utility in order to incorporate travelers' satisfaction levels (or ''happiness'') into a discrete-choice modeling framework.

Friman et al. (2013) treated satisfaction regarding travel as domain-specific subjective well-being that includes cognitive and affective components. In their view, traveler satisfaction is the degree to which a transport system provides a service that fulfills travelers' needs. In travel-behavior research, travel is regarded as an instrument that enables participation in activities in different places rather than as an objective in itself (Axhausen and Garling, 1992). An assessment of the level of need fulfillment generally depends on travelers' self-reported judgements of a transport system that take into account cost, travel time, and punctuality (Eriksson et al., 2008; Fellesson and Friman, 2008); however, Stradling et al. (2007) further identified non-instrumental factors such as cleanliness, privacy, safety, convenience, and scenery that influence traveler satisfaction with a bus service.

Several empirical studies have investigated the factors that affect traveler satisfaction during walking trips. Stradling et al. (2007) found that walking-trip satisfaction is primarily related to micro-scale factors such as crowdedness, air quality, the presence of trees, and pavement condition. Kim et al. (2014), analyzing the satisfaction segment of the 2009 Seoul pedestrian survey, identified the significant effects of meso-scale variables such as density, intersection density, and the presence of bus stops, as well as micro-scale variables such as sidewalk width and the presence of dedicated bus lanes, crossings, streetlamps, and trees. In summary, the experiences of pedestrians during their walking trips influence pedestrian satisfaction. While travel time and travel cost are major cognitive components, physical and non-physical environments also affect pedestrian satisfaction by influencing the types of events pedestrians experience.

2.2. Pedestrian volume and the built environment

The construction of a street environment that enables walking activities is one of the most widely researched topics in the field of urban planning and design. Opposed to modern urban development and urban sprawl, which disregard the urban fabric, Jane Jacobs (1961) argued in favor of rehabilitation to create vibrant and safe urban streets. Jacobs emphasized the value of mixed-use development, "eyes on the street," and old buildings. Also focusing on street environments, Jacobs (1993) advocated for qualities such as similar-height buildings, trees, transparent windows, and public spaces for rest and recreational walking as primary attributes of the "great street." Similarly, Whyte (1988) argued for the importance of physical elements that offer attractive visual experiences, diverse-use development that accommodates social interactions, buildings and public spaces that are open to streets, and the presence of trees and sitting areas. To test these theories, numerous empirical studies have investigated the relationship between the built environment and human behavior, operationalizing the concepts and the environmental attributes.

Since Cervero and Kockelman (1997) introduced the *3D* (*density, diversity*, and *design*) variables to measure built environments, the body of literature regarding the relationship between pedestrian activities and built environments has become vast, as shown in several *meta*-analyses (Ding and Gebel, 2012; Ewing and Cervero, 2010). These *3D* attributes were later expanded to *5D* to include *destination accessibility* and *distance to transit* (Cervero et al., 2009). The *5D* attributes are the most widely used variables for measuring *neighborhood walkability*. Overall, the literature suggests that the *5D* variables—higher residential and job density, mixed land use, better street connectivity, better destination accessibility, and shorter distance to transit—are associated with greater pedestrian volume (e.g., Ewing et al., 2016; Giles-Corti and Donovan, 2002; Giles-Corti et al., 2005; Hajrasouliha and Yin, 2015; Huston et al., 2003; Lee and Moudon, 2006; Lee et al., 2013; Moudon et al., 2005; Saelens et al., 2003).

Among the *5Ds*, design is generally regarded as street network characteristics of a neighborhood. However, this concept incorporates qualities of streets that can influence pedestrian experience, satisfaction, and even activity levels. Some urban designers focus on using street features to create vibrant street life, assuming that the micro environments of the street affect walking experience more critically than the overall qualities of an area such as land-use mix, average block size, and regional accessibility (Ewing et al., 2016).

While a meta-analysis of travel behavior and pedestrian environment literature found that fewer micro-scale streetscape features are researched than macro qualities (Ewing and Cervero, 2010), a number of studies have explored how street-scale features such as *streetlights* and *street trees* can also affect pedestrian experiences and activities (e.g., Saelens and Handy, 2008). Pikora et al. (2006) investigated the correlation between streetscape features such as trees, street maintenance, cleanliness, parks, views, sights, and architecture and walking behavior. Although their study identified no a significant relationship between these elements and walking behavior, they found some evidence that people living in aesthetically pleasing neighborhoods may walk more for recreation. Other research conducted by Boarnet et al. (2011) found that physical street elements such as sidewalks, pedestrian crossings, and traffic signals are more strongly correlated with physical activity and walking than natural elements, streetscape features, and neighborhood characteristics such as the presence of trees, historic buildings, and bars on windows.

Ewing and Handy (2009) attempted to operationalize streetscape features such as imageability, enclosure, human scale, transparency, and complexity to objectively measure the qualitative aspects of street environments; consequently, studies such as Ewing and Clemente (2013) and Ewing et al. (2016) identified factors that exert a significant influence on streetscape features such as the proportion of windows on the street, the proportion of active street frontage, the number of street-furniture pieces, and the corresponding impact on walking behaviors.

Although there are numerous studies on walkability, only a few have empirically examined the effects of street-improvement projects on walking behavior. Although the aim of many of these projects is to encourage pedestrian activities and the development of lively streets through adopting designs based on theoretical and empirical findings, only a few studies have evaluated the extent to which such street-improvement projects have successfully established lively and satisfactory environments.

Furthermore, cross-sectional studies in the field of urban and transportation planning aiming to estimate the causal effects of urban interventions try to mimic randomized experiments that compare equivalent treatment and control groups in terms of everything except for the effect of urban interventions. However, when the observed differences between the treatment and control groups result from omitted factors, it is rarely possible to perfectly control for unobserved effects; moreover, it is possible that the observed pre-treatment differences between the treatment and control groups are identical to the observed post-treatment differences. In this case, it is difficult to claim that the observed differences result from the treatment.

Therefore, analysis of change over time through repeated cross-sectional data, in which independent samples are collected at successive time points, makes it possible to evaluate the effect of an urban intervention because a before-and-after comparison can be made, and this can overcome the weakness of a cross-sectional comparison that cannot account for a potential baseline difference before an intervention. To analyze change over time, the present study investigates the effects of Design Street street-improvement projects by analyzing unique, repeated cross-sectional pedestrian-survey data. Because the overall aim of the Design Street Project is to create vibrant and satisfactory walking environments, our analyses tested the following two hypotheses:

Hypothesis 1. Street-improvement projects increase the level of pedestrian satisfaction by improving non-instrumental qualities of streets such as cleanliness, safety, convenience, and scenery, which may affect the experiences of pedestrians.

Hypothesis 2. Street-improvement projects increase the level of pedestrian volume by changing streetscape features such as the presence of streetlights and trees, the proportion of windows on the street, the proportion of active street frontage, and the number of street-furniture pieces that may attract pedestrians.

3. Setting and methods

3.1. Context

We conducted the present study in Seoul, which is the capital city of the Republic of Korea. Walkability is lacking in many of its street environments; that is, wide major roads with high-speed traffic discourage walking activities, and a dangerous mix of pedestrians and vehicles means that the sidewalks of numerous neighborhood streets are not appropriate for walking. The pedestrian death rate in Korea (11.3 for every 100,000 people as of 2010) is consequently the highest among all OECD countries.

In 2007, the Seoul Metropolitan Government planned the Design Street Project with the aim of encouraging walking and social activities on streets by improving physical street environments. They selected major pedestrian corridors of activity for these projects, and a master planner, cooperating with public officials, stakeholders, citizens, and professional planners, planned a comprehensive retrofit of the street-environment elements to reverse the ongoing deterioration of these public spaces. The Design Street projects include the improvement of sidewalks, public spaces, signs, fences, and other physical elements of the streets. The first Design Street project was completed in October 2009, and a total of 23 projects were implemented by 2010; however, only a few studies have empirically evaluated the impact of these improvements on pedestrian satisfaction and pedestrian volume. Thus, the present research paper examines the influence of the Design Street projects on walking behavior.

3.2. Survey design and data

The present study used comprehensive pedestrian-survey data that was collected by the Seoul Metropolitan Government. The pedestrian survey was repeatedly conducted at approximately 1000 locations during 2009 and 2012. The first survey was carried out from August to October 2009, and the second survey was conducted first in October and then again during November 2012. The 2009 survey was therefore completed before the implementation of the Design Street projects, and the 2012 survey collected data after the completion of the projects, thereby providing the opportunity for a before-and-after comparison.

The government selected the survey locations from amongst Seoul's major activity centers, transportation nodes, and major land-use areas. The survey was used to collect pedestrians' personal characteristics, their travel purpose and frequency, and levels of pedestrian satisfaction. Considering the time needed for surveyors to select respondents and for respondents to answer all the survey questions, each surveyor was asked to collect 12 responses in the morning (6 h) and 12 responses in the afternoon (6 h), yielding 24 responses per day. Each surveyor selected respondents who were passing by each location every 30 min. The surveyors gathered 72 responses at each survey location, conducting surveys with 24 pedestrians on each of the following days: Tuesday, Wednesday, and Friday. Auditors tallied pedestrian numbers at the locations for a total of five days per location, on Monday, Tuesday, Wednesday, Friday, and Saturday, between 7:30 a.m. and 8:30 p.m. The auditors also observed street-environment attributes, including sidewalk widths, lane quantities, and the presence of bus-dedicated lines, bus stops, subway stations, and other street elements within 50 m of each location.

Among the 1000 survey locations, 28 are included in Design Street projects, and these locations constitute the treatment group. To build the control group, we selected 218 matching locations from typical streets in the administrative areas (called "dongs" in Korea) that the streets of the Design Street projects run through or face (Fig. 1).

We acquired other socio-economic variables such as population density and employment density from the 2010 Korea census data in the form of dong-level data. Fig. 1 shows that the locations are clustered in dongs, so the pedestrian-

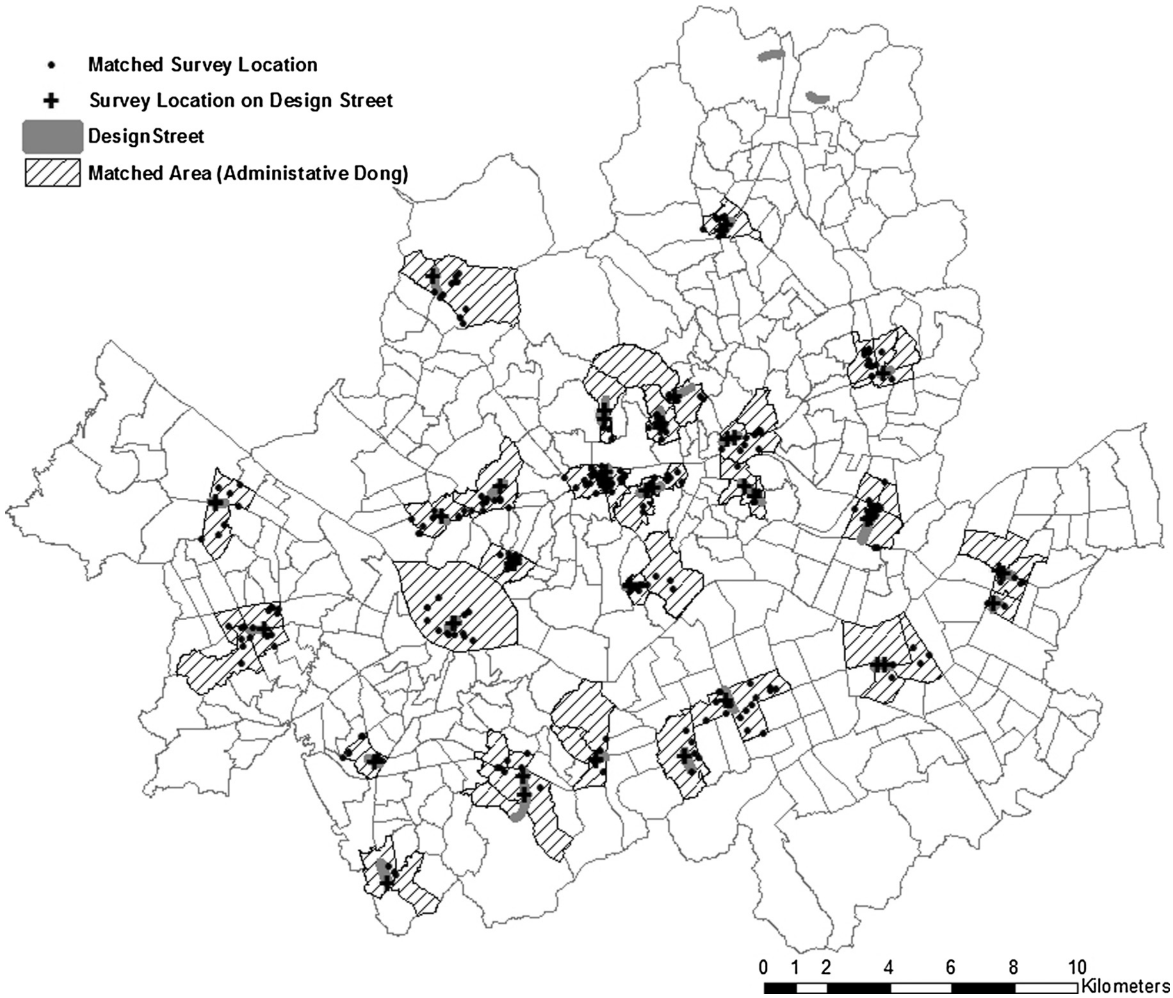

Fig. 1. Survey locations, Design Street areas, and matched areas of Seoul.

survey locations are matched to the dongs based on their spatial locations. As a result, the final dataset takes the form of a multilevel structure comprising the survey-location level (level 1) and the dong level (level 2).

3.3. Measures and descriptive statistics

Table 1 shows the definitions and descriptive statistics of the key variables for the full sample, treatment group, and control group. We measured pedestrian-satisfaction levels in the pedestrian survey using a 5-point Likert scale (1. Very dissatisfied; 2. Dissatisfied; 3. Neutral; 4. Satisfied; 5. Very satisfied). We generated the dependent variable *Pedestrian Satisfaction* by averaging the 72 responses at each location; the total *Pedestrian Satisfaction* mean of 3.177 is slightly above neutral. Notably, while overall pedestrian-satisfaction level decreased from 2009 to 2012, the pedestrian-satisfaction level at the Design Street locations increased during the same period. *Pedestrian Count* is the average of each of the five-day pedestrian-volume audits. Pedestrian numbers for the Design Street locations are greater than those for the typical streets, both in 2009 and 2012. A possible explanation for this is that the Design Street sites were selected from major streets in activity centers, and thus the Design Streets tend to have more pedestrians.[1] The pedestrian numbers for both the Design Streets and the typical streets increased during the same periods, while the pedestrian volumes (both before and after) of the Design Streets are greater than those of the typical streets. The second dependent variable, *Pedestrian Volume*, is the natural log transformation of *Pedestrian Count* because its distribution is skewed.

[1] We also observed this trend through an analysis of smartphone-based pedestrian volume data in Seoul. We estimated the number of pedestrians by counting smartphone call numbers, aggregated in 50 m by 50 m cells (https://sso.sbiz.or.kr/). We compared smartphone-based pedestrian counts in 2013 for the Design Streets and the typical streets using a *t*-test. The results also showed that while the differences between pedestrian counts for the two groups were not significant, the Design Streets (M = 1715.57, SD8=1548.12) tended to attract more pedestrians than the typical streets (M = 1491.87, SD = 1127.32), t(30.79) = 0.74, p < 0.465.

Table 1
Definitions and descriptive statistics of key variables.

		Full sample mean (S.D.)			Treatments: Design Street mean (S.D.)		Controls: typical street mean (S.D.)	
		Total	Base-line 2009	Follow-up 2012	Base-line 2009	Follow-up 2012	Base-line 2009	Follow-up 2012
Outcome variables								
Pedestrian satisfaction	Average satisfaction level (1. Very dissatisfied – 5. Very satisfied)	3.177 (0.512)	3.242 (0.477)	3.113 (0.539)	3.235 (0.559)	3.377 (0.481)	3.242 (0.467)	3.079 (0.538)
Pedestrian count	Average number of pedestrians per day	6848 (7303)	6606 (7013)	7091 (7589)	10,299 (12,689)	11,220 (15,165)	6132 (5789)	6560 (5824)
Pedestrian volume	Natural log of pedestrian count	8.514 (0.739)	8.475 (0.737)	8.554 (0.739)	8.855 (0.811)	8.942 (0.780)	8.426 (0.715)	8.504 (0.721)
Level-1 (Survey-location-level) Variables								
Design street	Design Street (0. no; 1. yes)	0.114	0.114	0.114	–		–	
Year	Year (0. 2009; 1. 2012)	–	–	–	0.500		0.500	
Sidewalk width	Sidewalk width (m)	4.278 (2.266)	4.382 (2.349)	4.175 (2.178)	4.418 (2.267)	5.082 (2.531)	4.378 (2.365)	4.058 (2.107)
Ln (Width)	Natural log of sidewalk width (m)	1.316 (0.536)	1.342 (0.525)	1.290 (0.547)	1.362 (0.516)	1.494 (0.545)	1.340 (0.527)	1.264 (0.542)
Lanes	Number of lanes for vehicles	3.760 (2.812)	3.703 (2.797)	3.817 (2.832)	4.786 (2.685)	4.786 (2.470)	3.564 (2.787)	3.693 (2.856)
Bus lane	Bus-dedicated lanes (0. no; 1. yes)	0.171	0.150	0.191	0.286	0.393	0.133	0.165
Pedestrian-dedicated	Presence of separated sidewalk (0. no; 1. yes)	0.707	0.691	0.724	0.821	0.893	0.674	0.702
Bus	Bus stops within 50 m (0. no; 1. yes)	0.368	0.325	0.411	0.429	0.500	0.312	0.399
Subway	Subway stations within 50 m (0. no; 1. yes)	0.230	0.191	0.268	0.107	0.250	0.202	0.270
Tree	Presence of trees (0. no; 1. yes)	0.268	0.268	0.268	0.464	0.464	0.243	0.243
n		492	246	246	28	28	218	218
Level-2 (Dong-level) Variables (N = 55)								
Population		0.422 (0.218)	–	–	–	–	–	–
Employment		0.163 (0.190)	–	–	–	–	–	–

The data structure of the present study is multilevel, with clustering of the 246 survey locations (level 1) in 55 dongs (level 2). Among the level-1 variables, *Design Street* is the question predictor that distinguishes the Design Streets from the typical streets. Approximately 11.4% of the survey locations are part of Design Street projects. *Year* is a dummy variable that differentiates between the 2009 and 2012 survey data. The average sidewalk width at the survey locations diminished, while the number of vehicle lanes increased, implying that the developmental direction of Seoul is vehicle oriented. We log-transformed the sidewalk-width data due to its skewed distribution. The government has tried to convert regular lanes into bus-dedicated lanes to promote bus usage; the increase in the percentage of the streets in the sample with bus-dedicated lanes reflects these efforts. Approximately 70.7% of the survey locations are on sidewalks that separate pedestrians from vehicular circulation. In terms of public-transportation access, bus stops were accessible within a 50 m range at 36.8% of the locations, and subway stations were available within a 50 m range for 23.0% of the locations. The increased percentages of bus and subway access result from the government's investment in public transportation. Trees were identified in only 26.8% of the survey locations, and the percentages for tree presence did not change over time; moreover, the Design Streets (46.4%) are more likely to have trees than the typical streets (24.3%). The level-2 variables are the population density and employment density of a dong, and because only the 2010 census data was available, the dong-level variables are time invariant.

3.4. Modeling

3.4.1. Difference-in-difference estimation

We compared pedestrian-satisfaction and pedestrian-volume levels in Design Streets (treatment) and nearby typical streets (control) both before treatment (in 2009) and after treatment (in 2012). If we had compared only the observed outcome variables from 2012, the estimated treatment effect could be biased; for example, because streets in major activity centers were selected as Design Street sites, the overall pedestrian volume of the Design Streets could be greater than that of the other streets, even before the treatment. In this case, a single difference in 2012 could overestimate the effect of Design Street treatment; therefore, the present study carries out a difference-in-difference estimation by including the interaction term between the *Design Street* and *Year* variables in the model.

3.4.2. Multilevel modeling

The multilevel nature of the dataset, whereby the level-1 units (survey locations) cluster within the level-2 units (dongs), poses a critical challenge for estimating satisfaction and volume levels. Because of the common physical and socio-economic environments present within each dong, the likelihood of similarities between survey respondents at locations from the same dong is higher than that for respondents from different dongs. Due to the within-cluster dependency, an ordinary regression-model estimation would likely produce incorrect standard errors that violate the assumption that observations are conditionally independent of each other. Multilevel modeling resolves this problem by including explanatory variables at different levels and through the inclusion of a location-specific random intercept in the model that is represented by u_j (RabeHesketh and Skrondal, 2012) as follows:

$$Y_{ij} = \beta_0 + \beta_1 DesignStreet_{ij} + \beta_2 Year_{ij} + \beta_3 DesignStreet_{ij} * Year_{ij} + \beta_4 X_{ij} + \beta_5 X_j + u_j + \epsilon_{ij},$$

where Y_{ij} represents the average pedestrian satisfaction and the average pedestrian volume at each location i in a dong j; β_0 is the mean outcome of year 2009 (baseline) for the typical streets; $\beta_0 + \beta_1$ is the mean outcome of 2009 for the Design Street locations; β_1 is the single difference between the Design Street locations and the typical streets in 2009; $\beta_0 + \beta_2$ is the mean outcome of year 2012 (follow-up) for the Design Street locations; $\beta_0 + \beta_1 + \beta_2 + \beta_3$ is the mean outcome of 2012 for the typical streets; and $\beta_1 + \beta_3$ is the single difference between the Design Street locations and the typical streets in 2012. β_3 is therefore the difference-in-difference. Further, X_{ij} represents the level-1 (location-level) variables; X_j represents the level-2 (dong-level) variables; ϵ_{ij} represents the residuals that are uncorrelated with both location and dong; and the dong-specific random intercept u_j is independently distributed across the dongs and is independent from the explanatory variables X_{ij}.

3.4.3. Limitations and future research

A limitation of the present research is the use of convenience sampling in the pedestrian survey. The results should therefore be interpreted with care; that is, even though drawing random samples from pedestrians is practically impossible, random sampling is required to properly estimate the causal influence of Design Street Project treatment. Despite this limitation, large-scale, repeated cross-sectional pedestrian-survey data is rare in the field of urban and transportation planning, and the present study can therefore provide insight into the effective elements of street improvement and thus supplement the findings of previous cross-sectional studies.

Further, the present study investigated specific street-improvement projects in major pedestrian corridors in Seoul; therefore, the study's external validity may be limited to similar types of streets. It is expected that parallel studies of other street-improvement projects such as road diet, residential-street improvement, and traffic calming will enhance the generalizability of the study, leading to a better understanding of the effects of creating active and satisfactory pedestrian environments.

4. Results

4.1. Pedestrian-satisfaction model

Table 3 presents the multilevel pedestrian-satisfaction model that we used to estimate pedestrian satisfaction. The intraclass correlation coefficient (rho) of 0.127 is statistically significant and justifies the use of this multilevel model instead of an ordinary least-square model. The dong-level, pseudo R-squared value indicates that between-dong residual variance declined by 12.0% with the addition of dong-level independent variables from the null model without independent variables. Location-level prediction is less successful in this analysis, reducing the within-dong residual variance by only 3.0%.

The result here confirms our first hypothesis, which associates high pedestrian-satisfaction levels with the implementation of the Design Street Project. The negative effect of the *Year* variable and the positive effect of the interaction between the *Design Street* and *Year* variables indicate that between 2009 and 2012 pedestrian satisfaction in the Design Street locations increased, whereas it decreased in typical streets. During this period, while the estimated standardized pedestrian-satisfaction level of the typical streets decreased by 0.164, from 3.256 to 3.092, in the Design Street locations it increased by 0.142, from 3.213 to 3.355 (Fig. 1A). Among the other explanatory variables, only the presence of trees is positively associated with satisfaction level.

4.2. Pedestrian-volume model

Table 3 also presents the result of the pedestrian-volume model. The significant rho value indicates that 19.8% of pedestrian-satisfaction variation is attributable to differences in dong-level attributes; therefore, the multilevel model is superior to the ordinary least-squared model, which produced incorrect standard errors in this case. The dong-level prediction is successful in this analysis, as the model reduced the between-dong residual variance by 21.8% due to the inclusion of dong-level predictors; that is, location-level variance declined by 13.7% through the addition of these predictors.

The result here does not support our second hypothesis; that is, although the effect of the Design Street Project on pedestrian volume is significant, the interaction between the *Design Street* and *Year* variables is insignificant. Pedestrian volumes in the Design Street locations in 2009 and 2012 are estimated at 7249.6 persons and 7908.6 persons, respectively, showing an increase of 659 persons; however, pedestrian volume in the typical streets also increased, in this case by 317.1 persons from 4488.4 in 2009–4805.5 in 2012 (Fig. 2A), meaning that the difference in 2012 is not significantly greater than the difference in 2009. Two transportation-related variables, the presence of bus-dedicated lanes and subway stations, are positively associated with the level of pedestrian volume. Among the dong-level variables, pedestrian volume in the streets of dongs with a higher employment density tends to be greater.

5. Implications and conclusions

5.1. Implications

As interest in walkable and active streets has grown, street-improvement projects have been implemented to create vibrant urban environments. While previous research studies investigated walkable environments (e.g., Moudon et al., 2005; Van Dyck et al., 2011), only a few studies have empirically examined the effects of street-improvement projects on pedestrian activities and satisfaction levels. The present study evaluated the effect of a series of street-improvement projects on pedestrian satisfaction by undertaking and analyzing a unique, large-scale, repeated cross-sectional pedestrian survey in Seoul. To empirically evaluate the influence of pedestrian-environment changes on pedestrian satisfaction and volume, the present study investigated the Seoul-based Design Street Project, which improved sidewalks, public spaces, and other physical elements of streets. We used multilevel models to estimate pedestrian satisfaction and pedestrian volume through a comparison between Design Street Project locations and matching typical streets located nearby. We used these models to analyze repeated cross-sectional pedestrian-survey data within a difference-in-difference framework that takes into account before-and-after differences between Design Street locations and typical streets; moreover, we also used these models to investigate the effects of the streets' environmental and socio-economic attributes.

The results from the pedestrian-satisfaction model show that pedestrians walking through Design Street Project locations tended to be more satisfied compared with those on typical streets. The significant interaction term indicates that the level of pedestrian satisfaction in the Design Street locations improved after Design Street Project completion; here, we controlled for both the inherent differences between the Design Street locations and the typical streets that existed before Design Street Project implementation and the overall pedestrian-satisfaction trends in Seoul (Model 1 in Table 3). The estimated satisfaction trend in Fig. 1A shows that pedestrian satisfaction in the Design Street Project locations, which is lower than that in the typical streets in 2009, remarkably increased after Design Street Project completion, despite decreasing satisfaction in typical streets; consequently, the satisfaction level on the Design Streets exceeded that on the typical streets in 2012.

Besides the presence of trees, no other environmental variables are significant in the pedestrian-satisfaction model. The results here are inconsistent with those of Kim et al. (2014), which identify significant effects of micro-scale factors such as the presence of bus stops and bus-dedicated lanes, sidewalk width, and the presence of street lighting. This inconsistency may come from the inclusion of the *Design Street* variable, which correlates with other environmental factors. Table 2 shows that the number of vehicle lanes, the presence of bus-dedicated lanes, and the inclusion of pedestrian-dedicated streets significantly correlate with both the pedestrian-satisfaction and *Design Street* variables; therefore, the inclusion of the *Design Street* variable might have attenuated the effects of the other environmental variables. Yet, the effect of trees remains significant, as streets with trees tend to result in more satisfied pedestrians when compared to those without trees.

In contrast, the pedestrian-volume model did not find evidence that the Design Street Project attracted more pedestrians. In Model 2 of Table 3, the *Design Street* variable is significant, but the interaction term is insignificant. This result indicates that although the number of pedestrians on the Design Street locations is greater than that on the typical streets, there is no evidence that this difference is due to the implementation of a Design Street Project. The trend in Fig. 2A shows that pedestrian volume on the Design Streets is larger than that on the typical streets in 2009; however, although Design Street pedestrian volume increased from 2009 to 2012, that of the typical streets also increased during the same period; this is because active pedestrian corridors were selected for the Design Street sites. It therefore appears that the Design Street Project has

Table 2
Pearson correlation matrix of key variables.

	Satis.	Ped. Vol.	Design Street	Year	Width	Lanes	Bus Lane	Ped. Ded.	Bus	Sub.	Tree	Pop.	Emp.
Satisfaction	1												
Pedestrian Volume	0.00	1											
Design Street	0.09*	0.19*	1										
Year	−0.13*	0.05	0	1									
Ln (Width)	0.09	0.17*	0.07	−0.05	1								
Lanes	0.17*	0.28*	0.13*	0.02	0.21*	1							
Bus Lane	0.10*	0.29*	0.16*	0.05	0.17*	0.51*	1						
Pedestrian-dedicated	0.12*	0.10*	0.12*	0.04	−0.16*	0.50*	0.23*	1					
Bus	0.11*	0.17*	0.07	0.09*	0.06	0.39*	0.19*	0.31*	1				
Subway	0.12*	0.36*	−0.04	0.09*	0.17*	0.37*	0.28*	0.16*	0.29*	1			
Tree	0.17*	−0.10*	0.16*	0	−0.06	0.19*	0.04	0.27*	0.12*	−0.03	1		
Population	−0.05	−0.18*	0.01	0	−0.13*	−0.11*	−0.02	−0.09	0.01	−0.05	0.03	1	
Employment	0.03	0.3*	−0.04	0	0.06	0.13*	0.02	0.04	−0.04	0.07	0.04	−0.42*	1

* $p < 0.05$.

Table 3
Multilevel-model results for pedestrian-satisfaction and log-transformed pedestrian-volume estimations.

Variables	Model 1: Average pedestrian satisfaction			Model 2: Log-transformed pedestrian volume		
	Coef.	(S.E.)	$P > \|z\|$	Coef.	(S.E.)	$P > \|z\|$
Level-1 (Survey-location-level) Variables						
Design Street	−0.093	(0.099)	0.348	0.543*	(0.121)	0.000
Year	−0.170*	(0.045)	0.000	0.037	(0.054)	0.492
Year × Design Street	0.291*	(0.131)	0.027	−0.052	(0.159)	0.743
Ln (Width)	0.044	(0.045)	0.328	0.077	(0.055)	0.159
Lanes	0.008	(0.011)	0.496	0.019	(0.013)	0.168
Bus lane	0.020	(0.069)	0.772	0.245*	(0.085)	0.004
Pedestrian-dedicated	0.041	(0.060)	0.490	−0.031	(0.073)	0.671
Bus	0.043	(0.050)	0.394	0.085	(0.061)	0.165
Subway	0.051	(0.060)	0.392	0.432*	(0.073)	0.000
Tree	0.141*	(0.054)	0.009	−0.294*	(0.067)	0.000
Level-2 (Dong-level) Variables						
Population	−0.038	(0.161)	0.815	−0.024	(0.229)	0.918
Employment	−0.005	(0.163)	0.978	0.802*	(0.239)	0.001
Constant	3.096	(0.117)	0.000	7.995*	(0.156)	0.000
σ^2_μ	0.176*	(0.037)		0.276*	(0.045)	
σ^2_e	0.460*	(0.016)		0.556*	(0.019)	
Rho (ρ)	0.127*	(0.048)		0.198*	(0.054)	
R^2_μ		0.120			0.218	
R^2_e		0.030			0.137	
n (locations)		492			492	
N (groups)		55			55	

* $p < 0.05$.

not been effective in attracting more pedestrians. Despite this trend in pedestrian volume, the results should be carefully interpreted because our analysis did not measure overall walking levels through a population-based survey; instead, it relied on data collected by simply counting the number of pedestrians passing by. Therefore, we did not observe the walking behavior of individuals (e.g., walking frequency and time) living around the Design Street areas.

In the pedestrian-volume model, we also identify the effects of transportation-related variables. Pedestrian volume on streets with bus-dedicated lines and subway stations tends to be greater than on other streets; meanwhile, the presence of bus stops did not affect pedestrian volume. This result is consistent with the findings of Ewing et al. (2016). The investigation of the dong-level variables shows that pedestrian volume tends to be higher in dongs with high employment density. This result is consistent with previous studies (e.g., Hajrasouliha and Yin, 2015). Population density, however, does not correlate with pedestrian volume. Lastly, our finding that pedestrian volume is likely to be smaller on streets with trees is somewhat unexpected; this may be explained by the street and block system in Seoul, which consists of wide arterials where trees define blocks and smaller streets divide blocks (the smaller streets, which are often treeless, are generally main pedestrian routes).

Our results have several policy implications regarding the development of pedestrian-environment-improvement projects. While the Design Street Project has increased pedestrian satisfaction to a certain degree, its influence on pedestrian volume is not significant. It seems that the project's capacity to cause new social activity among pedestrians by implementing street-level physical interventions such as the improvement of street facilities and the alteration of sign designs is therefore limited. In addition to its role as a public utility for facilitating physical movement, a "great street" is also a meeting space where social activity happens, and it should therefore be composed of physical qualities that are adequate for this objective (Jacobs, 1993). The results of this study show that the Design Street Project increased pedestrian convenience to a certain degree through the integration or simplification of street facilities; but it has been inadequate for inducing new social activities, as only simple, exterior improvements of facilities and signs were implemented. However, though failing to induce more walking trips, the increased pedestrian satisfaction level on Design Streets implies that street-level improvement can contribute to improved pedestrian experience and, furthermore, improved pedestrian well-being.

Isaacs (2000) pointed out that a picturesque streetscape increases the aesthetic experience of pedestrians, but it does not necessarily lead to a direct increase in pedestrian volume; therefore, an additional plan beyond the management of aesthetic elements is required to increase pedestrian volume (Oh and Seo, 2013:27). In addition to the appropriate design of street environments and boundaries between buildings and streets, aspects of urban spatial structures such as block size, land-use zoning, and the accommodation and combination of attractive purposes must also be considered; therefore, street-environment improvements that deal with urban complexity at various scales, including the neighborhood and street levels, should effectively rejuvenate urban activity. In addition, only a limited improvement of physical street elements can be expected from the Design Street Project, as changes in use and density are not reflected in the analysis results. Further studies should analyze the specific factors that increase pedestrian volume and pedestrian satisfaction in relation to the Design Street Project in order to establish the basis for constructing a pedestrian-oriented city for future street-environment-improvement projects.

Acknowledgment

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Science, ICT & Future Planning (2013R1A1A1057772). This work was also supported by the 2015 Hongik University Research Fund.

Appendix A

See Figs. 1A and 2A.

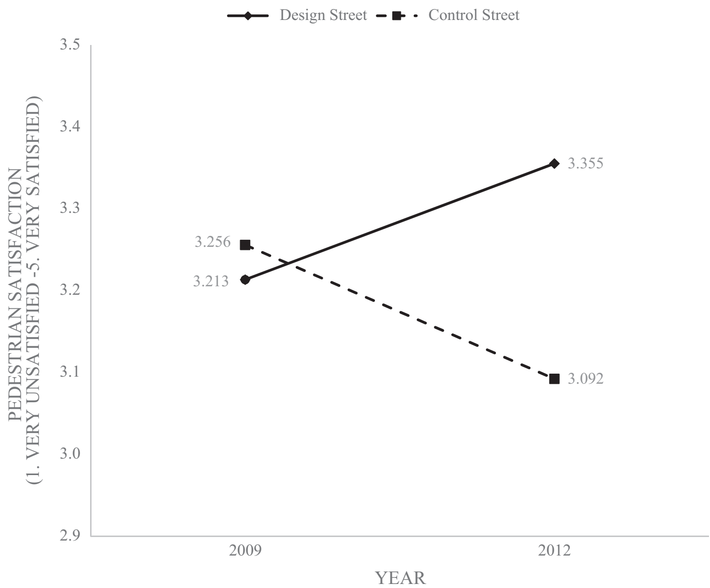

Fig. 1A. Average pedestrian-satisfaction estimates of Design Street and Control Street for 2009 and 2012.

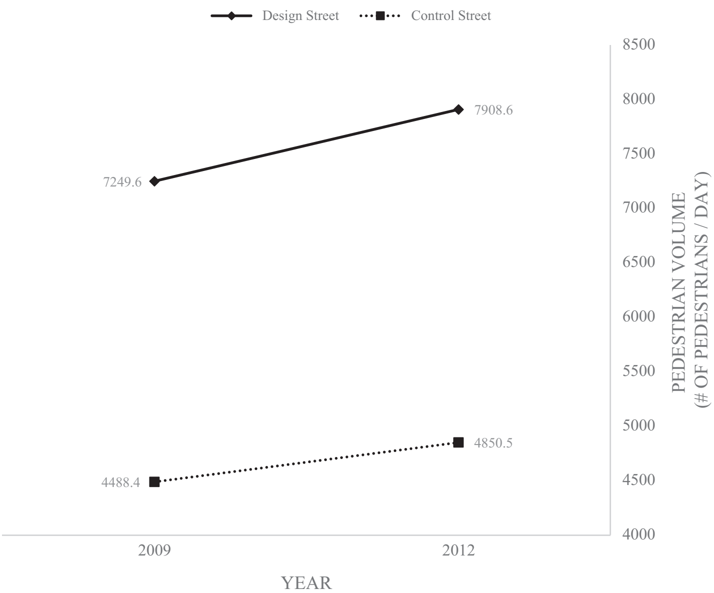

Fig. 2A. Pedestrian-volume estimates of Design Street and Control Street for 2009 and 2012.

References

Abou-Zeid, M., Ben-Akiva, M., 2011. The effect of social comparisons on commute well-being. Transp. Res. Part A: Policy Pract. 45, 345–361.

Abou-Zeid, M., Witter, R., Bierlaire, M., Kaufmann, V., Ben-Akiva, M., 2012. Happiness and travel mode switching: findings from a Swiss public transportation experiment. Transp. Policy 19, 93–104.

Amerigo, M., Aragones, J.I., 1997. A theoretical and methodological approach to the study of residential satisfaction. J. Environ. Psychol. 17, 47–57.

Axhausen, K., Garling, T., 1992. Activity-based approaches to travel analysis: conceptual frameworks, models, and research problems. Transport Rev. 12, 323–341.

Boarnet, M.G., Forsyth, A., Day, K., Oakes, J.M., 2011. The street level built environment and physical activity and walking: results of a predictive validity study for the Irvine Minnesota Inventory. Environ. Behav. 43, 735–775.

Calthorpe, P., 1993. The Next American Metropolis: Ecology, Community, and the American Dream. Princeton Architectural Press.

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

Cervero, R., Sarmiento, O., Jacoby, E., Gomez, L., Meiman, A., 2009. Influences of built environments on walking and cycling: lessons from Bogota. Int. J. Sustain. Transp. 3, 203–226.

Ding, D., Gebel, K., 2012. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? Health Place 18 (1), 100–105.

Eriksson, L., Friman, M., Gärling, T., 2008. Stated reasons for reducing work-commute by car. Transp. Res. Part F: Traffic Psychol. Behav. 11, 427–433.

Ettema, D., Garling, T., Olsson, L.E., Friman, M., 2010. Out-of-home activities, daily travel, and subjective well-being. Transp. Res. Part A 44 (9), 723–732.

Ewing, R., Cervero, R., 2010. Travel and the built environment—a meta-analysis. J. Am. Plann. Assoc. 76 (3), 265–294.

Ewing, R., Clemente, O., 2013. Measuring Urban Design: Metrics for Livable Places. Island Press, Washington, DC.

Ewing, R., Handy, S., 2009. Measuring the unmeasurable: urban design qualities related to walkability. J. Urban Des. 14 (10), 65–84.

Ewing, R., Hajrasouliha, A., Neckerman, K.M., Purciel-Hill, M., Greene, W., 2016. Streetscape features related to pedestrian activity. J. Plann. Educ. Res. 36 (1), 5–15.

Fellesson, M., Friman, M., 2008. Perceived satisfaction with public transport services in nine European cities. J. Transp. Res. Forum 47, 93–103.

Friman, M., Fujii, S., Ettema, D., Garling, T., Olsson, L.E., 2013. Psychometric analysis of the satisfaction with travel scale. Transp. Res. Part A 48, 132–145.

Giles-Corti, B., Donovan, R., 2002. The relative influence of individual, social and physical environment determinants of physical activity. Soc. Sci. Med. 54 (12), 1793–1812.

Giles-Corti, B., Broomhall, M., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., Donovan, R., 2005. Increasing walking: how important is distance to, attractiveness, and size of public open space? Am. J. Prev. Med. 28 (2S2), 169–176.

Ha, E., Joo, Y., Jun, C., 2011. An empirical study on sustainable walkability indices for transit-oriented development by using the analytic network process approach. Int. J. Urban Sci. 15 (2), 137–146.

Haines, A., McMichael, A.J., Smith, K.R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B.G., Campbell-Lendrum, D., Dangour, A.D., Davies, M., Bruce, N., Tonne, C., Barrett, M., Wilkinson, P., 2010. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. The Lancet 374 (9707), 2104–2114.

Hajrasouliha, A., Yin, L., 2015. The impact of street network connectivity on pedestrian volume. Urban Stud. 52 (13), 2483–2497.

Huston, S., Evenson, K., Bors, P., Gizlice, Z., 2003. Neighborhood environment, access to places for activity, and leisure-time physical activity in a diverse North Carolina population. Am. J. Health Promot. 18, 158–169.

Isaacs, R., 2000. The urban picturesque: an aesthetic experience of urban pedestrian places. J. Urban Des. 5 (2), 145–180.

Jacobs, A., 1993. Great Streets. The MIT Press.

Jacobs, J., 1961. The Death and Life of Great American Cities. Vintage Books, New York.

Kahneman, D., Wakker, P., Sarin, R., 1997. Back to Bentham? Explorations of experienced utility. Quart. J. Econ. 112, 375–405.

Kim, S., Park, S., Lee, J.S., 2014. Meso- or micro-scale? Environmental factors influencing pedestrian satisfaction. Transp. Res. Part D 30, 10–20.

Lee, C., Moudon, A.V., 2006. The 3Ds+R: quantifying land use and urban form correlates of walking. Transp. Res. Part D 11 (3), 204–215.

Lee, J.S., Zegras, P.C., Ben-Joseph, E., 2013. Safely active mobility for urban baby boomers: the role of neighborhood design. Accid. Anal. Prev. 61, 153–166.

McFadden, D., 2001. Disaggregate behavioral travel demand's RUM side – a 30 years retrospective. In: Hensher, D.A. (Ed.), Travel Behavior Research. Elsevier, Amsterdam.

Moudon, A.V., Lee, C., Cheadle, A., Garvin, C., Johnson, D., Schmid, T., Weathers, R., Lin, L., 2005. Operational definition of walkable neighborhood. J. Phys. Activ. Health 3 (S1), S99–S117.

Oh, S., Seo, S., 2013. Urban policy review for pedestrian city. Auri 27.

Park, S.H., Kim, J.H., Choi, Y.M., Seo, H.L., 2013. Design elements to improve pleasantness, vitality, safety, and complexity of the pedestrian environment: evidence from a Korean neighbourhood walkability case study. Int. J. Urban Sci. 17 (1), 142–160.

Pikora, T.J., Giles-Corti, B., Knuiman, M.W., Bull, F.C., Jamrozik, K., Donovan, R.J., 2006. Neighborhood environmental factors correlated with walking near home: using SPACES. Med. Sci. Sports Exerc. 38 (4), 708–714.

Pucher, J., Buehler, R., 2010. Walking and cycling for healthy cities. Built Environ. 36 (4), 391–414.

RabeHesketh, S., Skrondal, A., 2012. Multilevel and Longitudinal Modeling Using Stata Volume I: Continuous Responses. Stata Press Publication, College Station, Texas.

Saelens, B.E., Handy, S.L., 2008. Built environment correlates of walking: a review. Med. Sci. Sports Exerc. 40 (7 Suppl.), S550.

Saelens, B.E., Sallis, J.F., Frank, L.D., 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann. Behav. Med. 25 (2), 80–91.

Soltani, A., Hoseini, S.H., 2014. An analysis of the connection between built environment, physical activity and health: comparing three urban neighbourhoods from Shiraz, Iran. Int. J. Urban Sci. 18 (1), 19–30.

Stradling, S.G., Anable, J., Carreno, M., 2007. Performance, importance and user disgruntlement: a six-step method for measuring satisfaction with travel modes. Transp. Res. Part A 41, 98–106.

Van Dyck, D., Cardon, G., Deforche, B., De Bourdeaudhuij, I., 2011. Do adults like living in high-walkable neighborhoods? Associations of walkability parameters with neighborhood satisfaction and possible mediators. Health Place 17 (4), 971–977.

Whyte, W.H., 1988. City: Rediscovering the Center. University of Pennsylvania Press, p. 102.

Wilson, T.D., Gilbert, D.T., 2003. Affective forecasting. In: Zanna, M.P. (Ed.), Advances in Experimental Social Psychology. Academic Press, Waterloo, Ontario.