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Sugie Lee*[1], Hyungun Sung[2] and Ayoung Woo[3]

[1] Associate Professor, Department of Urban Planning and Engineering, Hanyang University, Korea
[2] Assistant Professor, Department of Urban Engineering, Chungbuk National University, Korea
[3] Assistant Professor, Department of Architecture, Sejong University, Korea

Abstract

Although many studies have documented statistically significant associations between built environments and walking activity in certain Western countries, little research has been done to explore the spatial variations of the relationship between built environment measures and pedestrian volume for Asian mega-cities. With the application of spatial statistics that control for spatial autocorrelation, this study examines the determinant factors of the built environment on pedestrian volume using the 2009 Seoul Pedestrian Flow Survey (SPFS), which includes 10,000 locations across the city of Seoul. As an unprecedentedly large database for pedestrian activity in the Korean mega-city, this survey data provides an invaluable opportunity to explore the relationship between the built environment and pedestrian volume. The analysis results indicate that most built environment variables such as density, diversity, distance, connectivity, and design have statistically significant associations with pedestrian volume in Seoul. However, this study also finds that the relationships between some built environment measures and pedestrian volume have different associations depending on whether they are in residential or commercial zones. This finding indicates that the relationships between the built environment and pedestrian volume should be examined in the context of spatial location and land use characteristics of the case study area.

Keywords: built environment; pedestrian volume; spatial statistics; urban design; walking

1. Introduction

Walking was regarded as a "forgotten mode" in the 1990s, though this human-powered travel is one of the most common and accessible forms of sustainable transportation (USDOT, 2010). Recently, there has been a convergence of support among planners and policymakers to promote walking activity because walking is an environmentally friendly and efficient transportation mode. In terms of urban sustainability, these characteristics are particularly obvious for walking short distances. Hence, walking has emerged as an important research topic for urban, transportation, and environmental studies. It is also important in integrated research fields dealing with public health. These trends have a theoretical background of sustainable development, compact cities, New Urbanism, and smart growth which emphasize the role of walking activity.

Jacobs (1961) claimed that there should be as many pedestrians as possible for street vitalization. She emphasized the roles of density, mixed land use, well-connected small blocks, and existence of old buildings as crucial to ensuring street activity and urban vitality. Although her claims did not receive much attention at that time, her ideas have influenced urban design practices such as pedestrian-friendly design, mixed land use, and transit-oriented development, demonstrated by the New Urbanist movement (Calthorpe, 1993; Sternberg, 2000). In addition, research has extensively examined the associations between these components and walking activity during the last decade (Christiansen *et al.* 2016, Duncan *et al.* 2010 and Frank *et al.* 2006, Grasser *et al.*, 2013; Knuiman *et al.*, 2014, Stewart *et al.*, 2016, Sung *et al.*, 2014).

However, urban scholars have not reached a consensus on the impacts of each built environment component on walking activity (Ewing and Cervero, 2010; Forsyth *et al.* 2007). The relationships may differ by neighbourhood location and walking purpose (Cho and Rodriguez, 2015). Also, inconsistent outcomes can be attributed to differences in case

*Contact Author: Sugie Lee, Associate Professor, Department of Urban Planning & Engineering, Hanyang University, 222 Wangsimniro, Seogdong-gu, Seoul 04763, Korea
Tel: +82-2-2220-0417 Fax: +82-2-2220-1945
E-mail: sugielee@hanyang.ac.kr
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study areas, measures of built environments, and analytical methodologies. Another critical issue is that most empirical studies focus on relatively low-density suburban settings, rather than high-density urban areas. Furthermore, the relationship between built environment and walking activity in Asian mega-cities would be different from those cities in Western countries due to spatial heterogeneity, and cultural and behavioral differences.

This study aims to examine the impact of the multidimensional concepts of the built environment (e.g., density, land use diversity, distance, street connectivity, and design) on pedestrian volume in a high-density urban environment in Seoul, Korea. We created objective built environment measures from the unique dataset of the 2009 Seoul Pedestrian Survey, which included 10,000 sites within the city. Addressing the associations between built environment variables and pedestrian volume, this study suggests policy implications for promoting pedestrian walking activities.

2. Literature Review

Walking is not only environmentally friendly, but also effective in promoting physical and mental health through physical activity (Hancock, 2012; Heesch *et al.*, 2015; Moor, 2013).Walking may provide vitality to city streets and chances for natural encounters with people in neighborhoods or communities (Jacobs, 1961; Sung *et al.*, 2015).

The study of the relationship between the built environment and travel behavior has a long history in transportation planning research. Many studies have well documented the relationship between land use and commuting behavior in terms of travel distance, time, and mode choice (Cervero and Kockelman, 1997; Ewing and Cervero, 2002; Frank and Pivo, 1994). The relatively recent research trend on the urban physical environment and walking behavior has been conducted as an extension of this research (Boarnet *et al.* 2008; Grasser *et al.*, 2013; Knuiman *et al.*, 2014).

Furthermore, a growing number of studies have shown that there are statistically significant associations between built environment characteristics (e.g., development density, land use diversity, and street connectivity) and walking activity; specifically, mixed land use and development density are significant variables for walking activity (Ewing and Cervero, 2010; Frank *et al.* 2006; Grasser *et al.*, 2013; Greenwald and Boarnet, 2002; Sung *et al.*, 2014). This study builds upon previous literature estimating impacts of built environments on pedestrian walking. Beyond previous studies, this paper specifies the multidimensional concepts of the built environment based on various datasets.

In addition, many previous studies focus on relatively low-density suburban contexts in Western countries, except for a few studies that have focused on a high-density built environment such as New York City (Freeman *et al.*, 2013; Lovasi *et al.*, 2012). Some studies have stated that the relationships between the built environment and walking activity are complicated due to spatial heterogeneity, self-selection issues such as attitudes and perceptions on walking behavior, and methodological differences (Chatman, 2009; Feuillet *et al.*, 2016; Forsyth *et al.* 2007; Joh *et al.*, 2012; Kamruzzaman *et al.*, 2016; Lacono *et al.*, 2010; Lin and Moudon, 2010).

Despite ample research on the relationship between the built environment and walking activity for Western countries, pedestrian-oriented transportation policies and walking activity have not received much attention in Asian mega-cities that have a high-density mixed land use and well-established public transportation systems. In addition, research on the relationship between built environment and pedestrian volume is rare due to the difficulties of data collection on pedestrians. Recently, a few studies have addressed the relationship between built environment variables and walking activities in transit-oriented high-density cities such as Seoul, Singapore, and Hong Kong (Cerin *et al.*, 2013; Nyunt *et al.*, 2015; Sung *et al.*, 2015; Sung and Lee, 2015). However, these studies did not fully address the spatial variations of the relationship between the built environment and walking activity in Asian mega-cities.

The relationships between the built environment and walking activity are not likely to be consistent due to the different characteristics of case study areas (Feuillet *et al.*, 2016). For instance, the relationship between the built environment and walking activity in Western cities would be different from Asian mega-cities that have a greater level of high-density and mixed-use development. In addition, the relationship in the commercial district would be different from the residential district. Multiple dimensions of the built environment measures may have different associations with walking activity in different land use zones.

Most of all, there is a growing consensus among researchers that spatial issues concerning empirical analyses are critical in specifying the associations between various environments and human outcomes. For instance, Species Distribution Models (SDMs)—innovative GIS-based methods—have been developed to produce predictive maps accounting for the interplay between various physical environments and species distributions (Franklin, 2009). In addition, spatial regression models have been used to account for spatial dependence issues in planning studies (Anselin, 2005, 2006); these models have been widely employed to clarify spatially autocorrelated factors and/or the effects of factors in geographical space. However, previous studies have overlooked the fact that survey data for walking activities tend to have a spatial dependence. Spatial regression models are rare in the literature of the relationship between the built environment and walking activity although a conventional multivariate regression model may not be appropriate due to spatial dependence issues.

The significance of this study can be summarized into three components. First, this study focuses on one of the Asian mega-cities to examine the relationship between the built environment and pedestrian volume. It thus expands the scope of previous studies by examining the city of Seoul as a non-Western study area.

Second, this study tests many different dimensions of the built environment including variations in density, diversity, connectivity, distance and design. Rather than using a simple measure for each dimension, this study examines diverse types of measures to capture the variations in density, diversity, distance, design, and others.

Finally, most previous studies have relied on multivariate regression to analyze the interaction between an urban physical environment and walking behavior. However, because a spatial dataset for walking activity is most likely to have spatial dependence issues, the conventional multiple regression model is not appropriate. Therefore, this study uses spatial-lag and spatial-error models to control for spatial autocorrelation using GeoDaSpace, a commonly used spatial statistical software.

3. Case Study and Methodology

This study examines the impacts of the built environment on walking activity in the city of Seoul. Seoul is one of the Asian mega-cities with a population of more than 10 million. Seoul has well-established bus, subway, and rail systems. As shown in Fig.1., Seoul has 25 administrative local government boundaries (gu) and 424 administrative neighborhoods (dong). The Han River flows from the east to the west dividing the northern and southern parts of city.

The data source for this study is the 2009 Seoul Pedestrian Flow Survey (SPFS) conducted by the Seoul Institute. Fig.1. illustrates the location of 10,000 survey points conducted during a four-month period in 2009. While survey points are more concentrated in the downtown and sub-center areas, they are more dispersed in the residential areas.

Each survey location records the number of people walking through the survey point from 7:30 AM to 8:30 PM during weekdays. The survey period for all locations was 4 months (August 10 to November 11, 2009); hence, it should be noted that the survey period of 4 months may give seasonal variances. The survey locations were carefully selected based on population density, land use, and public transportation systems. More specifically, the survey points were determined by the hierarchy of the road system in Seoul. All streets that are wider than 12m including driveways were considered for the survey points. However, the smaller streets less than 12m wide were arbitrarily chosen based on the proximity to CBD or subway stations (Byun and Seo, 2011). Therefore, this study excluded the samples from small streets to avoid sampling bias.

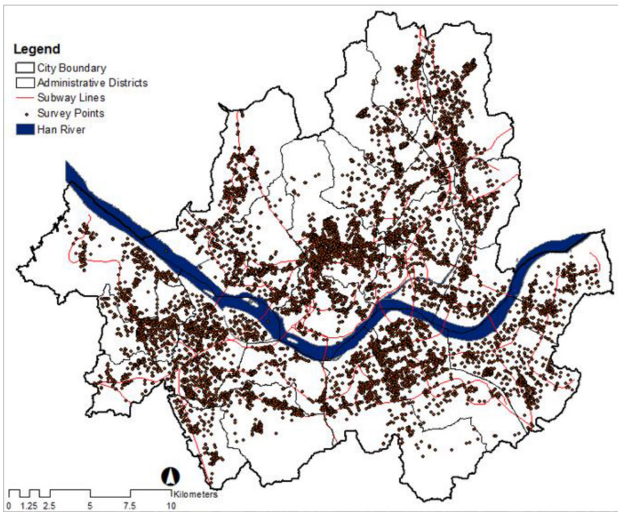

Fig.1. Pedestrian Volume Survey Points

Of the 10,000 survey points, this study extracted 5,114 locations that satisfy the criteria of 12m wide streets. If we separate 5,114 points by land use type, 3,717 points (72.7%) are located in residential zones and 815 points (15.9%) are located in commercial zones. Overall, we have balanced samples of survey points between residential areas and commercial areas based on the proportion of each land use type. The database also includes urban design features such as the width of the sidewalk, the number of lanes, the slope, the street furniture, and the crosswalk within 50m from the survey point. In addition to these urban design features, we measure built environment characteristics within a 100m Euclidian distance buffer from a survey point. We chose a buffer radius of 100m because we would like to consider the immediate built environment near survey locations, and 100m was a reasonable distance to avoid the duplication of buffer areas between survey points. Key independent variables including density, mixed use, connectivity, and building design were identified by previous studies (Cervero and Kockelman, 1997; Cerin *et al.*, 2013; Frank *et al.*, 2006; Jacobs, 1961; Sung *et al.*, 2014, 2015). Those built environment variables were calculated by the 100m buffer from the survey locations.

Regarding distance measures, we used the shortest Euclidean distance from each survey point to destinations such as bus stop, rail station, park, expressway, city center, and city sub-center. The street design variables represent the physical environments of a survey location as dummy variables. This study conducted a multi-collinearity test with variance inflation factor (VIF) and confirmed no multi-collinearity among independent variables. The basic multivariate regression model is as follows:

$$\begin{aligned} \ln y(\text{walking volume}) &= \beta_0 + \beta_1(\text{pop.density}) \\ &+\beta_2(\text{emp.den}) + \beta_3(\text{dev.den}) + \beta_4(\text{mixed use}) \\ &+\beta_5(\text{distance}) + \beta_6(\text{connectivity}) \\ &+\beta_7(\text{building design}) + \beta_8(\text{design feature}) + \varepsilon \end{aligned} \quad (1)$$

The dependent variable is the logarithmic value of the pedestrian volume. The pedestrian volume is an average value of total walking volumes on weekdays. We transformed the walking volume variable into the logarithmic value to reduce severe skewness in data distribution.

Independent variables include population and employment densities, development density, mixed land use, distances to transportation and parks, connectivity of street network, and block size. We also include urban design features such as the width of sidewalks, number of lanes, and dummy variables for slope, bus line, street furniture, fence and crosswalk.

For an analysis of the relationship between dependent and independent variables, this research used multivariate spatial regression models including spatial-lag and spatial-error models to control spatial autocorrelations (Anselin, 2006). The spatial-lag model includes the spatially lagged dependent variable to control for spatial autocorrelation. W_y is the weight matrix of the spatially lagged dependent variable y. The coefficient of spatially lagged dependent variable is rho (ρ) called the spatial autoregressive coefficient.

$$y = \rho W_y + \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon \qquad (2)$$

In contrast, the spatial-error model is a regression model with spatially autocorrelated errors. W_ε is the weight matrix of the spatially lagged error term. The spatially autoregressive parameter of the error term is called lambda (λ).

$$y = \lambda W_\mu + \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \mu \qquad (3)$$

For spatial regression models, we used the GeoDaSpace software package developed by the GeoDa center at Arizona State University (Anselin, 2005). As freeware, GeoDaSpace provides exploratory spatial data analysis (ESDA) and spatial regression models including spatial-lag and spatial-error models.

4. Analysis

Table 1. shows measurements and descriptive statistics for all variables. Of the 10,000 survey points, 5,114 observations were used for regression models, excluding missing data. This research used multivariate regression models to examine the relationship between built environment measures and pedestrian volume. Since we have identified spatial clusters of survey points across Seoul, we first tested the spatial autocorrelation of pedestrian volume variables to determine whether the spatial regression approach fits the data. Using GeoDaSpace, we tested the presence of spatial autocorrelation with a spatial weight matrix. We generated the spatial weight matrix based on the Euclidean distance band. We found that Moran's I value was statistically significant, indicating the presence of spatial autocorrelation. The presence of spatial autocorrelation problems may lead to biased and inconsistent estimation in the analysis. Hence, we employed spatial-lag and spatial-error regression models to account for spatial autocorrelation. Of the two spatial models, analysis outputs indicate that the spatial-error model has better goodness of fit than the spatial-lag model based on the Lagrange multiplier (LM) lag or error test even though the two models show similar results.

Table 2. compares two regression models: conventional Ordinary Least Square (OLS) model and spatial-error model stratified by land use zoning districts of residential and commercial zones. The lambda (λ) values in the spatial regression model indicated significant spatial autocorrelation across survey locations for pedestrian volume in Table 2. Therefore, the conventional OLS model is unable to provide the Best Linear Unbiased Estimator (BLUE) condition.

The key findings are as follows. First, population density for people 65 and over had a negative association with walking volume across both residential and commercial zones. The total employment density variable showed a positive association with walking volume consistently and significantly in all models. However, employment density variables by employment types show a different association with walking volume across zones. For instance, the employment density measure for restaurants and hotels (Emp_res_hotel) was only significant in a residential zone. In addition, the employment density measure for FIRE (finance, insurance, and real estate) industry (Emp_FIRE) showed a negative association in the residential zone and positive association in the commercial zone.

Second, development density measures showed different associations in residential and commercial zones. Residential development density (Res) was negatively associated with walking volume in a residential zone. However, it was not significant in a commercial zone. Commercial development density (Com) was positively associated with walking volume in all models, indicating the contribution of commercial function to pedestrian volume. Office development density did not show any statistical significance in all models.

Third, mixed-use measures (RNRn, RNRnd, and LUM3) confirmed that they were positively associated with walking volume. However, they were only significant in residential zones, indicating the importance of mixed-use development to pedestrian volume in residential zones.

Fourth, distance measures showed expected signs; these were significantly associated with walking volume. In particular, the distance variables of bus stops (dist_busstop) or rail stations (dist_railstation) indicated that pedestrian volumes were strongly associated with a shorter distance to bus stops or rail stations in all zones. On the other hand, the positive

Table 1. Variables and Descriptive Statistics

	Variable	Descriptions	Mean	Std. Dev.	Min.	Max.
Depen. Var.	Walking (ln)	Long-transformed value of pedestrian volume	7.767	0.910	2.079	11.573
Demo. &	Pop (65+) (ln)	Log-transformed net density of population over 65	-4.534	1.693	-10.207	4.678
Economic	Emp_tot (ln)	Log-transformed net density of total employment	-3.243	1.294	-9.157	5.745
	Emp_retail (ln)	Log-transformed net density of retail employment	-5.154	1.606	-10.354	3.908
	Emp_rest_hotel (ln)	Log-transformed net density of restaurant/ hotel emp.	-5.493	1.747	-10.268	2.234
	Emp_FIRE (ln)	Log-transformed net density of FIRE employment	-5.698	2.067	-10.208	2.501
	Emp_instit (ln)	Log-transformed net density of institution employment	-6.222	1.564	-10.217	1.792
Development	Res (ln)	Log-transformed net development density of resident. use	0.573	1.584	-6.872	9.982
Density	Com (ln)	Log-transformed net development density of comm. use	-0.285	1.161	-6.806	7.546
	Off (ln)	Log-transformed net development density of office use	-1.181	1.818	-8.098	6.259
	Pub (ln)	Log-transformed net development density of public use	-1.577	1.781	-8.244	9.160
	Oth (ln)	Log-transformed net development density of other uses	-1.616	1.882	-9.058	8.946
Land Ue	RNRd	Land use mix b/t residential use and daily use	0.426	0.226	0.000	0.995
Mix*	RNRnd	Land use mix b/t residential use and non-daily use	0.216	0.222	0.000	0.999
	LUM3	Land use mix entropy index among residential use, daily use. and non-daily use	0.636	0.219	0.000	1.000
Distance	Dist_busstop	Distance (m) to the nearest bus stop	80.829	70.307	0.867	698.995
	Dist_railstation	Distance (m) to the nearest rail station	478.371	353.796	1.879	3739.57
	Dist_park	Distance (m) to the nearest park	448.604	355.139	2.280	3152.25
	Dist_expressway	Distance (m) to the nearest expressway	1386.099	1076.405	0.417	6019.26
	Dist_cityhall	Distance (m) to the city hall (center)	8594.465	3995.592	11.405	17788.50
	Dist_Gangnam	Distance (m) to the Gangnam (sub-center)	10463.020	4439.981	200.803	21272.80
Connectivity	Nd_busstop	Net density of bus stops	0.00025	0.00018	0.000	0.00124
	Nd_railstation	Net density of rail stations	0.23161	0.14745	0.000	1.00000
	Nd_intersection	Net density of road intersection	0.00019	0.00019	0.000	0.00307
	4-way intersection	Percent of 4-way intersections to all intersections	0.00000	0.00002	0.000	0.00018
Building	Building_num.	Number of buildings	1209.294	1432.661	0.000	15784.00
	Building_marea	Average floor areas(m^2) of buildings	207.158	535.541	0.000	20708.33
Street Design	Sidewalk	Width of sidewalk	3.500	2.018	1.000	24.300
	Lane	Number of driveway lanes	4.418	2.253	2.000	18.000
	Dslope	Dummy variable for slope	0.247	0.431	0	1
	Dfurniture	Dummy variable for street furniture	0.122	0.327	0	1
	Dfence	Dummy variable for fence	0.950	0.217	0	1
	Dbusline	Dummy variable for bus line	0.245	0.430	0	1
	Dcrosswalk	Dummy variable for crosswalk	0.740	0.439	0	1

* RNRd is a land use mix index between residential use and daily use. It is calculated by the equation of "1-|(res. use - daily use)/(res. use + daily use) | "(sung *et al.* 2015)". LUM3 is entropy index of land use mix among residential use, daily use, and non-daily use. The equation is "LUM=$\sum(P_i*\ln P_i)$/ (ln(n)), where P_i is the proportion of building square footage of land use I and n is the number of land uses (Frank & Pivo, 1994).

associations with walking volume and the distance to expressways indicated that as distances to expressways increase, pedestrian volume decreases.

Fifth, the higher density of bus stops showed a significant association with higher walking volume. This finding indicates that bus stops are important factors of pedestrian volume in residential and commercial zones. In addition, as a connectivity variable of the street network, the net density of road intersection nodes was statistically significant in all models except the commercial zone. In contrast, the ratio of four-way intersection nodes to total nodes was only weakly significant in the commercial zone.

Sixth, the number of buildings was positively associated with walking volume in the residential zone and the average floor areas of buildings was negatively associated with it in the commercial zone. This finding indicates that smaller buildings are more likely to be associated with pedestrian volume.

Finally, micro-scale urban design variables showed expected associations with walking volume. Particularly, the width of sidewalks, number of lanes, slope, crosswalk, and bus line showed significant positive associations with pedestrian volume.

5. Conclusion

Pedestrian volume is a critical condition to promote on-street urban vitality (Jacobs, 1961). A walkable city initiative in Asian mega-cities is also a desirable policy goal for urban sustainability. This study explored the complicated relationship between the built environment and pedestrian volume in the spatial context of the Asian mega-city of Seoul, Korea.

The analysis results contribute to urban planning and design policies to promote walking activity in Asian mega-cities. This study identifies the consistent environmental factors that have positive associations with pedestrian volume regardless of land use zone types. They are population density of over 65, employment density, commercial use density, distance to bus stops or rail stations, distance to expressway, net density of bus stations, and some urban design features

Table 2. OLS and Spatial Statistics Models for Pedestrian Volume by Land Use Zones

Variables		All Zones				Residential Zone				Commercial Zone			
		OLS		Spatial Reg.		OLS		Spatial Reg.		OLS		Spatial Reg.	
		Coef.	t	Coef.	z	Coef.	t	Coef.	z	Coef.	t	Coef.	z
	Lambda			0.622***	17.38			0.530***	14.54			0.326**	2.23
Demo. &	Pop (65+) (ln)	-0.054***	-6.60	-0.042***	-5.03	-0.073***	-5.28	-0.054***	-3.94	-0.023*	-1.87	-0.023*	-1.92
Economic	Emp_tot (ln)	0.123***	8.34	0.109***	7.31	0.111***	6.46	0.110***	6.44	0.134***	3.27	0.134***	3.35
	Emp_retail (ln)	-0.026***	-2.61	-0.012	-1.16	-0.012	-1.04	-0.005	-0.47	-0.057**	-2.30	-0.056**	-2.30
	Emp_rest_hotel (ln)	0.027***	3.64	0.024***	3.27	0.022***	2.66	0.019**	2.29	-0.008	-0.35	-0.005	-0.21
	Emp_FIRE (ln)	-0.004	-0.68	-0.010	-1.59	-0.015**	-2.24	-0.019***	-2.75	0.036*	1.85	0.033*	1.71
	Emp_instit (ln)	-0.008	-1.02	-0.009	-1.15	0.005	0.51	0.001	0.06	-0.007	-0.38	-0.004	-0.22
Develop.	Res (ln)	0.002	0.18	-0.008	-0.82	-0.015	-1.05	-0.028*	-1.87	0.012	0.82	0.013	0.87
Density	Com (ln)	0.129***	9.60	0.120***	9.04	0.122***	7.72	0.109***	6.87	0.189***	5.16	0.181***	4.98
	Off (ln)	0.009	1.12	0.002	0.29	-0.003	-0.36	-0.008	-0.89	0.029	0.89	0.021	0.67
	Pub (ln)	-0.010	-1.55	-0.007	-1.14	-0.003	-0.37	-0.002	-0.27	-0.034**	-2.28	-0.033**	-2.23
	Oth (ln)	-0.019**	-2.43	-0.018**	-2.30	-0.014	-1.65	-0.017*	-1.92	-0.001	-0.02	0.003	0.11
Land Use	RNRd	0.283***	5.33	0.232***	4.10	0.337***	5.33	0.305***	4.63	-0.229	-1.60	-0.192	-1.33
Mix	RNRnd	0.093*	1.81	0.097*	1.79	0.166***	2.71	0.151**	2.39	-0.070	-0.47	-0.070	-0.48
	LUM3	0.089*	1.81	0.112**	2.22	0.150***	2.70	0.185***	3.28	0.167	1.10	0.183	1.19
Distance	Dist_busstop	-0.002***	-12.10	-0.002***	-11.57	-0.002***	-10.75	-0.002***	-9.63	-0.002***	-3.29	-0.002***	-3.42
	Dist_railstation	-3.18E-04***	-10.35	-4.15E-04***	-10.68	-2.50E-04***	-7.46	-3.11E-04***	-7.41	-9.64E-04***	-7.72	-1.00E-03***	-7.81
	Dist_park	1.56E-05	0.52	1.92E-05	0.47	4.08E-05	1.22	3.68E-05	0.82	-5.69E-05	-0.62	-4.53E-05	-0.49
	Dist_expressway	9.82E-05***	9.44	1.14E-04***	5.82	8.76E-05***	6.82	1.05E-04***	4.99	1.20E-04***	3.94	1.13E-04***	3.35
	Dist_cityhall	-1.25E-05***	-3.98	-1.70E-05**	-2.39	-1.00E-05***	-2.65	-1.15E-05	-1.60	-5.50E-06	-0.56	-8.50E-06	-0.71
	Dist_Gangnam	-6.70E-06**	-2.47	-8.10E-06	-1.29	-5.90E-06*	-1.91	-8.20E-06	-1.44	-1.41E-05	-1.44	-1.42E-05	-1.15
Connectivity	Nd_busstop	315.288***	5.54	280.449***	4.82	300.718***	4.68	282.759***	4.34	438.289***	2.71	477.704***	2.98
	Nd_railstation	674.538	1.17	784.710	1.30	400.234	0.62	538.015	0.78	-2066.859	-0.65	-3046.485	-0.97
	Nd_intersection	415.566***	5.61	451.740***	5.46	458.343***	5.38	479.715***	5.18	230.759	0.91	234.020	0.92
	4-way intersection	0.116	1.58	0.063	0.84	0.110	1.27	0.091	1.06	0.390*	1.75	0.379*	1.70
Building	Building_num.	6.38E-05***	7.29	6.37E-05***	7.15	8.83E-05***	7.14	8.13E-05***	6.48	2.62E-05*	1.71	2.46E-05	1.63
	Building_marea	-2.19E-05	-1.02	-4.27E-05**	-2.01	-4.22E-05	-0.84	-3.45E-05	-0.69	-7.28E-05***	-2.84	-7.27E-05***	-2.91
Design	Sidewalk	0.057***	10.19	0.054***	9.82	0.059***	8.03	0.054***	7.54	0.050***	4.92	0.048***	4.79
	Lane	0.021***	3.79	0.023***	4.17	0.014**	2.10	0.016**	2.52	0.049***	3.94	0.050***	4.09
	Dslope	-0.072***	-2.96	-0.088***	-3.63	-0.046	-1.62	-0.058**	-2.05	-0.097*	-1.67	-0.106*	-1.86
	Dfurniture	0.089*	1.89	0.092**	1.98	0.062	1.14	0.048	0.90	0.279**	2.49	0.286***	2.61
	Dum_fence	0.114***	4.61	0.113***	4.68	0.129***	4.41	0.131***	4.57	0.019	0.32	0.009	0.15
	Dum_busline	0.155***	4.48	0.153***	4.46	0.146***	3.50	0.135***	3.26	0.227***	2.98	0.223***	3.01
	Dcrosswalk	0.137***	5.80	0.144***	6.16	0.164***	6.08	0.171***	6.40	0.011	0.17	0.014	0.23
Constant		7.229***		7.349***	55.39	7.021***	51.74	7.117***	46.72	7.588***	25.49	7.629***	24.50
	N	5114		5114		3717		3717		815		815	
Summary	R-sq /Pseudo R-sq	0.3664		0.3628		0.3115		0.3088		0.4406		0.4399	
	Akaike info criterion	1731.596		-		8202.641		-		1731.596		-	
Statistics	Moran's I	0.0449***		-		0.0489***		-		0.0119***		-	
	LM lag/error	-		382.516***		-		237.037***				3.002*	

*p<0.10; **p<0.05; ***p<0.01

such as sidewalk, number of lanes, and bus lines. With the comprehensive and the unique pedestrian flow survey data in Seoul, this study demonstrated a few important findings.

First, demographic and socioeconomic variables such as the employment density measures showed a significant positive association with pedestrian volume regardless of land use zones. However, employment densities of business types showed different associations with pedestrian volume. For instance, the employment density of restaurants and hotels showed a positive association in the residential zone, while it was not significant in the commercial zones. In addition, the employment density of the FIRE sector showed opposite associations by land use zones. This finding also indicates that the impact of certain types of employment on pedestrian volume would be different from the residential or commercial zones.

Second, the land development density measures also showed significant associations with walking volume. The commercial development density measure was a significant variable regardless of land use types. In other words, commercial development has positive impacts on pedestrian volume in the residential zone. However, residential or office development density showed no impact on pedestrian volume in the commercial zone.

Third, this study also confirms that mixed land use is a key measure to explain pedestrian volume; we found that the relationships between built environments and pedestrian volume vary across the type of land use zone, such as residential and commercial zones. However, all land use mix variables did not show any significant associations with pedestrian volume in the commercial zones. This finding indicates that land use mix policies for promoting pedestrian volume may be more effective in the residential zone.

Fourth, the distance variables and street connectivity measures showed significant associations with walking volume. The study confirmed that the existence of bus stops and rail stations near the survey points are most likely to be associated with higher walking volume. The density of bus stops showed strong positive associations with walking volume in residential and commercial zones. However, the density of rail stations did not show a significant relationship in both zones. This finding indicates that the average distance to rail stations is more important than the density of rail stations to explain pedestrian volume.

Fifth, the number of buildings showed a strong positive association with pedestrian volume in the residential zone. In contrast, the average floor area of buildings showed a negative association with pedestrian volume in the commercial zone. These findings indicate that many small-scale buildings—rather than a few large buildings—are more likely to be associated with pedestrian volume in the residential zone or commercial zone. These findings suggest an important policy implication for walkable city movements in urban design practice. Many small-scale buildings offer not only a variety of land uses, but also a human-scale urban built environment. In other words, many small-scale buildings are more likely to promote walking activities with land use diversity and human-scale street environment.

Sixth, street design features showed expected relationships with walking volume. The width of sidewalks was a very significant and strong measure for higher walking volume. The number of lanes for a road beside the survey point or the existence of bus lines also showed a significant positive association with walking volume because the number lanes or bus lines are related to larger sidewalk and non-residential land uses on the street.

Finally, when it comes to examining the relationships between walking activity and the built environment, this study showed that spatial regression approaches should be considered to account for the spatial dependence issue. The analysis results show that spatial autocorrelations are statistically significant, demonstrating the biased estimations of the OLS model. This study further showed that the spatial-error model was better than the spatial-lag model.

Despite some significant associations between the built environment and pedestrian volume, this study could not address the causal relationships between them. Time-series or spatial panel data for built environment and pedestrian volume may illustrate the causal relationship. In addition, this study could not consider the diverse types of land use zones beyond residential or commercial zones in Seoul. Lastly, this study did not consider survey points on the small streets due to sampling bias in Seoul. However, this study contributes to the implementation of the key concepts of new urbanism and smart growth initiatives which can be applied to Asian mega-cities.

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