Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

COMBINING SPACE SYNTAX WITH GIS-BASED BUILT ENVIRONMENT MEASURES IN PEDESTRIAN WALKING ACTIVITY

098

Sugie Lee
Hanyang Unviersity
e-mail: sugielee@hanyang.ac.kr

Kyung Wook Seo
Kyonggi University
e-mail: kseo@kgu.ac.kr

Abstract

This study combines space syntax measures and GIS-based built environment variables for an analysis of pedestrian walking volume using the walking survey data for 10,000 locations across the city of Seoul. The results indicate that two syntactic variables of global integration and control show statistically significant associations with the average walking volume for weekdays in Seoul. Global integration measure shows a statistically significance in residential zone, but it did not show any association with walking volume in commercial zone. On the other hand, control value shows a statistically significance in commercial zone, but it did not show any association with walking volume in residential zone. Of built environment variables, statistically significant variables are net employment density and net commercial land use density variables. Accessibility measures to pubic transportation and urban design characteristics show statistically significant association with pedestrian walking volume. This study concludes that combining space syntax with GIS-based built environment measures has a great potential for analyzing pedestrian walking activities.

Keywords: *Built Environment, GIS, Space Syntax, Urban Morphology, Walking*

Theme: *Urban Space and Social, Economic and Cultural Phenomena*

Introduction

The purpose of this study is to examine built environment factors that affect pedestrian walking volume using the integrated approach with space syntax techniques and geographic information systems (GIS). A few studies indicate that urban morphological variables from space syntax analysis would be significant determinants for pedestrian or traffic volume. For instance, Baran et al. (2008) applied space syntax techniques to examine walking activities in a New Urbanist and suburban neighourhoods and found consistent positive relationship between total utilitarian walking and two of the space syntax variables such as control and global integration. Jung and Choi (2010) also applied space syntax analysis to examine the pedestrian volume in downtown Daegue in Korea and suggested that street integration variable supplemented by accessibility factor would be helpful to estimate pedestrian volume.

While several studies in architectural fields have tried to address urban morphological factors for walking volume on the urban street, the urban morphological measures from space syntax analysis have ignored the physical and socioeconomic characteristics of surrounding urban built environment. Since GIS is one of the most powerful tools for an analysis of urban built environment, combining GIS-based built environment variables to space syntax would have a great potential to examine pedestrian walking activities. This research examines whether the composite model that combines space syntax measures and built environment variables explains more variations of the pedestrian walking volume on the streets in Seoul. The source of data is from the Seoul Pedestrian Volume Survey (2010) that covered 10,000 locations across the City of Seoul and was conducted from July 2009 to June 2010. This database is a comprehensive survey data not only including pedestrian volume by date and time, but also including specific information of various facilities on the streets. This study develops multivariate statistical models for estimating pedestrian volume including urban morphological variables from space syntax analysis and urban built environment variables such as development density and land use mix.

This research would illustrate the advantage of the composite model that combines space syntax and GIS to estimate and predict pedestrian walking volume and extend the usefulness of space syntax techniques for analyzing built environment in both architecture and urban planning.

Literature Review

Space syntax is a kind of spatial language that is able to explain the relationship between a spatial form and the human behavior developed by Bill Hillier and his colleagues at the Bartlett School at University College London in the 1980s. Space syntax theory and its analytical methods have been applied for morphological analysis in architectural design and urban form. Previous research indicates that space has its own social logic that affects human behavior such as pedestrian movement from one place to another (Hillier and Hanson, 1984; Hillier, 1998; Penn et al. 1998)

Space syntax theory focuses on the urban grid system of street network for pedestrians and other transportation modes. Hillier et al.(1993) argued that “the configuration of the urban grid itself is the main generator of patterns of movement.” They called the movement by the configuration of the urban grid as “natural movement.” Natural movement addresses natural human activities in configuration of urban grid. The background of the statement is that the configuration of urban grid is the historical and cultural product of the space presenting human activities. To the extent that we interpret the configuration of urban grid, therefore, it means that we could predict human activities in space.

Space syntax related research show that space syntax theory would be a useful technique to investigate not only pedestrian movements but also the other aspects of built environments such as land use patterns, social and economic performance, or crime patterns in urban area (Hillier and Hanson, 1984; Hillier et al, 1993). For an application to urban planning fields, notably, Baran et al.(2008) examined the relationship between space syntax measures and walking in a New Urbanist and suburban neighbourhoods. They found that significant relationships between the number of leisure trips and space syntax measures such as control, location integration and global integration. They also found consistent positive relationship between total utilitarian walking and two space syntax variables of control and global integration.

However, little research has been conducted to examine the impact of built environment on walking activity using the integrated approach between space syntax measures and other important built environment variables. In addition, space syntax theory has several computational issues for its measures in urban context because space syntax measures depend on axial line which has not been clearly defined (Ratti, 2004). Furthermore, space syntax technique is unable to take into account surrounding land use, which is a critical limitation to estimate or predict pedestrian volume and walking activities (Batty et al. 1998).

Despite a few limitations of space syntax technique, space syntax theory and its application have great potential to explain walking activity if we can combine space syntax variables with built environment variables into analytical models. Pedestrian walking activities are associated with surrounding built environments such as land use, destinations, and public transportation. Jiang and Claramunt (2002) also pointed out that a collaborative integration of space syntax into GIS would give new perspectives for an analysis of urban morphology.

Case Study and Methodology

The case study area for this study is the city of Seoul which is an Asian mega city with well-established public transportation systems and higher development density in terms of residential and commercial land uses. The source of data for walking activities is the Seoul pedestrian volume survey(2010) that includes 10,000 locations across Seoul. The survey was conducted from July 2009 to June 2010. The survey points have been selected strategically based on population density, land use, and transportation systems across the city of Seoul. This raw data provided total number of pedestrians who passed the survey points from 7:30 AM to 8:30 PM from Monday to Friday. The raw data also included street design features such as sidewalk, slope, fence, and crosswalk within 50m from each survey point. In addition, zoning information such as residential zone or commercial zone was included in the dataset. This data is a comprehensive and unique data source for pedestrian volume survey in Korea. Figure 1 illustrates 10,000 locations for pedestrian volume survey in the city of Seoul.

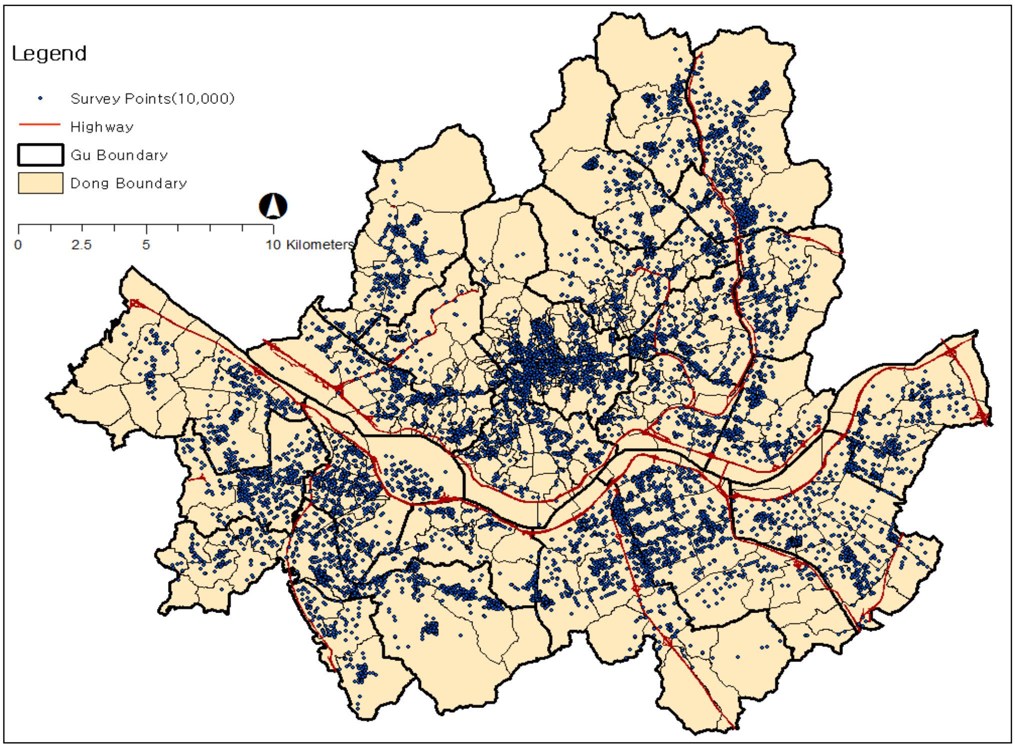

Figure 1. Pedestrian Survey Locations in Seoul

Space syntax theory and its analytical technique have been updated with the sophisticated analytical soft wares such as Depth Map and Axwoman in ArcGIS for morphological analysis in architectural design and urban studies. This study utilizes Axwoman extension in ArcGIS 10 for axial map generation and space syntax analysis. Although there are a few soft wares for an analysis of space syntax, this research used Axwoman in ArcGIS 10 because it is a very efficient method for integrating space syntax measure with GIS variables. The Axwoman extension in ArcGIS system was developed by Jiang(1998) for urban morphological analysis using space syntax theory. Figure 2 is the output of axial line generated from the centerline of transportation network in Seoul. We eliminated a few isolated axial lines because they are disconnected with the whole transportation system.

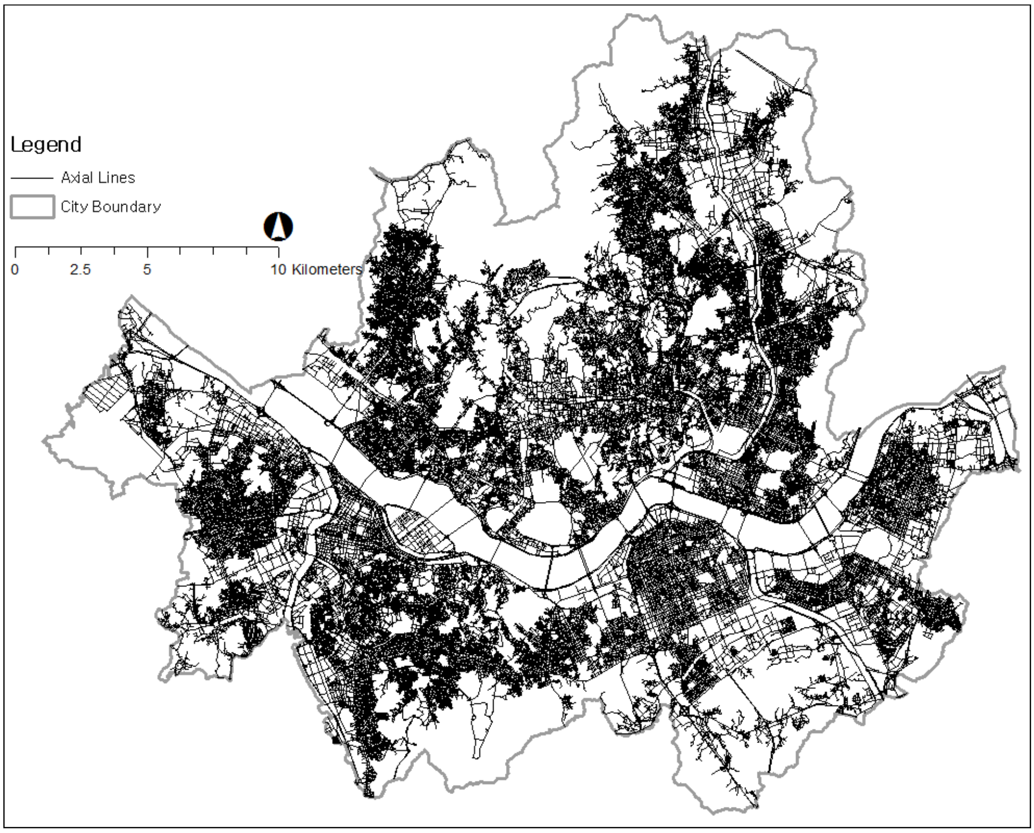

Figure 2. Axial line map using the center line of transportation network in Seoul

The Axwoman extension in ArcGIS 10 produced the attribute table that includes four key variables of connectivity, control value, global integration, and local integration. Figure 3 represents the spatial distribution of axial lines for global integration. The global integration measure in space syntax describes the average depth of a space to all other spaces in the network systems. The global integration values range from 0(lowest) to approximately 1(highest). The higher value of global integration indicates that the axial lines can be accessed easily from all other axial lines. As we expected, the global integration map shows higher values in the central area of Seoul and sub-center areas in Seoul.

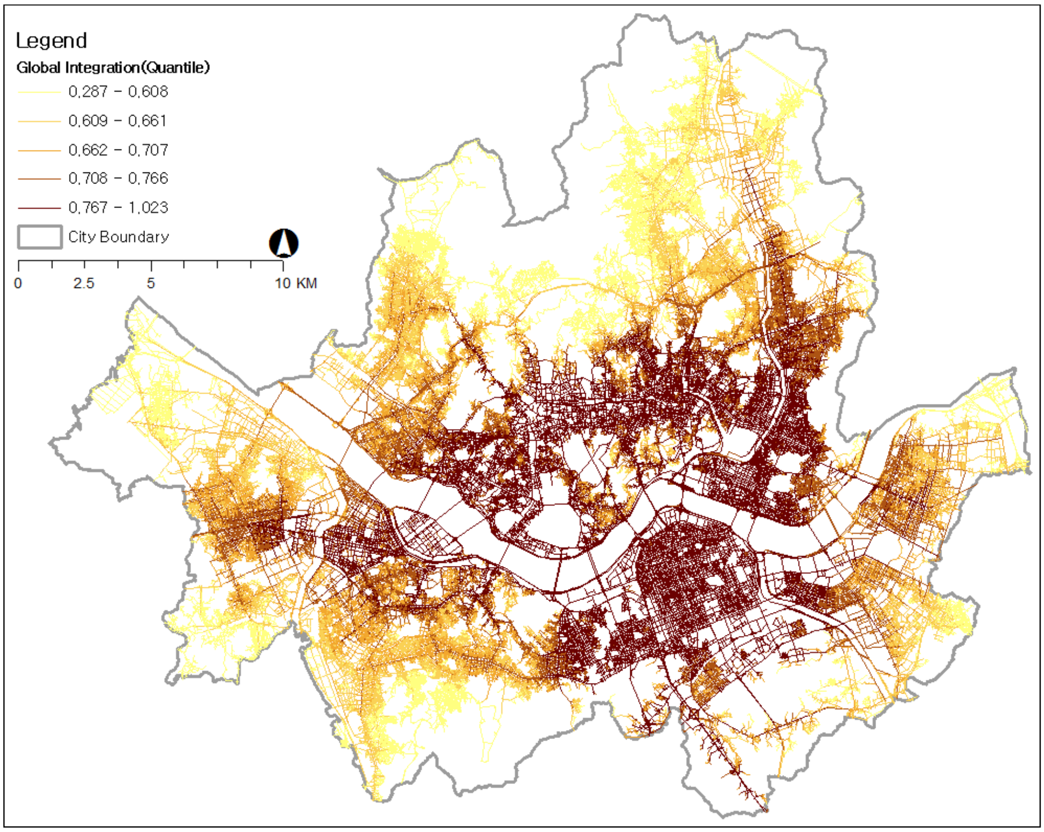

Figure 3. Global integration measure in space syntax

Although global integration value is a representative value of each axial line in the whole system, it is a limited measure to capture local integration of street network. The local integration value in space syntax usually represents local integration value in radius three. The city of Seoul has a polycentric urban form with city center and several sub-centers. Figure 4 represents local integration measure that reflects local condition of transportation network. The local integration measure indicates the average depth of a space to all other spaces within three depths in the network systems.

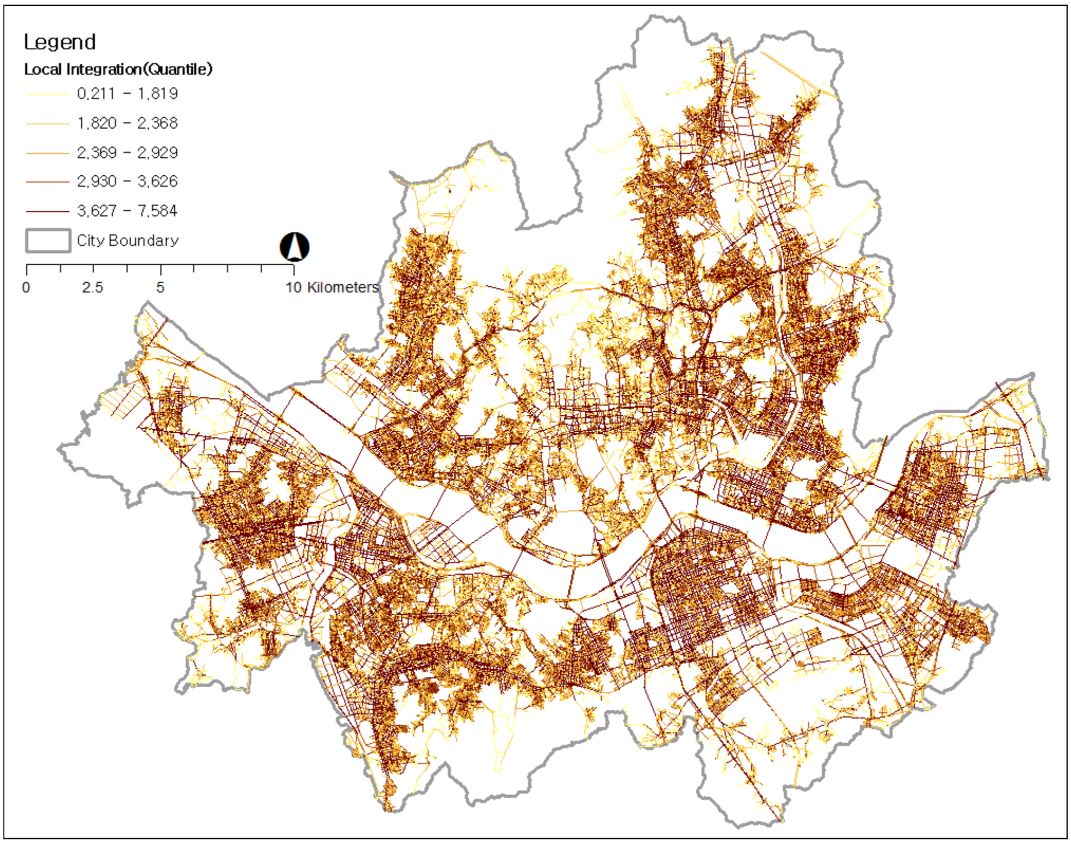

Figure 4. Local integration measure in space syntax

Figure 5 illustrates information of land use, axial lines, and buffers. Once we calculated space syntax variables using Axwoman extension in ArcGIS, we created 100m buffers from the survey points and extracted built environment variables within 100m buffers using intersect method between buffer and axial map. Then we aggregated mean value of space syntax measures within each buffer and joined the aggregated table to the survey point information. This study created several built environment variables in the 100m buffers. Those variables include population density, employment density, development densities for residential, commercial, and office uses, accessibilities to public transportations, expressway, and park, and street design features.

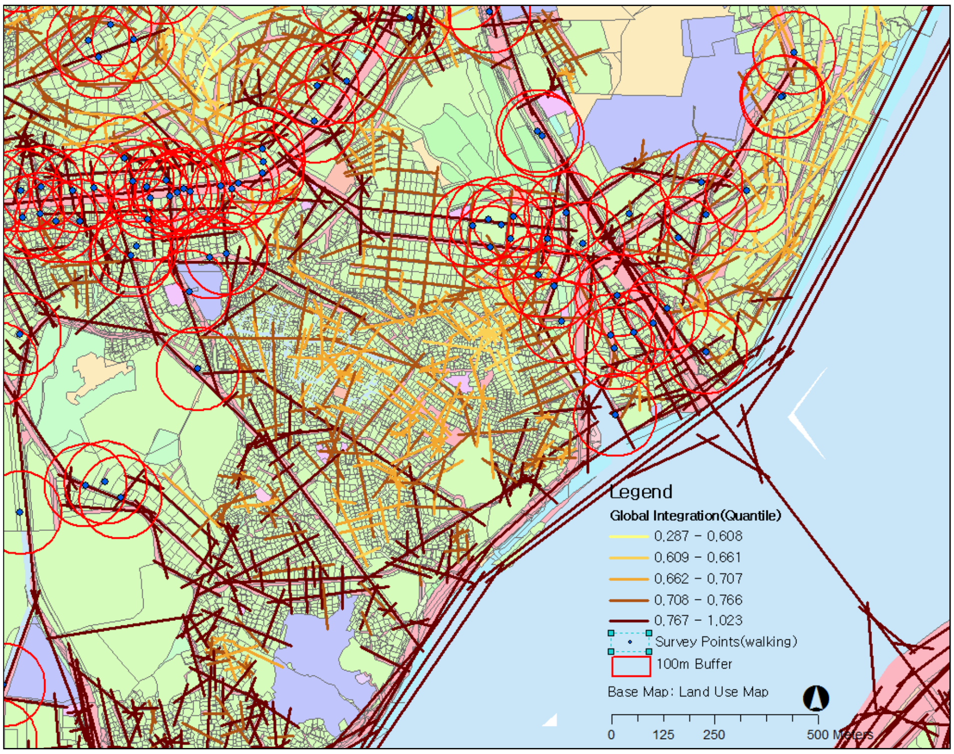

Figure 5. Buffer (100m) from survey points and global integration

Table 1 shows descriptive analysis table for dependent variable of walking volume and independent variables. Of 10,000 survey points, we exclude 1,459 observations because they have missing values or they are not correctly located on the map. Independent variables are density measures, space syntax measures, public transportation measures, accessibility to park, building scale measures, and street design features as shown in Table 1. For density measures, we applied net density excluding undevelopable lands such as parks and water bodies.

Table 1. Descriptive Analysis for Variables

	Variable	Description	Obs	Mean	Std. Dev.	Min	Max
Walking	Walking_volume	Mean walking volume	9,541	3,120.566	3,786.922	8.000	106,186.000
Density	Pop_den	Net population density	9,541	0.068	0.124	0.000	6.078
	Emp_den	Net employment density	9,541	0.006	0.009	0.000	0.208
	Res_den	Net residential use density	9,541	0.726	0.814	0.000	12.502
	Com_den	Net commercial use density	9,541	0.626	0.826	0.000	14.242
	Off_den	Net office use density	9,541	0.205	0.618	0.000	9.937
	Indus_den	Net industrial use density	9,541	0.034	0.258	0.000	7.665
	Educul_den	Net edu. and cultural use density	9,541	0.053	0.154	0.000	4.661
	Oth_den	Net other building density	9,541	0.011	0.072	0.000	2.709
Trans. Network	Busstop_den	Net density of bus stops	9,541	0.000	0.000	0.000	0.003
	Railstat_den	Net density of rail station entrances	9,541	0.000	0.000	0.000	0.000
	Dist_busstop	Distance to nearest bus stop(m)	9,541	93.716	69.819	0.856	698.755
	Dist_railstat	Distance to nearest rail station(m)	9,541	498.137	465.891	2.426	5,265.322
	Dist_express	Distance to nearest expressway(m)	9,541	1,420.133	1,085.768	0.417	6,017.037
Building	Bldg_num	Number of buildings	9,541	81.091	55.654	0.000	363.000
	Bldg_marea	Mean area of all building floors	9,524	380.746	1,357.145	42.651	73,118.220
Design Features	Sidewalk	Width of sidewalk(m)	9,541	3.974	2.163	1.000	24.300
	No_lane	Number of lanes	9,541	2.829	2.372	1.000	18.000
	Slope	Dummy of slope	9,541	0.250	0.433	0.000	1.000
	Busline	Dummy of busline	9,541	0.069	0.253	0.000	1.000
	Furniture	Dummy of street furniture	9,541	0.923	0.266	0.000	1.000
	Fence	Dummy of fence	9,541	0.150	0.357	0.000	1.000
	Crosswalk	Dummy of crosswalk	9,541	0.460	0.498	0.000	1.000
Space Syntax	Connect	Connectivity	9,541	9.042	4.689	1	63.800
	Control	Control value	9,541	1.787	0.825	0.024	9.892
	Ginteg	Global integration	9,541	0.750	0.098	0.454	1.023
	Linteg	Local integration	9,541	3.512	0.710	0.211	7.088
	Totdepth	Total depth	9,541	1,218,868	159,498	894,142	1,936,743
	Locdepth	Local depth	9,541	104.300	73.307	3	785

*Note: All variables were measured in the 100m buffer from the survey point except the design feature variables which were measured in the 50m buffer. Net density measures are based on the 100m buffer area except parks and water bodies.

Analysis

Table 2 shows correlation analysis between average walking volume for weekdays and space syntax variables by land use zones (i.e., residential, commercial, and industrial). The most consistent variables across land use zones are employment density, commercial land use density, transportation related measures, sidewalk width, number of lanes, and the existence of fence. Other variables show different correlation with walking volume by land use zones. Overall, commercial land use density, employment density, and bus station density in the 100m buffer have relatively higher correlation with walking volume than other variables.

All space syntax measures show significant correlation with walking volume in the residential zone. They are not significant in the commercial zone except global integration and total depth variables. In addition, no space syntax variables are significant in the industrial zone. Among syntactic variables, global integration variable shows consistently positive association with walking volume except the industrial zone. Local integration and control variables only show positive association in the residential zone. In addition, local integration variable shows relatively higher correlation with walking volume in the residential zone.

Overall, these findings indicate that space syntax variables may play different roles in walking activity by different land use types. The correlation table in Table 2 is a preliminary analysis to examine bivariate correlation between walking and space syntax variables ignoring the impacts of other built environment factors on walking activity.

Table 2. Correlation analysis between walking volume and independent variables by land use zone

		Total	Residential Zone	Commercial Zone	Industrial Zone
		walking volume	walking volume	walking volume	walking volume
Density	pop_den	-0.079**	-0.038**	-0.110**	0.047
	emp_den	0.282**	0.231**	0.229**	0.104*
Land use	res_den	-0.138**	-0.093**	-0.150**	-0.066
	com_den	0.286**	0.265**	0.109**	0.213**
	off_den	0.141**	0.170**	-0.034	0.061
	ind_den	0.005	-0.013	-0.088**	0.130**
	edu_den	0.023*	0.053**	-0.019	-0.009
	etc_den	0.002	0.018	-0.050	-0.056
Trans. Networks	bus_nd	0.280**	0.255**	0.252**	0.181**
	rail_nd	0.169**	0.190**	0.061**	0.191**
	bus_dist	-0.136**	-0.151**	-0.095*	-0.173**
	rail_dist	-0.136**	-0.143**	0.053*	-0.167**
	exp_dist	0.190**	0.044**	0.292**	0.216**
Building	bld_num	-0.070**	-0.065**	0.034	-0.115**
	bldmarea	0.039**	0.028*	-0.041	0.232**
Design	sidewalk	0.165**	0.114**	0.203**	0.182**
	lane	0.229**	0.235**	0.215**	0.275**
	dslope	-0.073**	-0.088**	-0.039	-0.025
	dbusline	0.187**	0.182**	0.213**	0.041
	dbarrier	0.050**	0.052**	0.051	0.034
	dfence	0.087**	0.104**	0.069**	0.116**
	dcrosswalk	0.111**	0.146**	-0.024	0.123**
Space Syntax	connect	0.083**	0.127**	0.002	0.028
	control	0.075**	0.097**	0.028	0.051
	ginteg	0.193**	0.129**	0.168**	-0.014
	linteg	0.095**	0.133**	0.017	-0.018
	totdepth	-0.184**	-0.126**	-0.158**	0.005
	locdepth	0.104**	0.148**	0.019	0.014

* significant at alpha= 0.05; ** significant at alpha=0.01 level

This research used multivariate regression to analyze built environment factors including space syntax variables. The dependent variable is the average walking volume. We transformed the dependent variable into the logarithmic value of walking volume because original variable has significant skewness in data distribution. The basic model is a multivariate regression model below.

$$y(walking\,volume) = \beta_0 + \beta x^*(development\,density) + \beta y(space\,syntax\,measures) + \beta z(public\,transportation) + \beta\gamma(accessibilities) + \beta v(design\,features) + \epsilon$$

For space syntax variables, we consider global and local integration and control value excluding connectivity and total depth due to multicollinearity problem with integration measures. The street design characteristics include the width of sidewalk, number of lanes, dummy variables of slope, fence, street furniture, and crosswalk.

Table 3 is the resultant table of regression analysis. Most independent variables without zone separation show statistically significant associations with the dependent variable of logarithmic value of average walking volume for weekdays. Regarding space syntax variables, global integration shows statistically significant association with walking volume in the Model 1. This finding would be related with intra-zonal variation of space syntax measures. For instance, global integration in commercial zone may not have significant variation among survey points in commercial zones because most of axial lines in commercial zones would have relatively higher global integration values.

Four models in Table 3 show that employment density variable is the only one showing consistently positive association with walking volume regardless of land use zones. In addition, commercial or educational-cultural land use density variable has a positive association with walking volume in the residential zone.

Transportation network density variables including bus stops and rail stations are statistically significant indicating that net density of bus stops or rail stations are positively associated with walking volume. This finding indicates that walking people is more likely to be increased near bus stops and rail stations. The other two distance variables for bus stops and rail stations also support the finding in the residential zone. The nearest distance to express way shows statistically significant relationship to walking volume indicating that walking volume is more likely to be decreased near express way.

All street design feature variables are statistically significant. The width of sidewalk and number of driveway lanes are very strong independent variables for walking volume. Other street design related variables also show expected associations with walking volume.

Table 3. Regression analysis for average walking volume for weekdays

		Model 1 (All Zones)			Model 2 (Residential Zone)			Model 3 (Commercial Zone)			Model 4 (Industrial Zone)		
		Coef.	sig	t	Coef.	sig	t	Coef.	sig	t	Coef.	sig	t
Density	Pop_den	-0.0433	**	-6.32	-0.0524	**	-5.54	-0.0387	**	-2.61	0.0709	**	3.27
	Emp_den	0.3486	**	32.50	0.3547	**	26.34	0.3331	**	13.37	0.1448	**	2.95
Develop. Density	Res_den	0.0078		0.74	0.0139		1.08	-0.0292		-1.46	-0.0002		0.00
	Com_den	0.1046	**	8.65	0.1818	**	8.85	0.0193		1.21	0.2113	**	3.25
	Off_den	0.0552	**	3.91	0.0063		0.24	0.0309		1.63	0.1363	**	2.76
	Indus_den	-0.0924	**	-2.56	-0.4769	*	-2.30	-1.9237	**	-3.37	0.0928		1.85
	Educul_den	0.3862	**	7.38	0.3814	**	6.55	0.0663		0.49	0.6188	*	2.34
	Oth_den	-0.1164		-0.81	0.1592		0.80	-0.5997	*	-2.17	0.1057		0.33
Trans. Networks	Busstop_den	268.4907	**	8.17	292.6211	**	7.13	233.3726	**	3.97	375.6491	*	2.09
	Railstat_den	2457.7780	**	8.28	2384.3110	**	6.40	1963.0440	**	3.61	4757.7770	**	3.31
	Dist_busstop	-0.0007	**	-5.32	-0.0007	**	-4.71	0.0004		0.81	-0.0010		-1.93
	Dist_railstat	-0.0002	**	-8.44	-0.0002	**	-7.76	-0.0001		-0.86	-0.0002	**	-2.65
	Dist_express	9.55E-05	**	11.93	9.87E-05	**	10.40	1.02E-04	**	4.97	0.0000		0.77
Building	Bldg_num	-2.75E-05		-0.16	1.41E-04		0.75	-6.94E-04		-1.39	-0.0004		-0.40
	Bldg_marea	-3.89E-05	**	-2.80	-5.47E-05	**	-3.32	3.97E-05		1.20	0.0001		0.99
Design Features	Sidewalk	4.49E-02	**	11.84	4.11E-02	**	9.34	4.95E-02	**	6.02	0.0574	**	3.30
	No_lane	5.18E-02	**	11.79	4.92E-02	**	9.84	6.69E-02	**	6.29	0.0380	*	2.07
	Slope	-7.93E-02	**	-4.27	-9.43E-02	**	-4.56	-1.22E-02		-0.26	0.0071		0.08
	Busline	0.1295	**	3.69	0.1112	**	2.76	0.2609	**	3.32	-0.0182		-0.11
	Furniture	0.1441	**	4.86	0.1678	**	5.00	0.1521	*	1.97	-0.1078		-1.01
	Fence	0.1380	**	5.83	0.1547	**	5.77	-0.0010		-0.02	0.1846	*	2.14
	Crosswalk	0.2218	**	12.20	0.2717	**	13.19	-0.0215		-0.48	0.1867	*	2.50
Space syntax variables	Ginteg	0.8280	**	8.28	0.8581	**	7.57	0.3859		1.37	0.4086		0.62
	Linteg	-0.0105		-0.57	-0.0169		-0.78	0.0837		1.76	-0.1438		-1.78
	Control	0.0012		0.08	-0.0041		-0.23	0.0046		0.12	0.0820		1.59
	__cons	8.0756	**	70.00	8.0164	**	61.03	8.1927	***	28.07	8.1396	**	14.50
Obs.		9,385			7,469			1,404			512		
F		F(25,9359)= 230.09	**		F(25,7443)= 151,71	**		F(25,1378)= 28.89	**		F(25,486)= 8.69	**	
R^2		0.3807			0.3376			0.3439			0.3090		

* significant at alpha= 0.05; ** significant at alpha=0.01 level

Conclusion

This research combines space syntax measures and GIS-based built environment variables to examine pedestrian walking volume using the walking survey data for 10,000 locations across Seoul.

Of built environment variables, statistically significant variables are net employment density and net commercial land use density variables. Accessibility measures to public transportation such as bus stops or rail stations show statistically significance with walking volume. For street design characteristics, the width of sidewalk, number of driveway lanes, and existence of crosswalk show positive associations with walking volume and slope shows negative association with walking volume.

Regarding space syntax variables, the results indicate that global integration among space syntax variables only shows statistically significant associations with the average walking volume for weekdays in Seoul. However, it is only significant in the residential zone. In addition, despite of its alleged importance for pedestrian movement, local integration value is not statistically significant in the regression models. These results suggest that space syntax measure of global integration is only one important factor for pedestrian movement at the mega city level.

This study concludes that the employment density and built environmental variables are stronger indicators for modeling walking volume than space syntax variables. Of space syntax variables, the most consistently significant variable is global integration for walking volume.

References

Baran, P. K., D. A. Rodriguez, and A. J. Khattak. 2008. “Space syntax and walking in a New Urbanist and suburban neighborhoods.” *Journal of Urban Design*, 13(1) 5-28.

Batty, M., B. Jiang, and M. Thurstain-Goodwin. 1998. *Local movement: Agent-based models of pedestrian flow.* University College London, London: Centre for Advanced Spatial Analysis.

Claramunt, C. and B. Jiang. 2002. “Integration of space syntax into GIS: New perspectives for urban morphology.” *Transactions in GIS* 6(3): 295-309.

Jung, C. and M. Choi. 2010. “Analysis of traffic volume using space syntax model supplemented by accessibility factor in downtown Daegu.” *Journal of Korean Planning Association* 45(5): 1129-140.

Hillier, B. 1998. *Space is the Machine*. Cambridge University Press.

Hillier, B. and J. Hanson. 1984. *The social logic of space*. Cambridge University Press

Hillier, B., A. Penn, J. Hanson, T. Grajewski, and J. Xu. 1993. “Natural movement: or. Configuration and attraction in urban pedestrian movement.” *Environmental and Planning B: Planning and Design* 20(1): 29-66.

Penn, A., B. Hillier, D. Banister and J. Xu. 1998. Configurational modelling of urban movement networks.” *Environment and Planning B: Planning and Design* 25(1): 59-84

Ratti, C. 2004. “Urban texture and space syntax: Some inconsistencies.” *Environment and Planning B: Planning and Design* 31(4):487-499.