Integrative Analysis of Land-use and Road Network Structure

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***Abstract*— In urban spaces, road and land use interact with each other. To understand urban spaces and make appropriate plans, integrative analyses considering these two simultaneously are required. So far, advancement in urbanization has led to a higher building density, rather than to a sprawl of urban areas. Therefore, the purpose of this study is to conduct integrative analysis and evaluation of road and land use considering the characteristics of modern cities. Based on road as an appropriate accessibility variable, modified importance performance analysis was conducted with development density and the results were categorized into four areas. To apply appropriate accessibility variable, space syntax theory considering the structure of road network was introduced for road. For land use, to consider both horizontal and vertical development densities of residential and commercial buildings were used. The proposed method was applied to Gangnam-gu, a central business district area in Seoul, and results were analyzed and visualized using geographic information system.**

Keywords-road network; space syntax; development density; IPA; integrative analysis.

I. Introduction

Road is closely related to land use and the structure of road composition significantly affects the structure of land development. For sustainable urban development, integrative analysis considering road and land use simultaneously is required.

Modern cities are in the structure of compact cities in which high density developments are proceed rather than urban space expand outward. For the proper analysis of urban spaces, not only their horizontal aspects but also their vertical aspects should be examined. In relation to this, previous studies mainly used data, such as populations and employees for analyzing urban density [1][2]. However, such data are usually summed up by administrative districts and thus, they are not proper for detailed analysis related road structure at finer level. As accessibility related data, Euclidean distances between two areas or facilities have been widely used [3][4]. However, using Euclidean distances that measure the direct distances between two points have limitations in that standards for to and from points do not exist and they do not reflect the form of road network. Recently, studies have been conducted in relation to space syntax in which the structure of road network based on visibility are considered. These studies showed that attributes calculated by space syntax are closely related to city components [5][6][7][8]. Although there was a study on transformation of urban patterns through analysis of urbanization rate with space syntax [9], studies that conducted integrative analysis and utilization of the attributes in combination with land use are insufficient.

The purpose of this study is to conduct integrative analysis and evaluation of road and land uses considering the characteristics of modern cities where road and land-use developments interact with each other. First, for road network, global integration was used among attributes calculated by the space syntax theory considering the structure of road network. For land use, to consider both horizontal and vertical development densities, the building plan areas and gross floor areas of residential and commercial buildings were used. In addition, to apply appropriate accessibility variables that would become criteria for analysis, the explanatory power of three variables, namely, Euclidean distance, global integration and length-reflected global integration were compared. The explanatory power of these variables was expressed using development density and land price. Finally, a modified importance performance analysis model based on road as an accessibility variable was conducted with development density of residential and commercial land uses and the results were visualized. This study was tested on 22 administrative districts in Gangnam-gu of Seoul City, a planned central business district area developed in the 1970s.

The paper begins with introduction of research. In Section 2, methodology of space syntax theory and modified IPA and data construction is described. The explanatory power of accessibility variables were compared in Section 3. Then results of IPA were expressed in Section 4. Concluding remarks are given in Section 5.

II. Methods and Data Construction

A. *Methodology Space Syntax theory*

Space syntax is a method that analyzes relative accessibility quantitatively based on visibility of roads recognized by humans [10][11][12]. Space syntax uses ‘the depth’ of spaces instead of Euclidean distances in order to compute the attribute values of the model. The depth means the minimum number of connecting lines that should be gone through when moving from a certain space to another. The depth between adjacent spaces is 1 and it increases as the levels where a space to pass to another increases. In space syntax, axial maps should first be prepared with the

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minimum number of lines that connect the longest possible straight lines with each other as shown in Figure 1. The attribute values are calculated and assigned in axial lines instead of intersecting points as with transportation network.

In this study, global integration was used among the attributes of space syntax. This attribute is calculated based on roads that connect all axial lines in the scope of the subject of analysis assuming that the axial lines are starting points and end points and the depths. A large value of global integration in a certain space means that the numbers of axial lines that are gone through to move all other spaces are relatively small. That is, a large value of global integration in a certain space means that the space is the center of all spaces, accessibility to all other spaces is high, and movements to all other spaces are easy.

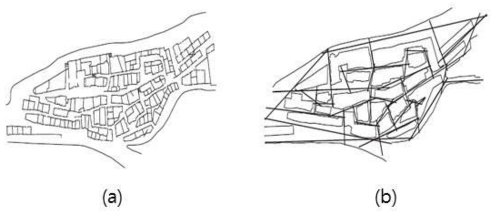

Figure 1. Preparation of axial map: (a) Subject of analysis (b) Axial map

B. *Modified IPA*

Importance-Performance Analysis (IPA) was developed by Martilla & Jame to establish efficient strategies to invest limited resources in the area of marketing [13]. In this analysis, importance and performance are expressed with two dimensional graphs having x and y axes and each of the graphs are divided into four areas based on the average value of each axis. That is, this is an evaluation method for comparing and analyzing the relative importance and performance of goods or services simultaneously.

In this study, a modified IPA was developed and conducted for integrative analysis and evaluation of roads and land uses in urban spaces. The X and Y axes were made to indicate road network and development density respectively. More rightward points on the X axis indicate higher accessibility and higher points on the Y indicate higher development density. The Cartesian space in Figure 2 was made using average values by administrative districts on individual axes and development density was defined into four areas as follows based on road network.

- Area 1 (Density-Road Balanced):
  Both accessibility and development density are high.
- Area 2 (Density > Road):
  Development density is higher compared to accessibility.
- Area 3 (Low Density-Road):
  Both accessibility and development density are low.
- Area 4 (Density < Road):
  Development density is lower compared to accessibility.

Figure 2. Definition of modified IPA area

C. *Study area*

In this study, Gangnam-gu was selected as a study area, which is approximately 10 km away from the Han-river to the southeast and plays the role of a sub-center of Seoul. Gangnam-gu is a planned area for which land compartmentalization rearrangement projects were implemented in the 1970s in which wide orthogonal main roads were developed except for greenbelts on the southern part. Currently, Gangnam-gu consists of 22 administrative districts and its area is 39.55 km² that corresponds to 6.53% of Seoul. Of the area, 56.28% is residential areas, 6.14% is commercial areas and greenbelt areas. Therefore, land uses are relatively in harmony with balance. The residential areas are mostly large apartment complexes or multi-unit dwellings and have been evenly developed throughout the entire area and commercial areas include few industrial regions. Figure 3 shows road network and development density of Gangnam-gu.

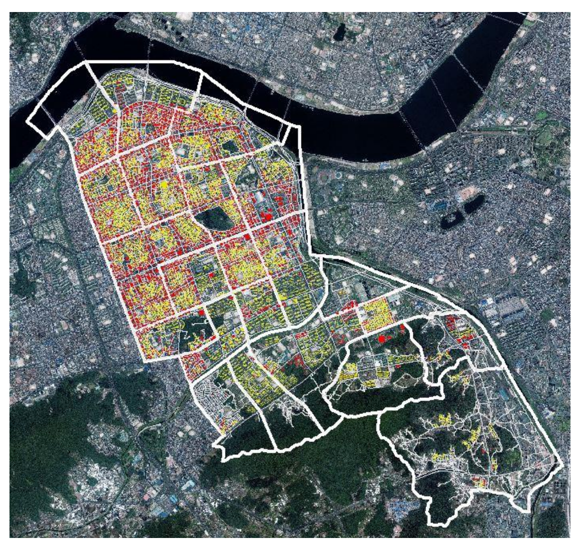

Figure 3. Gangnam-gu road network and development density

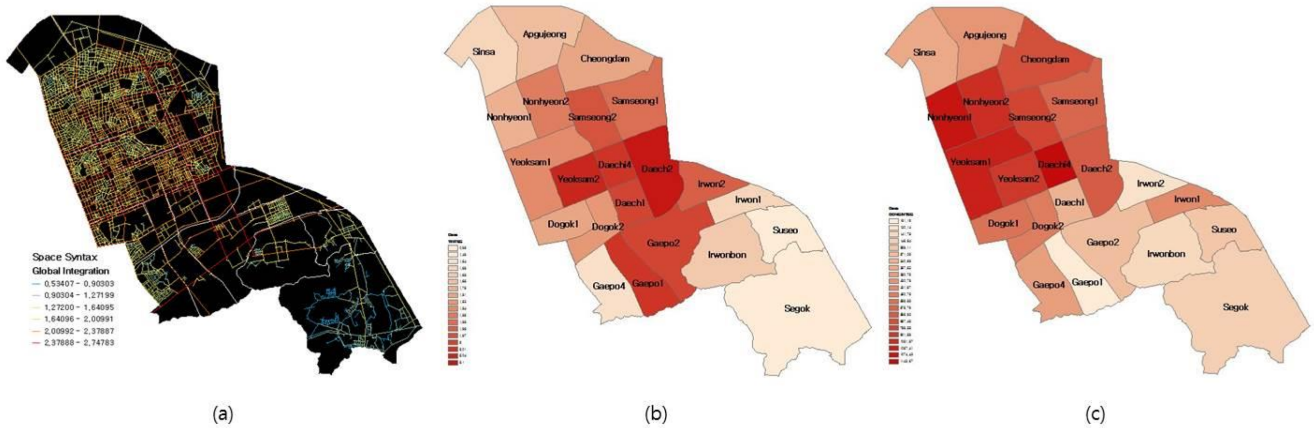

Figure 4. Construction and processing of global integration: (a) Gangnam-gu axial map (b) Global integration (c) Length-reflected global integration

D. Generation and storage of the simulation results

In this study, to analyze the density and structures of spaces, the 2009 Seoul KOTI spatial data and the 2006 publicly notified individual land price were utilized. The average area of 22 administrative districts in Gangnam-gu is 1.8 km². Because the sizes of space units vary from 0.73 to 6.36 km², the constructed data were processed in proportion to areas.

1) Accessibility variable: As accessibility variables, Euclidean distance, global integration, and length-reflected global integration were constructed.

a) Euclidean distance: This is the linear distances from the center of each parcel to the nearest road link. The averages of the distances were calculated as follows.

$$E_A = \sum_{i=0}^{n} PD_i \tag{1}$$

where E_A is the average of distances of parcels to roads of area *A*, PD_i is distance of parcel *i* to the nearest road, and *n* is the number of parcels in area *A*.

b) Global Iintegration: To construct global integration, as mentioned earlier, the axial maps of Gangnam-gu were built using Axwoman as shown in Figure 4-(a). The global integration is a value obtained by (2).

$$G_A = \frac{\sum_{i=0}^{k} I_i}{k} \tag{2}$$

where G_A is the average global integration of area *A*, I_i is the global integration of road *i*, and *k* is total number of roads (axial lines). Figure 4-(b) shows the calculated values that are between the highest at 2.1 and the lowest at 0.98. The values above 1 mean the strong 'integration', while the values between 0.4 and 0.6 show somewhat 'segregation'.

c) Length-reflected Global Integration: The space syntax stemmed from the study of architecture, and the related studies have shown that the element 'depth' had higher explanatory power than 'Euclidean distance' [14]. Spaces syntax reflects the structure of road network in the computing but it excluds actual capacity (*e.g.*, length) of roads. However, since the centers of urban spaces have higher road capacity than the outskirts, weighted values should be given in accordance with areas. Therefore, as the third variable, the global integration that reflected road lengths was calculated as shown in (3).

$$GL_A = \sum_{i=0}^{k} L_i I_i \tag{3}$$

where GL_A is the global integration with road length of area *A*, and L_i is length of road (axial line) *i*, I_i is global integration of road *i*, and *k* is total number of roads. Figure 4-(c) shows the calculated values that are between the highest at 1143.67 and the lowest at 121.12. The average value was shown to be 535.51.

2) Development density and land price: Development density values were obtained for residential and commercial uses separately. Plan areas and gross floor areas of buildings were processed to analyze horizontal and vertical densities. Plan areas were obtained from building data and gross floor areas were calculated by multiplying plan areas by the numbers of building floors. The average plan areas of residential and commercial buildings are 754.75 and 631.20 respectively and the average gross floor areas of residential and commercial buildings are 5484.61 and 4204.41. Figure 5 shows the values of residential and commercial buildings devlopment density by administrative districts. The effects of land price on accessibility variables explanatory power and the development of residential and commercial areas were examined. Land prices were calculated as averages weighted by the ratio of individual parcels.

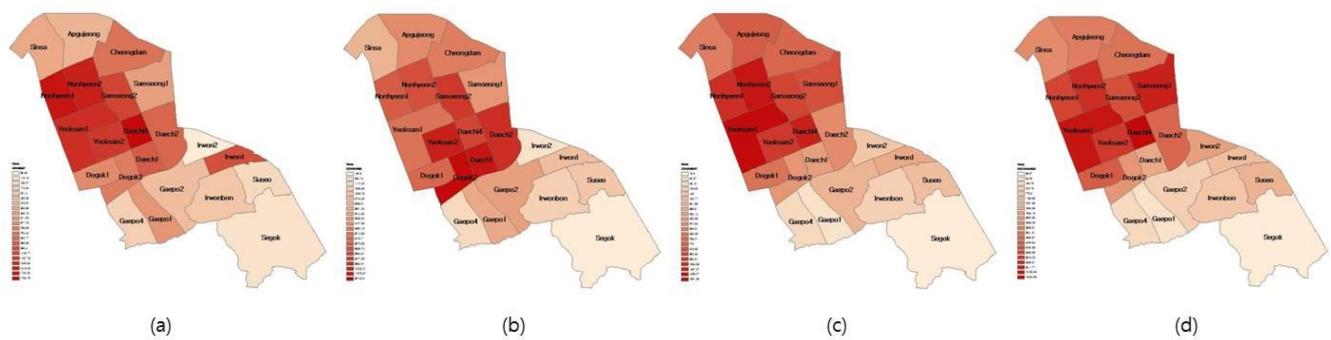

Figure 5. Construction and processing of development density: (a) Residential buildings plan areas (b) Residential buildings gross floor areas (c) Commercial buildings plan areas (d) Commercial buildings gross floor areas

III. EXPLANATORY POWER OF ACCESSIBILITY VARIABLES

To apply appropriate accessibility variables, the correlations of Euclidean distance, global integration and length-reflected global integration were analyzed each with development density and land price as shown in Table I. The Euclidean distance showed significant correlation only with commercial density and showed negative (-) relationships. This means that the shorter the distances for access of areas are, the higher the development density of the areas is. The global integration showed relatively high correlation with land prices and residential density and showed higher explanatory power for land prices. The length-reflected global integration had high correlation and explanatory power in most cases. In particular, its correlation with commercial density showed high explanatory power while the correlation with residential density showed relatively low explanatory power for gross floor areas compared to plan areas due to high residential density where many apartments are located. In general, commercial uses are greatly affected by accessibility and commercial zones are formed along the roads. The analysis also showed that commercial development is more affected by the lengths of roads than other factors.

TABLE I. EXPLANATORY POWER OF ACCESSIBILITY VARIABLES

		Euclidean distance	Global integration	Length-reflected global integration
Land price		-0.361 (<0.99)	0.686 (<0.01)	0.636 (<0.01)
Plan area	Residential	-0.392 (<0.071)	0.460 (<0.05)	0.910 (<0.01)
	Commercial	-0.551 (<0.01)	0.361 (<0.09)	0.946 (<0.01)
Gross floor area	Residential	-0.166 (<0.46)	0.432 (<0.05)	0.341 (<0.12)
	Commercial	-0.452 (<0.05)	0.372 (<0.08)	0.874 (<0.01)

Therefore, the length-reflected global integration was selected as an appropriate accessibility variable to be applied to the study.

IV. RESULTS OF IPA

As mentioned earlier, IPA was conducted for integrative analysis of road network and development density and the results for individual areas were visually expressed. The x-axis was defined as length-reflected global integration in road network and the y-axis as development density or land price.

A. *Road network-residential density*

The x-axis was defined as road network and the y-axis was residential building plan areas and gross floor areas relatively as shown in Figure 6 (a) and (b). Area 1 is blue areas where both accessibility and residential development density are high. Area 2 represented with red is the areas that show residential development density is higher compared to accessibility. Area 3, yellow color areas, shows both low accessibility and low residential density. Area 3 includes most districts in the southern part of Gangnam-gu. The reason that these areas show relatively low development density is because large greenbelts are located in the southern part. Area 4, in green color, show that residential development density is lower compared to accessibility. Although this area has low residential density compared to its accessibility, its commercial density seems to be high. On comparison of residential buildings, it can be seen that Cheongdam, Yeoksam 1, and Ilwon 1 districts moved to areas 3 and 4. This means that the gross floor areas of residential buildings are relatively small in these areas.

B. *Road network-commercial density*

The x-axis was defined as road network and the y-axis was commercial buildings plan areas and gross floor areas, as shown in Figure 6 (c) and (d). Area 1 is blue areas where both accessibility and commercial development density are high. Most districts in the central part of Gangnam-gu are included in this area. Area 2 is represented with red is the areas that show commercial development density is higher compared to accessibility. Area 3 includes the yellow areas where both accessibility and commercial density are low.

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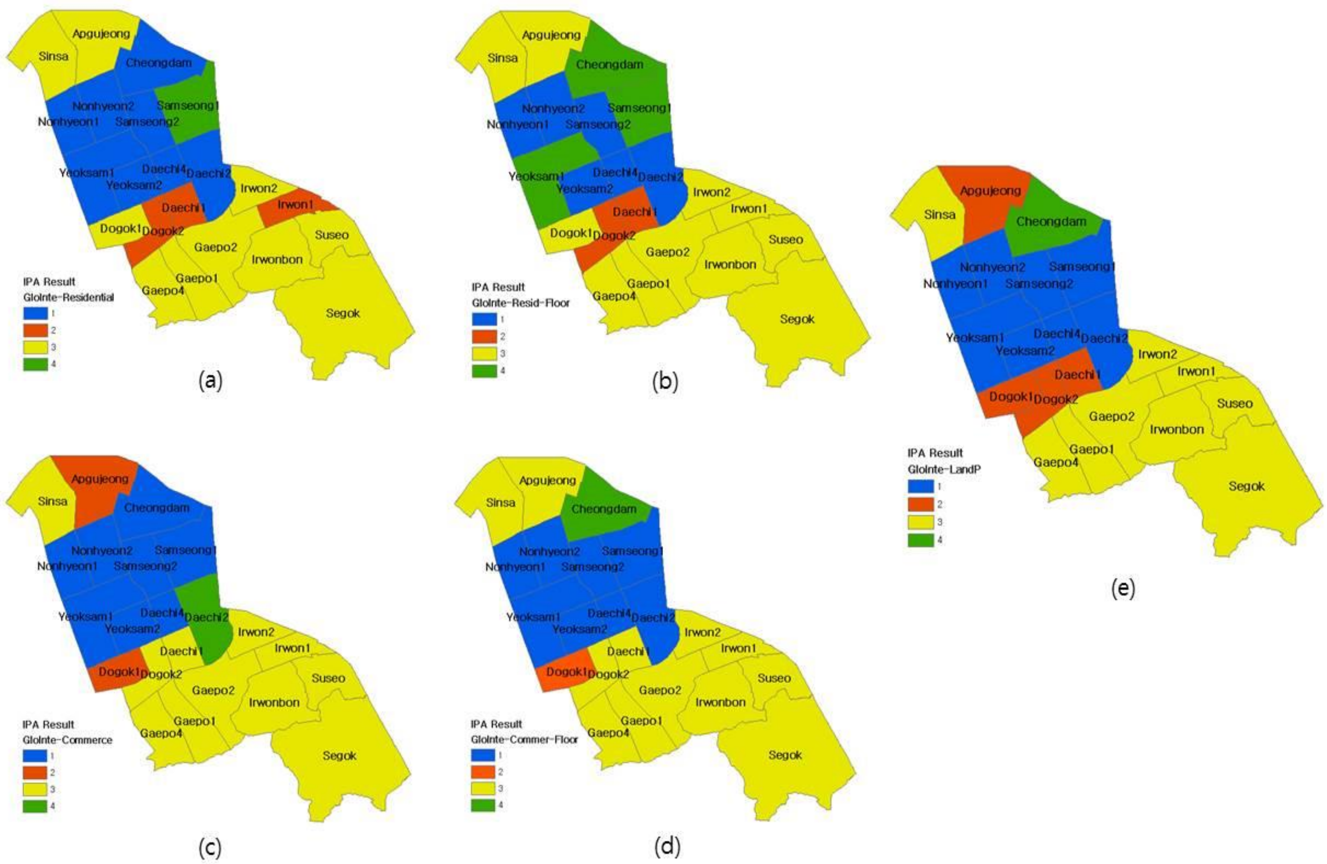

Figure 6. Results of modified IPA: (a) Residential buildings plan areas (b) Residential buildings gross floor areas (c) Commercial buildings plan areas (d) commercial buildings gross floor areas (e) land price

Since the ratio of greenbelts was high, commercial density in this area was shown to be similar to residential density. Area 4, with green color, show that commercial development density is lower compared to accessibility. Although Daechi 2 district is included in this area, the gross floor area of commercial buildings was shown to be relatively large. On the other hand, Cheongdam and Apgujeong districts were shown to have relatively small gross floor areas of commercial buildings.

C. *Road network-land price*

The x-axis was defined as road network and the y-axis was land price as shown in Figure 6-(e). Based on road network, how the effects of land price are applied to development density can be examined. Most areas are included in the same areas based on both land price and development density. To review those districts that were included in different areas by residential and commercial density, land price in Daechi 1, Dogok 2, and Daechi 2 districts were affected by residential density, those in Dogok 1, Samsung 1, and Apgujeong districts were affected by commercial density, and those in Cheongdam district were affected by the gross floor areas of residential and commercial buildings.

V. CONCLUDING REMARKS

In this study, integrative analysis of roads and land use was conducted with 22 administrative districts in Gangnam-gu, is a planned CBD. In order to consider the characteristics of the city, spatial data such as road structures and development density were used. Space syntax theory was employed for computing road structure and global integration was used among its attributes. For land use, to analyze both horizontal and vertical densities, the building plan areas and gross floor areas of residential and commercial buildings were used.

The levels of explanatory power of Euclidean distance, the global integration, and the length-reflected global integration were compared with each other. The correlations between these accessibility variables and development density and land price were analyzed. According to the results of the analysis, the length-reflected global integration showed low explanatory power for residential buildings gross floor areas but showed high explanatory power for residential buildings plan areas. In particular, it showed high explanatory power for commercial density which is closely related to accessibility. Therefore, it was selected as an appropriate accessibility variable.

A modified IPA model that use the length-reflected global integration and development density was conducted and the results were visualized using GIS. Gangnam-gu was classified into four areas based on average values on individual axes and the areas were relatively analyzed. These four areas were defined as ‘density-road balanced area’, ‘density > road area’, ‘low density-road area’, and ‘density < road area’ respectively; also, how the effects of development density acted on land price were identified. It is viewed that, with more refinement, the method suggested here can be used in analyzing urban development in microscopic level considering road structure.

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