What Determines Mixed Land Use?

Analysis of Big Data on Commercial Districts in Seoul, South Korea

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Abstract

Each downtown commercial district has a different degree of mixed land use. Some commercial areas are a huge cluster with monotonous retail use, while others consists of a wide variety of land uses including residential or office uses as well.

Locational factors such as proximity to other amenities such as transit and public services have a great influence on land use mix (LUM). TOD around the railway station leads to mixed land use in the area due to efficient transit (Chen et al., 2016). Also, retail and food establishments demonstrate a certain location pattern in the urban area, making the neighborhood more diverse (Sevtsuk, 2014). A certain age or sex group of customers may also affect LUM in a commercial area due to their love of variety. Some young adults and the elderly prefer homes close to various urban amenities, and thus they tend to be attracted to a higher mix of land use (Blumenberg et al., 2019).

This paper aims to find the causes of differences in LUM in terms of the location and socioeconomic environments of each commercial districts and the demographic characteristics of visitors and residents, especially focusing on public transit and automobile accessibility. To this end, we introduce a micro-scale approach wherein LUM is defined by the entropy index, utilizing data for more than 40,000 individual buildings, based on Rodriguez et al (2013)'s comparison of results using Monte Carlo simulation. The existing studies on the relationship between land use and human activity usually use data collected at a specific time by a survey or the aggregation of existing data. The fixidity of the time dimension of data makes it difficult to examine the dynamic changes of visitors to downtown areas. The real-time big data on visitors enable us to overcome this limitation. By processing mobile phone GPS data, visitor demographics are examined based on a real-time big data and comprise the Seoul Living Population (De Facto population counts with mobile phone GPS) from January 1, 2017 to December 31, 2018; we analyzed the distribution of visitors in the city of Seoul and their travel patterns in downtown commercial districts along the time dimension. We use the daily average of total visitors and residents for each commercial district, dividing them into young adults (20-34) and old adults (35-64) as explanatory variables, in addition to the locational and socioeconomic factors for each district.

The expected results of the analysis are as follows: First, the total number of visitors increases the variety of LUM in a commercial district. Second, the LUM is relatively high in the commercial areas where the proportion of young adult (20-30s) visitors and residents is higher than those in other age groups. Lastly, higher transit accessibility increases the variety of LUM by reducing the need for

parking space and prompting walkable streetscape. These results may help planners design and regulate land use for downtown commercial areas in terms of LUM in an appropriate way.

Key words

mixed land use, urban commercial clusters, transit accessibility, big data, applied GIS

Citations

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1. Introduction

Urban commercial clusters, often jointly located within downtowns of a megacity, consist of vibrant streets full of passersby, workers, and residents entangled by various activities: shopping, wining and dining, having a coffee break, etc. These urban-ish dynamics were generated by clustered buildings of various uses. Loosened land-use restrictions in the downtown area enabled several uses coinciding in one district or even within one building. While this heterogeneity in commercial districts is associated with very different activities at the same time, it takes a role as a spatial syntax in the way in which it affects 'sense of place'.

It is believed that commercial districts can be stereotyped with several criteria. Some are concentrated with similar types of shops and businesses, i.e., a row full of offices or a shopping mall. On the other hand, some are or composed of various compartments with residential buildings, shops restaurants, and cafes. In this way, some commercial areas became a huge cluster with monotonous use, while others consisted of a wide variety of land uses. There has also been active discourse about how mixed use affects people's travel behavior in a certain districts (Ewing & Cervero, 2010; Frank et al., 2008) or, even extended further, whether mixed use is indeed desirable in terms of walkability or health benefits (Frank, 2000; Forsyth et al., 2008; Oakes et al., 2007) or effective in the implementation of TOD in urban areas (Ewing and Hamidi, 2014; Ewing & Cervero, 2017).

Meanwhile, even among the proponents of mixed-use development, scarce dispute exists about the factors – i.e., surrounding built environment, demographic characteristics of residents and visitors – that affect mixed use, despite the abundance of evidence on vice versa. In spite the fact that Penn & Turner (2004)'s simulation successfully demonstrated how the morphology of urban environment and location of shops generate a land use agglomeration, the experiment has its limitations on its presumption and experimental condition itself: fine scaled 12x12 grid like space facilitated assessment of behavior-generated agglomeration and behavior-induced change in urban morphology and land use patterns; however, spatial analysis on a larger scale still remains as a gray area. The reason why analyzing larger spatial units is important is because urban planners need justification for introducing mixed use policies. In order to promote mixed use in downtowns, the mechanisms of mixed-use commercial districts should be identified in priori.

At the core of downtowns, there is much evidence that mixed use is more prevalent than in any other area in a city, therefore making it the most suitable place to test the generation and evolution of mixed use in urban spaces. Thus, the purpose of this study is to analyze the spatial components and demographic characteristics of visitors and residents of each commercial area that affects the entropy of urban spaces, which can be deconstructed by each building unit. To avoid violating the error of the dichotomy, it is not a matter of simply dividing into a commercial district with great complexity and a commercial district with strikingly homogenous use, but rather to grasp the tendency according to the degree of each district's entropy. By defining mixed land use at the micro level – each building located in commercial districts in Seoul – this study attempts to examine how locational factors such as proximity to transit and certain types of land use (i.e., residential use, retail, food establishments and nightlife) have a great influence on mixed use considering a certain age group of visitors and residents. From this analysis, we aim to find out the influence of diversity strategy or cluster strategy adopted by each commercial district in Seoul.

2. Review of Literature

2.1 Is "Mixed Use" Merely an Illusion?

There has been a controversy over the role of strict land use regulation in modern cities, in contrast to the industrial age, which intended to protect residents from harmful pollutants emitted from the factories by separating residential area from other uses (Hirt, 2015; Platt, 2004). In post-industrial staged cities, the main concern of land use policy is whether mixed use really fosters street vitality. Thereby a city becomes livelier, following the idea of Jane Jacobs (2016) that mixed use allows people to intermingle in an organic, spontaneous, and untidy spaces.

As a response to the radical declaration made by Jacobs in the 60s, a number of studies have focused on how mixed use affects the travel pattern of visitors in terms of increased pedestrian activity (Cerin et al., 2007; Forsyth et al., 2007; McCormack et al., 2012), as well as the health effects of walkability in mixed use neighborhoods (Gibson et al., 2015). With a more detailed approach, Cho & Rodriguez (2015) examined the association between walking and mixed use on a neighborhood scale: transportation-related walking was positively associated with mixed use; however, a negative association was confirmed with recreation-related walking. Within the discourse of mixed use efficacy, there are several discrepancies regarding the effect of the mixed use of walking, which does not constantly ameliorate the transit accessibility and leisure of walking.

Meanwhile, mixed-use development has been in the limelight because of its notable strengths, including the way in which it reinforces transit accessibility and public transportation use, as proven by a series of studies that demonstrate enhanced choice ridership. In extension of a desirable association between non-motorized commuting and mixed use in terms of time saving for commuting and low vehicle ownership (Cervero, 1996; Cervero & Gorham, 1995), Chen and Zegras (2016) examined the correlation between rail transit and factors associated with population, employment, and land use mix. Evidence from Boston, Massachusetts suggests that transit efficiency is associated with street design, transit accessibility and the location of stations. Moreover, Chatman (2013) broadens the scope of mixed use and transit accessibility, associating them with parking availability, bus service, housing, and employment opportunities to avoid hastily associating TOD only with railway transit.

Recently, in addition to emphasizing mixed use development (MXD) as an effective planning tool to concentrate the various functions of a city in one place, as downtowns become densely populated and compactly developed to maximize transit accessibility, Cervero et al. (2017) discussed the mixed use and public transit as a catalyst to an inclusive and sustainable city by ensuring the mobility of low-income and various ethnic groups.

2.2 Behavior transforms the spatial structure

Counting on conventional wisdom, rearrangement in a neighborhood, downtown area and commercial districts generates variation in travel behavior; whereas the micro-scale mechanism evolves within the urban area as a response to a human dynamics. For instance, recursive travel behavior and visiting pattern transform the streetscape, especially in commercial districts:

In fact, the degree of mixed use is substantially determined by the zoning system or planning codes, however, the microscopic land use regarding business mix within commercial districts are surely influenced by the preferences of consumers. Accompanied with a willingness to gain maximum utility in minimum time, consumers expect to visit multiple stores at once in a single commercial district, given that time spent on traveling around shops can be respectively decreased (Borgers & Timmermans, 1986). In accordance with visitors' behavioral pattern, a business mix is intended to provide convenient multi-purpose shopping to visitors – potential consumers – in one place (Arentze et al., 2005; Teller et al., 2012; 2016).

As O’Kelly (1983a; 1983b) demonstrated, the size and distribution of commercial facilities are largely decided by consumers' choices and behavioral patterns regarding visitors’ travel behaviors, which demand multipurpose trips that yield interaction between retail use and other land uses. Since the visitors, who are prospective customers, prefer various shopping attractions in one place, the retail establishments and, even further, commercial areas evolve into heterogeneous uses in terms of business mix, along with their trip patterns (Minner & Shi, 2017).

In regard to activity-driven mixed use, the possibility of land use evolvement entices the indigenous aspects of human activity, travel behavior, and land use. This series of studies has found that multipurpose travel between commercial activities and other land uses might be a driving force to transform the streetscape of commercial corridors and even the urban spatial structure on a larger scale: the downtown area and surrounding central city neighborhoods.

2.3 New Urban Norm: Downtown Resurgence

As an extension of Markusen et al.(1986)'s advocacy of agglomeration economies, in a cluster of small and medium-sized businesses that form a new high-tech industrial district and enhance regional competitiveness, the expectations of the agglomeration of economies leads to a discussion of the competitiveness of cities (Buck et al., 2005; Gordon & McCann, 2005; Hall, 2003). In addition to engaging with its benefits of industrial location, agglomeration economies are also considered as a driving force of urban development. In addition, Chatman et al. (2016) discussed the engagement between local agglomeration accompanied by transit accessibility and firm birth in metropolitan cities. Other than knowledge-sharing and the expected spillover effect, railway ridership facilitated innovation and dense development in urban areas.

By intensifying urban density to facilitate consumption as cities become centers of consumption, such virtue-easy access to shops and restaurants became regarded as an important amenity (Glaeser et al, 2001). Moreover, Mulligan and Carruthers (2011) emphasized the importance of these urban amenities (i.e., transit, consumption and cultural experience) for the quality of life in urban areas and regional development. In this sense, commercial districts in a city are also considered as urban amenities: Sevtsuk (2014) demonstrated that the charm of urban commercial clusters consists of retail shops, cafes, and diners, which constitute a bliss of walkable neighborhoods. Regarding the mixture of commercial and residential uses, various leisure opportunities of one site and jobs in the vicinity of one's home are surely considered great benefits; nevertheless, dense development in the area and proximate locations were not favored (Tian, Ewing, & Greene, 2015).

Contrary to the decades-long trend that saw suburbs as a better residential and educational environment, downtown residential areas have attracted Millennials and Gen Zs who seeks dynamic experiences in day-to-day living. Even though Blumenber et al. (2019) refuted the common belief of back-to-the-city movement of young adults, the result clearly confirmed that young adults prefer urban neighborhoods to suburbia or rural town more so than older adults. It is apparent that downtown areas in the metropolis witnessed a resurgence of street-scale commercial clusters and urban living as Jane Jacobs (1958) expected, which become a new norm in urban life accomplished with enhanced transit accessibility, shortened commute distance, and off-work amenities.

3. Methodology

3.1 Data

The study area covers 251 'Developed Commercial Zones (DCZs)'located in the Seoul Metropolitan City. The DCZ is identified by the Ministry of SMEs (Small and Medium-sized Enterprises) and Startups as an area where many restaurants, retail shops, and small offices concentrated with abundant jobs and traffic working in the surrounding areas. DCZs are mainly located in downtown areas and regional centers in Seoul, which is distinguished from other districts with greater job opportunity, the number of enterprises, and transit accessibility.

Due to the limitations of data – 'De Facto Population' data are available since 2017, and 2019 annual census data are not released yet – the scope of this research only focuses on 2017 and 2018.

3.1.1 Building Ledger

Building ledger provides a summary of the current land use of individual buildings in South Korea, and National Spatial Data Infrastructure (NSDI) Portal provides GIS data based on building ledger since 2016.

For each DCZ, by using GIS(ArcMap 10.3)'s 'Select By Location – have their centroid in the source layer' and 'Spatial Join feature – have their centroid in the source layer (Join_One_To_Many option)'features, we extracted buildings whose centroid is located within each DCZ and assigned the ID of the DCZ to the extracted buildings in order to aggregate the data into individual DCZ scale.

The data used for the analysis (total 364,470 building units) consists of 8 quarters within 3-month terms in 2017-2018, respectively. March 2017 and June 2018 data were not provided; therefore, we used the next month's data instead.

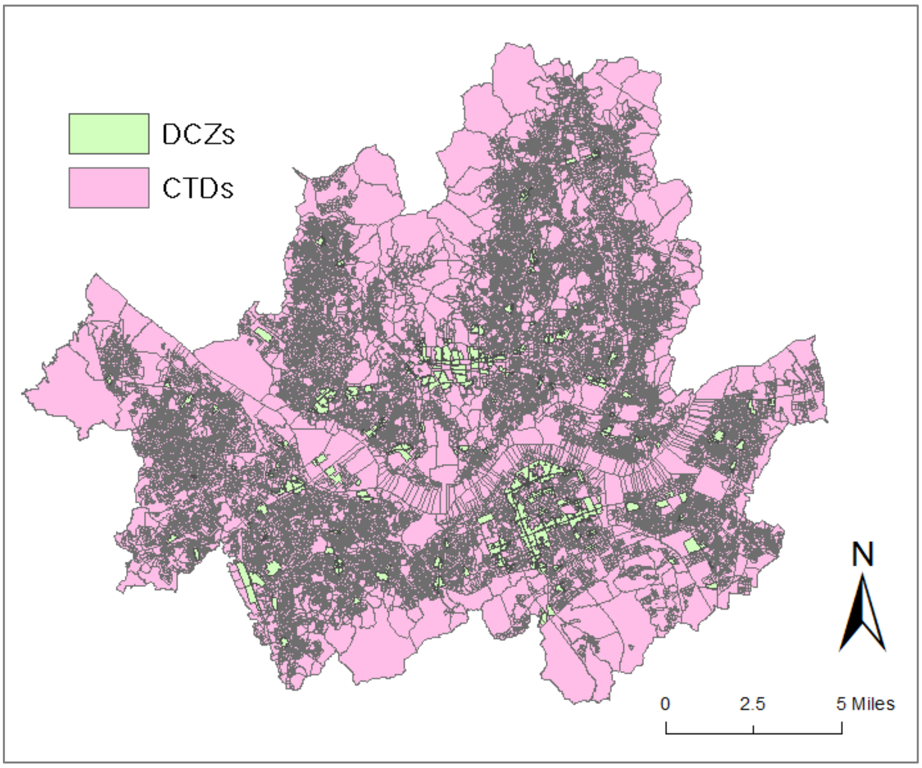
	Apr 2017	**Jun 2017**	**Sep 2017**	**Dec 2017**	**Mar 2018**	**Jul 2018**	**Sep 2018**	**Dec 2018**
No. of Buildings located in DCZs	48,101	43,813	44,806	45,350	45,460	45,623	45,671	45,646

[Table 1] Number of buildings located in DCZs per quarter 2017-2018

3.1.2 Census Data

Given the nature of Annual Census data, the default collection unit of data is a census tally district (CTD), which is a smaller spatial unit than the smallest administrative unit, Dong. Usually, several CTDs are included in a Dong. Census data provides the number of residents, employees, and enterprises in each CTD on a yearly basis in South Korea. In detail, it provides a data containing the age and gender of residents in each CTD. The CTD consists of a minimum population of 300 and a maximum of 1,000.

Since the boundaries of some DCZs are not consistent with the boundaries of census tally districts, all of the CTDs that include the boundaries of the commercial area are counted within the scope of the study. By using 'Select By Location – intersect' and 'Spatial Join feature – intersect (Join_One_To_Many option)' features, 1,256 CTDs out of 19,153, in total, were assigned to 251 DCZs for analysis.



[Figure 1] Location of DCZs in Seoul Metropolitan Area

3.1.3 De Facto Population

The Seoul Metropolitan Government provides 'Seoul Living Population (SLP)' data, which means a De Facto population. At the time of the data collection, the 'De Facto Population' included not only those who have an address in Seoul, but also those who temporarily stay in Seoul or visit Seoul for business, medical care, shopping, education, etc.

Detected with LTE (Long Term Evolution, a 4G mobile communications standard) signal data provided by KT (Korea Telecom), the data is based on GPS data collected for 19,153 CTDs in Seoul by dividing the population located in the districts of each 24-hour unit by sex and age (5-year interval, all ages from 10 to 69, under 9 and over 70) on a daily basis. This study covers 9,395,695,680 (14 age groups * 2 male/female * 19,153 CTDs * 24 hours * 365 days * 2 years) data cells in total from January 1, 2017 to December 31, 2018.

Date	Time	CTD_Code	Total	Male 0-9	Female 0-9	Male 10-14	Female 10-14	Male 15-19	Female 15-19	...	Male 60-64	Female 60-64	Male 65-69	Female 65-69	Male over 70	Female over 70
20201014	0	1101072010001	540,7499	32,1053	20,4575	18,5762	19,1934	23,5031	17,9646	...	24,4767	10,2848	9,4214	17,124	16,0715	9,6296
20201014	1	1101072010001	740,4684	16,8396	10,7302	19,3542	21,4339	40,9618	23,2258	...	16,7769	19,6226	17,6472	38,091	19,9288	11,9407
20201014	2	1101072010001	486,9708	23,0325	14,6764	28,3346	17,8594	15,0308	4,7895	...	21,6932	13,1589	8,6174	20,7467	26,2203	15,7105
20201014	3	1101072010001	235,2092	9,8444	6,2729	7,1176	0	10,5791	10,631	...	12,6846	8,6408	4,5957	5,762	12,4672	7,47
20201014	4	1101072010001	539,321	27,3035	17,3978	28,5134	19,9074	18,2308	8,1822	...	24,095	13,3314	9,473	21,5602	25,8174	15,4691
20201014	5	1101072010001	194,3641	0	0	4,5325	0	0	5,2076	...	6,9902	4,1269	0	16,534	11,9088	7,1354
20201014	6	1101072010001	234,6892	6,5542	4,1763	6,6025	4,539	7,9333	8,7331	...	10,8971	6,8579	0	11,2176	12,6495	7,5793
20201014	7	1101072010001	730,6584	44,9687	28,6542	26,01	27,8095	31,7561	23,9073	...	32,9826	12,6305	12,5957	23,179	20,5018	12,2841
20201014	8	1101072010001	813,9251	18,1018	11,5345	19,023	14,0358	34,2895	30,3634	...	19,5638	19,2093	16,8317	42,8547	20,8571	12,497
20201014	9	1101072010001	732,0207	41,9945	26,759	30,93	27,5479	29,1074	19,02	...	32,9252	14,751	12,7154	25,554	26,1245	15,6531
20201014	10	1101072010001	251,1781	0	0	6,5375	4,9434	5,9922	7,7064	...	9,7738	6,2703	0	16,2313	14,2857	8,5596
20201014	11	1101072010001	242,7104	0	0	5,6574	4,7802	0	6,5001	...	8,7252	5,1511	0	20,6376	14,8645	8,9064
20201014	12	1101072010001	389,8055	20,4363	13,0221	12,9222	10,9916	17,146	14,9118	...	19,1049	10,1289	7,1071	11,2223	15,3457	9,1947
20201014	13	1101072010001	554,1401	17,1443	10,9244	10,6904	9,9941	25,8078	15,9523	...	16,195	14,8561	11,7084	25,8915	16,2412	9,7313
20201014	14	1101072010001	888,9029	24,9754	15,9144	26,0727	25,7728	36,8055	23,404	...	19,9239	21,0154	18,9651	37,596	29,027	17,3922
20201014	15	1101072010001	291,4022	4,0313	0	7,7952	9,3238	5,7312	6,9949	...	8,6962	6,0154	4,1036	18,0927	14,9033	8,9296
20201014	16	1101072010001	778,5603	26,4755	16,8703	25,5225	22,5128	20,5933	16,4215	...	17,4943	16,1119	14,502	25,1162	30,3998	18,2147
20201014	17	1101072010001	671,0607	22,2387	14,1705	21,8367	19,243	17,5622	14,2515	...	15,3094	13,8965	12,3742	22,5509	26,5822	15,9273
20201014	18	1101072010001	699,3441	23,7817	15,1538	22,9256	20,2222	18,498	14,7506	...	15,7143	14,4726	13,0264	22,5607	27,3067	16,3614
20201014	19	1101072010001	678,0258	22,2555	14,1813	21,7589	19,6163	19,9621	15,0111	...	15,2277	14,4311	12,9967	23,2339	25,6076	15,3434
20201014	20	1101072010001	130,9805	5,4821	0	0	0	5,8912	5,9201	...	7,0637	4,8118	0	0	6,9426	4,1598
20201014	21	1101072010001	650,8633	22,2217	14,1597	21,4674	27,2017	22,2125	40,1128	...	18,79	12,4283	8,3758	25,7083	6,117	0
20201014	22	1101072010001	1347,195	55,5235	35,3797	42,6093	64,8851	71,3206	84,2305	...	60,1015	18,6717	18,0283	49,1188	18,2357	10,9263
20201014	23	1101072010001	728,7867	34,7881	22,167	38,6854	35,2151	23,3832	9,8007	...	32,7209	17,9568	14,2251	36,2955	26,4965	15,876
20201014	0	1101072020004	45,1874	0	0	0	0	0	0	...	0	0	0	0	0	0
20201014	1	1101072020004	993,479	36,2014	23,0676	62,8169	67,6292	25,9353	12,0289	...	38,2734	33,8934	24,7866	71,6739	18,3385	10,9879
20201014	2	1101072020004	401,2495	21,6022	9,601	9,9754	6,322	7,8502	9,4938	...	8,3444	12,6425	9,3192	21,5347	21,8014	11,6793
20201014	3	1101072020004	1735,632	70,3011	31,2449	36,8085	57,341	50,3627	58,1708	...	60,1371	54,0689	41,1306	64,3163	56,8427	30,4514
20201014	4	1101072020004	1533,771	63,1718	28,0764	32,8043	42,8173	46,1998	43,49	...	42,5246	47,4394	32,7994	56,3297	62,9157	33,7048
20201014	5	1101072020004	875,8642	27,2481	12,1103	15,2757	57,6519	35,606	43,1582	...	39,7604	19,4698	18,3905	43,4019	0	0
20201014	6	1101072020004	597,0586	7,953	0	18,3915	22,4893	21,218	33,1328	...	20,0561	10,7121	12,5374	46,8352	6,2297	0
20201014	7	1101072020004	502,6765	8,2739	0	16,5068	10,7066	21,1052	24,9827	...	10,2123	11,7267	10,3384	29,2015	14,0492	7,5264

[Figure 2] Number of buildings located in DCZs per quarter 2017-2018

In this study, the basic unit of analysis is CTDs and total number. Therefore, data cells are aggregated to a monthly unit, summing data of 24 hours in a day without differentiating gender and grouping age 20-34 and 35-64. The number of minors and elderlies were excluded due to data reliability, since they have relatively low smartphone penetration rate, while the other age groups in Korea have more than 99% smartphone penetration rate.

Again, the daily data of a sum value in each CTD are aggregated on a monthly basis. In accordance with building ledger data, we use a sum value of 3 months in total: Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec in 2017 and 2018. In summary, data units consisting of CTDs are aggregated into each DCZ. In this way, the total sum of the De Facto population in each DCZ consists of age groups 20-34 (young adult) and 35-64 (old adult).

3.2 Estimated Model

3.2.1 Panel Formation

Commercial districts in South Korea change rapidly, especially in Seoul, where over 9.6 million people live, around 20% of the entire South Korean people. During a short period of time, many new stores are opened and many are closed due to the lifestyle of metropolitans. Thus, it is important to observe these short periods of change because this study uses data for individual buildings, rather than data for district units.

Therefore, 8-quarter panels were used for 2 years in order to confirm changes in a short period of time. The panel used in this study is a strongly balanced panel, with a gap consisting of 8 quarters at three-month intervals for a total of two years from 2017-2018.

3.2.2 Entropy Index

Land Use Mix (LUM) is an Entropy Index indicating the degree of mixture of land use with a range of values from 0 to 1. The closer the LUM is to 1, the higher the complexity (Lee & Moundon, 2006).

$$\mathrm{LUM} = -\sum P_U \ln(P_U)/\ln(n) \qquad ...(1)$$

P_U: The ratio of total floor area of land use type 'U'
(Calculated based on the land use classification below)

n: Number of land use in the DCZ (total: 12)

In equation (1), $\mathrm{P_U}$ represents the total area ratio of specific use in each DCZs, and n represents the number of land use The area ratio for each use was calculated based on sum of the total area of each building unit. To avoid being gauged as a simple binary (0 for homogenous use and 1 for heterogeneous use), we calculated LUM using each building unit's total area. Land use classification used in this study is based on Building Act Enforcement Decree Article 3-5 and zoning code regulations. The specific division is as follows:

1	Residential	**7**	Sports Facilities
2	Retail & Food Establishments	**8**	Tourism & Amusement Parks
3	Large Market & Indoor Malls	**9**	Education & Welfare
4	Night Life	**10**	Hospitals & Medical Care
5	Offices	**11**	Transport Terminal
6	Culture & Leisure	**12**	Etc.

[Table 2] Land Use Classification

Instead of implementing other types of land use mix index, Entropy Index was chosen due to atypical land parcels that consist of DCZs. Despite its limitations in multi-dimensional measures, Entropy Index is the most desirable option for this study (Turner et al., 2001; Song et al., 2013) because we use individual building as a unit of measure, a heterogeneity in the unit of measure from other indexes: Herfindahl–Hirschman Index (HHI), Atkinson Index (ATK), Dissimilarity Index (DIS), etc. Gıven that individual buildings are in atypical shapes, not uniform squares, the measure's level of sensitivity to district size is hard to capture.

3.2.3 Variable descriptions

Explanatory variable	**LUM of Each DCZs**		**Entropy Index of Each DCZs**
Predictor variable	The size of DCZs		ln(size(m^2))
	Land Use Ratio	Residential	Ratio of Residential Use Per Total Buildings
		Retail & Food	Ratio of Retail&Food Use Per Total Buildings
		Night Life	Ratio of Night Life Use Per Total Buildings
		Offices	Ratio of Office Use Per Total Buildings
		Transport	Ratio of Transportation Use Per Total Buildings
	Local Streets and Road Volume		ln(sum area(m^2))
	No. of public transit lines		ln(No. of Bus and Subway Lines Encompass Boundaries)
		No. of subway lines	No. of Subway Lines Encompass Boundaries
		No. of bus lines	ln(No. of Bus Lines Encompass Boundaries)
	No. of Visitors Per Day - Young Adults (20-34)		ln(Total SLP Per Day of Each DCZ)s
	No. of Visitors Per Day - Old Adults (35-64)		ln(Total SLP Per Day of Each DCZs)
	Resident population - Young Adults (20-34)		ln(No. of Young Residents of Each DCZs)
	Resident population - Old Adults (35-64)		ln(No. of Old Resident of Each DCZs)
	Average Enterprise Size		Average no. of employees per business of Each DCZs

[Table 3] Variable descriptions

4. Empirical Analysis

4.1 Heteroskedasticity and Autocorrelation

Prior to selecting an estimation model, heterogeneity among data should be tested to avoid the risk of obtaining biased results increases because panel data presumes that observations are heterogeneous (Baltagi, 2013). The regression model must satisfy the basic assumption that the variance of errors must be homogeneous, and the error terms of individual observations must be independent (Gujarati, 2009). However, in this study using short-term panel data, there is a high probability of time series autocorrelation and heteroskedasticity in error terms. Thus, it is necessary to apply Wooldridge and Wald tests to verify autocorrelation and heteroskedasticity, respectively.

This study consists of two models: one for examining the effect of public transit in general and another for bus and subway respectively. The other variables are identical, in order to contrast the result of these models.

According to Wooldridge Test in [Table 4], the null hypothesis was rejected, indicating that this model has first-order autocorrelation. Also, the result of Wald's Test in [Table 5] indicates that heteroskedasticity exists between individual observations.

Null Hypothesis	H0: no first order autocorrelation	
Result	Transit Model	Bus / Subway Model
	F(1, 1998) = 612.26 Prob > F = 0.0000	F(1, 1998) = 677.68 Prob > F = 0.0000

[Table 4] Test for Time Series Autocorrelation

Null Hypothesis	H0: sigma(i)^2 = sigma^2 for all i	
Result	Transit Model	Bus / Subway Model
	chi2(251) = 1.7e+10 Prob > chi2 = 0.0000	chi2(251) = 1.7e+10 Prob > chi2 = 0.0000

[Table 5] Test for Heteroskedasticity

4.2 General Least Square (GLS) Model

As the data used in this study have autocorrelation and heteroskedasticity, if the basic assumptions of the regression model are violated, the ordinary least squares (OLS) estimator is not efficient. Therefore, when autocorrelation and heteroskedasticity exist in the error term in the panel data, a more efficient estimator can be obtained by using generalized least squares (GLS) (Baltagi, 2013).

4.3 Result of Panel GLS Model

Variable		Coef.	S.E.	Coef.	S.E.
Size of DCZs		0.27 ***	0.10	1.71 ***	0.32
Land Use	Residential	0.26 **	0.11	1.21 ***	0.23
	Retail & Food	-0.29 **	0.11	-1.21 ***	0.22
	Office	0.03	0.09	0.23 **	0.10
	Transportation Terminal	-0.96	0.65	-0.59	0.65
	Nightlife	514.79 ***	136.22	854.65 ***	153.50
Road Volume		-0.25 **	0.12	-2.10 ***	0.41
Public Transit		-0.13 **	0.05		
	Bus			0.27 ***	0.10
	Subway			-0.68 ***	0.14
Young Adult (20-34) Visitors		0.00	0.04	-0.01	0.04
Old Adult (35-64) Visitors		-0.02	0.05	0.00	0.05
Young Adult (20-34) Residents		0.09 **	0.03	0.00	0.04
Old Adult (35-64) Residents		-0.11 **	0.05	-0.10 **	0.05
Enterprise Size		0.01	0.02	0.02	0.02
_cons		0.59 **	0.30	3.25 ***	0.64
Number of obs			2008		2008
Number of Groups			251		251
Time Periods			8		8

'***' 0.001 '**' 0.01 '*' 0.05

[Table 6] Estimation Result

The GLS analysis results from the two models are as follows in [Table 6]. According to the results, the mixed use of downtown commercial districts has a correlation with the area size, residential use, nightlife use, road volume, and old adult residents in common. A Difference in office use and young adult residents was detected in two models, however, the contrasting result became obvious when public transit was subdivided into the bus and subway respectively.

According to the model using public transit as a variable, the coefficient value of area size is 0.27, with 0.26 for residential use, -0.29 for retail&food service, and the 514.79 for nightlife. This indicates the size of downtown commercial districts has a positive correlation with its mixed use, along with residential and nightlife use while retail&food service use represents negative association. Also, the result suggests that the demand for housing in the downtown commercial districts and nightlife venues such as bars, karaoke and nightclubs affects the mixed land use within the area. Although the retail&food service use represents the negative coefficient value, it needs further investigation as to whether it is negatively associated with mixed use in general or simply whether retail&food service positively associates with only a few uses, i.e. residential or office use.

In this model, neither road volume nor public transit has a positive effect on mixed land use in downtown commercial districts. A number of prior studies examined the negative effect of automobile use and mixed use (Cervero & Radisch, 1996; Stewart et al., 2012; Sung & Oh, 2011). This corresponds with the results of prior investigations: mixed use degenerates the amount of automobile travel. However, the opposite direction of the coefficient value of public transit requires further scrutiny. There are two contrasting possibilities: one is that one specific use greatly associates with transit accessibility such as office or retail & food establishments, while the other is that either the bus or the subway has the dominant, negative influence. This hypothesis will be tested in the later model.

Nevertheless, the young resident population has a positive correlation with mixed use, while the number of visitors identified by the de facto population is insignificant. The coefficient value of young adults (ages 20 to 34) is 0.09, which denotes that young adult residents positively associate with the degree of mixed use in downtown commercial districts. On the other hand, the coefficient value of older adults (ages 35 to 64) is -0.11, which corresponds to the result discussed in Blumenberg et al.(2019): younger adults do prefer homes close to various urban amenities and thus tend to be attracted to a higher mix of land use than older adults.

The model using bus and subway respectively has yielded similar results: the coefficient value of area size is 1.17, with 1.21 for residential use, -1.21 for retail & food service, and 854.65 for nightlife. However, office use has a coefficient of 0.23, which is positive, indicating that the office use has a positive correlation with other uses in a commercial district.

While road volume consistently represents a negative effect on mixed use, the major difference in this model is detected in the difference between the coefficient value of bus and subway: Bus associates with mixed use in downtown commercial districts positively while subway associates with it negatively. We employed log transformation for the number of bus lines, making the bus coefficient much smaller than the subway, which do not utilize the log transformation. This is why this variable represents negative coefficients in the model using public transit as a variable. As Chatman (2013) pointed out, better bus service can be more effective in managing TOD (Transit Oriented Development) than railway transit does. This result implies that the findings can be applied to the downtown commercial districts in Seoul, even though this study only includes the number of bus lines and subway lines encompassing the districts, not the actual number of passengers. Thus, further studies, including the actual passenger ridership could generate a different result.

However, in this model, none of the visitor groups has a significant effect. Furthermore, younger adult residents do not have a consequential effect while the older adult residents variable maintains the negative coefficient value and is sufficiently significant. According to the comparison between the two models, older adult residents commonly correlate negatively with mixed use, which aligns with the results of Blumenberg et al. (2019) as well.

5. Findings and Implications

This study examined the surrounding built environments and socioeconomic factors affecting the mixed land use in downtown commercial districts. The results of the study clearly show that mixed use positively correlated with some specific uses, i.e. residential use and nightlife use. The higher the ratio of residential and nightlife use buildings, the higher the degree of land use mix (LUM) in the commercial area. This result aligns with our prior research (Oh & Park, 2020): a higher degree of mixed use engages the maximum number of visitors at nighttime. Furthermore, we verified that younger adult residents have a positive effect on mixed use under certain conditions while older adult residents consistently have a negative effect on mixed use. Moreover, public transit needs further study to examine whether it has a more relevant effect.

In conclusion, the land use diversity of downtown commercial districts shows a mutual association with various physical structures and the characteristics of people visiting or living in the area. Mixed use in the commercial area could be seen as a product of the planning procedure, wholly regulated by the zoning system or planning codes. However, it is also a product of human dynamics, generated by a diverse activity that takes place in the same place. This indicates that downtown is becoming a huge social melting pot that is providing a basis of dynamic activity for different groups of people. As Talen (2012) and Penn et al. (2009) noted, mixed use can be both a planning tool for efficient land use and a prompt for designing places for diversity and inclusive urban communities.

6. Limitations and Further research

This study aimed to identify the factors affecting mixed use of downtown commercial districts as an extended discourse of the “Space Syntax Theory”, which maintains that building scale and spatial layout affect pedestrian movement in the streets, thus accelerating the evolution of the space itself (Hillier et al., 1976; Hillier & Hanson,1989). The way in which the theory was implemented was often confined to a building or street scale; in spite of this limitation, this study attempted to examine the external dynamics of individual building-led vitality and diversity encompassing a larger scale.

However, in order to identify more specific influential factors, further study is required to examine other various determinants other than land use that cause - not correlate with - heterogenous use clusters in commercial districts. Moreover, the comparison between models consisting of fewer specific uses is needed to examine the effect of those uses in particular. Also, in order to produce more precise results, a more sophisticated index is needed to measure the degree of land use mix in a commercial district with land use defined by building units, not by land parcel units.

Furthermore, this study defined older adults as individuals between the ages of 35 and 64, in comparison with younger adults in general. However, if the older adult group is subdivided into younger-old adults (35-54) and baby boomers (55-64), this may yield different results since Lee et al. (2014) proved that baby boomers use more public transit and are more inclined to live in urban areas in comparison with other age groups. Since the mobility of adults over 65 varied by a number of specific environmental characteristics and travel modes in association with public transport (Yang et al., 2018), this study was not able to cover the age group’s travel behavior due to data restriction.

In sum, a finer grasp on measures of mixed land use and the demographic difference is required to examine whether mixed-use development indeed has a significant effect on people's mobility, in terms of enhanced transit accessibility and increased choice ridership.

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