Master's Thesis of Engineering

Innovative Urban Planning in Spatial Structure of City under the COVID-19 Pandemic

COVID-19 대유행과 도시 공간구조의 연결성에 관한 연구

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Abstract

Innovative Urban Planning in Spatial Structure of City under the COVID-19 Pandemic

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This thesis aims to reveal the relationship between COVID-19 and urban spatial structure, local economy, social and environmental factors, in order to present urban planning strategies that can respond to future infectious diseases. Humanity has continuously improved urban spatial structure in order to overcome the crises of infectious diseases and natural disasters. The pandemic has served as a catalyst for changing urban and economic structures, people's lifestyles, which has ushered in a new era. In 2019, an unprecedented pandemic of COVID-19 emerged, and transmission was very fast through human-to-human contact, terrorizing the whole world. However, the infectious nature of COVID-19 varies among different countries. The purpose of this thesis is to show the connection between COVID-19 and the urban spatial structure in Korea's metropolitan area and to suggest urban planning strategies that can

help to cope with future infectious diseases.

To analyze the connection between COVID-19 and urban spatial structure precisely, infected persons' travel routes were analyzed to find out the on-site conditions. A buffer zone within 1 km was applied to the travel routes in order to analyze the urban, geographical, economic, and social characteristics of the contaminated area. Since the information of infected persons was restricted, the characteristics of the region were converted into sigungu (city and county) units. The confirmed cases were used as the dependent variable; however, major group infections and overseas infections were excluded from the number of confirmed cases in order to determine how local infections occur. Since COVID-19 transmits through the air, this study used the spatial econometric model in order to control spatial dependency. The results of the analysis can be summarized as follows:

A previous study related to COVID-19 found that population density affects the contagiousness of COVID-19 less than government organizational power and social distancing do. Instead, the better the medical system is equipped, the significantly lower the mortality rate from COVID-19. However, the analysis shows that increased commercial and building density means increased floating population, which has a positive relationship with the COVID-19 transmission rate. The metropolitan area has health capabilities regardless of population density, and the gap between regions is not large. In Korea, health capabilities are included as a control variable; therefore, the

density of a city is shown to affect the COVID-19 transmission rate. A higher building coverage ratio (BCR), average wind speed, and financial independence lower the COVID-19 transmission rate. On the contrary, the higher BCR of detached houses, the floor area ratio of multi-unit dwelling, older building age, and slope increases the COVID-19 transmission rate. Areas with weak fiscal power were judged to have a higher COVID-19 transmission rate due to insufficient urban and sanitary management. Finally, based on the analysis results, this study suggests appropriate response directions for future urban planning to cope with epidemics.

Keywords: COVID-19, pandemic, urban spatial structure, urban density, spatial lag model, infected travel route

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Table of Contents

List of Tables

List of Figures

Ⅰ. Introduction

1.1. Study Background and Purpose of Research

Epidemic and pandemic infectious diseases have historically been part of humanity in every era. From the past, urban planning has been carried out to cope with epidemics, along with the role of protecting people from external enemies. Humanity has continuously improved the spatial structure of cities to overcome the crisis of infectious diseases and natural disasters. Epidemics have served as a catalyst for changing the urban and economic structure and people's way of life, and ushering in a new era (Jung Jae-yong, 2020).

The plague (Black Death) that hit medieval Europe in the eighteenth century spread mainly through mice, easily infecting large cities. This resulted in the death of 30~60% of the total population of Europe, leading the economic structure of Europe into depression. In addition to the Black Death, Cholera, which spread through sewage, was a pandemic from the nineteenth century to the twentieth century. This pandemic caused population decline in every era and had a significant impact on economies and societies. Governments were challenged to improve urban problems related to sanitation, which resulted in the improvement of road conditions and the creation of urban parks in order to address the poor conditions in medieval cities (Jung Jae-yong, 2020). In response to the Cholera epidemic, the water and sewage system was established and flush toilets became mandatory in every house. In the twentieth century, the Spanish flu was a major epidemic, which was caused by highly dense populations and poor residential conditions. In order to deal with these urban problems, people tried to provide healthier housing, which influenced the birth of modernism. The representative alternatives of urban planning in the era of modernism were Le Corbusier's "Radiant City" and Howard's "Garden City." These alternatives were aimed to find ways to improve the residential environment, emphasizing light and ventilation, and a mid-density city was proposed for self-sufficiency. The density and residential environment of the city have historically been associated with the transmission rate of infectious diseases. Therefore, the spatial structure of cities was continuously developed to improve the residential environment.

In 2019, an unprecedented coronavirus disease (COVID-19) pandemic emerged, and its spread among humans was so fast that it terrorized the whole world. Unlike previous outbreaks such as the Middle East Respiratory Syndrome (MERS), the Severe Acute Respiratory Syndrome (SARS), and others, COVID-19 has continued unabated for a long time, resulting in 72 million infections and 1.63 million deaths worldwide by December 17, 2020 (World Health Organization, 2020). The World Health Organization (WHO) declared COVID-19 a "pandemic," the highest alert level for infectious diseases. In the United States and India, which have the largest number of confirmed COVID-19 cases, the cumulative numbers of confirmed cases were 16.89 million and 9.55 million, respectively. In Korea, there were 40,000 confirmed cases and 600 deaths by

December 17, 2020. The unprecedented movement prohibition and lockdowns in cities are being enforced in all countries around the world. As a result, many industries, including tourism are collapsing in every part of the world. In addition, COVID-19 changed the lifestyle in offices, and the largest closure rate and unemployment crisis has occurred. According to the KDI (Korea Development Institute) "Presentation of Employment Shock and Policy Implications due to COVID-19" report, the spread of COVID-19 has led to a sharp decline in demand for local services and the number of employed people, especially in the local service industry. In the trade industry, the decline in the number of employed people is expanding, especially in the manufacturing industry, due to sluggish exports because of the falling global demand. About 160,000 jobs have been lost in the manufacturing sector due to COVID-19, and if prolonged, about additional 160,000 service jobs could be lost, especially in non-metropolitan manufacturing areas.

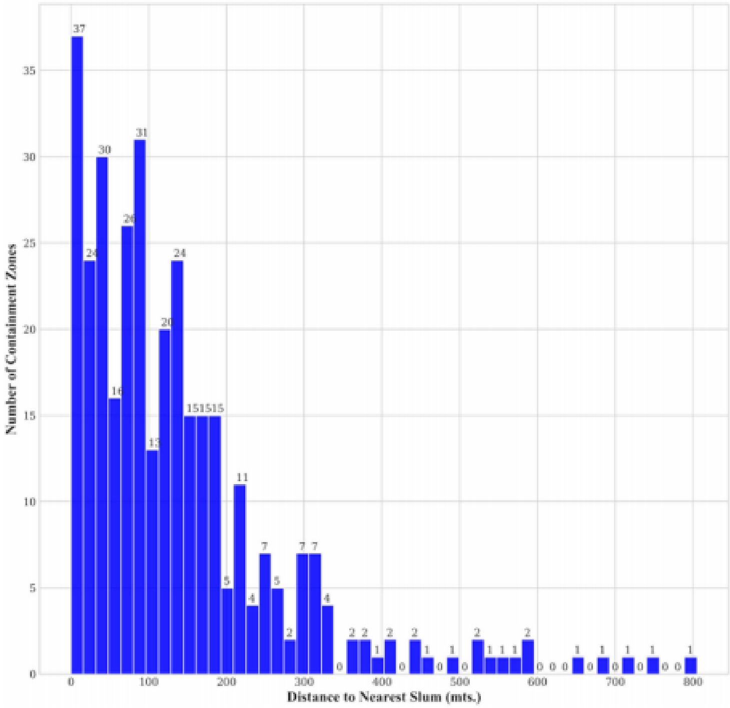
There has not been much research on the relationship between COVID-19 transmission rate and the spatial structure of cities, even though many citizens suffer and the economies are collapsing. COVID-19 spreads through respiratory droplets and coughing, indicating that this virus transmits through the air (WHO, 2020). This type of infection can make high-density populated areas vulnerable to COVID-19. As a result, the spread of infectious diseases will be affected by the urban spatial structure, and the relationship between the pandemic and urban space should be investigated. Rosès (2020) argues that the COVID-19 pandemic will fundamentally change the relationship between public space and other spaces that make up a city. Rosès also argues that it is very important to study and measure these changes in the planning and designing of cities around the world. The Korea Institute of Land, Infrastructure, and Transport (2020) argues that it is important to strengthen digital infrastructure rather than the urban spatial structure to quickly identify infectious diseases and isolate those infected to minimize transmission. As such, there are many studies and articles dealing with COVID-19 and cities; however, it is difficult to find a quantitative analysis of what features of cities affect COVID-19 infectivity.

Currently, cities take the form of an agglomeration economy in which business and industrial facilities gather for economic efficiency. This choice of location can be expressed in clusters and networks, and it is a strategy to foster the growing industry through the synergy of corporate aggregation (Jeong Su-yeon, 2012). Many of the same or different industries are concentrated in specific areas; thus, there are many areas that are concentrated in the financial sector, such as Yeouido and Gangnam, and value face-to-face work. In addition to commercial and industrial districts, there is also a tendency to concentrate on each type of housing due to infrastructure. Today, the world is focusing on the fourth industrial revolution and, accordingly, people are interested in constructing the Smart City and the Compact City. A Smart City is an advanced, networked, and intelligent city that seeks to improve the quality of life in the city (Yoo Sung-min, 2014).

Future cities such as the Smart City and the Compact City will take a denser form than before and will seek to become an agglomeration economy. Since smart buildings in smart cities account for a high proportion, the average of the Floor Area Ratio (FAR) in a smart city will be higher than before (Yoo Sung-min, 2014). This structure of the future city will emphasize more interpersonal exchange, competition, density, and convergency of space. Consequently, pandemics such as COVID-19 are likely to spread faster than in the previous city structure.

This concern is supported by historic events, the higher the density of cities, the higher the transmission rate. However, there are conflicting opinions about the relationship between the spatial structure of a city and virus contagiousness. Previous research that analyzed the relationship between population density and COVID-19, concluded that in the United States, higher population density reduced the mortality rate of COVID-19 due to better medical system establishment (Shima, 2020). Another study argues that government organizational power and social distancing are more important factors than population density (Myounggu Kang, 2020). In India, which has the world's second-largest number of confirmed cases of COVID-19, cases of COVID-19 are more confirmed near slum areas.

Figure 1−1. Distribution of confirmed cases and distance from slum areas



Source: Myounggu Kang, 2020

As time goes by, the frequency of pandemics is increasing (Jeong Jae−yong, 2020), and even if COVID−19 ends, new pandemics can occur at any time, causing urban economies to stagnate. In addition to population density, it is necessary to identify what factors affect the spread of infectious diseases, and suggest directions on how to plan future cities. There are differences in COVID−19 infectivity from country to country. Therefore, this study aimed to identify the relationship between COVID−19 and the spatial structure of a city in Korea. In addition, the study aimed to propose urban planning strategies to cope with future epidemics.

1.2. Purpose of Research

This study aims to find out the relationship between COVID-19 and the urban spatial structure, regional economic, social, and environmental factors, in order to suggest urban planning strategies to cope with future epidemics. The study area was set as Seoul, Gyeonggi province, and the Incheon metropolitan city. The time range was set from the date of the first COVID-19 outbreak in the metropolitan area to December 1, 2020.

The activity radius of confirmed patients' travel routes in the metropolitan area was set up to extract urban characteristics within the radius, and it was analyzed using the spatial lag model (SLM). When analyzing the transmission rate of COVID-19, detailed analysis is possible if the confirmed people's residential addresses and clear data on their travel routes are given; however, the information around the confirmed person is very limited, consisting only of the city and county unit address. The reason the activity radius of the confirmed persons' travel routes was used is that analyzing urban characteristics in county units could not be accurate and reflect the site condition properly. The travel routes of confirmed people can be inferred by utilizing the website of each city, blog, and private sites. This study assumed that the travel routes of confirmed people will affect the transmission rate of COVID-19 in each city, due to their activities as carriers.

A premise needs to be set in order to analyze using the travel path of the confirmed person. It was assumed that as the carrier moves and acts, COVID−19 is spread through the air in the nearby area, thus affecting the surrounding area.

In this study, the dependent variable was the rate of confirmed cases by city and county, and the independent variables were the variables that represent the characteristics of the city. This allowed us to see how various factors, such as the economy, geography, and form of the city affect the spread of COVID−19. Based on the results, this study suggests the design/planning direction of future cities to prepare for highly contagious diseases that may occur at any time in the future.

To identify the relationship between the characteristics of the city's spatial structure and COVID−19, this thesis consists of six chapters. Chapter 1 presents the research background and purpose of this study. Chapter 2 reviews previous studies on epidemics and pandemics, COVID−19 and cities, and articles related to the range of activities and SLMs used in this study. Chapter 3 presents the research problem based on previous studies. To address the research problems, the hypotheses of this study are presented. Chapter 4 describes the research method of the study, the analysis flow, and the variables used in the analysis. In addition, this chapter explains why the metropolitan area of Korea was chosen as the study area. Chapter 5 presents the analysis results of this study and presents suggestions for future urban planning directions. Finally, Chapter 6 draws conclusions and policy implications of this study and presents the limitations of the study.

Ⅱ. Literature Review

2.1. Infectious Diseases and the City

Epidemics and humanity are very closely related historically, and cities have steadily developed to overcome the crisis of epidemics. Efforts have been made to prevent the spread of infectious diseases by improving water supply, residential environment, building wide roads, parks, and green areas. First, this study examined how Korea has responded to epidemics historically.

Before predicting future epidemics, it is important to understand the characteristics of previous infectious diseases in Korea. The characteristics of epidemics in Seoul were studied from a historical perspective by Choi Chung-ik (2015). The spread of infectious diseases in large cities has a significant impact on the local economy and urban development policies, suggesting that urban historical research on infectious diseases has significant implications. After Korea's liberation from Japan's colonial rule, the influx of Koreans from overseas and infectious diseases caused by poor sanitary conditions and nutrition after the Korean War were rapidly spreading in Seoul. In addition, after the war, the introduction of Western values and open sex ethics led to the rapid spread of sexually transmitted diseases in Seoul. As the economy entered an economic stabilization period, the spread of infectious diseases rapidly decreased due to the improvement of the sanitary environment and the rise of hygiene concepts due to urban development. However, Korea has, to date, steadily ranked highest in tuberculosis incidences and mortality among OECD (Organisation for Economic Co-operation and Development) countries. Tuberculosis is highly contagious, raising vulnerability in densely populated cities, such as Seoul. Seoul is a hygienic and modern high-tech city; however, due to many inflows from abroad and surrounding mountainous areas, this city risks the emergence of new diseases (Choi Chung-ik, 2015). In addition, 10 million people are concentrated in a small area; therefore, the ripple effect of the epidemic is greater than in other cities.

One study has developed a prediction model of the spread of infectious disease, MERS, a pre-COVID-19 epidemic. Jeon Sang-eun et al. (2018) simulated the spread of MERS epidemics in real-time to produce results through inter-object interactions in the space, and proposed an actor-based spatial model. The variables used were transmission rate, floating population, bus utilization rate, hospital density, and road network. According to an analysis of quarantine activities using the model, it is very important to discover the infection as soon as possible to minimize the magnitude of the outbreak and prevent the spread of the disease. It explains that quarantining a large floating population area and hospital density is very efficient. In addition, it is efficient to quarantine exposed people in the area first.

According to previous studies mentioned above, Korea, especially Seoul, is a high-tech city that is hygienic and modernized, but it is more vulnerable to infectious diseases than other cities due to its distribution of mountainous areas, high inflow rate, and high population density. COVID-19 should also be checked whether high transmission rates in certain areas are related to a large floating population and high density, in the same context as previous diseases.

S. Harris Ali et al. (2006) analyzed the propagation power of infectious diseases (focusing on SARS) caused by globalization. Using network analysis, they proved that infectious diseases are also easily spread between countries due to globalization networks. They developed a model by placing the floating population volume and bacterial infectivity as variables in the network analysis. They concluded that cities are more susceptible to infectious diseases than in rural areas.

In 2015, Vespignani's team presented a simulation model called “GLEAMviz” based on human-to-human and transportation networks. Using this model, they conducted a simulation, assuming that H1N1, a flu virus from Hong Kong, affected five patients in Hong Kong in 2015. Simulations were based on network theory and this model is evaluated as predictive analysis considering the characteristics of past pandemic virus cases. The analysis was conducted by inputting the medical level, national level, speed of national response to infectious diseases, and the possibility of transmission of infectious diseases through aviation networks. When measuring the transmission power of infectious diseases in foreign countries, it was confirmed that the variables commonly used were the amount of the floating population, medical and national level, and national ability.

To sum up, the contagion rate, floating population, bus utilization rate, hospital density, and road network information are commonly used to identify the transmission power of infectious diseases in Korea. In foreign countries, the floating population and medical and national levels are commonly used in analyses. In research, floating population data are commonly used and confirm that it is an important variable. However, it is not possible to determine what structural features of the city make infectious disease propagation stronger in previous studies. Therefore, in this study, variables with urban characteristics were used to examine the relationship with the COVID−19 transmission rate.

2.2. COVID−19 and the City

COVID−19 began to spread on a large scale from the beginning of 2020, and not much quantitative research has been conducted yet. Internationally, studies have analyzed the relationship of infectious the COVID−19 and urban structure, but not on the macro−analysis of regional units to discuss the direction of urban planning in response to the pandemic. In Korea, no study has quantitatively analyzed the relationship between COVID−19 and urban spatial structure, but studies on the COVID−19 response and urban policy direction exist. According to Jeong Jae−yong (2020), a plan for the appropriate balance between the floating population and the resident population in the city center, a detailed plan for density and land use considering quarantine, and a spatial distribution plan for social infrastructure should be are necessary. The studies on COVID−19 and urban spatial structure abroad are as follow.

Wan Yang et al. (2020) developed a meta−population network model to analyze the transmission rate of COVID−19 in New York City and predicted what the infection rate and mortality rate will be in the future. The analysis was done based on city, county, and district units and the model was developed using age, transmission and mortality, and floating population data. Wan Yang et al. insisted that the government should continuously check children’s health conditions and frequently quarantine schools because of the high COVID−19 transmission among children.

Hamidi (2020) analyzed the association between COVID−19 infectivity and population density in the United States. The study area included 913 metropolitan counties in the United States. Hamidi examined the effect of density on the infection and mortality rate of COVID−19 directly and indirectly. It was suggested that the population of a metropolitan area was the most significant variable in the spread of infectious diseases and that the county's population density was not significant in the spread of COVID−19. Hamidi's study concluded that higher−density counties have a better medical system, which significantly lowers the death rate due to COVID−19. The reason for the high contamination rate in metropolitan areas is that as cities become larger, more counties develop economic, social, and commuting relationships, leading to greater interaction and more face−to−face activities. Therefore, Hamidi argued that inter−city connectivity had a greater impact on the COVID−19 epidemic rate than the county's population density, thus advocating higher−density development for urban developers. Kang Myung−gu (2020) diagnosed that the transmission rate of COVID−19 is more influenced by government organization and social customs than population density. Previous studies related to infectious diseases and COVID−19 are summarized in Table 2−1.

Table 2-1. Previous studies on infectious diseases and COVID-19

Disease	Researcher	Main Content	Variables used
Infectious diseases	Choi Chung-ik (2015)	Study on the characteristics of Epidemics in Seoul	Density, Mountainous area
	Jeon Sang-eun (2018)	Establishing agent-based pandemic prediction model using spatial big data, focusing on MERS	Floating population, Bus utilization, Hospital density, Road network
	S. Harris (2006)	Globalization and the Outbreak of Epidemics	Floating population
	Vespignani (2015)	Hong Kong Flu Virus H1N1 Epidemic Spread Simulation	Healthcare level, National level, National response rate, Aviation network
COVID-19	Wan Yang (2020)	New York City's COVID-19 Transmission Forecasting Model	Age, Floating population
	Hamidi (2020)	COVID-19 and Population Density Association Analysis	Density, Socioeconomic variables

Pandemics such as COVID-19 will be contagious depending on the population and urban characteristics. Various factors such as floating population and density are highly related to the transmission rate of COVID-19; however, no empirical analysis has been conducted. Therefore, in this study, the relationship between COVID-19 and the spatial structure of a city is analyzed using floating population, building, and economic characteristic variables. This study aimed to determine which factors other than population density influence the spread of infectious diseases.

2.3. COVID-19 and the City

2.3.1 Setting activity radius of the patient's travel route

When analyzing the transmission rate of COVID-19, detailed analysis is possible if the confirmed people's residential addresses and clear travel route data are provided, but the confirmed person's information is only confined to the city and county units. However, if the analysis is conducted in the city and county units, it may not be accurate, thus unable to reflect the conditions of the site properly. Therefore, data on the travel path of confirmed people were collected, and the paths of confirmed people were analyzed by assigning a range of activity zones to the travel paths because they affect a certain range of areas as carriers. To establish the range of activity zone of confirmed people, previous studies related to neighborhood unit, radius of activity zone, and extent of influence were reviewed.

Brody's (2009) study, which discusses the transformation of Clarence Perry's concept of neighborhood between 1929 and 1969, argues that Perry's concept of neighborhood was a leading idea in urban planning and development in the United States in the twentieth century but insisted that it should change as times change. Sharifi (2015) also argues that over time, neighborhood plans and scope have changed, expanding its traditional focus on place creation and quality of life to include various sustainability-related issues such as inclusiveness, climate resilience, efficient resource management, and carbon management. Therefore, it is necessary to define the scope of a living radius according to the size of the community and the various patterns and ranges of people's activities.

The living zone is an important concept used as a standard for the layout of public and service facilities for the convenient lives of citizens. Many research and plans are being made to unite the living zone. In addition, community planning, which focuses on pedestrian-centered neighborhood living areas represented by New Urbanism and Urban Village, is considered a new paradigm for urban planning (Oh Byung-rok, 2012).

There are various studies related to the scope of human activities, commercial districts, station areas, and neighborhood, and there are various standards for different researchers. In general, when specifying the aforementioned scope of activities, commercial districts, station areas, and neighborhoods, the administrative area boundary is commonly used. Some studies have suggested criteria for the radius of activity, judging that it is difficult to limit the scope of human activities and associated influences to the administrative boundary. The radius of activity is a unit of living space where everyday activities of residents take place regardless of administrative districts, and it is intended to discuss the area of "activity zone" (So-yu-jeong 2017).

First, Clarence Perry presented the criteria for the radius of activity as a concept of urban residential planning in the Neighborhood Unit theory. Perry's neighborhood claims a radius of 400 m, which represents an area of 64 ha. Based on this theory, several scholars and researchers have proposed criteria for the radius of activity as a planned unit based on various criteria. A study by Park and Rogers (2015) suggests that one neighborhood unit is based on a 1.0 km radius. According to Rewellin−Davis's community design approach, the community has been designed with a grid system of a 1 km radius, based on the premise of a network. Similar to the community design approach of Lee Wellin−Davis, the neighborhood district unit applied to Changwon City was established based on a 1 km radius of walking distance with elementary schools and neighborhood living facilities in the district (Park Byung−chul, 2009).

In addition to the zone of living areas, Choi Jae−hong (2005) conducted a study based on the radius of the subway station area. The average value of 104 experts' answers about the typical station area radius was 530 m, and there is a rate of change in housing prices depending on the distance from the station to 1,000 m. Kim Jae−yeon (2008) conducted an analysis by forming a buffer zone of 1 km and 3 km for each commercial facility to determine the impact of a commercial district.

In a study by Oh Byeong−rok (2014), who analyzed the size of living areas by actual distance using household traffic survey data, the living area was classified as the neighborhood living area, small living area, middle living area, and large living area according to the hierarchy. Oh Byeong−rok’s study analyzed the scope of living rights based on areas where department and arrival traffic are concentrated through commuting, shopping, and leisure, which represent the range of the daily activities of residents. As a result, the scope of the neighborhood living area by walking was analyzed to be 700 m, and the range of the neighborhood living area generated by bicycles and village buses was 2 Km.

In this study, the travel paths of confirmed people in the metropolitan area were organized, and the data points, which were the destinations of the travel routes, were generated through the geocoding process, and a 1 km buffer zone was applied to each point. After establishing the area, data were extracted and analyzed such as geography, economy, and urban form located within the active range. This study sought to find out how the characteristics of the city affect the COVID-19 transmission rate using the spatial econometric model.

2.3.2 Spatial Econometrics Model and Spatial Lag Model (SLM)

The term “spatial econometrics analysis” was first used by Paelinck and Klaasen in the 1970s, and a measuring model was proposed by Luc Anselin in 1988. In the presence of spatial dependence and heterogeneity, the discomfort, efficiency, and consistency of the estimation coefficients cannot be guaranteed. Spatial dependence means that a particular event is spatially correlated, and spatial heterogeneity refers to an irregular distribution that occurs in a large area. Spatial−weighted matrices have emerged to address spatial dependencies, and SML have begun to be utilized. The studies that have used SLM are as follows.

Choi Myung−seop (2016) wanted to select a more suitable model for the forecasting by comparing the predictive power of various housing price estimation models in Seoul. The average housing price of 1,991 apartments in Seoul was estimated using OLS (Ordinary Least Squares), SLM, spatial error model, geographical weighted regression model, and geographical additive model. Since then, the average square root error using the actual price of the house and the estimated price is derived from the model, and the predictive power is compared between models. As a result, the SLM was the most appropriate model, and Choi Myung−seop identified the spatial externality, judging that the methodology and logic were excellent. However, the analysis results may vary depending on the assumption of spatial weight matrix that must be established. Nevertheless, it is said that applying the spatial econometrics model in the housing price model can increase the predictive power of the model in that it reflects the nonlinear structure of the space as well as the spatial autocorrelation.

Just as COVID-19 travels through the air, fine dust travels through the air too. Lim Hyung-sun (2020) analyzed how air pollution levels were transmitted and affected by the characteristics of the city and studied the cost of medical generation due to air pollution. Since air pollution is a dependent variable that is affected by region, Lim Hyung-sun developed a panel model using an SLM. Variables such as urban area, tree ratio, temperature, precipitation, and wind speed were determined to have a significant impact on air pollution. Furthermore, Lim Hyung-sun concludes that leveraging an SLM better describes the properties of space than general OLS analysis.

Similar to the air pollution level, COVID-19 also propagates through the air, so there must be a spatial dependence among regions. Since COVID-19 in a particular region can be propagated to the next region, conducting multiple regression analyses cannot guarantee the discomfort, efficiency, and consistency of the estimated coefficients. Therefore, the SLM was used, consisting of the spatial weight matrix, established according to the criteria for adjacent administrative districts and was built under the “Rook” method.

Ⅲ. Research Problem and Hypothesis

3.1. Research Problem

Earlier, Hamidi (2020) suggested that the population of a metropolitan area is the most significant variable in the spread of infectious diseases and that a county's population density is not significant in the spread of diseases. Hamid analyzed that higher-density counties have a better medical system, which significantly lowers the death rate due to COVID-19 and, therefore argued that inter-city connectivity had a greater impact on COVID-19 transmission rates than population density, thus advocating higher-density development for urban developers. This denied the social perception that the spread of infectious diseases increases as the population density rises, indicating that high-density development can continue. In addition, Kang Myung-gu (2020) diagnosed that the transmission rate of COVID-19 is more influential in government organizational power and social distancing than in population density. In Korea, there is a small regional deviation at the medical level, and the central government-led COVID-19 quarantine is taking place; thus, the research problem is whether the density is related to the spread of COVID-19. The following research questions were asked:

1) The Korean metropolitan area has a small medical level deviation and central government-led quarantine is carried out. Is there a link between density and COVID-19 transmission rate in Korea?

2) What other factors besides density affect the COVID-19 transmission rate?

In the case of India, which has the world's second-largest number of confirmed cases of COVID-19, more confirmed cases of COVID-19 are found near Slum Street. This means that the local economic level has a negative (-) relationship with the transmission rate of COVID-19. This is because the poorer the region, the poorer the medical system is, the less quarantined it is, and the less sanitary the environment is, causing the disease to spread more easily. In Korea, there are places where local standards fall, such as "Daldong area," but it cannot be confirmed that there is a relationship between the local level and COVID-19 infectivity since the medical system is well established and masks are routinely used in the metropolitan area. This raised a research question on whether the economic characteristics of the region are related to the spread of COVID-19.

3) In Korea, is the regional level and economic characteristics related to the spread of COVID-19?

Based on the above research problems, this study sought to examine the relationship between the epidemic rate of COVID-19 and urban spatial structural factors. The geographical, building characteristics, and economic variables that make up the city were compiled to represent urban spatial structural elements, and the association with the transmission rate was examined using the spatial econometrics model.

3.2. Research Hypothesis

This section presents the research hypotheses of this study based on the theoretical background and previous studies discussed in Chapter 2 and the backgrounds discussed in Section 1 of this chapter, which led to the research questions.

The hypotheses of this study are as follows :

(1) In the Korea metropolitan area, since the medical level is controlled due to the small medical level gaps between regions, areas with high-density and high-rise buildings will have a higher rate of COVID-19 transmission through the air due to the high floating population and population density.

(2) Even if central government-led quarantine and mask routinization continue, areas with weak fiscal autonomy regions will have a high COVID-19 transmission rate due to insufficient urban and sanitary management.

Ⅳ. Methodology and Scope of Analysis

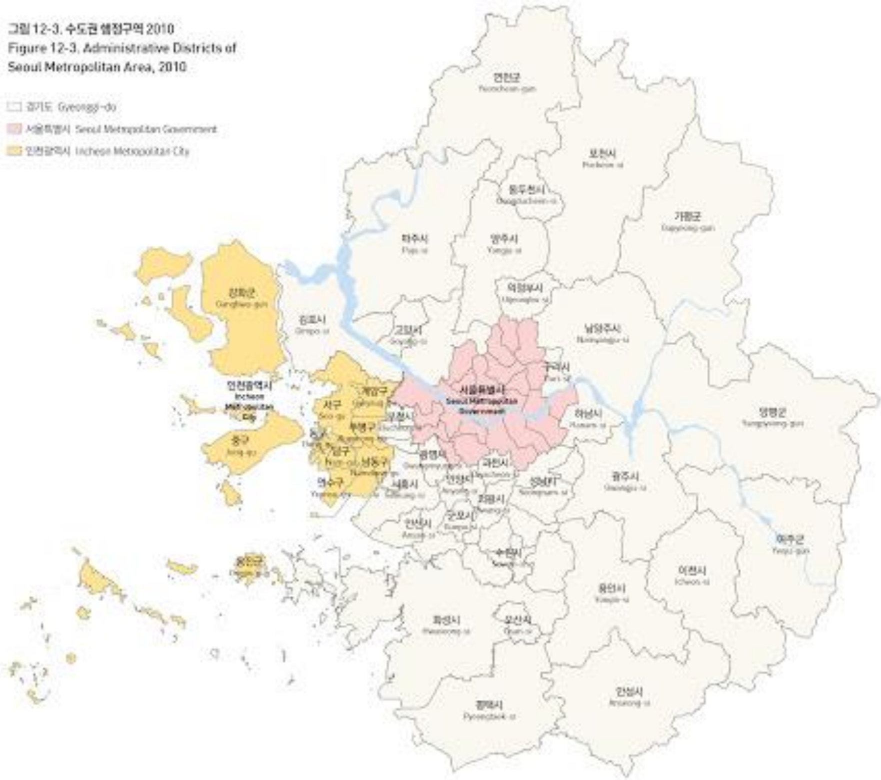
4.1. Study Flow and Analysis Model

4.1.1 Study Area

This study aimed to find out the relationship between the epidemic rate of COVID-19 in Korea and the urban spatial structure and to propose urban planning strategies to cope with future epidemics. Therefore, Korea was established as the research area focusing on the metropolitan area. The metropolitan area includes Seoul, Gyeonggi Province, and Incheon Metropolitan City. As of December 19, 2020, the number of confirmed COVID-19 cases was 14,240 in Seoul, 11,453 in Gyeonggi, 7,472 in Daegu, 2,186 in Incheon, 1,962 in Busan, 1,252 in Chungnam, 1,011 in Gyeongnam, 896 in Gangwon, 852 in Gwangju, 756 in Chungbuk, 693 in Daejeon, 646 in Jeonbuk, 539 in Ulsan, 495 in Jeonnum, and 205 in Jeju. Seoul, Gyeonggi Province, and Incheon Metropolitan City (the metropolitan area), have the largest percentage of confirmed cases in Korea, and it is estimated that there are many local infections due to the large population density and multi-use facilities. Other cities with a large number of confirmed COVID-19 cases, such as Daegu, were not analyzed in this study because the metropolitan area is in the center of Korea. Since population and economic activities are concentrated in the metropolitan area, suggesting urban planning directions to respond to future pandemics in the metropolitan area is more effective. Infectious diseases have caused great repercussions in the economy and industry, which are mainly carried out in the metropolitan area; therefore, the study area was limited to the metropolitan area of Korea. In addition, the study area was limited to the metropolitan area because it was easier to acquire data related to local infections, not indoor mass infections, due to the active floating population and work activities. However, there are many cases of mass infection among the confirmed people due to the large floating population, work activities, and leisure activities. The analysis results are only applicable to Korea due to the lower number of local infections than other countries due to high civic awareness in Korea. Despite these shortcomings, the metropolitan area was considered the most suitable area to conduct this study because the analysis of the metropolitan area guides the future urban planning direction of Korea.

In this study, the information of confirmed people was collected from the date of the first confirmed case to December 1, 2020, to determine the impact of the city's spatial structure on the spread of COVID-19, and the administrative boundary of cities and counties in the metropolitan area were used as the units of analysis. The data related to the spatial structure of the city were constructed by establishing the spatial structure data of the buffer zone of confirmed persons' travel routes. This paper had intended to analyze in more detail the “Dong” unit as an administrative district; however, the government provided information on city and county units only. Cities with fewer than 10 regional confirmed cases, such as Dong-gu, Woongjin-gun, Anseong-si, Yeoncheon-gun, were excluded from the study. Therefore, 62 cities and counties were analyzed in this study.

Figure 4-1. Korea metropolitan area



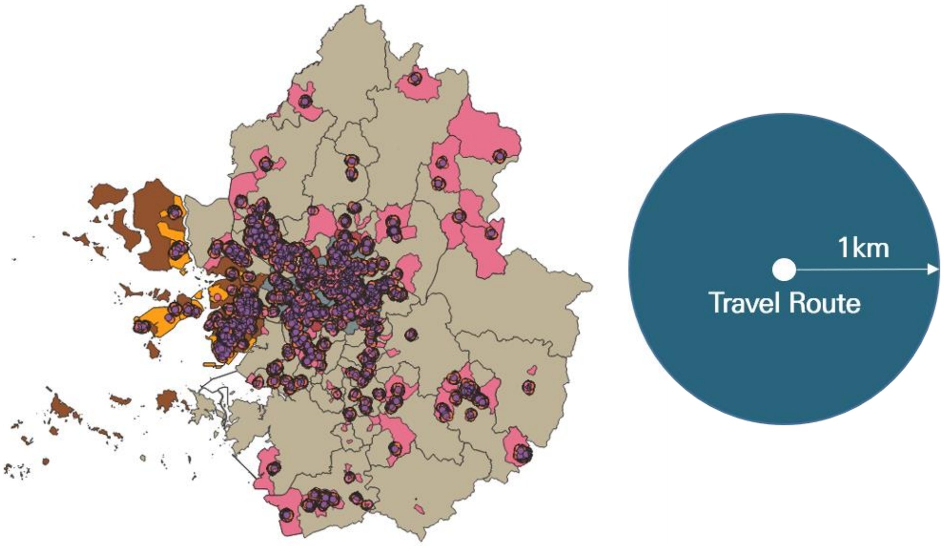
4.1.2 Research Flow

This study aimed to examine the relationship between the transmission rate of COVID-19 and urban spatial structural factors. The geographical, building characteristics, and economic variables that make up the city were compiled to represent the urban spatial structural variable, and the association with the transmission rate was examined using the SLM.

The study also aimed to verify the infectious nature of COVID-19 by applying the number of confirmed cases of each city and county. Multi-use, business, and commercial facilities are concentrated in the metropolitan area, resulting in active floating population and economic activities; therefore, there are many cases of group infections. Group infections are rarely seen as being caused by the structure of the city. In order to examine the relationship between local infections and urban spatial structure, the analysis was centered on those who were infected locally, excluding major group infections. Major group infections such as those at Sincheonji, Call Center, Itaewon Club, various church group infections, 8.15 Liberation Day rallies, and Fitness Center were excluded from the analysis sample. The ratio of confirmed people was determined by referring to the information about the confirmed person provided by each city hall.

The confirmed patients act as carriers of the COVID-19 virus would have spread the disease along their travel routes. As a result, when constructing urban spatial structural factors, a range of 1 km activity zone on the confirmed case's travel path was set to explore the urban and geographical characteristics of the contaminated region. The travel route of the confirmed people was found at the website and blog of each district office, and on private sites such as Corona Pass, Mainz Lab Corona 19, Corona Map information, and open-api data. Based on this, it was determined that analyzing using units of the travel route could be more precise and reflect on-site conditions than analyzing using units of cities and counties where confirmed people live. If the characteristics of the city are not analyzed based on the paths used by confirmed people, but the characteristics of the city are simply extracted as a unit of the city and county where the confirmed person lives, the macro urban flow, not the characteristics of the region and city, will be read. For example, the places where the confirmed person has visited can have a high FAR and can be highly concentrated, but the average FAR and density may be low in the scale of city and county units. Such errors can lead to incorrect information about the city, resulting in errors in the estimated values of the model. Places where confirmed people stopped were converted into data points via geocoding, and a 1 km buffer zone was applied on these points using the GIS (Geographic Information System) program.

Figure 4-2. Travel route and buffer zone



<Points of travel route of confirmed person and travel route buffer zone>

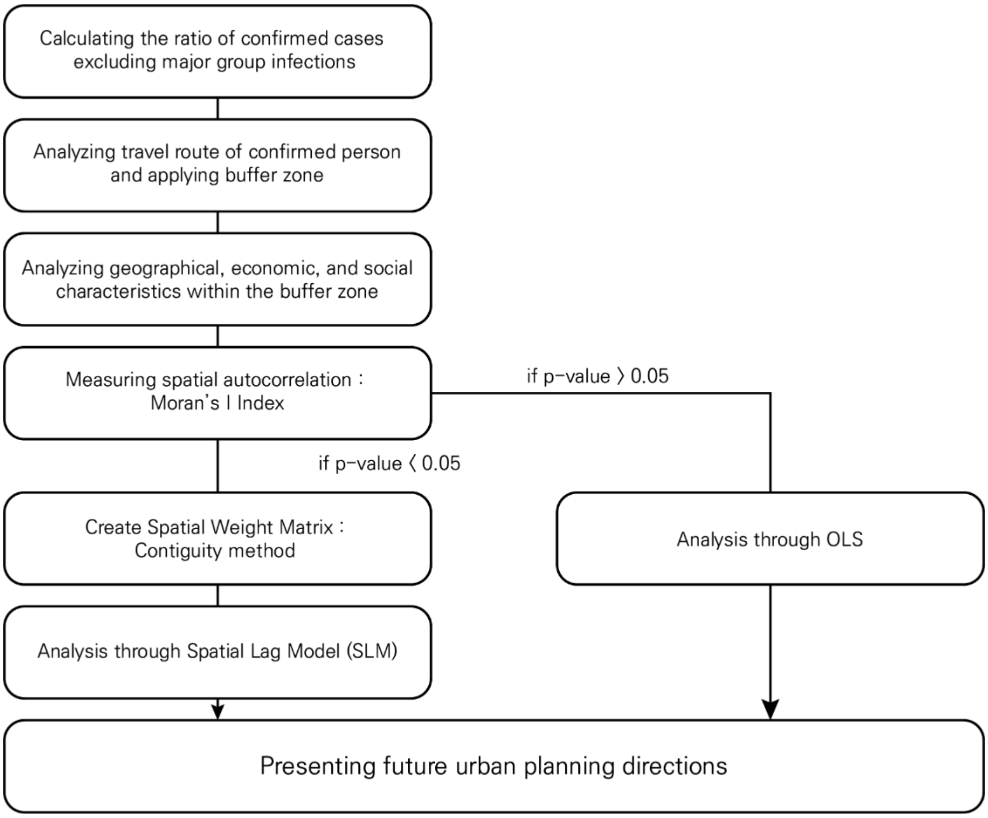
Geographical, economic, and social characteristics within the buffer zone were analyzed and used as representative variables of urban spatial structures. The variables that might represent urban spatial structures may include anchor facilities, major facilities, number of businesses, apartment standard price, commercial vacancy rate, revenue, floating population, population density, income level, building to land ratio, FAR, floor level, commercial density, slope, land price, multi-use facility density, park area, lease ratio, financial independence of city, road width, wind speed, and tree distribution. There is a premise to be set in order to analyze using the path of a confirmed person. Since COVID-19 spreads through the air, it was assumed that as the carrier moves and acts, he or she spreads

COVID−19 through the air in the nearby area, affecting the surrounding area's infection rate.

The average value of each buffer zone was derived by analyzing the variables in the buffer zone. Confirmed persons' information was provided only in the city and county units; thus, it was not possible to analyze the same unit of the buffer zone. Therefore, variables were converted into city and county units. The COVID−19 virus is an infectious disease transmitted through the air and it is therefore highly likely to have a spatial dependence of infection rate in nearby cities and counties. Thus, spatial autocorrelation was measured using Moran's I analysis. By analyzing the results and judging that there is a spatial dependency, spatial weight matrix was generated and the analysis was conducted using the SLM among the spatial econometrics models.

Based on the analysis results, this study found out which spatial structural variables in the city influence the COVID−19 transmission rate, and proposes a strategy on how the planning direction of future cities should be done.

Figure 4-3. Research Flow

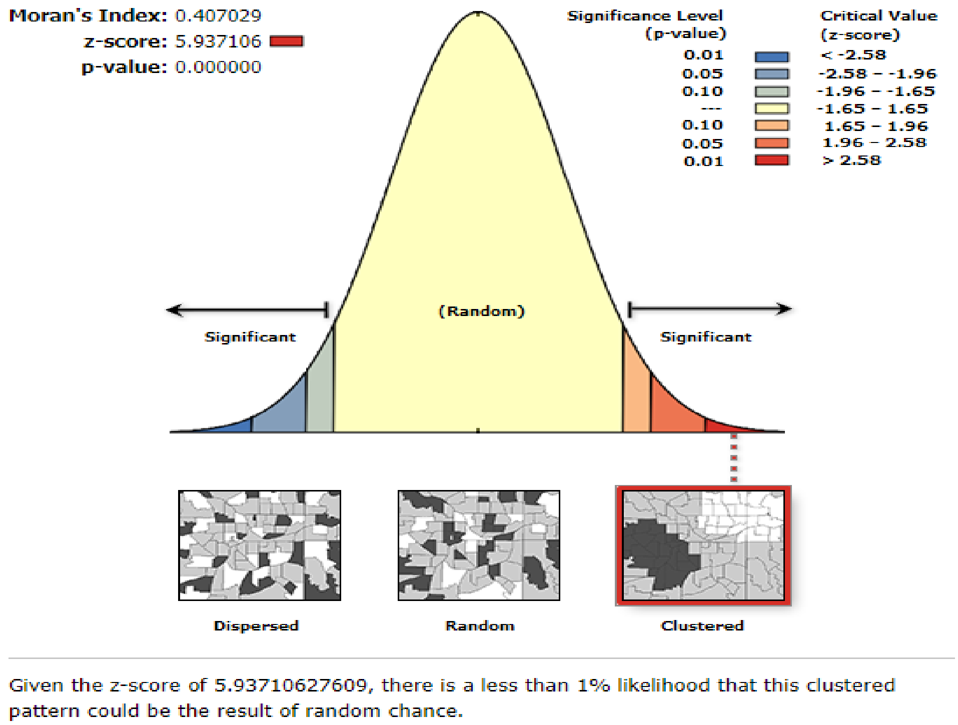


4.1.3 Spatial Econometric Model

In this study, a spatial econometric model was used to analyze the changes in the COVID-19 transmission rate based on the urban spatial structure. The universally used multiple regression analysis does not assume the existence of spatial influence such as spatial dependence, spatial heterogeneity, etc. (Jeon Hae-jeong, 2012). Spatial dependence is the presence of spatial correlations of specific events, and spatial heterogeneity refers to irregular distributions that occur in large areas. In the presence of spatial dependencies and heterogeneity, the discomfort, efficiency, and consistency of the coefficient estimation cannot be guaranteed. Models that fail to control their influence based on space have a problem of invalid specification, estimates are no longer optimal linear discomfort estimates, and there is a risk of reaching incorrect statistical estimates (Jeon Hae-jeong, 2012). In addition, there is a problem that estimates of parameters and standard error may be biased, which affects statistical inference (Park Jong-ki, 2011). In this study, we considered that since COVID-19 is transmitted through the air, neighboring regions can influence the COVID-19 transmission rate in the specific region. In response, the SLM, a model of the spatial econometric model considering spatial dependencies, was used to determine how physical, location, and environmental factors in an urban space affect the COVID-19 transmission rate.

The Moran's I value was checked to determine whether spatial dependencies exist for the COVID−19 transmission rate. As a result, spatial dependence was shown to be significant, and it was found to have a positive (+) spatial correlation. The information on this is shown in Figure 4−4 below.

Figure 4−4. Result of Moran’s I



The significant spatial dependence is shown by the fact that the p−value of Moran's I is less than 0.05. This suggests that areas with high COVID−19 transmission rates will also have neighbors with high COVID−19 transmission rates, and it can be seen that they affect each other. The Moran's I values were derived using GIS, and clusters of the COVID−19 transmission rate are shown in Figure 4−5.

Figure 4-5. Ratio of confirmed cases in each city

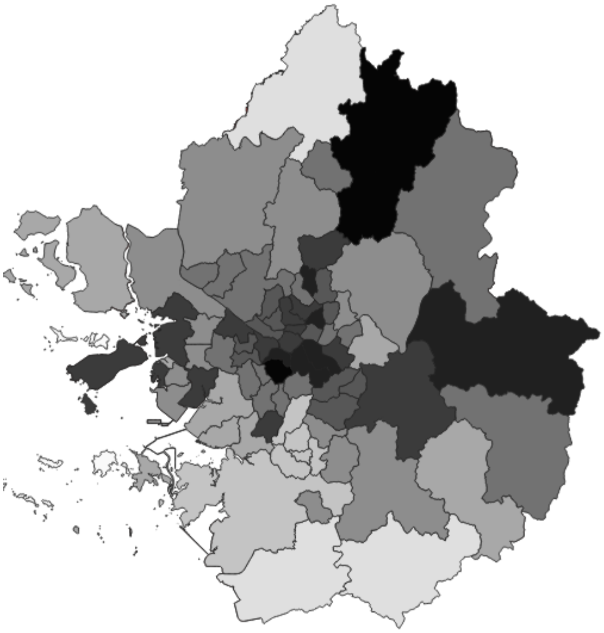
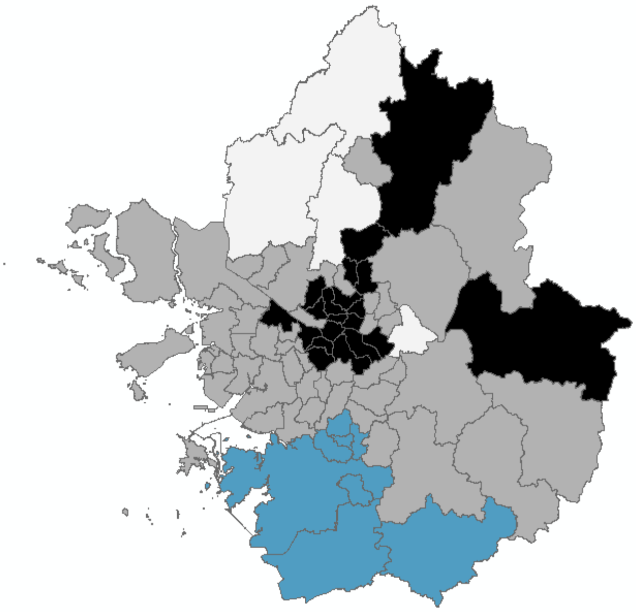


Figure 4-6. Cluster of confirmed case ratio



The ratios of confirmed cases in the metropolitan area are significantly high in Seoul, Yangpyeong-gun, and Pocheon-si. Except for Seoul, this phenomenon can be explained by the small absolute number of confirmed people than in other cities and counties, but the proportion of confirmed people is higher due to the small population, which is the denominator. As shown in Figure 4-6, which shows the clustered ratios of confirmed people, Seoul, Yangpyeong-gun, Gyeonggi-do, and Pocheon-si are grouped into clusters with high percentages of confirmed people. The northern and southern parts of Gyeonggi-do Province are cluster-bound, while other regions, the remaining part of Gyeonggi-do Province, and Incheon can be cluster-bound.

The spatial autocorrelation analysis in the spatial econometric model requires the composition of a spatial weight matrix. This spatial weight matrix allows us to test or estimate inter-regional interactions or spatial correlations by placing high weights on more spatially adjacent regions (Kang Hee-chan, 2019). There are various methods to create spatial weight matrices, among which the most frequently utilized are to weigh the contiguity or use space coordinates (Kang Hee-chan, 2019). In this study, a spatial weight matrix was constructed using a method that weights the contiguity because the analysis of this study was intended to use city and county units. Since the analytical unit was a polygon-type administrative boundary, this paper used a distance-based matrix, weighted with 1 adjacent case and 0 otherwise. The spatial weight matrix used in this study was 62 × 62 matrix, with all elements of the diagonal matrix being zero.

The SLM considering the spatial autocorrelation of the COVID−19 transmission rate is shown in Equation (1) below.

$$P_{it} = \rho \sum_{i=1}^{N} w_{ij} P_{jt} + \delta' Z_{it} + \upsilon_{it}\,, \qquad \upsilon_{it} = \eta_i + \varepsilon_{it} \quad (1)$$

In the above expression, P refers to the transmission rate of COVID−19 and is applied as a dependent variable. Z stands for socioeconomic, geographical, and environmental variables, and W stands for the spatial weight matrix, and the matrix is constructed on the basis of adjacent city and county districts. ρ means spatial effect, η means regional effects of time fluctuation, and ε means error term. The above equation (1) is reconstructed as shown in the following expressions (2) and (3).

$$P_t = \rho W P_t + Z_t \delta + \upsilon_t \quad (2)$$

$$P_t = (I - \rho W)^{-1} (Z_t \delta + \upsilon_t) \quad (3)$$

The above spatial econometric model refers to the model in Anselin et al. (2008) and many of the above models are used in studies dealing with fine dust and inter−urban influences (Lim Hyung−sun, 2020). In this study, we judged that there is no problem in using the above model because COVID−19 is propagated through the air, and fine dust is also propagated into the air.

4.2. Data and Variables

In this study, the goal was to find out how the transmission rate of COVID-19 is related to urban spatial structure. The time range was set from the date when the COVID-19 transmission began in the metropolitan area to December 1, 2020. Variables describing urban spatial structures were collected from data of 2020 and, if not present, replaced with the data of 2019. Of the 66 cities and counties in the metropolitan area, Incheon Dong-gu, Incheon Ongjin-gun, Gyeonggi Anseong-si, and Gyeonggi Yeoncheon-gun, with fewer than 10 confirmed cases excluding major group infections, were excluded. Therefore, this study analyzed a total of 62 cities and counties.

Data covering the confirmed persons' information can be obtained from each city hall's website. Through this, it is possible to identify the administrative districts of the city, county, and district where the confirmed person resides and the approximate infection route. In order to check the travel route of confirmed cases, data were received from websites and blogs of 66 district offices. In addition, places that do not specify the mutual name were inferred using private corona-related sites. By using the OpenApi service at the Corona Pass website, the paths of confirmed people were inferred, and the travel routes of confirmed people were identified using the location of confirmed people's destination at the Corona Map site and the Mainz Lab Corona 19 route tracking function.

The following variables were used in the SLM. For the dependent variable, the ratio of confirmed cases, excluding major group infections and foreign infections, were used. Independent variables include the square value of date from initial infection (based on the date of the onset of regional infection), commercial density in buffer, building density in buffer, open space density, building−to−land ratio, FAR, multi−unit dwelling's building−to−land ratio and FAR, detached house's building−to−land ratio, multi−unit dwelling building age, average wind speed, average slope, and financial independence. The reason for using the square value of the first infection date passed was to reflect the first, second, and third wave of the COVID−19 pandemic in Korea. The commercial density in the buffer was calculated using the data from National Spatial Information Portal, and commercial buildings referred to recreational facilities, first−class neighborhood living facilities, second−class neighborhood living facilities, and sales and business facilities. Commercial density was calculated by dividing the buffer area by the total floor area of the commercial facility in the buffer zone. The density of the building in the buffer was calculated by dividing the buffer area into the total floor area of the building. This is helpful in that it reflects roads and public land by reflecting the entire area, not only the building land area, unlike the BCR(Building Coverage Ratio) and FAR. The density of the open space in the buffer was calculated by dividing the buffer area into the area of various parks, squares, green areas, public spaces, and amusement parks. The BCR and FAR were extracted from the National Spatial Information Portal using integrated building data and utilized them to confirm the impact of urban spatial structure on the spread of COVID−19. The impact of the residential space structure was also identified by classifying the BCR and FAR as multi−unit dwellings and detached houses. The average slope was also available on the same portal. The average wind speed was extracted from EOSDIS (Earth Observing System Data and Information System) on NASA's website. The data for 2020 was only available until August; therefore, the annual average wind speed data for 2019 was used. Financial independence of each city was available from KOSIS (Korean Statistical Information Service). The spatial effect is estimated by applying the spatial weight matrix to the COVID−19 transmission rate. Since the analytical unit is a polygon−type administrative boundary, it is a distance−based matrix, with adjacent cases weighted 1 and otherwise zero. The spatial weight matrix is 62 × 62 matrix, and all elements of the diagonal matrix are zero. The information about the variables used in the analysis is shown in Table 4−1.

Table 4-1. Variables used in the analysis

Category	Variable	Description	Source
Dependent Variable	Ratio of confirmed cases (excluding major group infections and foreign infections, up to December 1, 2020)	※Major group infection: Shincheonji, call center, Itaewon club, various church infections, 8.15 Liberation Day rallies, nursing hospitals, fitness, military units, etc.	Each city's website
Independent Variable	Square value of date	Square value until December 1, based on the start date of local infection	Each city's website
	Commercial density in buffer	Entertainment facilities, types 1 and 2 neighborhood living facilities, sales facilities, sales and business facilities items ※Commercial floor area/buffer urban area	NSDI Portal (National Spatial Data Infrastructure Portal)
	Building density in buffer	Total building floor area/buffer area	NSDI Portal
	Open space density	Square, park, green, public park, amusement park	data.go.kr
	BCR in buffer	Building area/site area	NSDI Portal
	FAR in buffer	Total floor area/site area	NSDI Portal
	Multi-unit dwelling BCR	※Multi-unit dwelling: Apartment, row houses, multi-family house, dormitories	NSDI Portal
	Detached house BCR	※Detached house: detached house, multi-family house	NSDI Portal
	Multi-unit dwelling FAR	Total floor area/site area	NSDI Portal

	Multi-unit dwelling building age	Average building age	NSDI Portal
	Average wind speed	Average annual wind speed (m/s) for 2019	NASA, EOSDIS
	Average slope	Average Slope	NSDI Portal
	Financial independence	Level of financial independence of local governments	KOSIS

Variables related to density among independent variables were decided on by referring to Hamidi's (2020) study, and the initial infection date was also based on Hamidi's (2020) study. The average wind speed independent variable was based on the calculation method of Lim Hyung-sun (2020), and the BCR, FAR, average slope, financial independence, open space, and commercial density variables were used to meet the objectives of this study.

Ⅴ. Analysis Results

5.1. Spatial Lag Model Analysis Results

To determine how the transmission rate of COVID−19 is influenced by the urban spatial structure and socioeconomic environment, this paper utilized the SLM. The hypotheses of this study were as follows:

(1) In the Korea metropolitan area, since the medical level is controlled due to the small medical level gaps between regions, areas with high−density and high−rise buildings will have a higher rate of COVID−19 transmission through the air due to the high floating population and population density.

(2) Even if central government−led quarantine and mask routinization continue, areas with weak fiscal autonomy regions will have a high COVID−19 transmission rate due to insufficient urban and sanitary management.

To verify the above hypotheses, density, high−rise−related density, BCR, and FAR data were used as independent variables, and financial independence data were used to measure local organizational power as a proxy variable.

The Eviews10 program was used to build the model using the variables described earlier, and the results are shown in Table 5−1.

Table 5-1. Results of SLM analysis

Property	Variable	Coefficient	Std. Error	t-Statistic	Prob.	VIF
General Property	Constant	0.000364	0.000156	2.34	0.0239**	
	Spatial effect	0.298601	0.130806	2.28	0.0271**	2.01
	(Days since first case)^2	2.07E-09	6.45E-10	3.22	0.0024***	1.28
City Property	Commercial density	0.000856	0.000241	3.55	0.0009***	2.62
	Building density	2.45E-05	7.39E-06	3.31	0.0018***	1.27
	Openspace density	-1.88E-05	8.11E-06	-2.32	0.0248**	1.40
	BCR	-1.04E-05	2.99E-06	-3.47	0.0012***	5.50
	FAR	6.06E-07	6.77E-07	0.89	0.376	6.77
	Multi-unit dwelling BCR	-0.00121	0.000264	-4.60	0***	4.35
	Detached house BCR	0.00091	0.000252	3.61	0.0008***	5.55
	Multi-unit dwelling FAR	0.000158	3.96E-05	3.99	0.0002***	4.18
	Multi-unit dwelling building age	9.84E-06	4.33E-06	2.27	0.0277**	1.48
Geography & Climate Property	Average wind speed	-9.75E-05	3.76E-05	-2.59	0.0128**	1.55
	Average slope	0.001485	0.000324	4.58	0***	1.37
	Mountainous region dummy	0.000217	5.27E-05	4.12	0.0002***	1.26
Economic Property	Financial independence	-3.05E-06	1.13E-06	-2.69	0.0099***	1.45
Adjusted R^2 : 0.760, Durbin-Watson stats: 2.10						

Among the independent variables utilized in the model, independent variables except for the FAR in buffer had statistical significance. The model's adjusted R^2 was 0.76, and the Durbin Watson Statistic was 2.10, that is, close to 2. The transmission rate of COVID-19 has been shown to have a positive relationship with the number of days passed after the initial infection, commercial and building density in buffer, BCR of detached houses, multi-unit dwelling's FAR and building age, average slope, and mountainous dummy variables. It has been shown to have a negative (-) relationship with open space density, BCR in buffers, BCR in multi-unit dwelling, average wind speed, and financial independence variables.

Higher commercial and building density leading to higher transmission rates of COVID-19 means that areas with a large number of markets have a large floating population, which increases the probability of transmission. The high ratio of the total floor area of the building to the area of the buffer means that many buildings are concentrated in a small space, which serves to attract many people. In addition, high building density means that the area of open spaces or roads is small, leading to a higher possibility of transmission due to close contact between people. It has been confirmed that when the population is concentrated, the COVID-19 transmission rate will increase even if wearing masks is a routine.

If the number of open spaces increases, the transmission rate of COVID-19 decreases. Open spaces refer to parks, squares, public spaces, and amusement parks, which enhance comfort by securing air and openness within the city. Open spaces serve as an air circulation path for air purification, which is related to wind speed. The wider the area that serves as an air channel, the better the air circulation, which weakens the infectivity of COVID−19. It can also be seen that historically, the poor environment has been removed from large cities, and wide roads and urban parks have been created to ensure a healthy life and reduce the concentration of pandemics in cities. As the area of the open space and park widens, it guarantees a healthy life and improves the poor environment; therefore, the transmission rate of COVID−19 is reduced.

The BCR in the buffer has a negative (−) coefficient, which means that the wider the building area compared to the land area, the lower the COVID−19 transmission rate. BCR means the building−to−land ratio for the entire building, and generally, a wider building area makes it easier to maintain social distancing between people inside buildings and weakens the strength of the COVID−19 virus transmitted through the air. This is a different concept from building density variables, which increase the inflow and activity population of cities and reduce the ratio of the open space. In addition, since commercial density and building density are control variables, the negative coefficient of BCR has meaning. The volume rate in the buffer did not have a significant relationship.

It can be confirmed that as the BCR of multi−unit dwelling increases, the spread of infectious diseases is suppressed. On the contrary, the increase in the BCR of detached house promotes the spread of COVID−19. In general, apartments have a low building−to−land ratio. A wider building area of apartments means that the spread of COVID−19 will be insignificant. On the other hand, detached houses have a high BCR and low FAR. Except for detached houses in wealthy areas, the narrower gap between detached houses means the higher possibility of COVID−19 transmission.

The higher FAR of multi−unit dwelling, the easier the transmission of COVID−19, as shown in analysis results. The higher the FAR, the higher the number of floors, the easier the spread inside the building, and the higher the transmission rate of COVID−19 as people gather in narrow spaces such as elevators.

The building age of multi−unit dwelling has a positive relationship with the COVID−19 transmission rate. As the building age increases, the apartment sale price decreases, and the possibility of deterioration of infrastructure and building management increases. As a result, hygiene management is insufficient, which can easily lead to the spread of COVID−19.

The average wind speed has been identified to have a negative effect on the transmission rate of COVID−19. This means that the better the ventilation, the less contagious COVID−19 becomes due to the spreading out of the virus in the air. Lim Hyung−sun's (2020) study also confirmed that the air pollution level decreases as the wind speed becomes stronger, and because COVID−19 also travels through the air, the transmission rate decreases when the wind speed becomes stronger.

The mountainous areas have a positive relationship with the COVID−19 transmission rate. When considering the percentage of confirmed people as discussed in Chapter 4, it was found that the percentage of confirmed people in the region was high because the number of confirmed people was small, but the percentage of confirmed people was higher than in other regions. Choi Chong−ik (2015) also explained that mountainous areas have a greater ripple effect than other cities. This means that even though mountainous areas are not densely populated, there is a high possibility that urban infrastructure is not well established and that they are not well managed, which makes such areas vulnerable to infectious diseases.

It can be seen that the higher the slope, the higher the COVID−19 transmission rate. The slope is the most significant and influential variable in this model, but there is no clear reason for why a high slope increases the transmission rate of COVID−19. According to Arruda (2017), the disease transmitted through the air will be hindered by obstructions such as trees and buildings in areas with high slopes, and the influence will vary depending on the region. According to the spatial distribution of single−family housing in areas with low slopes, this area tends to have a high youth age ratio, high educational level, and high percentage of single−person households (Seong Eun−young, 2016). It is said that the proportion of old houses is low and that there are many types of monthly rent. Examples of this area include Singil−dong, Sinsa−dong, and Sindaebang−dong. In contrast, the area with a high slope tends to have a higher percentage of elderly people, concentration of old houses, lower educational level, higher ratio of self-ownership, and highest density of housing (Seong Eun-young, 2020). Examples of such an area include Jeongneung-dong, Junggyebon-dong, and Wolgye-dong. Lee Hoon (2018) pointed out that in such areas, excluding the Gangnam area, slopes have a negative impact on all types of housing prices. As the slope increases, the proportion of elderly people with low immunity to infectious diseases increases as detached houses become old and dense. As a result, an increase in the slope may lead to an increase in the COVID-19 transmission rate, especially in detached houses. According to Kim Sung-hwan (2017), there is a lack of ventilation, lighting, insulation, and open space as aging small houses are formed in high density on steep slopes. According to Jeong Dong-hoon (2012), 51.3% of Seoul's old-age sloped dwellings were detached houses, and most of them had less than 1.5 million won in income. To sum these up, as the slope increases, aging detached houses tend to be concentrated, the majority of low-income people and the residential environment is vulnerable. Chung Chun-sook of the Democratic Party of Korea concluded that low-income people are more vulnerable to COVID-19 and confirmed that low-income earners are at risk of being exposed to infectious diseases such as COVID-19, as they have to carry out economic activities in poor surroundings for a living. This means that as the slope increases, the density of aging detached houses increases; thus, urban management and sanitation management may be affected by COVID−19, and there are mainly low−income people living in poor conditions, increasing the risk of transmission of COVID−19. In this study, local analysis was conducted based on the travel path of the confirmed person's movement, and urban areas with slopes rather than mountainous areas were analyzed; therefore, the above inference applies. An additional reason for this result is that urban areas with high slopes may continue to have the virus in the area due to lack of ventilation and lighting in high−density detached houses. In addition, the risk of temporarily lowering the mask due to the increased slope and difficulty in breathing may increase, resulting in the spread of COVID−19.

The higher the financial independence, the lower the transmission rate of COVID−19. This means that there is a relationship between the local region's fiscal power and the transmission rate of COVID−19. High fiscal power suggests that additional quarantine activities can be implemented for urban and sanitation management. The increase in financial independence affects the quarantine capacity of the corresponding region, which leads to a decrease in the COVID−19 transmission rate.

In order to reflect the first, second, and third wave of the COVID−19 pandemic in Korea, this paper used the square value of the first infection date passed. To determine whether the model using the square value of ‘Days since first case’, this paper compared models with linear and exp value of ‘Days since first case’

Table 5-2. Comparing square value, linear, exp value of date passed

Property	Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
General Property	Constant	0.000364**	Constant	3.04E-04*	Constant	4.11E-04**
	Spatial effect	0.298601**	Spatial effect	2.85E-01**	Spatial effect	2.31E-01
	(Days since first case)^2	2.07E-09***	Days since first case	8.56E-07***	Exp(Days since first case)	9.93E-127
City Property	Commercial density	0.000856***	Commercial density	8.74E-04***	Commercial density	7.78E-04***
	Building density	2.45E-05***	Building density	2.43E-05***	Building density	2.05E-05**
	Openspace density	-1.88E-05**	Openspace density	-1.88E-05**	Openspace density	-1.87E-05**
	BCR	-1.04E-05***	BCR	-1.05E-05***	BCR	-9.68E-06***
	FAR	6.06E-07	FAR	5.91E-07***	FAR	7.59E-07
	Multi-unit dwelling BCR	-0.00121***	Multi-unit dwelling BCR	-1.21E-03***	Multi-unit dwelling BCR	-1.21E-03***
	Detached house BCR	0.00091***	Detached house BCR	8.87E-04***	Detached house BCR	9.34E-04***
	Multi-unit dwelling FAR	0.000158***	Multi-unit dwelling FAR	1.59E-04**	Multi-unit dwelling FAR	1.61E-04***
	Multi-unit dwelling building age	9.84E-06**	Multi-unit dwelling building age	1.01E-05**	Multi-unit dwelling building age	7.99E-06
Geography & Climate Property	Average wind speed	-9.75E-05**	Average wind speed	-1.02E-04**	Average wind speed	-8.38E-05**
	Average slope	0.001485***	Average slope	1.51E-03***	Average slope	1.41E-03***
	Mountainous region	0.000217***	Mountainous region	2.10E-04***	Mountainous region	2.42E-04***
Economic Property	Financial independence	-3.05E-06***	Financial independence	-3.08E-06***	Financial independence	-2.36E-06*
Adjusted R^2		0.760	0.760		0.706	

As a result of using the square, linear, exp value of ‘Days since first case’, the model using the square value had better model explanation and higher statistical significance in independent variable. Although there was no significant difference between the square and linear value, using the exp value significantly reduces the model explanation and the significance of the independent variables. This paper concluded that model using square value of ‘Days since first case’ describes the first, second, and third wave of the COVID−19 pandemic in Korea better.

Since the transmission of COVID−19 occurs through the air, it is considered to have a spatial dependency. Therefore, this study used the spatial econometric model. By comparing the results analyzed using OLS and the results analyzed using the SLM, this study sought to determine which model would be more suitable when measuring the propagation power of infectious diseases. Table 5−2 shows the results using OLS.

Table 5-3. Results of OLS analysis

Property	Variable	Coefficient	Std. Error	t-Statistic	Prob.	VIF
General Property	Constant	0.000489	0.000152	3.22	0.0023***	
	Spatial effect					
	(Days since first case)^2	1.84E-09	6.64E-10	2.76	0.0081***	1.24
City Property	Commercial density	0.000842	0.000251	3.35	0.0016***	2.62
	Building density	2.50E-05	7.71E-06	3.24	0.0022***	1.26
	Openspace density	-2.42E-05	8.10E-06	-2.99	0.0044***	1.28
	BCR	-1.13E-05	3.09E-06	-3.66	0.0006***	5.39
	FAR	6.46E-07	7.07E-07	0.91	0.3653	6.76
	Multi-unit dwelling BCR	-0.00121	0.000276	-4.40	0.0001***	4.34
	Detached house BCR	0.001021	0.000258	3.96	0.0003***	5.34
	Multi-unit dwelling FAR	0.000187	3.90E-05	4.80	0***	3.73
	Multi-unit dwelling building age	1.13E-05	4.47E-06	2.52	0.0152*	1.45
Geography and Climate Property	Average wind speed	-0.00013	3.65E-05	-3.54	0.0009***	1.33
	Average slope	0.001631	0.000332	4.91	0***	1.31
	Mountainous region dummy	0.000221	5.50E-05	4.02	0.0002***	1.26
Economic Property	Financial independence	-3.22E-06	1.18E-06	-2.73	0.0088***	1.43
Adjusted R^2 : 0.739, Durbin-Watson stats: 1.92						

Multiple regression analysis and SLM analysis are not significantly different. The variable significance and coefficient values in the multiple regression and in the SLM are similar. However, in the adjusted R^2 , the SLM is 0.76, and the multiple regression analysis is 0.73, which makes the SLM more suitable. The Durbin-Watson statistics show no significant difference in the values between the SLM and multi-regression analysis; however, this study determined that the SLM model would be more suitable considering the spatial autocorrelation of the error term and the AIC value.

Using the SLM, this study sought to find out the relationship between COVID-19 and the urban spatial structure. Based on the analysis results, this section verifies the hypotheses presented in this study. The two hypotheses of the study were as follows:

(1) In the Korea metropolitan area, since the medical level is controlled due to the small medical level gaps between regions, areas with high-density and high-rise buildings will have a higher rate of COVID-19 transmission through the air due to high floating population and population density.

(2) Even if central government-led quarantine and mask routinization continue, areas with weak fiscal autonomy regions will have a high COVID-19 transmission rate due to insufficient urban and sanitary management.

Previous studies related to COVID-19 (Hamidi, 2020; Kang Myeong-gu, 2020) found that population density affects the prevalence of COVID-19 less than government organizational power and social distancing. Cities with higher density tend to have better medical systems, which significantly lower the mortality rate from COVID-19. However, in this study, the analysis shows that increasing the commercial and building density means an increase in the floating population, which leads to a positive relationship with the COVID-19 transmission rate. The metropolitan area has health capabilities in each city regardless of population density, and the gap is not large. In Korea, since there is a small regional deviation at the medical level, health capabilities were used as a control variable, indicating that the density of cities influences the COVID-19 transmission rate. We also confirmed that the higher the financial independence, the lower the transmission rate of COVID-19. Areas with weak fiscal power were judged to have a higher transmission rate of COVID-19 due to insufficient urban and sanitary management. These results were found to be consistent with the two hypotheses of this study.

5.2. Future Urban Planning Direction

Earlier, an analysis using the SLM showed that the transmission rate of COVID-19 increased due to the increase in commercial density, building density, BCR of detached houses, and FAR of multi-unit dwelling among urban spatial structures. This seems contrary to the direction in which the compressed city is aiming. As the open space density, BCR, wind speed, and financial independence increase, the infection rate of COVID-19 decreases. As the slope increases, the transmission rate of COVID-19 increases, which can be explained by the aging of detached houses, increased density, and proportion of elderly people with weak immunity.

Although the coefficient of the variables is contrary to what the compressed city is aiming for, planning the urban spatial structure considering the coefficient value may increase the FAR and decrease the BCR, with no additional confirmed cases due to the urban spatial structure. A compressed city is an urban planning concept that includes high residential density and mixed use of land. The research results showed that the COVID-19 transmission rate decreases when the slope decreases and financial independence increases. Areas where low-income people are concentrated have low financial independence due to falling tax acquisitions and high welfare spending. Although there is a limit to this study in determining exactly what the slope variable represents, the study assumed that the slope variable represents the aging and density of detached houses. To summarize, this study suggests ways to disperse areas where low−income people are concentrated. Active use of policies that increase the FAR through the mandatory provision of affordable housing, such as Inclusionary Housing and Zoning, can reduce the COVID−19 transmission rate by spreading low−income residents in underdeveloped areas. In addition, urban planning is needed to build open spaces in many places to create a healthy life and wind path. Commercial facilities generate a large floating population; therefore, it would be better to implement a decentralizing commercial facility policy.

Another way to reduce the transmission rate even if the density of buildings increases is to utilize the logic that the stronger the average wind speed and the higher the open space density, the lower the COVID−19 transmission rate. One way to utilize this logic is to create a wind hole in the center of the building to ensure good outdoor and indoor ventilation. In the Asian region, creating holes in buildings is not preferred for superstitious reasons such as "luck flows out" or "good fortune escapes"; however, it is deemed necessary to prevent future infectious diseases. Urban planning techniques using the "Venturi Effect," which speeds up the wind as wind escapes through narrow passageways between buildings, should also be introduced. In addition, areas with low fiscal independence lack fiscal power, which makes them less capable of coping with infectious diseases. Therefore, the central government should help regions with low fiscal independence to come up with quarantine and countermeasures.

Ⅵ. Conclusion

The purpose of this study was to identify the connection between the COVID−19 epidemic transmission rate and urban spatial structure in the Korea metropolitan area and to present urban planning strategies to cope with future epidemics. In order to analyze relationships and reflect field conditions accurately, the analysis was conducted using the confirmed person’s travel route. The confirmed individual's travel route was used because confirmed cases affect surroundings since the confirmed persons are carriers. A 1 km buffer zone was applied to the travel route to analyze the urban, geographical, economic, and social characteristics of the contaminated area. Since the information of confirmed people is provided by city and county units only, the characteristics of the contaminated regions were converted into city and district units and were then analyzed. This study analyzed how local infections occur by excluding major group infections and overseas infections from the total number of confirmed cases. Since COVID−19 is transmitted through the air, this study considered that neighboring areas can influence the COVID−19 transmission rate in the region. In response, the SLM, a spatial econometric model considering spatial dependence was used to examine how physical, location, and environmental factors in the urban space affect the COVID−19 transmission rate. The analysis results and policy implications can be summarized as follows:

First, this study aimed to further reflect the field conditions by tracing the path of movement of confirmed persons. Quantitative studies on infectious diseases and city connectivity have only analyzed regional characteristics in city and county units so far. Korea, unlike other countries, has disclosed limited information of the travel routes of confirmed cases'. Therefore, this study aimed to take advantage of this information to reflect the local conditions more realistically. However, the confirmed persons' residence data were only disclosed in city and county units; therefore, we had to convert the regional characteristics within the scope of the activity to the city and county units. In addition, private sites were used to confirm COVID-19 path data, but not all clear paths had been provided. In the future, when the COVID-19 pandemic ends and all information is released, research on the path of confirmed people should be conducted actively.

Second, the COVID-19 pandemic has the characteristic of transmitting; therefore, this study utilized an SLM. The universally used multiple regression analysis does not assume the existence of spatial influence such as spatial dependence, spatial heterogeneity, etc. (Jeon Hae-jeong, 2012). This study considered the fact that neighboring regions can influence the transmission rate of COVID-19 into the region. In response, the SLM, a model of the spatial econometric model considering spatial dependencies, was used to determine how physical, location, and environmental factors in the urban space affect the COVID-19 transmission rate. The Moran's I value was calculated to determine whether spatial dependence exists on the transmission rate. The results showed spatial dependence, and it was found to have a spatial correlation of integers (+).

Finally, the results derived from the analysis in this study were as follows. In a previous study related to COVID-19, population density was found to affect the contagiousness of COVID-19 less than government organizational power and social distancing. Instead, the better the medical system is equipped, the significantly lower the mortality rate from COVID-19. However, the analysis in this study showed that increasing the commercial and building density means an increase in the floating population, which indicates a positive relationship with the COVID-19 transmission rate. The metropolitan area has health capabilities regardless of population density, and the gap between regions is not large. As health capabilities are a basic control variable in Korea, the density of cities has been shown to influence the COVID-19 transmission rate. As the BCR increases, the transmission rate of COVID-19 decreases, and as the FAR of a multi-unit dwelling increases, the transmission rate increases. The more open spaces and stronger average wind speed leads to a lower transmission rate of COVID-19. It was also confirmed that the higher the financial independence, the lower the COVID-19 transmission rate. Areas with weak fiscal power were judged to have a higher transmission rate of COVID-19 due to insufficient urban and sanitary management. The results of this study were consistent with the research hypotheses.

Although the coefficient of the variables is contrary to what the compressed city is aiming for, planning the urban spatial structure considering the coefficient value may increase the FAR and decrease the BCR, with no additional confirmed cases due to the urban spatial structure. This study suggests ways to spread out people in areas where low−income people are concentrated. Active use of policies that increase the FAR through the mandatory provision of affordable housing, such as Inclusionary Housing and Zoning, can reduce the COVID−19 transmission rate by distributing low−income residents in underdeveloped areas. In addition, distributing commercial facilities, building more open spaces, and urban planning using the "Venturi Effect" may reduce the transmission rate.

However, due to the limited data on COVID−19 used in this study, the spread of infectious diseases and urban characteristics cannot be fully explained. Since the COVID−19 pandemic has not ended, its pattern of spreading may change, and since data contains personal information of confirmed people, not all movements and infection routes of all confirmed people have been disclosed. In addition, the error range of data can grow as many "unknown" infections occur, which even local governments and the Korea Centers for Disease Control and Prevention have not been able to determine the routes through which they were infected. In addition, this study limited the study area to the metropolitan area; therefore, the results may be different in other regions or countries. Furthermore, the analysis shows that the higher the slope, the more significant the COVID−19 transmission rate increases and, although it is a major factor in the increase in model explainability, it was not clear what characteristics it represents. The increase in slope may influence the rise in the COVID−19 transmission rate due to the aging of detached houses, increased density, and the increase in the proportion of elderly people with weak immunity, and other effects that have not been identified.

Therefore, to address the limitations of this study, futher studies are needed on how the results differ over various time ranges, based on various regions, after the end of the COVID−19 pandemic. This will allow us to come up with more accurate plans for future cities. Despite these limitations, there have been few cases that quantify and analyze data related to COVID−19 so far. Therefore, this study is significant in that it has suggested guidelines for future urban planning and appropriate countermeasures against epidemics.

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국문 초록

본 연구는 코로나19와 도시 공간구조 및 지역 경제·사회·환경 요인 간 연결성을 밝히는 것을 목적으로 두고 있으며, 이를 통해 미래의 전염병에 대응할 수 있는 도시계획 전략을 제시하고자 한다. 인류는 전염병과 자연재해의 위기를 극복하고자 도시 공간구조를 지속적으로 개선해왔으며, 전염병은 도시 및 경제구조, 사람들의 삶의 방식을 바꾸고 새로운 시대의 흐름을 가져오는 촉진제의 역할을 하였다. 올해 2020년도에 유례없는 코로나바이러스 감염증-19(COVID-19, 코로나19)라는 전염병이 등장하였고 사람 간의 전염이 매우 빠르게 이루어지면서 전 세계를 공포로 몰아넣었다. 국가 별 코로나19 전염성의 차이가 존재하며, 우리나라 수도권의 경우, 코로나19와 도시 공간구조 간 연결성을 밝혀내 미래의 전염병에 대응할 수 있는 도시계획 전략을 밝히고자 한다.

코로나19 전염성과 도시 공간구조의 연결성을 정밀히 분석하고 현장 여건을 잘 반영하기 위해서 확진자 이동 경로를 활용하여 분석하였다. 확진자들은 보균자로서 활동한 일정 범위에 영향을 미치기 때문에 확진자 이동 경로를 활용하였다. 이동 경로에 1km 버퍼 존을 적용하여 해당 지역의 도시, 지리적, 경제적, 사회적 특성을 분석하였다. 확진자들의 정보가 시군구 단위로만 제공되기 때문에 지역의 특성들을 시군구 단위로 변환하여 분석하였다. 종속변수인 확진자 비율 중 주요 집단 감염, 해외 감염자들을 확진자 수에서 제외하여 지역감염이 어떻게 일어나는지 확인해보았다. 코로나19는 공기를 통해 전파되기 때문에 인접 지역이 해당 지역에 코로나19 전염률에 영향을 줄 수 있는 점을 고려하였다. 이에 공간 종속성을 고려한 공간계량경제 모형인 공간 시차 모형(SLM)을 이용하여 도시 공간의 물리적, 입지, 환경 요인이 코로나 전염률에 어떤

영향을 미치는지 살펴보았다. 분석 결과 다음과 같이 요약할 수 있다.

코로나19와 관련된 선행연구에서 인구 밀집은 정부 조직력 및 사회관습보다 코로나19의 전염성에 영향을 적게 주며, 오히려 인구가 밀집될수록 의료시스템이 잘 갖추어 코로나로 인한 사망률이 현저히 떨어지고, 인구 밀도보다 도시 간 연결성이 코로나 전염률에 영향을 미친다고 하였다. 하지만 분석한 결과 상업, 건물의 밀도 증가는 곧 유동인구 증가를 의미하며, 이는 코로나 전염률과 정(+)의 관계를 맺는다. 수도권은 인구 밀도와 상관없이 최소한의 보건 능력은 다 갖추고 있으며, 격차가 크지 않다. 우리나라는 보건 능력이 통제변수로 들어가 있어, 도시의 밀도가 코로나19 전염률에 영향을 미치는 것으로 나타났다. 공동주택의 건폐율, 평균 풍속, 재정자립도가 높아질수록 코로나19 전염률이 감소한다. 반대로 단독주택 건폐율, 공동주택 용적률 및 건축연령, 경사도가 높아질수록 코로나19 전염률이 높아진다. 자치구 재정 자율성이 약한 지역은 도시 및 위생 관리가 미흡하여 코로나19 전염률이 높아지는 것으로 판단하였다. 마지막으로 분석 결과를 바탕으로 미래 도시계획 및 전염병에 대한 적절한 대응책 방향성을 제시하였다.

주요어 : 코로나19, 전염병, 도시 공간구조, 도시 밀도, 공간 시차 모델, 확진자 이동 경로

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