도시계획학 석사학위논문

# Modeling Gentrification with Theoretical Physics of Complex Systems: Epidemic Spreading

## 전염병 확산 모델을 활용한 젠트리피케이션 모델링 연구

**2018년 8월**

서울대학교 환경대학원

환경계획학과 도시 및 지역계획학 전공

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이 논문을 도시계획학 석사 학위논문으로 제출함

**2018년 4월**

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박이레의 석사 학위논문을 인준함

**2018년 6월**

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# Abstract

Since Glass researched “gentrification” for the first time in history, most of the conventional research on gentrification have focused on the social aspect of the phenomenon conducted with qualitative methodology. Despite of some strengths of qualitative methodologies, research with quantitative methodologies would suggest more solid basis to the research on gentrification with urban data acquired from real space.

Quantitative approaches to analyze and simulate gentrification have appeared after 2000. They considered numerous possible geographical, economical, and social factors and variables that might be related with gentrification. They calculated and simulated gentrification numerically based on a ″decision making algorithm″ and the change of social, economic, and physical characteristics of a neighborhood with time.

However, few research that analyzed gentrification analytically using research methodologies from theoretical physics could be found. With more concise equations and variables, the quantitative analysis using physical methodology would help our understanding on mechanisms and dynamics of complicated gentrification phenomenon conceptually.

Components such as buildings, roads, transportations systems, and people in a city compose complex ″urban network systems″ and interact with each other, generating diverse urban activities. Urban form and structure can be considered as spatial network systems, ″graphs whose nodes represent the dynamical units, and whose links stand for the interaction″.

The gentrification phenomenon, a result of complex combination of

numerous urban activities, could also be analyzed and described using complex systems by viewing neighborhoods as spatial network systems.

This research focuses on the physical aspect of gentrification. Physical transformation can be measured with the demolition and construction of building because in gentrified neighborhoods many buildings are repaired and replaced rapidly.

This research is based on the hypothesis that neighboring buildings interact with each other, i.e. when a building in a neighborhood is replaced with a new one, buildings next to that would be pressured to be changed: the development of a building is commonly followed by developments of contiguous buildings, which is caused by attracting visitors and/or new residents and increase of property value.

An assumption of this research is to define the gentrification phenomenon as the "spreading of reconstructions" by applying the epdemic spreading model. The purpose of this research is to build a model describing the "spreading of constructions" in a bounded gentrifying area.

According to the interpretation of gentrification as a process involving the spread of an infection, the old buildings correspond to "S" (susceptible state) and the new buildings relevant to "I" (infection state). Based on this relationship between the gentrification and the epidemic model, when the gentrification is progressed, there would be no step corresponding to the recovering process. As there is no process that new buildings transform back to the old buildings. Among the various epidemic models, I selected the "SI" model which does not consider recovering process to calculate the gentrification.

The gentrification models consist of three factors. In addition to the epidemic spreading mechanism, I introduced two other factors influencing reconstructions, deterioration and economic boom, for modeling gentrification. According to the combination of three factors, I defined the following four models to modeling gentrification: The Basic Model, Age Model, Economic Boom Model, and Integrated Model.

This model was applied to three residential communities in Seoul which is gentrified with commercialization, containing 400 to 500 buildings within walking distance, Bong Cheon, Hong Dae, and Garosu Gil.

According to results of modeling, reconstruction of buildings has spread most rapidly in Bong Cheon where land use was changed in 1998. On the other hand, Garosu Gil, where transformations have occurred by remodeling the existing buildings, was redeveloped in a rate less slowly than the rate of reconstructions induced by deterioration. However, reconstructions in Garosu Gil were most brisk from 2001 to 2004, economically booming periods.

By using two model testing indicators, RMSD and MAPE, it was verified that considering two factors, the Age factor and Economic Boom factor makes the modeling more articulate to describe the change close to actual data. Particularly in the Integrated Model, values of MAPE were less than 8% in all of the three sites (Bong Cheon: 7.7%, Hong Dae: 4.8%, Garosu Gil: 2.5%) and values of RMSD were not more than 1% (Bong Cheon: 1.0%, Hong Dae: 0.6%, Garosu Gil 0.7%).

With the Integrated Model, Buildings in Bong Cheon where Parameter G is the largest are predicted to be most rapidly reconstructed, 70% of buildings being predicted to be reconstructed by 2040. In Garosu Gil with Smallest G, 40% of buildings are predicted

to be reconstructed by 2040. 50% of buildings in Hong Dae are expected to be reconstructed for the same period.

A similarity of the trend of parameter G was found in 3 sites. It implies the correlation between parameter G and economic condition of real estate market. The relationship was confirmed by comparing the trend of G and the Housing Price Index in Seoul.

This research confirmed that land use change can accelerate the reconstruction of buildings. The rapid reconstructions can lead to the increase of housing price and rent, followed by the displacement of residents in the sites. Public interventions to prevent gentrification are required to the areas whose land use was changed, especially whose limit of FAR has been increased. For the site where reconstruction of building is activated like Bong Cheon, more careful interventions by local government are required to facilitate the supply of affordable housings.

**Key words : Gentrification, Physical Transformation, Theoretical Physics, Complex Network Systems, Epidemic Spreading, Quantitative Analysis**

**Student ID : 2016-24500**

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# Ⅰ. Introduction

## 1. Research Background and Objectives

### 1) Research Background

Since Glass researched “gentrification” for the first time in history, (Glass, R., 1964) gentrification has appeared as a main issue for countless urban researches. Most of the conventional research on gentrification have focused on the social aspect of the phenomenon conducted with qualitative methodology. Although qualitative methodologies still have some strengths in analyzing the social aspects, research on gentrification with quantitative methodologies could suggest more solid basis to the research on gentrification, as we could interpret and analyze gentrification with observable data and variables.

Moreover, many theories regarding gentrification and results from qualitative research could be verified with quantitative modeling approach based on urban data acquired from real space. For instance, an impact of public intervention or policies on urban changes in a gentrifying neighborhood (such as increase of housing rent and degree of displacement) could be examined using scientific methodologies.

It is useful to approach gentrification quantitatively by ″modeling urban areas as graphs whose nodes represent the dynamical units, and whose links stand for the interaction between them"[1], which so-called complex network systems in theoretical physics. “Complex systems are very often organized under the form of networks where nodes and edges are embedded in space.”[2]

Likewise, urban form and structure can be considered as spatial network systems. Components such as buildings, roads, transportations systems, and people compose complex "urban network systems" and interact with each other, generating diverse urban activities. (Porta, S., Crucitti, P., Latora, V., 2006; Strano, E., et al., 2013; Goh, S., Choi M., Lee, K., Kim, K., 2016). Gentrification phenomenon, a result from complex combination of numerous urban activities, could also be analyzed and described with the complex systems by viewing neighborhoods as spatial network systems.

Implementing a deductive modeling approach to draw gentrification phenomenon, some assumptions would be supposed to establish the model. Some of them could imply the mechanisms or dynamics by which gentrification occur. Comparing the results of modeling and actual transformations in an urban context, the mechanisms and dynamics assumed in developing the model could be validified whether they could explain the developing process of the complex phenomenon.

Quantitative approaches to analyze and simulate gentrification have appeared after 2000. O'Sullivan (2002) and Torrens and Nara (2006) calculated gentrification quantitatively based on simulation using cellular automata and/or agent automata approach in the spatial context of Salt Lake City in Utah and Hackney in London. They established the models to describe gentrification based on mechanisms

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1) Boccaletti, S., et al., 2006, "Complex networks: Structure and Dynamics", *Physics Reports*, 424(4), 175.

2) Barthelemy, M., 2011, "Spatial networks", *Physics Reports*, 499(1), 1

by which residents make a decision to stay or leave their villages and/or residence.

They considered numerous possible geographical, economical, and social factors and variables that might be related with the gentrification, including characteristics of buildings and residents. They calculated and simulated gentrification numerically based on a "decision making algorithm" and the change of social, economic, and physical characteristics of a neighborhood with time. Those models would describe and analyze complexity of gentrification closely to reality.

However, few research that analyzed gentrification analytically using research methodologies from theoretical physics could be found. By establishing mathematical equations based on mechanisms and dynamics, the process of gentrification could be expressed briefly and intuitively with simple equations containing several variables. With more concise equations and variables, the quantitative analysis using physical methodology would help our understanding on mechanisms and dynamics of complicated gentrification phenomenon more conceptually.

### 2) Research Objectives

In this research, I would assume gentrification as "spreading of reconstructions" by applying the epidemic spreading model. The purpose of this research is to build a model describing the "spreading of constructions" in a bounded gentrifying area.

This research would define some variables and equations representing an aspect of gentrification and develop a analytical model to describe gentrification phenomenon by assuming mechanisms and dynamics derived from theoretical physics of complex systems. In addition, this research aims to introduce and examine new dynamics and mechanisms, "Epidemic Spreading", to describe gentrification, applying the methodology of theoretical physics.

I would define a parameter, derived from the epidemic spreading model, to modeling gentrification instead of using numerous variables. It would indicate the degree of physical transformation in gentrifying areas and make it possible to analyze gentrification more systematically, such as spatial analysis.

These are research questions to be raised for this research, among others: (1) Can theoretical physics of complex systems, especially the epidemic spreading model, describe gentrification phenomenon? (2) How different is the value of parameters among the spatial areas and what factors cause the difference?

## 2. Research Methodology

### 1) Operational Definition of Gentrification


**Diagram 1** An example of application of Epidemic Model to Gentrification

According to earlier researches on gentrification, the phenomenon generally consists of three types of transformations which are physical, social, and economic. When gentrification occurs, all the three changes are observed at the same time. In gentrifying neighborhoods, old buildings and infrastructures are replaced with new ones, some local residents and retailers move to other villages, and the value of real estate properties rises, simultaneously.

In former researches that analyze gentrification quantitatively, they consider a number of factors and variables that might be related with the phenomenon. While previous models would help the understanding of the process of gentrification, the models are so complicated that they do not show the dynamics and mechanisms of gentrification conceptually. To extend our understanding of gentrification more conceptually and intuitively, a new approach with theoretical physics of complex networks could be effective.

Among the various possible approaches to analyze gentrification, this research would focus on the physical aspect of gentrification. Physical transformation can be measured with the demolition and construction of building because in gentrified neighborhoods many buildings are repaired and replaced rapidly. This research assumes that gentrification can be measured with how much and how fast buildings are changed.

One of the questions about gentrification in this research is about the dynamics and mechanisms of gentrification: how the urban change spreads. By applying mechanisms of epidemic spreading to the urban context, this research would define gentrification as the "spreading of building reconstructions" in a bounded neighborhood.

This research is based on the hypothesis that neighboring buildings interact with each other, i.e. when a building in a neighborhood is replaced with a new one, buildings next to that would be pressured to be changed: the development of a building is commonly followed by developments of contiguous buildings, which is caused by attracting visitors and/or new residents and increase of property value.

Based on the reasoning, we can see that the spread of building-constructions are similar with the spread of a kind of epidemic. This research analyzed the gentrification phenomenon with the view of the Epidemic Network Model. In the model, we supposed that, if a building was replaced with a new building, it has been infected with an epidemic virus.

# Ⅱ. Previous Research and Related Theory

## 1. Research on Gentrification

### 1) Qualitative Research

In 1960s, Ruth Glass stated "one by one, many of the working class quarters have been invaded by the middle class - upper and lower ... Once this process of 'gentrification' starts in a district it goes on rapidly until all or most of the working class occupies are displaced and the whole social character of the district is changed"[3].

In traditional research, debate related with gentrification was the causes and the social impact of gentrification. Smith argued capital investments are the prime stimulus of gentrification, which is known as 'structural' theories (Smith, N., 1987). On the other hand, Ley claimed the main cause of gentrification is the increase of the economic status and cultural profile of the middle classes, known as 'agency' theories (Ley, D., 1994).

Researches on social segregation by race and ethnicity (Wyly, E. K. and Hammel, D. J., 2004; Hwang, J. and Sampson, R. J., 2014) and displacement of residence (Atkinson, R., 2000; Newman, K. and Wyly, E. K., 2006; Betancur, J., 2011; Shaw, K. S. and Hagemans, I. W., 2015) have also been the main issues related on gentrification.

Today, Gentrification is not a local issue, but a global agenda in both developed and developing countries. And gentrification has been

3) Glass, R., 1964, *London: Aspects of Change*, London: Centre for Urban Studies.

started to occur in the cities of non European and American regions. (Smith, N., 2002; Janoschka, M., Sequera, J., Salinas, L., 2014)

### 2) Quantitative Research

"There have been some notable achievements in modeling gentrification"[4] from 2000 to analyze the phenomenon quantitatively (O'sullivan, D., 2002; Torrens, P. M. and Nara, A., 2007; Diappi, L. and Bolchi, P., 2008; Sabri, S., M. Ludin, A., Ho, C., 2012).

There has been research on modeling gentrification based on simulation using cellular automata and/or agent automata approach (O'Sullivan, D., 2002; Torrens, P. M. and Nara, A., 2007; Sabri, S., M. Ludin, A., Ho, C., 2012). They established the models to describe gentrification mainly based on mechanisms by which residents make a decision to stay or leave their villages and/or residence.

They considered numerous possible geographical, economical, and social factors and variables that might be related with the gentrification, including characteristics of buildings (building use, price and rent, tenure, vacancy rate, accessibility to amenities etc.) and residents (income level, ethnicity, settled status etc.). They calculated and simulated gentrification numerically based on a "decision making algorithm" and the change of social, economic, and physical characteristics of a neighborhood with time. Those models describe and analyze complexity of gentrification closely to reality.

Most recently, Sabri (2012) researched the modeling New-build gentrification with Multi-Criteria Evaluation and Geographical

4) Sabri, S., M. Ludin, A., Ho, C., 2012, "Conceptual Design for an Integrated Geosimulation and Analytic Network Process (ANP) in Gentrification Appraisal", *Applied Spatial Analysis and Policy*, 5(3), 254.

Automata Systems and confirmed that "land use change from brownfield to residential"[5] can induce New-build gentrification.

Furthermore, there was a research that showed the relationship of urban form and gentrification with an urban morphology approach in London. (Venerandi, A., et al., 2017)

## 2. Complex Networks and Epidemic Model

### 1) Complex and Spatial Networks

#### (1) Basic Concept of Complex Networks

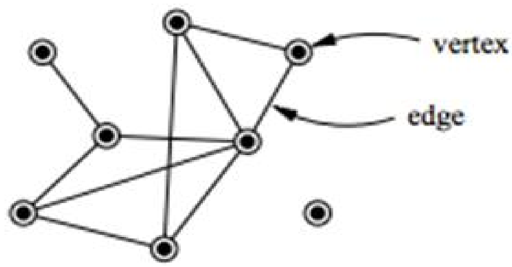


**Diagram 2** An example showing vertices and edges in a network.

Network is a topological object that describes a "connection structure". The topological object means that the network does not depend on geometrical properties such as length, area, volume etc. Network is a graph only depending on a "connection structure" defined by edges between two other vertices. Numerous variables derived from a network are closely related with a "connection

5) Ibid., 256.

structure”.

Generally, the “connection structure” of a network is determined by whether a pair of vertices, which belongs to the network, is connected at an edge. It is notable that the characteristics of the edge through which the two vertices are connected does not reveal any significant meaning about the network. Regardless of the property of the connection (i.e. physical or social, etc), if two networks have same connection structure, they are regarded as a same network in network theory.

Complex Network Theory has been applied to a variety of field of research including transportation networks, infrastructure networks, mobility networks, neural networks,[6] social networks, internet and the World Wide Web, genetic networks[7], etc.

In urban research, the "urban morphology" approach is based on the concept of the complex network system. Some research analyzed the urban street networks with complex network. (Porta, S., Crucitti, P., Latora, V., 2006; Strano, E., et al., 2013)

### (2) Network Systems according to "Connection Structure"

As mentioned above, networks could be categorized by the “connection structure”.

6) Barthelemy, M., 2011, "Spatial Networks", *Physics Reports*, 499(1), p.2

7) Boccaletti S., et al., 2006, "Complex networks: Structure and Dynamics", *Physics Reports*, 424(4), p. 176

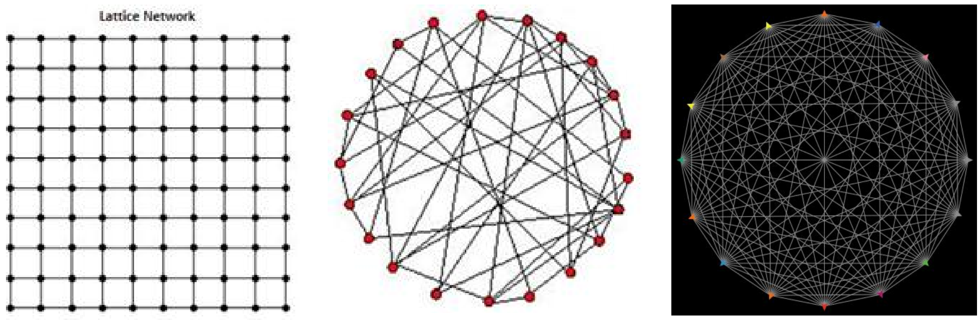


**Diagram 3** Examples for the Lattice Network, Random Network(ER) and All-to-All Network

Firstly, the “Lattice Network” has a regular connection structure. In lattice network, all vertices are arranged in a space regularly and only connected to the nearest vertices by an edge. Thus, all vertices in the lattice network are linked to the same number of edges.

Secondly, the “ER Network” has a connection structure given by a random process. In ER network, whether a pair of two vertices is connected by an edge is determined by probability. The fact that the probability distribution of an edge in the ER network corresponds to the Poisson distribution is well known in the network research.

Finally, the “All-to-all Network” has a connection structure that all pairs of two vertices in the network are connected at an edge. In the all-to-all network, when total number of vertices is “N”, the total number of the edges is given as “N(N+1)/2”.

### 2) Epidemic Model

The “epidemic model” is a physical model that describes a progress of infectious disease. The epidemic models are categorized by the procedure of infection. Especially, whether there is a recovering step in the infectious disease progress is the most important criteria distinguishing among the epidemic models.

Related with the Epidemic model, model for the context of the transmission of infectious diseases (Anderson, R. M. and May, R. M., 1991; Diekmann, O. and Heesterbeek, J. A. P., 2000; Keeling, M. J. and Rohani, P., 2008) was developed by various researches. Network models were applied to explain and predict the pattern of infectious disease transmission. (Keeling, M. J., et al., 2001; Eames, K. T. D. and Keeling, M. J., 2002; Keeling, M. J., and Eames, K. T. D., 2005, Kiss, I. Z., Green, D. M., Kao, R. R., 2005, 2006a, b)

There was an application of the epidemic spreading model to the other domain of research (Kiss, I. Z., et al., 2010). Kiss et al. (2010) suggested a new approach to describe the spread of research topics across disciplines using epidemic models.

In this model, I interpret gentrification as the infection progress. The old buildings correspond to “S” (susceptible state) and the new buildings relevant to “I” (infection state). Based on this relationship between gentrification and the epidemic model, when gentrification is progressed, there would be no step corresponding to the recovering process. As there is no process that new buildings transform back to the old buildings. I selected the “SI” model, which does not consider recovering process, to calculate gentrification.

| Epidemic Model | Existence of Recovering State | Existence of Re-Infection State |
|---|---|---|
| SI | X | X |
| SIS | X | O |
| SIR | O | X |
| SIRS | O | O |

**Table 1** Various epidemic models according to the existence of recovering state and re-infection state

# Ⅲ. Developing a Gentrification Model: Gentrification Epidemic Model

## 1. SI Epidemic Model with All-to-All

### 1) All-to-All Connection Structure

A “connection structure” among land parcels or buildings within a neighborhood can be assumed; we can apply the network theory to analyze gentrification in a village. A building itself corresponds to a vertex in the network. An interaction between two different buildings can be seen as an edge. In the real world, there would be many different types of interaction between two buildings. This research would suggest that all those interactions could be described by an edge in the network theory.

In this research, I would concentrate on small neighborhoods in Seoul where someone can walk from one end to the other on foot in 10 minutes. It is reasonable that all pair of the buildings in a small neighborhood interact with each other. This environmental situation means that a small neighborhood in Seoul has the “connection structure” that all pairs of two vertices (building) are connected by an edge (interaction). It would be exactly same with the “all-to-all network”.

### 2) SI Model with All-to-All

Basically, the “SI” model consists of only one step of the infectious progress. If a “S” individual (susceptible state) interacts with an “I” individual (infected state), the “S” transform to the “I” with an infection rate “A”. Generally, the “SI” model with any connection structure can be described by two differential equations as follows.

$$\frac{dS_i}{dt} = -A\ \Sigma_{j(i)} \frac{S_i I_{j(i)}}{N}\ ;\ \frac{dI_i}{dt} = +A\ \Sigma_{j(i)} \frac{S_{j(i)} I_i}{N}$$

A constant N is the total number of the vertices in a network and the independent variable t means the time. The subscript “i” means that “i”-th vertex in the network and the “j” means that the nearest vertices of the “j”-th vertex. In the all-to-all network, all of the “S” can interact with all of the “I”. With this principle of the all-to-all network, the equation can be expressed as more simple form.

$$\frac{dS_i}{dt} = -A\ \frac{S_i I}{N}\ ;\ \frac{dI_i}{dt} = +A \frac{S I_i}{N} \underset{\Sigma_i}{\Rightarrow} \frac{dS}{dt} = -A\ \frac{SI}{N}\ ;\ \frac{dI}{dt} = +A \frac{SI}{N}$$

By applying the relation (N=S+I) to the differential equations, I could obtain one differential equation given as follow. Finally, by the separation of the variables, I could solve the differential equation as follows. ($I_0$ is the number of infected states at the initial time in the solution.)

$$\frac{dI}{dt} = -A\ \frac{(N-I)I}{N} \quad \Rightarrow \quad \mathrm{I(t)} = \frac{I_0\, e^{At}}{N-I_0+I_0 e^{At}}$$

The solution can be expressed with a variable of “infection rate”.

The small “i” in the solution means the “infection rate”, i.e. the number of infected nodes (I) divided by the number of all nodes (n). Naturally, value of “i” becomes larger as time goes by. ($i_0$ means the initial rate of the infected nodes)

$$i(\mathrm{t}) = \frac{i_0\, e^{At}}{1-i_0+i_0 e^{At}}$$

## 2. Basic Model

This research defines the state of the nodes (or land parcels in the site on gentrification) as two different types of variables: “susceptible” (S) and “infected” (I). An “infected node” means a land parcel where the old building has been replaced with new one. If a land parcel is “infected”, nearby buildings and land parcels are exposed to the “gentrification virus”. Then, the exposed nodes become “susceptible nodes”, which are not infected yet, but become potential “infected nodes”. Sum of the number of “susceptible nodes” and “infected nodes” is constant, which is same with the “number of all nodes in the definite district” (N).

In a small enough area to walk around, it would be reasonable to think that a reconstruction of one building may influence all the land parcels in that district. If interactions between each node are supposed to be all-to-all epidemic network, equations that describe the relation between S and I in an All-to-All SI Epidemic Model are represented by a couple of differential equations below, where G is constant.

$$ds/dt = - G*s*i$$

$$di/dt = + G*s*i$$

Parameter G means the probability of which a susceptible node can be infected, when a susceptible node is exposed by an infected node.

| | i(t) = 10% | i(t) = 20% | i(t) = 50% | i(t) = 80% | i(t) = 90% |
|---|---|---|---|---|---|
| di/dt (yearly) | 1*G | 2*G | 3*G | 2*G | 1*G |

**Table 2** The Number of Reconstructed Buildings (di/dt) is determined by Parameter G, multiplied with a constant: di/dt is maximum with 3 times of Parameter G when infection ratio is 50%.

The solution of the simultaneous differential equation for s and i is shown below. Small "i" in the solution means the "infection ratio", i.e. the number of infected nods (I) divided by the number of all nods (N). Naturally, the value of "i" becomes larger as time goes by as susceptible nodes are exchanged with infected nodes. ($i_0$ means the initial infection ratio at t=0)

$$i(t) = \frac{i_0 e^{Gt}}{1 - i_0 + i_0 e^{Gt}}$$

The constant "G" in the equations and solution represents how fast "gentrification virus" spreads in a neighborhood. A neighborhood with a larger G would be transformed at high speed physically, which could indicate that gentrification occurs in that area. This research define the "parameter G" as an index representing how fast and how much gentrification spreads in a neighborhood and by which I would compare gentrification quantitatively between neighborhoods.

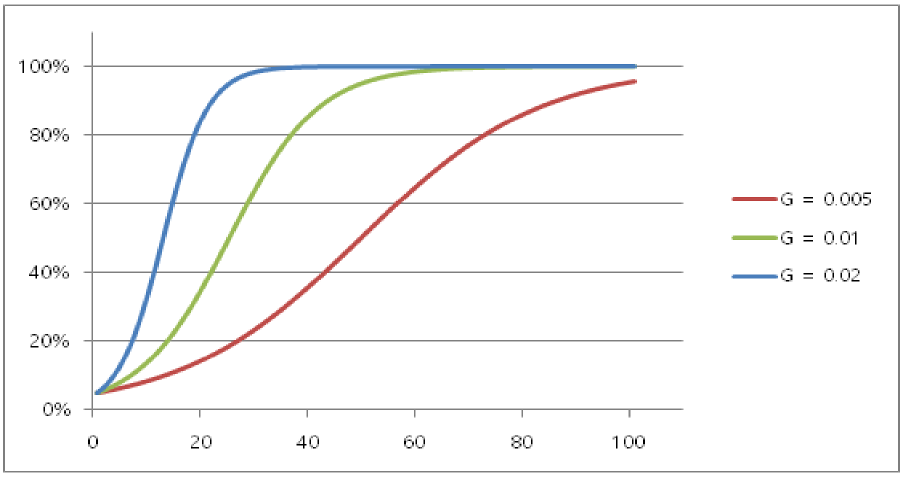


**Diagram 4** An Example for Epidemic Models with various G value (x axis: year, y axis: infection ratio(%))

The number of buildings reconstructed in a neighborhood with 400 buildings can be calculated with parameter G and I, which is [G x i(1-i) x 12 x 400]. For instance, in a neighborhood with 320(S) susceptible buildings and 80(I) infected building among 400(N) of all buildings, infection ratio of the area is 20%. If we assume that the parameter G of the site is 1%, 8 buildings(2% of 400 buildings) are reconstructed yearly commonly.

## 3. Age Model

The assumption of the Basic Model is that all the reconstructions are induced by transmission of the gentrification virus. However, the mechanisms of real building construction are not so simple. Reconstructions in a real urban context can be separated by two types according to the age of demolished building.

Reconstruction of a building can be caused by natural deterioration, as well as gentrification. The "Age Model" was established based on this idea. For Age Model, if a building is demolished and reconstructed when it is "maximum building age", it can be seen as reconstruction by deterioration. In contrast, if a building is demolished and reconstructed before "maximum building age", it would be induced by gentrification.

In this model, a susceptible node can be infected with different two reason, deterioration and gentrification. Two equations for s and i below represent the mechanism of Age Model. The term (A*s) in the equation means the reconstruction by deterioration.

$$ds/dt = - G*s*i - A*s$$

$$di/dt = + G*s*I + A*s$$

An equation below shows the solution of Age Model in terms of i(t).

$$i(t) = \frac{A}{A+G} - \left(\frac{1}{1-i_0} - \frac{G}{A+G}\right)e^{(A+G)t}$$

"Parameter A" means the probability of reconstruction by deterioration among the susceptible buildings and is constant. That is, a constant ratio of susceptible buildings is reconstructed by deterioration. If parameter A is 1% in a neighborhood with 320 susceptible buildings among all the 400 buildings, 3.2 buildings (1% x 320) are reconstructed by deterioration yearly.

## 4. Economic Boom Model

A Diagram below shows the reconstruction rate of 3 sites in Seoul (Bong Cheon, Hong Dae, and Garosu Gil) drawn from actual data. From 2001 to 2004, increase of reconstruction graphs was very steep. To establish a model describing the data accurately, this steep increase should be reflected on the model.

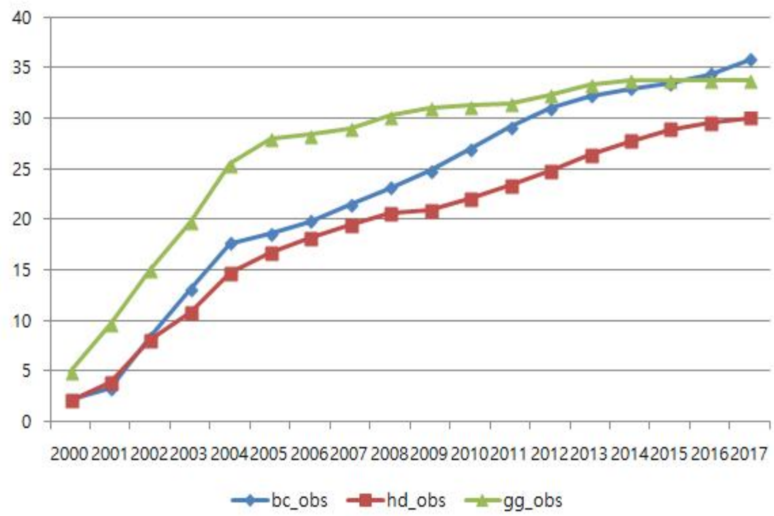


**Diagram 5** Reconstruction Ratio of 3 sites from actual data

This period of 4 years, from 2001 to 2004, can be regarded as economically booming periods, especially in the building construction market. The assumption can be confirmed by a graph below representing the trend of Housing Price Index (HPI), normalized by setting housing price in 2005 as 100. In the diagram below, housing price increased largely in that period from 2001 to 2004. The rise of real estate market of housing could have facilitated the reconstruction of buildings in Seoul during this period.

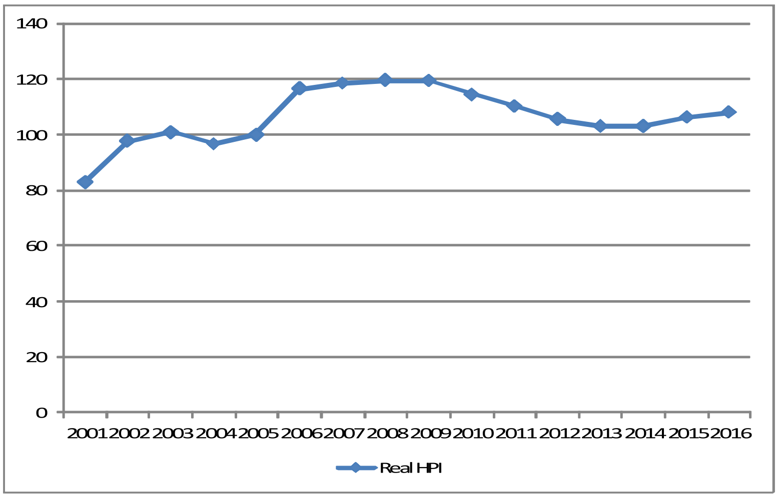


**Diagram 6** Real Housing Price Index of Seoul

Impact of economic boom on reconstructions can be represented with "Dirac Delta Function" in the differential equations. The delta function δ(x) is a mathematical function which has function value for infinity when variable x is 0 and 0 elsewhere. The other property of delta function is that integration result of the function is 1. The two characteristics can be expressed into two equations below.

(1) $\delta(x) = \begin{cases} 0, & \text{if } x \neq 0 \\ \infty, & \text{if } x = 0 \end{cases}$ (2) $\int_{-\infty}^{\infty} \delta(x)dx = 1$

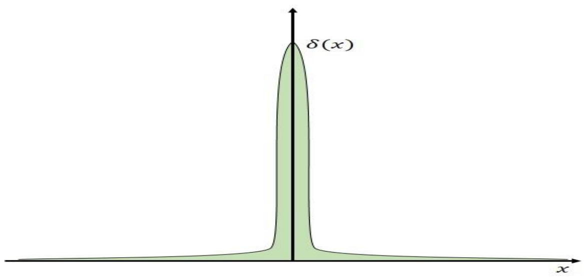


**Diagram 7** Dirac Delta Function

"Dirac Delta Function" can be applied to describe "short economic shock" during the booming periods. Four delta functions, d(2001), d(2002), d(2003), and d(2004), in equations for Economic Boom Model below represent the economic shock for each year. The coefficient of delta function, parameter E, becomes the degree of reconstruction increase by economic booming for each year, as delta function becomes 1 if integrated.

ds/dt = - G*s*i - E[d(2001) +d(2002) +d(2003) +d(2004)]

di/dt = + G*s*i + E[d(2001) + d(2002) + d(2003) + d(2004)]

The solution i(t) of Economic Boom Model is shown below.

$$i(t) = \frac{i_0 e^{Gt}}{1 - i_0 + i_0 e^{Gt}} \qquad \text{when } t < 2001$$

$$i(t) = \frac{i_0 e^{Gt}}{1 - i_0 + i_0 e^{Gt}} + E \qquad \text{when } t = 2001$$

$$i(t) = \frac{i_0 e^{Gt}}{1 - i_0 + i_0 e^{Gt}} + 2E \qquad \text{when } t = 2002$$

$$i(t) = \frac{i_0 e^{Gt}}{1 - i_0 + i_0 e^{Gt}} + 3E \qquad \text{when } t = 2003$$

$$i(t) = \frac{i_0 e^{Gt}}{1 - i_0 + i_0 e^{Gt}} + 4E \qquad \text{when } t > 2003$$

## 5. Integrated Model

The Integrated Model is formed by aggregating all the three factors considered in former models, which are Spreading, Age, and Economic Boom. Equations and the Solution of Integrated Model are shown below.

ds/dt = - G*s*i - A*s - E[d(2001) +d(2002) +d(2003) +d(2004)]

di/dt = + G*s*i + A*s + E[d(2001) + d(2002) + d(2003) + d(2004)]

$$i(t) = \frac{A}{A+G} - (\frac{1}{1-i_0} - \frac{G}{A+G})e^{(A+G)t} \quad \text{when t} < 2001$$

$$i(t) = \frac{A}{A+G} - (\frac{1}{1-i_0} - \frac{G}{A+G})e^{(A+G)t} + E \quad \text{when t} = 2001$$

$$i(t) = \frac{A}{A+G} - (\frac{1}{1-i_0} - \frac{G}{A+G})e^{(A+G)t} + 2E \quad \text{when t} = 2002$$

$$i(t) = \frac{A}{A+G} - (\frac{1}{1-i_0} - \frac{G}{A+G})e^{(A+G)t} + 3E \quad \text{when t} = 2003$$

$$i(t) = \frac{A}{A+G} - (\frac{1}{1-i_0} - \frac{G}{A+G})e^{(A+G)t} + 4E \quad \text{when t} > 2003$$

In summary, Gentrification Models in this research consist of three factors, Spreading, Age, and Economic Boom, and are sorted to four types of model according to the combination of the three factors.

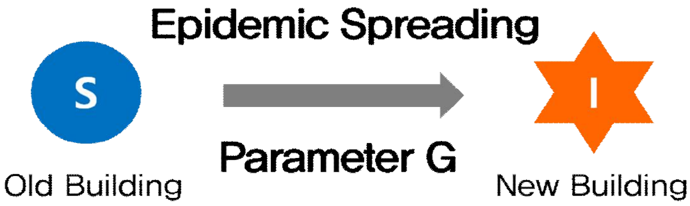


**Diagram 8** A diagram representing reconstruction by epidemic spreading

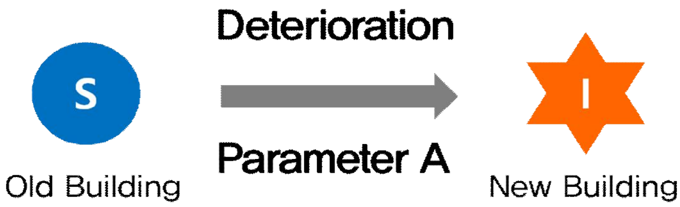


**Diagram 9** A diagram representing reconstruction by deterioration

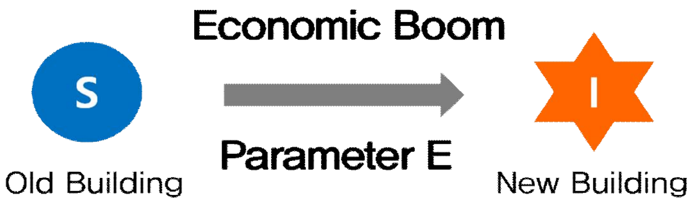


**Diagram 10** A diagram representing reconstruction by economic boom

| Factor | Representation in Equations | Parameter |
|---|---|---|
| Spreading | G*s*i | G |
| Age | A*s | A |
| Economic Boom | E*[d(2001)+d(2002)+d(2003)+d(2004)] | E |

**Table 3** The 3 factors composing Gentrification Model

| Model | Equation | Parameters |
|---|---|---|
| Basic Model | Spreading | G |
| Age Model | Spreading + Age | G, A |
| Econ. Boom Model | Spreading + Econ. Boom | G, E |
| Integrated Model | Spreading + Age + Econ. Boom | G, A, E |

**Table 4** Concept of 4 Gentrification Models according to the combination of 3 factors

# Ⅳ. Applying the Model to 3 sites

## 1. Site Overview

### 1) Criteria for Site Selection

Due to some social issues, employment and marriage becomes more and more difficult in Seoul, the number of single households has been increasing for recent years, especially in the case of young generations. Today, single households comprise the highest rate among the types of household in terms of the number of person in Seoul.

In the City of Seoul, one of the areas where young single households are concentrated is Gwanak-gu. A lot of facilities and services for young people such as universities (Seoul National University, Soongsil University, etc.) and private education are located in Gwanak-gu. Moreover, two advantages of Gwanak-gu-(1) good accessibility to the “Gangnam Business District” by subway stations and (2) relatively low housing rent- attract many young office workers.

To satisfy the increasing demand on the housing for single households, plenty of residential buildings are constructed by private developers. Most of the buildings are high rise compared to the existing residential and commercial buildings. Therefore, there can be some possibilities that gentrification occurs in the area. For this reason, I selected a district within Gwanak-gu for modeling gentrification as “Bong-Cheon” site.

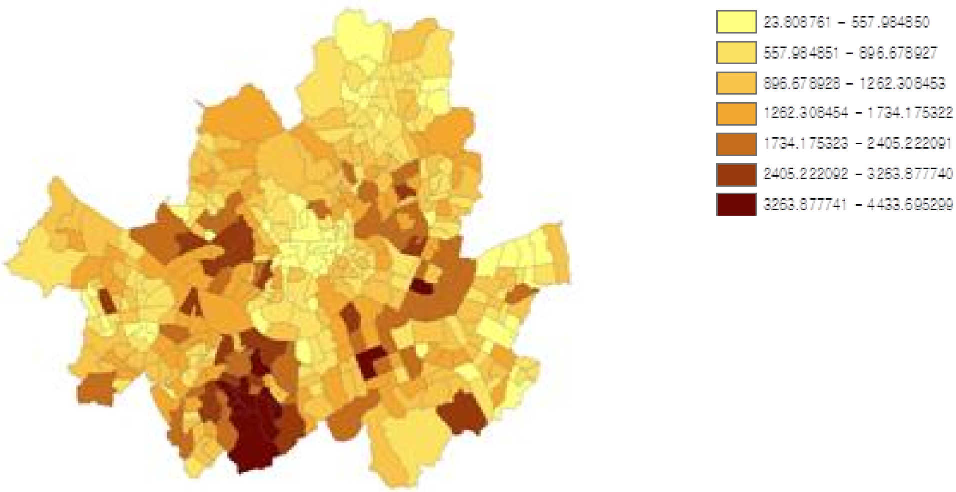


**Diagram 11** A Distribution of Young (20~30s) Single-Housing Units in Seoul (2015): dark brown areas represent the high density of young single-housing units. (Data Source: 2010, 2015 Census Data by Statistics Korea)

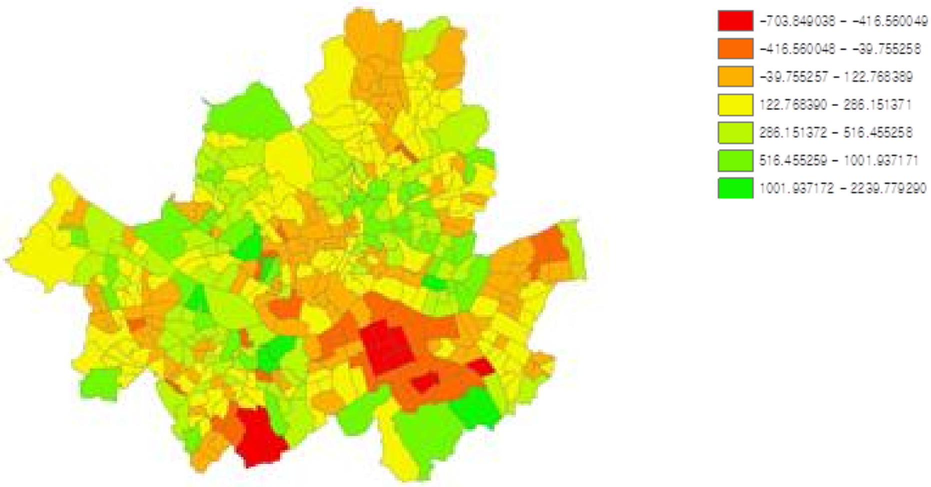


**Diagram 12** A Distribution for the Change of Young (20~30s) Single-Housing Units in Seoul (between 2010 and 2015): the number of single-housing units decreased in red areas and increased in green areas. (Data Source: 2010, 2015 Census Data by Statistics Korea)

In addition to “Bong-Cheon” site, I selected other two sites, “Hong-Dae” and “Garosu-gil,” well-known areas for the gentrified neighborhoods in Seoul. I selected the two sites additionally to verify the gentrification model and compare the results of modeling with that of “Bong-Cheon” site.


**Diagram 13** Three Areas in Seoul for Modeling Gentrification

## 2) Bong Cheon

“Bong-Cheon” site is located between the Seoul National University subway station and Bong-Cheon subway station. The land use for the site is manly quasi-residential, and partially commercial. Diagrams below show the location and building distribution by age and Floor Area Ratio(FAR) for the site.


**Diagram 14** "Bong-Cheon" site is located between the two subway stations of line number 2-Seoul National University (Gwanak-Gu Office) Station and Bong-Cheon Station. (Source of Map: http://map.daum.net)

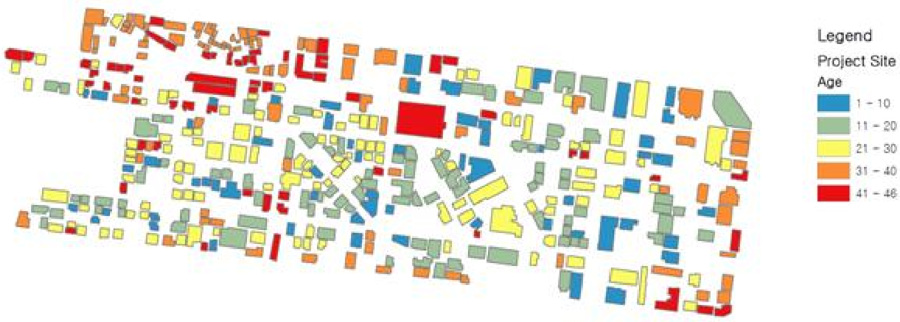


**Diagram 15** "Bong-Cheon" site: Age Distribution for the buildings (Data Source: Information for the buildings from Korea National Spatial Data Infrastructure Portal)


**Diagram 16** “Bong-Cheon” site: Floor Area Ratio Distribution for the buildings (Data Source: Information for the buildings from Korea National Spatial Data Infrastructure Portal)

### 3) Hong Dae

“Hong-Dae” site is located between Hongik University subway station and Hapjeong subway station. The land use for the site is manly general residential 2, partially general residential 3 and commercial. Diagrams below show the location and building distribution by age and FAR for the site.


**Diagram 17** “Hong-Dae” site is located between Hongik University subway station and Hapjeong subway station (Source of Map: http://map.daum.net)


**Diagram 18** “Hong Dae” site: Age Distribution for the buildings (Data Source: Information for the buildings from Korea National Spatial Data Infrastructure Portal)


**Diagram 19** “Hong Dae” site: Floor Area Ratio Distribution for the buildings (Data Source: Information for the buildings from Korea National Spatial Data Infrastructure Portal)

## 4) Garosu Gil

“Garosu-gil” site is located near to the Sinsa subway station. The land use for the site is manly general residential 2, partially general residential 3 and commercial. Diagrams below show the location and building distribution by age and FAR for the site.


**Diagram 20** "Garosu-gil" site is located near to Sinsa subway station (Source of Map: http://map.daum.net)

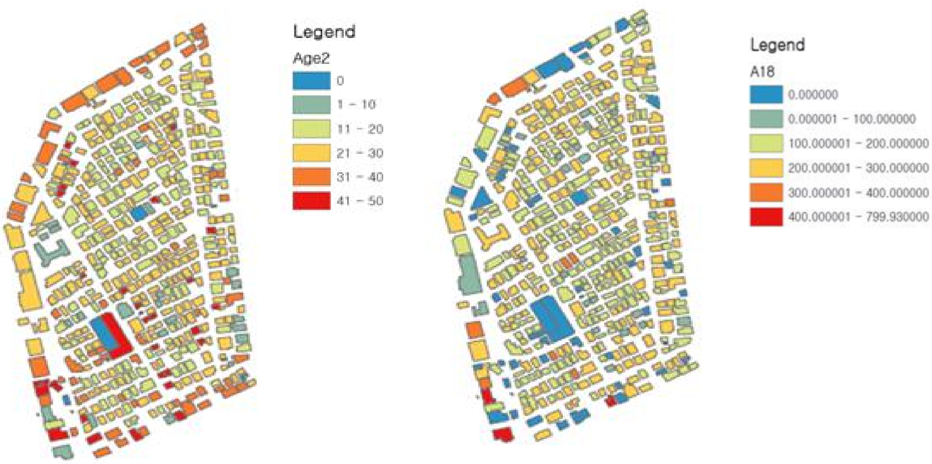


**Diagram 21** "Garosu-gil" site: Age and FAR Distribution for the buildings (Data Source: Information for the buildings from Korea National Spatial Data Infrastructure Portal)

### 5) Floor Area Ratio of New Buildings

For the "Bong-Cheon" site, I drew a graph showing the floor area ratio (FAR) of new buildings in terms of the date when each building was approved of use by local government. I found that, after the year of 1998 when the site was designated as the "Urban Design District" and land use was changed, the FAR of new buildings increased. While FAR of most new buildings had been between 100~200% before 1998, from that year FAR of new buildings have risen up to 200~400%. For this reason, I viewed that "gentrification virus" invaded the "Bong-Cheon" site in 1998. The buildings constructed from 1998 would be considered as "infected".

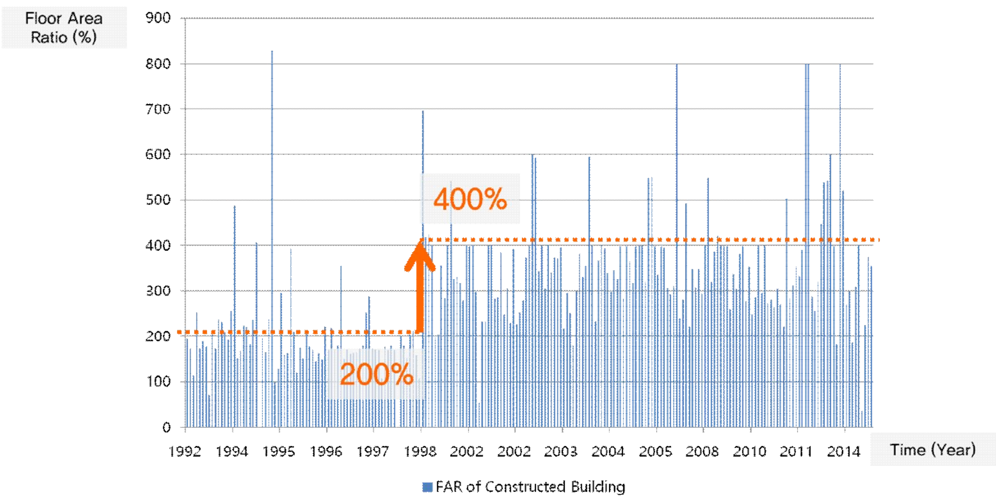


**Diagram 22** FAR(%) of constructed buildings in Bong-Cheon site from 1992 to 2016

## 2. Establishing Basic Settings

From 1998 to 2016, I calculated value of parameter G for Basic model and Age Model of each year. I found that, from 1998 to 2004, the G value fluctuates with large deviation and, from 2005, G value has been settled in all the three sites in Basic Model.

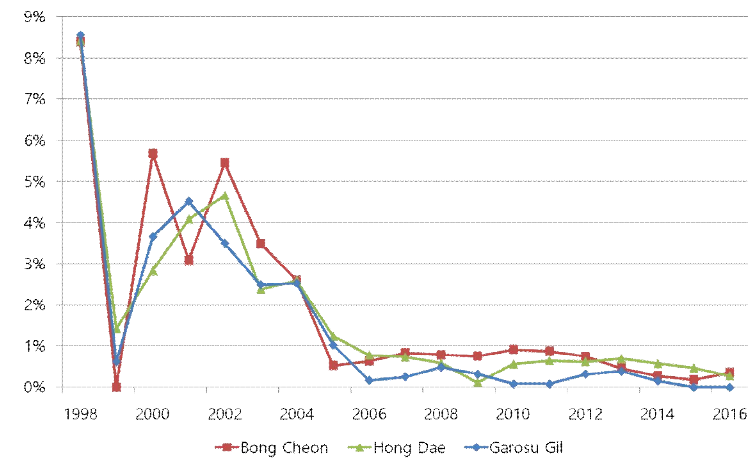


그림 23 Parameter G for each year: Basic Model

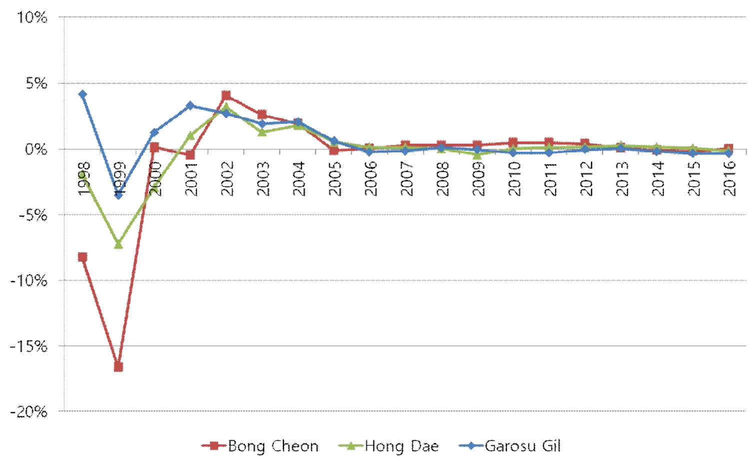


그림 24 Parameter G of each year: Age Model

In Age Model, Parameter G fluctuate smaller than Basic Model. But, in the first two year of 1998 and 1999, parameter G deviated largely in the two models all. It is because in 1998 and 1999, South Korea underwent a serious economic crisis. As the first two years are cases of extraordinary circumstances, I calculated the parameter G except 1998 and 1999.

In order to calculate the "parameter G" of the Age Model and Integrated Model, "parameter A" should be defined first. This research would assume that age of buildings are uniformly distributed in a neighborhood and it was checked by real GIS data (see diagram 15, 18, 21). Then, the number of reconstruction by deterioration is almost same with the number of oldest buildings, because oldest buildings would be reconstructed by deterioration earliest. Thus, I defined the parameter A (ratio of reconstruction by deterioration monthly) with [ 1/ maximum age/ 12 ] (%).

The age of the oldest building among three sites is 60 years old in Hong Dae. As three sites are gentrified neighborhood, maximum age of building to be reconstructed by deterioration would be bigger that 60 years. Thus, in modeling, I assumed the maximum age with 70 years in all three sites.

The value of Parameter A is same in three sites, with 0.12%, because the reconstruction by deterioration would not be various with site, but related with the characteristics of buildings and, having been developed in almost same periods, buildings in the three sites share similar structural characteristics.

I calculated the parameter G in the Basic Model and Age Model by averaging from 2000 to 2016. In the Economic Boom and Integrated Model, parameter G and E were calculated simultaneously to make a model having the least deviation from the actual with python.

Before implementing the model, the modeling results for parameter G and E could be expected from observed data of reconstruction ratio. Parameter E is related with the increase of reconstruction ratio from 2001 to 2004, the period considered as economic boom.

Steepness of the graph in that period becomes the value of Parameter E. Therefore, expected results for Parameter E would be Garosu Gil>Bong Cheon>Hong Dae.

Likewise, Parameter G would be related with the increase of reconstruction ratio from 2005 to 2016. Steepness of the graph in that period becomes the value of Parameter G. As a result, expected results for Parameter G would be Bong Cheon>Hong Dae>Garosu Gil.

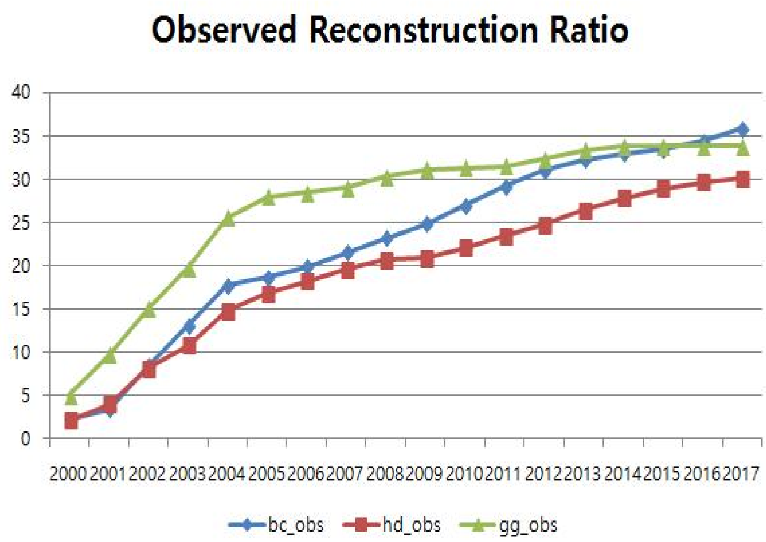


**Diagram 25** Observed Reconstruction Ratio in 3 Sites

## 3. Modeling Result

### 1) Results of Parameter G and E

Modeling results of Parameter G and Parameter E for 3 sites in terms of the 4 models can be seen as below.

|  | Basic Model | Age Model | Economic Boom Model | Integrated Model |
|---|---|---|---|---|
| Bong Cheon | **1.6%** | 0.59% | 1.2% | **0.20%** |
| Hong Dae | **1.4%** | 0.31% | 1.2% | **0.01%** |
| Garosu Gil | **1.2%** | 0.58% | 0.6% | **-0.42%** |

**Table 5** Modeling Result: Parameter G for each model in 3 sites

|  | Basic Model | Age Model | Economic Boom Model | Integrated Model |
|---|---|---|---|---|
| Bong Cheon | N/A | N/A | **3.5%** | **2.3%** |
| Hong Dae | N/A | N/A | **3.3%** | **1.8%** |
| Garosu Gil | N/A | N/A | **5.2%** | **4.3%** |

**Table 6** Modeling Result: Parameter E for each model in 3 sites

Results of modeling for Parameter G, especially calculated from Integrated Model and Basic Model, correspond to the hypothesis well (Parameter G: Bong Cheon>Hong Dae>Garosu Gil). It means that reconstruction of buildings has spread most rapidly in Bong Cheon among the 3 sites. The result might be attributed to the land use c hange at Bong Cheon in 1998.

Negative number of Parameter G of Garosu Gil in Integrated Model means buildings were developed in a rate less slowly than the rate of reconstructions induced by deterioration. It seems due to the fact that transformations in Garosu Gil have occurred by remodeling the existing buildings far from reconstructions.

On the other hand, results of modeling for values of Parameter E calculated from Integrated Model and Economic Boom Model, correspond to the hypothesis well (Parameter E: Garosu Gil>Bong Cheon>Hong Dae). It means reconstructions were most brisk in Garosu Gil from 2001 to 2004.

The next four diagrams below show the graphs for reconstruction ratio comparing the actual data and the expected values by each model.

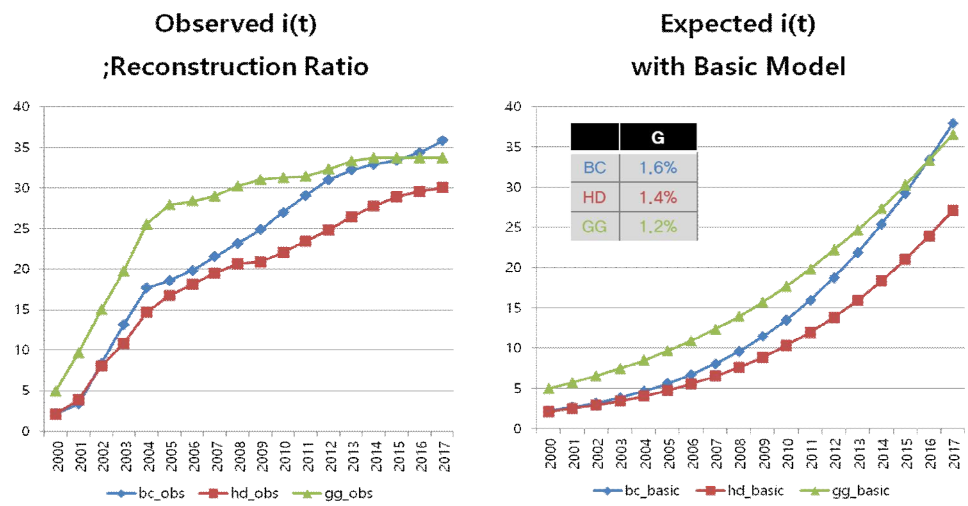


**Diagram 26** Reconstruction Ratio: Observed data vs. Basic Model

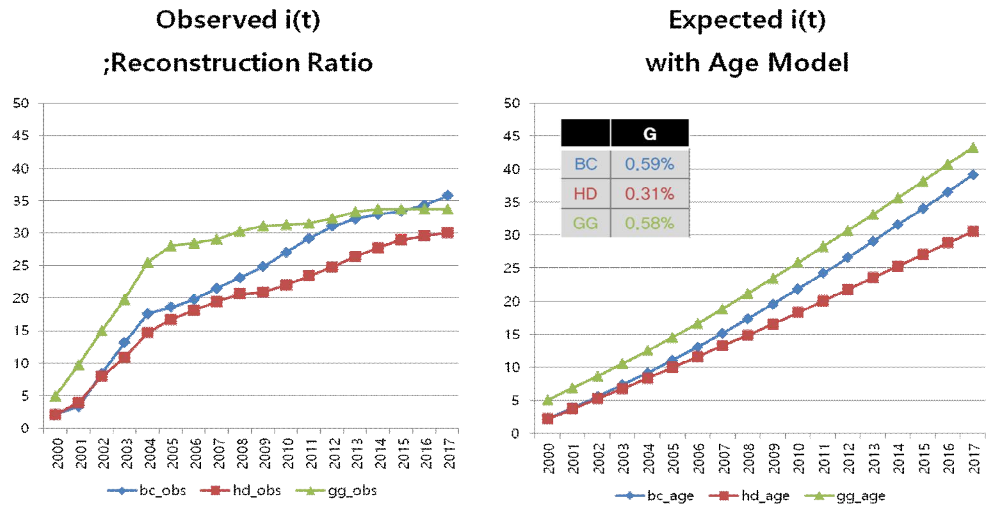


**Diagram 27** Reconstruction Ratio: Observed data vs. Age Model

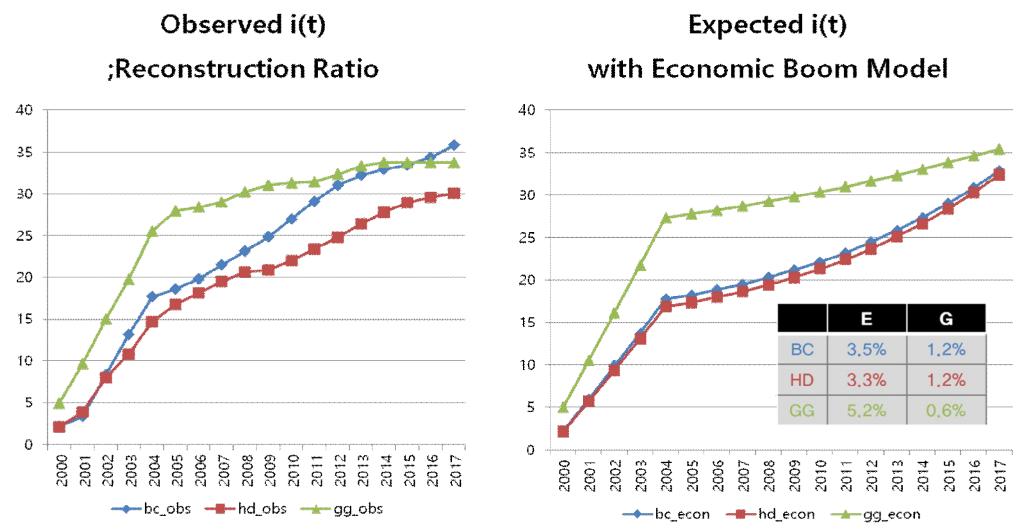


**Diagram 28** Reconstruction Ratio: Observed data vs. Economic Boom Model

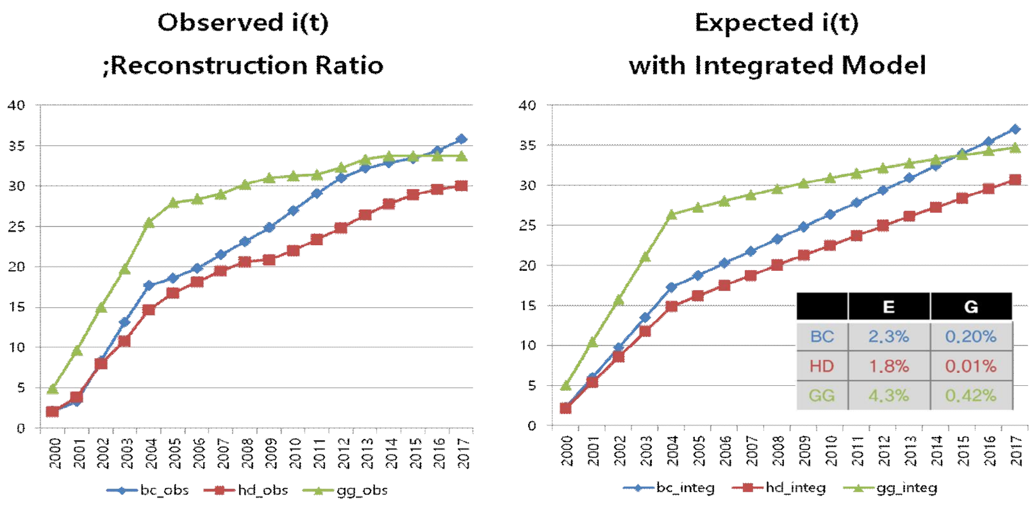


**Diagram 29** Reconstruction Ratio: Observed data vs. Integrated Model

## 2) Model Testing

I used two indicators for the model testing, which are Root Mean Square Deviation (RMSD) and Mean Absolute Percentage Error (MAPE) (Demetriou, D., 2016). RMSD and MAPE are tools for testing model by calculating error between observed values and expected values. RMSD shows the size of error only, but MAPE shows the size of error relative to size of data, which is relative error by percentage(%).

$$RMSD = \sqrt{\sum_i \frac{(E_i - A_i)^2}{n}}$$

$$MAPE = \frac{100\%}{n} \sum_i \left| \frac{A_i - E_i}{A_i} \right|$$

($A_i$: Observed Value, $E_i$: Expected Value)

| | Basic Model | Age Model | Economic Boom Model | Integrated Model |
|---|---|---|---|---|
| Bong-Cheon | 10.2% | 4.8% | 3.7% | 1.0% |
| Hong-Dae | 9.6% | 4.1% | 1.3% | 0.6% |
| Garosu-gil | 11.8% | 7.7% | 1.0% | 0.7% |

**Table 7** Model Testing: RMSD of each model in 3 sites

| | Basic Model | Age Model | Economic Boom Model | Integrated Model |
|---|---|---|---|---|
| Bong-Cheon | 41.7% | 21.1% | 15.3% | 7.7% |
| Hong-Dae | 47.1% | 19.9% | 8.3% | 4.8% |
| Garosu-gil | 38.5% | 25.2% | 3.5% | 2.5% |

**Table 8** Model Testing: MAPE of each model in 3 sites

When value of RMSD or MAPE is large, it means that the error is also large. Values of RMSD and MAPE were the least at Integrated Model in all of 3 sites. It means Integrated Model has the least deviation from actual data and is the most valid model. Except for Integrated Model, Economic Boom has the least error followed by Age Model and Basic Model.

In particular, values of MAPE in Integrated Model were less than 8% in all of the 3 sites (Bong Cheon: 7.7%, Hong Dae: 4.8%, Garosu Gil: 2.5%). By considering two factors, Age factor and Economic Boom factor, modeling could be more articulated to describe the reconstruction ratio quite close to actual data.

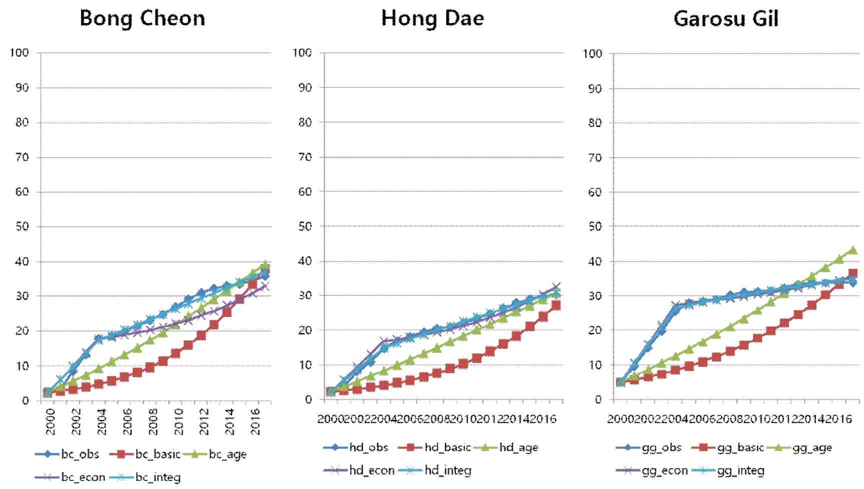


**Diagram 30** Reconstruction Ratio: A Comparison between actual data and 4 models

### 3) Prediction of Reconstruction Ratio

With the results of parameter G and E, I calculated the future trend of reconstruction ratio in the three sites from Integrated Model.

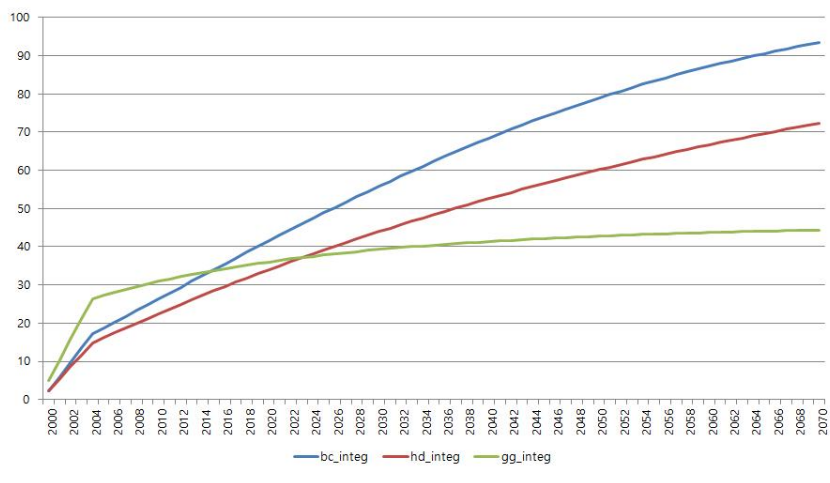


**Diagram 31** Prediction of Reconstruction Ratio: from Integrated Model

This prediction is based on the ground that parameter G would be constant, excluding other external economic effects.

Buildings in Bong Cheon where Parameter G is the largest is predicted to be most rapidly reconstructed, 70% of buildings being predicted to be reconstructed by 2040. Garosu Gil with smallest G is expected to be changed most slowly, 40% of buildings being predicted to be reconstructed by 2040. 50% of Buildings in Hong Dae are expected to be reconstructed for the same time period.

## 4. Parameter G and Housing Price

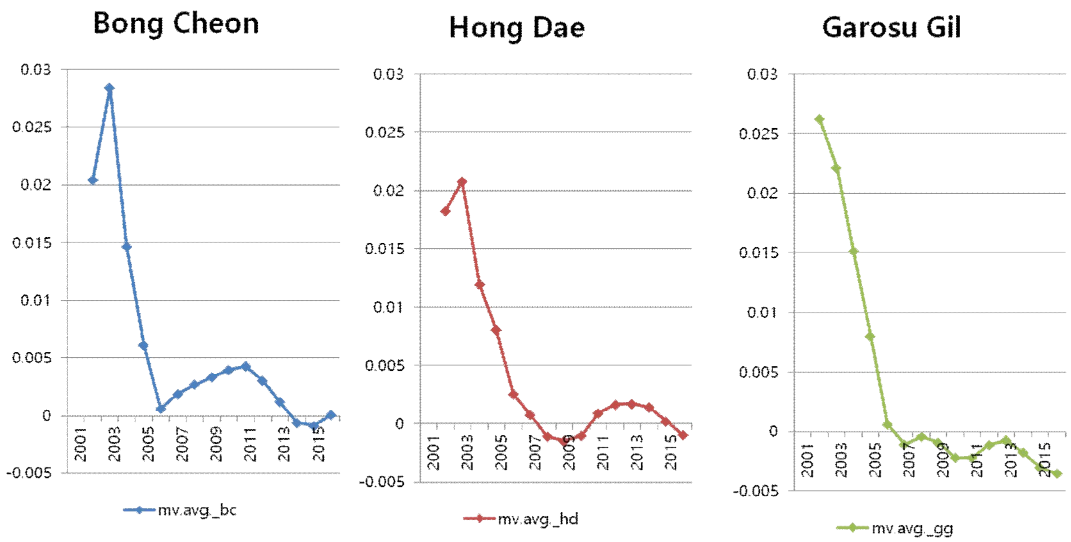


**Diagram 32** Parameter G by year in 3 sites

The similarity of the trend of the “G value” within the three sites, as appeared in diagram 32, seems to result from the mechanism where the “G value” is affected by the macroscopic state of the real estate market. From 2001 to 2004, the period marked by economic prosperity, parameter G is relatively large in all three sites. After this particular time frame, parameter G has been settled generally, which means reconstruction of buildings has been stabilized from 2004.

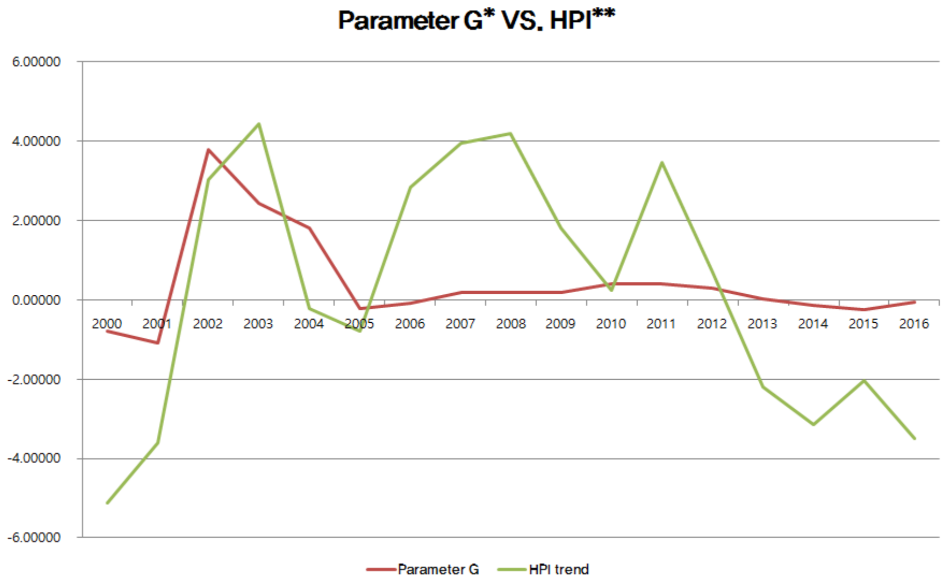


**Diagram 33** Parameter G and HPI Trend (*Parameter G: 100 times of original value, **HPI: Original value - expected value of regression line)

The similarity of parameter G imply the relationship of parameter G and the housing price. Parameter G can be compared with an index representing the real estate market, Housing Price Index (HPI)[8]. HPI is an index that aggregate the price of housings to show the ups and downs of the housing price in the macroscopic housing market, reported by KB.

Diagram 33 shows the parameter G and HPI trend from 2000 to 2016. Signs of the values for G and HPI are synchronizing in that period from the diagram. This result suggests that parameter G is associated with the economic trend of housing market.

8) Data Source: KB Housing Price Index

# Ⅴ. Conclusion

## 1. Summary and Implications

This research developed a new model to describe the gentrification with the epidemic spreading model of complex systems network. The model suggests an integrated parameter G to describe the physical aspect of the gentrification phenomenon by adopting a mechanism by which an epidemic virus spreads. This model proposes a new approach in order to understand the gentrification phenomena more intuitively and conceptually.

To make the concise model, this research concentrated on the physical transformation of buildings in the bounded gentrifying areas. Neighborhoods with numerous land parcels and buildings were examined as a network system in which the buildings are connected and interact with each other.

In the case study for the three sites (Bong-Cheon, Hong-Dae, and Garosu-gil), I analyzed and described the physical transformation in these neighborhoods with the All-to-All SI epidemic model. From the results, it is possible to observe that buildings in a neighborhood interact with each other and they form an all-to-all epidemic network, especially SI model.

To establish a model to expect the reconstruction ratio of buildings, the model could be more articulated by considering two more factors, 1) reconstructions by deterioration and 2) economic boom, on top of mechanisms of Epidemic Spreading.

I defined an integrated parameter G as an index which indicate the gentrification. According to the model, physical transformation of buildings in a neighborhood can be represented by a “parameter G” and the spreading speed of “gentrification virus” is determined by the value of “G”. The “gentrification virus” spreads more rapidly in a neighborhood with a larger “G value”.

Bong Cheon where land use was changed in 1998 has the largest Parameter G. This result verifies the theory that land use change can accelerate the reconstruction of buildings. The rapid reconstruction can lead to the increase of housing price and housing rent, followed by the displacement of residents in the sites. Public interventions to prevent the gentrification are required to the area whose land use is changed, especially whose limit of FAR has been increased.

For the sites where reconstruction of housing and "officetel" is activated like Bong Cheon, more careful interventions by local government are required. For example, strong financial and taxation incentives could be provided to the private developers to induce them to supply affordable housing or "share house" in gentrifying areas.

## 2. Issues for Further Research

This research proposed a new perspective to understand gentrification by applying the complex network of theoretical physics. I established a concise model with the SI Epidemic Model. This model can be further improved to describe the gentrification more precisely by considering other possible factors.

Physical model for gentrification in this research can be integrated with other factors of gentrification like the increase of property values, or the degree of displacement. This would describe gentrification more synthetically.

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국문 초록

# 전염병 확산 모델을 활용한 젠트리피케이션 모델링 연구

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1964년에 Glass가 역사상 처음으로 젠트리피케이션이라는 용어를 사용한 이래로, 젠트리피케이션에 관한 기존 연구는 대부분 질적 연구 방법론을 활용하여 젠트리피케이션의 사회적 측면을 분석하는데 초점을 맞추어왔다. 질적 연구 방법론이 여러 가지 장점을 가지고 있음에도 불구하고, 정량적인 방법론을 활용한 연구는 실제 도시 데이터를 활용함으로써 기존 젠트리피케이션 연구에 보다 견고한 기반을 제공해 줄 것으로 기대된다.

도시 내에 건물, 도로, 교통 시스템, 사람들과 같은 구성 요소들은 복잡한 "도시 네트워크 시스템"을 구성하고, 서로 상호 작용하면서 도시 내에서 다양한 활동들을 만들어낸다. 도시의 형태와 구조는 "결절점(nodes)이 동적 단위(dynamical unit)를 나타내고, 선(edges)이 결절점 사이의 상호 작용을 나타내는“ 공간상의 네트워크 시스템으로 간주 할 수 있다.

이와 마찬가지로, 젠트리피케이션 현상도, 하나의 마을을 네트워크 시스템으로 간주함으로써, 복잡한 활동이 결합된 현상을 직관적으로 분석할

수 있다.

젠트리피케이션을 정량적으로 분석한 연구는 2000 년 이후에 등장하기 시작했다. 기존의 연구는 젠트리피케이션과 관련된 수많은 지리적, 경제적, 사회적 요인을 고려하였다. 그중 일부는 "의사 결정 알고리즘"을 적용하여, 마을의 사회적, 경제적, 물리적 특성의 시간에 따른 변화를 수치적으로 계산하고 예측하는 모델을 구축하였다.

그러나, 이론 물리학의 연구 방법론을 사용하여, 젠트리피케이션 현상을 분석 한 연구는 찾아 볼 수 없었다. 물리학적 방법론은 좀 더 간결한 방정식과 변수를 사용함으로써, 복잡한 젠트리피케이션 현상의 메커니즘을 개념화하고 직관적으로 이해하는데 도움을 줄 수 있다.

본 연구는 젠트리피케이션 현상의 여러 측면 중에서 물리적 변화에 초점을 맞추었다. 젠트리피케이션이 일어나는 지역에서는 재건축이 활발한 경우가 많기 때문에, 건물의 철거와 신축의 정도를 측정하여 마을의 물리적 변화를 수치화 할 수 있다.

본 연구는 이웃한 건물들끼리 서로 상호 작용한다는 가정을 기초로 연구를 수행하였다. 어떤 지역의 건물이 활발히 재건축되면, 이는 그 지역에 외부인이나 신규 거주자를 끌어들이는 요인이 되며, 따라서 부동산 가격의 상승을 유도하기도 한다. 이는 결국 주변 건물을 재건축 압박에 노출시키게 된다.

본 연구는 전염병 확산 모형을 적용하여, 젠트리피케이션 현상을 "재건축의 확산" 으로 조작적으로 정의하였다. 본 연구의 목적은 경계가 정해진 지역 내에서 일어나는 "재건축의 확산"을 묘사하는 모델을 구축하는 것이다.

젠트리피케이션을 전엽병 확산 과정으로 이해하였을 때, 오래된 건물은 "S"(면역력이 있는 상태)에 해당하고 새 건물은 "I"(감염 상태)로 표현된다. 젠트리피케이션이 일어나는 과정에서는 전염병 모델의 회복 과정에 대응하는 단계가 없다. 왜냐하면 새로운 건물이 오래된 건물로 되돌아가는 과정이 없기 때문이다. 다양한 전염병 모델 중에서 본 연구는 젠트리피케이션을 설명하는 모델로서 회복 과정을 고려하지 않는 "SI" 모델을

선택하였다.

젠트리피케이션 모델을 설명하는 방정식은 세 개의 항으로 구성된다. 전염병 확산 메커니즘 뿐 아니라, 건물 재건축에 영향을 미치는 다른 두 가지 요인(건물 노후화, 거시 경제 상황)을 도입하였다. 세 요소의 조합에 따라 네 가지 젠트리피케이션 모델(기본 모델, 연령 모델, 경제적 호황 모델, 통합 모델)을 도입하였다.

본 모델은 상업화 젠트리피케이션이 일어나는 서울시 내 세 주거 지역(봉천, 홍대입구, 가로수길)에 적용되었다. 이 지역들은 400-500 개의 건물로 구성되어 있고, 지역 내에서 걸어서 이동할 수 있는 지역이다.

모델링 결과에 따르면, 1998 년에 토지 용도가 변경된 봉천 지역에서 건물 재건축이 가장 빠르게 확산되었다. 반면에 주로 기존 건물을 리모델링하여 젠트리피케이션이 일어난 가로수길은 건물 노후로 인해 재건축되는 속도 보다 느리게 재건축이 확산되었다. 반면, 경제적 호황기였던, 2001년부터 2004년까지는 가로수길에서 건물 재건축이 가장 활발히 진행되었다.

모델의 정확성을 검증하기 위해 두 가지 지표(RMSD, MAPE)를 사용하였다. 모델 테스팅 결과, Age 요소와 Economic Boom 요소를 고려함으로써, 기본 모델보다 실제 데이터를 더 정확하게 예측하는 모델을 구축할 수 있음을 확인할 수 있었다. 특히 통합 모델에서는 세 사이트에서 모두 MAPE 의 값이 8 % 미만이었고 (봉천: 7.7 %, 홍대: 4.8 %, 가로수길: 2.5 %), RMSD 의 값은 1 % 이하였다. (봉천: 1.0 %, 홍대: 0.6 %, 가로수길: 0.7 %).

통합 모델을 활용하여 미래 재건축 추세를 예측한 결과, 매개 변수 G 의 값이 가장 큰 봉천 사이트에서 건물이 가장 빠르게 재건축 될 것으로 예상되었다. 2040년까지 봉천 사이트 건물의 70%가 재건축 될 것으로 예측된다. 같은 기간 동안, G의 값이 가장 작은 가로수길 사이트에서는 건물의 40%, 홍대 사이트는 건물의 50 %가 재건축 될 것으로 예상된다.

매개 변수 G의 시간에 따른 변화를 계산했을 때, 세 사이트에서 유사한 추세를 가지는 것을 확인하였다. 이러한 현상은 매개 변수 G와 부동산

시장 상황과의 상관관계를 암시한다. 두 변수간의 상관관계는 매개 변수 G와 서울의 주택 가격 지수의 추세를 비교함으로써 확인할 수 있었다.

본 연구에서는 토지 용도의 변화가 건물의 재건축을 가속화 할 수 있다는 기존 연구의 결과를 정량적으로 확인하였다. 건물 재건축의 급격한 확산은 주택 가격과 임대료 인상으로 이어질 수 있고. 결과적으로 젠트리피케이션을 유발할 수 있다. 토지 용도가 변경된 지역, 특히 상한 용적률이 높아진 지역에서는 젠트리피케이션을 방지하기 위해 공공의 개입이 필요하다. 특히, 봉천 지역과 같이 현재 건물 재건축이 활발하게 진행되고 있는 지역에서 젠트리피케이션이 일어나는 것을 막기 위해, 적정한 가격의 임대주택이 공급을 유도하는 지방 정부의 개입이 절실하다.

**주요어 : 젠트리피케이션, 물리적 변화, 이론 물리학, 전염병 확산 모델, 복잡계 네트워크, 정량적 분석**

학번 : 2016-24500