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**Conference Paper**

## Simulating the Impact of Compact City Policy on Two Korean Cities: Daejeon and Hwaseong

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# **Simulating the Impact of Compact City Policy on Two Korean Cities: Daejeon and Hwaseong**

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## **Abstract**

The notion of compact city has become an important planning agenda to achieve a sustainable urban future. Although there is no universally accepted definition of a compact city, in terms of land use, the concept generally focuses on high-density and mixed-use development along with the promotion of public transport. It is then generally agreed that such urban development practices would yield various economic, environmental, and social benefits.

To understand the impact of the compact city better, we need to develop and use relevant scientific policy support tools. Spatially explicit urban models hold some answers because they yield a logical framework for understanding complex urban systems and provide a virtual laboratory for investigating the outcomes of various urban policy actions. Whereas some urban models are developed for a specific purpose or region, some are developed as generic models to answer general urban policy questions across different cities and regions.

The main goal of this research is to suggest ways of using and developing urban models in order to study compact city systems with empirical case studies. We conducted two separate but related urban simulations, first applying a generic urban model to Hwaseong, Korea. There is a wide range of generic urban models, but many of them are proprietary and require a comprehensive input data set to run the model. Thus, the usability of many generic urban models is limited, and in this research, we attempt to use a non-proprietary urban model with fewer data requirements than most. The SLEUTH model fits this purpose well.

Although the model is not designed to study the impact of the compact city itself, it is one of the most widely used urban growth simulation models capable of offering some implications for the study of the compact city. Second, it develops an experimental but dedicated urban simulation model for the compact city system. Because developing a comprehensive model for the compact city requires long-term, large-scale research and development, we attempted to develop a pilot model focusing on the impact of compact city policy on urban growth. Then, we drew implications for the further development of a “compact city model.”

# 1. Introduction

## 1.1. Background and Goal

The notion of *compact city* has become an important planning agenda to achieve a sustainable urban future. Although there is no universally accepted definition of a compact city, in terms of land use, the concept generally focuses on high-density and mixed-use development along with the promotion of public transport (Burton, 2000). It is then generally agreed that such urban development practices would yield various economic, environmental, and social benefits.

To understand the impact of the compact city better, we need to develop and use relevant scientific policy support tools. Spatially explicit urban models hold some answers because they yield a logical framework for understanding complex urban systems and provide a virtual laboratory for investigating the outcomes of various urban policy actions. Whereas some urban models are developed for a specific purpose or region, some are developed as generic models to answer general urban policy questions across different cities and regions.

The use of a generic model versus the development of a dedicated model has both advantages and disadvantages. Generic models are built around their own theoretical and methodological backgrounds that reflect different research emphases, and they offer limited implications for the study of the compact city. However, one can choose a desired model without a complicated model development process. On the other hand, developing a dedicated model would be a better option for studying a compact city, but doing so requires a significant research effort and investment. A practical solution for this dilemma is to use an existing generic urban model in a limited sense and/or to develop a dedicated model in an incremental way.

The main goal of this research is to suggest ways of using and developing urban models in order to study compact city systems with empirical case studies. We conducted two separate but related urban simulations, first applying a generic urban model to Hwaseong, Korea. There is a wide range of generic urban models, but many of them are proprietary and require a comprehensive input data set to run the model. Thus, the usability of many generic urban models is limited, and in this research, we attempt to use a non-proprietary urban model with fewer data requirements than most. The SLEUTH model fits this purpose well. We selected this model, first, because it is easily obtainable free of charge and does not demand heavy data use. Although the model is not designed to study the impact of the compact city itself, it is one of the most widely used urban growth simulation models capable of offering some implications for the study of the compact city. Second, it develops an experimental but dedicated urban simulation model for the compact city system. Because developing a comprehensive model for the compact city requires long-term, large-scale research and development, we attempted to develop a pilot model focusing on the impact of compact city policy on urban growth. Then, we drew implications for the further development of a “compact city model.”

## 1.2. Research Scope and Methodology

Since the 1960s, various urban models have been developed to study urban systems and to address planning policy questions. Earlier urban models were generally built around an analogy with Newton's gravity law with a focus on the relationship between land use and transportation in an aggregate fashion. Whereas these models are still useful for many urban problems, one disadvantage of these land use transportation interaction (LUTI) models is the heavy data requirement and resulting impracticality (Lee, 1973). On the other hand, recent urban models have paid more attention to microscopic approaches and have thus offered a more spatially explicit and location specific result with less of a data requirement (Iacono et al., 2008, Batty, 2009).

Cellular automata (CA) and agent-based modeling (ABM) approaches have been at the forefront of such microscopic urban modeling approaches over the past few decades (Benenson and Torrens, 2004). While the strength of CA is in modeling land-use change with a relatively simple model structure and fewer data requirements, ABM has an advantage in incorporating the behavior of various actors in the process of land-use change.

The impact of the compact city is multi-dimensional and multi-scale. It may be best understood, even if imperfectly, by a comprehensive and multi-method integrated model rather than by a partial and specific approach. The development and use of such a comprehensive model may be necessary in the long term, but it is impractical in the short- to mid-term. Thus, this research focuses first on CA and ABM approaches because the use and development of microscopic models offers more flexibility than those of LUTI models and provides geographically more specific simulation results.

The OECD has suggested some necessary indicators to measure the impact of compact city policy (Table 1). The model should be able to produce relevant outcomes in order to measure the impacts of compact city policies. Yet, no single urban model can fully grasp the characteristics of urban systems. This problem can be solved by developing a purpose-built compact city model; thus, this study attempts to analyze the model outcomes only in a limited sense.

**Table 1. Core compact city indicators proposed by OECD (2012)**

	Category	Indicator	Description
<b>Indicators related to compactness</b>	Dense and proximate development patterns	1. Population and urban land growth	-Annual growth rate of population and urban land within a metropolitan area
		2. Population density on urban land	-Population over the surface of urban land within a metropolitan area
		3. Retrofitting existing urban land	-Share of urban development that occurs on existing urban land rather than on greenfield land
		4. Intensive use of buildings	-Vacancy rates of housing and offices

		5. Housing form 6. Trip distance 7. Urban land cover	-Share of multi-family houses in total housing units -Average trip distance for commuting/all trips -Share of urban land in a metropolitan area
	Urban areas linked by public transport systems	8. Trips using public transport 9. Proximity to public transport	-Share of trips using public transport (for commuting/for all trips) in total trips -Share of population (and/or employment) within walking distance (e.g., 500 meters) of public transport stations in total population
	Accessibility to local services and jobs	10. Matching jobs and homes 11. Matching local services and homes 12. Proximity to local services 13. Trips on foot and by bicycle	-Balance between jobs and homes at the neighborhood scale -Balance between local services and homes at the neighborhood scale -Share of population within walking distance (e.g., 500 meters) of local services -Share of trips on foot and by bicycle (for commuting/for all trips) in total trips
<b>Indicators related to the impact of compact city policies</b>	Environmental	14. Public space and green areas 15. Transport energy use 16. Residential energy use	-Share of population within walking distance (e.g., 500 meters) of green space accessible to the public -Transport energy consumption per capita -Residential energy consumption per capita
	Social	17. Affordability	-Share of household expenditure on housing and transport in total household expenditure
	Economic	18. Public service	-Expenditure on maintaining urban infrastructure (roads, water facilities, etc.) per capita

Source: OECD (2012), Compact City Policies: A Comparative Assessment, OECD Publishing, Paris.

## 2. The Use of the Generic Urban Model SLEUTH: Simulation for Hwaseong, Korea

### 2.1. Introduction

The first case study for Hwaseong, Korea, applies the SLEUTH model, a CA urban model developed by Keith Clarke at the University of California, Santa Barbara (Clarke et al., 1997). The model builds upon the core notion of CA as well as other statistical methods, and it is one of the most widely used cellular urban models for simulating land use change and urban growth (Clarke, 2008, Jantz et al., 2010, Rafiee et al., 2009, Silva and Clarke, 2005). One of the most important strengths of this model is its “compact” data requirement; even without an intensive use of socio-economic data, this model efficiently simulates land use changes and the urban growth process.

In terms of studying the compact city, this model offers opportunities to simulate some compact city policies, such as land-use regulations and the provision of the transportation networks, and to examine the impacts of those policies on urban and environmental landscape. It is important to note that, because of the nature of the model, SLEUTH has certain limitations for considering more diverse socio-economic determinants, and it uses a physical perspective to create results for land use

change and urban growth. Nevertheless, the simulation with SLEUTH for Hwaseong will demonstrate the merit of using a generic urban model as well as the possible model outcome in studying a compact city.

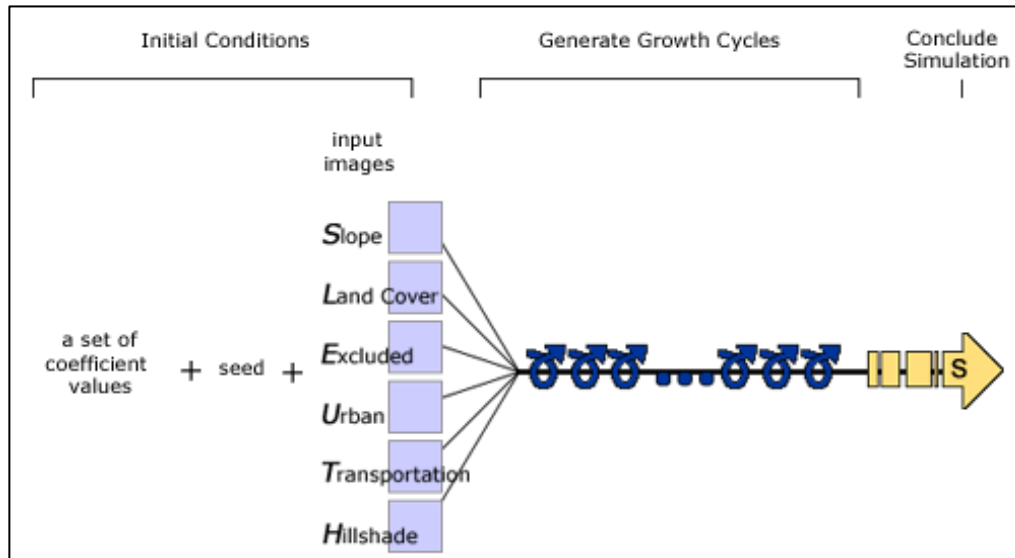
## **2.2. Model Description**

The SLEUTH model, as mentioned earlier, is developed around the notion of the CA system. The name of the model comes from the input data requirements of the model: slope, land use, excluded area, urban area, transportation, and hillshade. The model captures changes in land use, representing them as individual cells with a set of transition rules. The growth rules—i.e., cell transition rules—form the core of urban growth dynamics in SLEUTH. These rules regulate how individual cells become “urban” or remain “non-urban” when they meet certain conditions.

The urban growth process in SLEUTH is represented by four types of growth rules: spontaneous growth, new spreading centers, edge growth, and road-influenced growth. Spontaneous growth represents new urbanization that occurs without pre-existing urban areas and transportation networks. New spreading centers attempt to control whether such spontaneous growth will further expand and become a new urban center for continued urban development. Edge growth defines urbanization from the surroundings of existing urban areas, and road-influenced growth represents urbanization along with transportation networks.

These four growth rules are then controlled by five growth coefficients: dispersion, breed, spread, slope, and road gravity. Each parameter has a range of 0 to 100 and controls one or more growth rules. Together, these parameters control the importance and amount of each of the growth rules.

The SLEUTH model simulates future urban growth with the above input data, growth rules, and parameters. The model uses the random stochastic disturbance factor in the growth rules in order to increase the reality of model outcomes; thus, the model produces final outcomes after multiple Monte Carlo runs. The overall model structure is illustrated in Figure 1.



Source: <http://www.ncgia.ucsb.edu/projects/gig/About/bkStrSimulation.html>

**Figure 1. Growth Rules and Controlling Coefficients**

### 2.3. Application to Hwaseong, Korea

#### Input data

Figure 1 shows the required six types of input data layers, as previously mentioned—i.e., slope, land use, etc. These layers should be in grayscale, 8 bit GIF image format, and each layer holds relevant cell values that range from 0 to 255. All layers should have the same extent and resolution.

As already mentioned, a strength of the SLEUTH model is that it requires less data compared to traditional urban models, but this also limits the consideration of various factors affecting urban growth. One possible remedy is to take various factors into account when making the exclusion layer. To do so, exclusion/attraction layers were further developed for the study region. We identified factors that would either attract development or repel development. These exclusion and attraction factors were combined using GIS overlay modeling and the class values of the resulting map ranged from 5 (attraction) to 90 (strong resistance), with 50 representing a neutral value. We then identified lands that would be completely excluded from development, such as water bodies and protected zones (Table 2), assigned a value of 100 to indicate complete resistance, and added those features to the final excluded/attraction layer. The overall input layers for the Hwaseong simulation are depicted in Figure 2, and Figure 3 illustrates all of the data layers included for the exclusion/attraction models and the final exclusion/attraction layers used for model calibration.



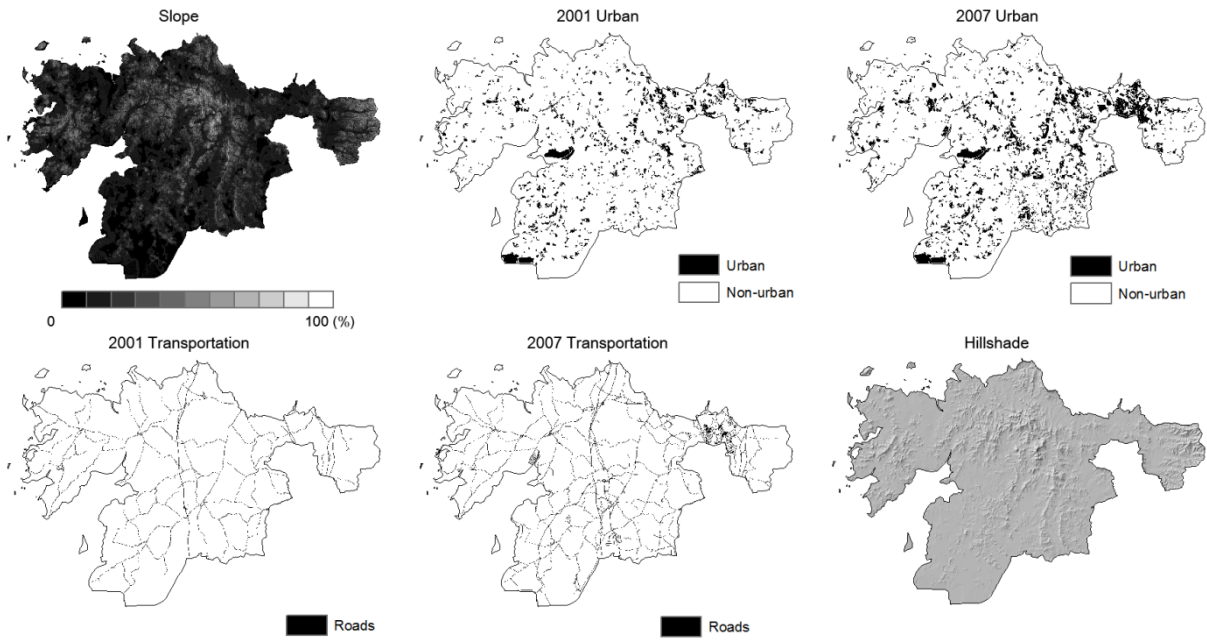


Figure 2. Input layers for the urban growth simulation of Hwaseong

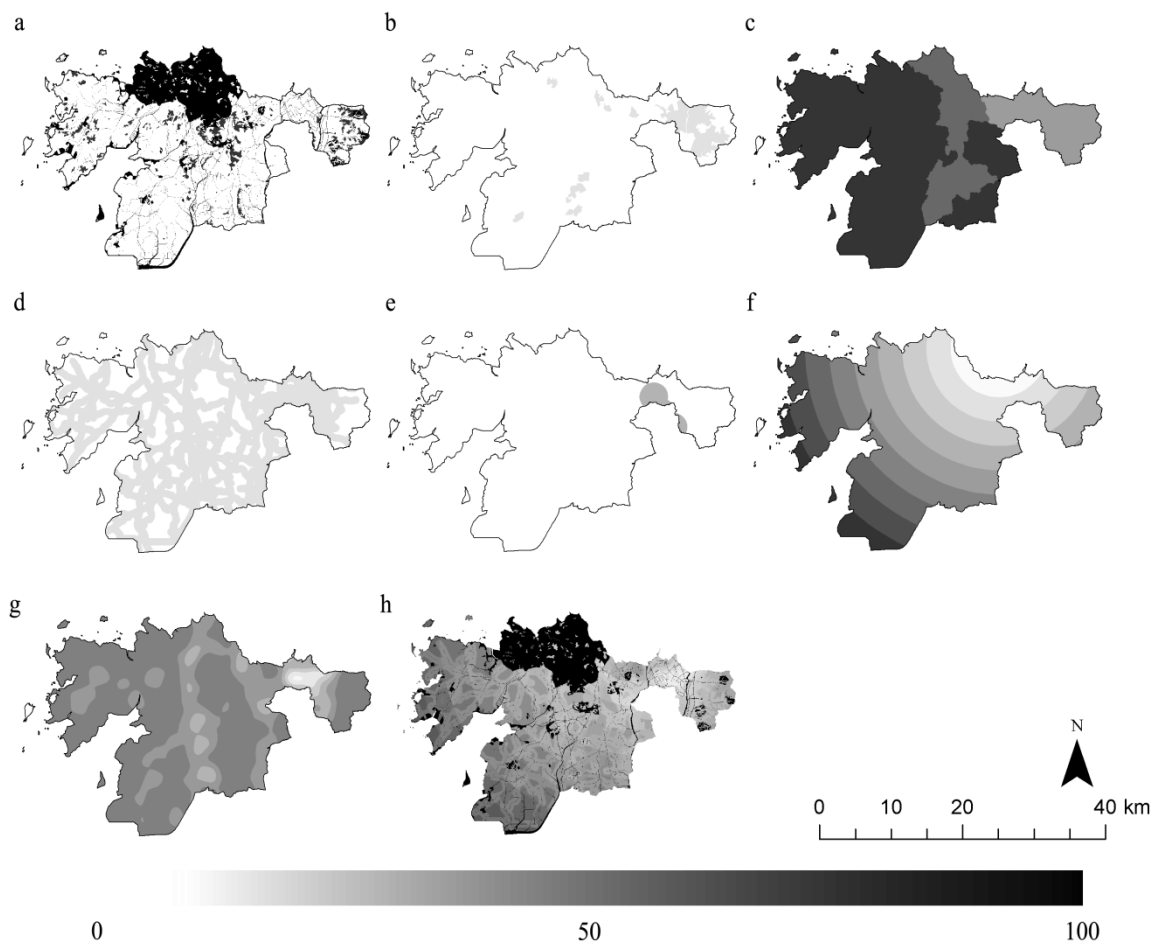


Figure 3. Attraction and resistance layers used for calibration: a) protected lands, b) residential development district, c) population density, d) distance from roads, e) distance from rail stations, f) distance from Suwon,

**g) road density, and h) final exclusion/attraction map**

**Table 2. Exclusions/attractions for both business-as-usual and compact-growth scenarios**

	Description	Business as usual	Compact growth with best protection of natural resources and environment
		Level of protection (%)	
Protected areas	Lakes and water bodies	100	100
	Wetlands	100	100
	Riparian buffer zones (300-meter buffer around wetlands, lakes, and other water bodies)	50	100
	Green belt for preservation	100	100
	Wildlife and plant conservation area	100	100
	Conservation forest with common interests	100	100
	Conservation forest with forestry goods	80	80
	Park and nature preservation area	100	100
Other resistance/attraction	Distance to major roads (500-meter buffer around the roads)	30	30 (1500-meter buffer for motorways, major roads, and junctions)
	Distance from rail stations	30 (2000-meter buffer from rail stations)	30 (2000-meter buffer from rail stations)
	Distance to Suwon	10~100 (classified into 10 classes)	10~100 (classified into 10 classes)
	Population density by EMD	5 ~100 (classified into 7 classes)	10 ~100 (classified into 7 classes)
	Residential development district	10	10
	Green Corridors	NA	90 (first class) 70 (second class)

**Scenarios**

To simulate future urban development patterns over the next 20 years under different conditions, we designed two urbanization scenarios for Hwaseong: business as usual and compact development. The first scenario assumes that current urban patterns will continue 20 years into the future; thus, no specific policy actions are assumed. The second scenario reflects the concept of the compact city. Along with a high level of protection for natural resources and the environment, more proximate and clustered developments are assumed in this scenario. Table 3 explains the key assumptions in two scenarios.

**Table 3. Alternative future scenario narrative for Hwaseong**

Scenario 1	Business-as-usual scenario - Assume no changes in policies or land-use change drivers
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Scenario 2	<p>A compact city with a high level of protection for natural resources and the environment</p> <ol style="list-style-type: none"> <li>1. Assume continued protection of all existing protected lands.</li> <li>2. Assume a protected buffer (300m) around water bodies, streams, wetlands, and coastal areas.</li> <li>3. Assume growth will occur in or near existing villages and near primary road networks or rail stations.</li> <li>4. Assume no new roads in or near existing villages.</li> <li>5. Enhance proximity to the Suwon region as a driver.</li> <li>6. Retain existing population density trends.</li> <li>7. High density development will occur.</li> <li>8. Encourage development in or near existing villages, expanded by adding a 300-meter buffer.</li> </ol>
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Based on these narratives, an exclusion/attraction map was generated for each scenario to represent the corresponding spatial changes to policies or drivers of land-use change. For the business-as-usual scenarios, we used the same exclusion/attraction layers that were used for calibration, assuming no change in land-use policies (Figure 3). For the compact growth scenario, forecasts of future urbanization were created through modifying the exclusion/attraction layers and by applying alternative future growth rates using SLEUTH's self-modification function (Table 3).

## 2.4. Simulation and result analysis

### Model calibration

The calibration of SLEUTH is to determine the best fit values for the five growth coefficients: dispersion, breed, spread, slope, and road gravity. The SLEUTH model offers a range of measurement metrics that can be used for determining the best parameter set. Two measurements were used in this study to identify the best fit values for the growth parameters (Jantz et al., 2010): the population fraction difference (PFD), which measures a direct comparison between the number of urban pixels in the urban land maps and the corresponding simulated maps, and the cluster fractional difference (CFD), which measures a direct comparison between the number of urban clusters in the urban land cover maps and the corresponding simulated maps. Table 4 presents the selected parameters and the value of two measurement metrics.

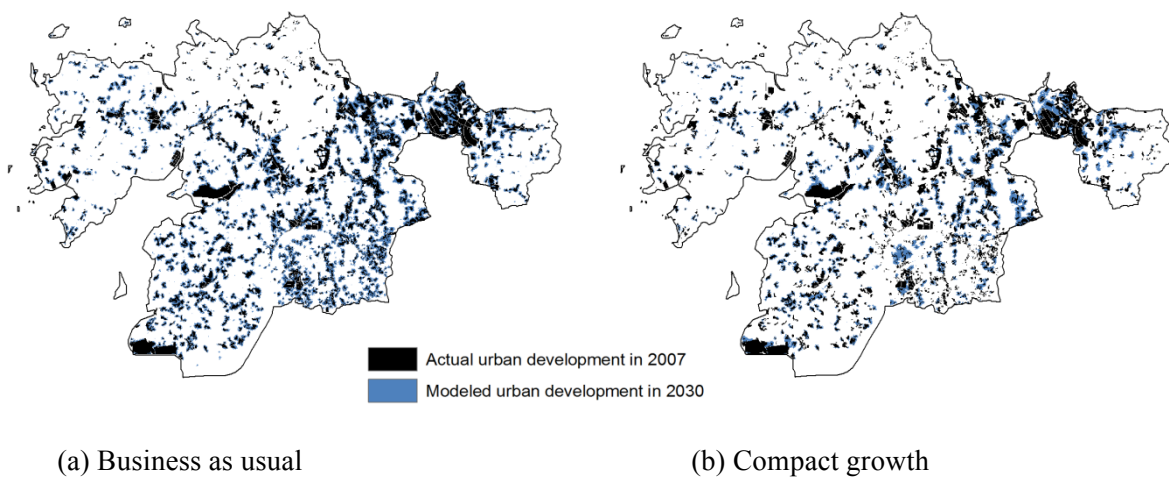
**Table 4. Best fit parameters derived from the calibration**

	Diffusion	Breed	Spread	Slope	Road growth	PFD	CFD
Hwaseong	1	90	100	1	20	-0.137	0.118

### Simulation results

The simulations for Hwaseong show a continuation of scattered urban development over the next 20 years. Spontaneous and edge growth dominates the growth in Hwaseong City. This is largely owing to the current urban form and spatial structure of the city. However, the results indicate that the overall amount and detailed spatial pattern of urban development between the two scenarios is different. The business-as-usual scenario resulted in a higher level of urban growth with a more dispersed growth pattern, but the compact growth scenario generated a lower level of growth with more clustered patterns.

The result of the business-as-usual scenario presents an intensification of scattered urban development across the region. Some notable urban clusters occur around Dongtan and Bongdam new town development areas, but some places—like Songsan, Hyangnam, Balan, and Paltan, which are currently experiencing urban sprawl—will be likely to experience further scattered development in the future. On the other hand, the results of compact growth show reduced urban sprawl. Major urban clusters will form around Dongtan and Bongdam in this scenario also, but sprawling development around Songsan, Hyangnam, Balan, and Paltan are reduced. Figure 4 shows comparisons of urban development in 2030 between the current-trends scenario and the alternative scenarios for compact growth.



**Figure 4. Comparison of alternative futures for Hwaseong**

Table 5 shows more detailed urban growth trends under the two scenarios. The business-as-usual scenario increases urbanized areas by 188 percent, to 173Km<sup>2</sup>. The compact growth scenario leads to a 150 percent growth, to 138Km<sup>2</sup>. The net increase for the business-as-usual scenario is 88 Km<sup>2</sup> but 49 Km<sup>2</sup> for the compact-growth scenario.

**Table 5. Total urban areas under two scenarios**

	(Km <sup>2</sup> )	
Year	Business as usual	Compact growth
2007	92	92
2010	113	98
2015	139	109
2020	159	119
2025	166	129
2030	173	138
Increase between 2007 and 2030	88	49

These two types of urban growth were further analyzed for a better understanding of the characteristics of the two development scenarios in light of the compact city. It would be ideal to analyze the simulation results by using the compact city indicators listed in Table 1, but doing so would require the development of a full-scale, comprehensive compact city model as well as further specification of compact-city indicators. Thus, the analysis was conducted with a couple of trivial indicators, and it gives rise to some research questions.

Table 6 summarizes the results of the analysis. As shown above, the compact-city scenario leads to less urban development, implying the need for denser urban use in the future. If the same future population is assumed, urban population density will be 3,334 people per square kilometer for the business-as-usual scenario and 4,206 for the compact-development scenario. However, the implications from the results for the rest of the indicators are not as clear. Since the new urban growth and total urban area is far greater in the business-as-usual scenario, urban areas and urban population close to transportation nodes and local services are also greater in the business-as-usual scenario. Indeed, the SLEUTH model simulated changes in future urban land only, and changes in urban transportation networks, local services, and population are not considered. These results clearly imply both the merits and limitations of using a specific generic model for the study of compact city. Use of this model can be a practical solution that cuts down on time and cost. However, a different type of urban model and indicators are necessary for a good understanding of the impact of the compact city.

**Table 6. Urban Characteristics by Scenarios in 2030**

	Scenarios	
Measurements	Business as usual	Compact growth
Total urban area by 2030 (Km <sup>2</sup> )	173	138
Percentage of urban land (%)	31.6	27.2
Projected population by 2030*	576,745	576,745

Urban population density (capita/Km <sup>2</sup> )	3,334	4,206
Urban area within 500m of transportation nodes** (Km <sup>2</sup> )	123.3	95.5
Urban population within 500m of transportation nodes (capita)	410,985	401,488
Percentage of urban population within 500m of transportation nodes (%)	51.9	51.2
Urban area within 500m of local services (Km <sup>2</sup> )	76.7	61.8
Urban population within 500m of local services*** (capita)	255,683	259,862
Percentage of urban population within 500m of local services (%)	50.5	49.5

\* Population projection by the National Statistical Office Korea.

\*\* Transportation nodes: rail and bus stations

\*\*\* Local services: banks, schools, retail shops

### **3. The Development of the Dedicated Compact City Model: Simulation for Daejeon, Korea**

#### **3.1. Introduction**

The second case study for Daejeon, Korea develops an agent-based urban simulation model. As mentioned before, the nature and impact of the compact city is multi-dimensional, and only a purpose-built comprehensive model may sufficiently cover all necessary aspects of the compact city. However, because the development of such a model is a long-term project, this research develops an experimental pilot model with a focus on one particular important component of the compact city—new development, redevelopment, and densification. Dense development is often considered a critical component of the compact city. The impact includes mitigation of urban sprawl as well as reduced commuting and shopping trips.

An ABM integrated with microeconomic location-choice theories fit very well into our study of the compact city in this context. Because there is no existing generic urban simulation model available for this purpose, this case study adopts and extends the urban simulation model developed in the work of Kim and Batty (2011) and Kim (2012). These studies extended the bid-rent theory of Alonso (1964), Mills (1967), and Muth (1969) in order to define the location-choice behavior of households and conducted various theoretical and semi-empirical simulations. In a similar vein, this research will define the urban location-choice behavior of households with reference to the random utility maximization principle. The preference for urban development will be considered a part of the utility function, and the model will present the formation of the resulting urban growth.

This pilot model narrowly focuses on the impact of dense urban development on urban growth. For this research, the model behavior was developed and tested with the use of actual geographic data for Daejeon. A logistic regression was conducted to determine model variables on an

empirical basis, but on a limited scale because of the constraints on the time and budget. Thus, the model and results are experimental and explorative. However, because the land-use model forms the core of any comprehensive urban model and the impact of dense development is less studied by existing urban models, the pilot model in this research will provide useful implications for the further development of a compact city model.

### **3.2. Model Description**

ABM is a simulation method composed of agents that interact with each other and their environments. It is a computational modeling approach in that it takes the form of a computer program and in that there are inputs and outputs for the program. The program holds attributes of agents and environments, and defines the behavior of agents as well their interaction with their environment (Macy and Willer, 2002, Gilbert, 2008). Here on the conceptual level, the agents and environments are merely generic terms describing their general characteristics, and there are no fixed definitions of their forms, attributes, and behaviors. These are rather defined by a specific target system of modeling, so there could be widely different operational definitions of agents and environments. Thus, many different academic domains, such as biology and economics, can use ABM with their own research focuses.

ABM as an approach to the study of land-use change and urban growth is a relatively new idea. The urban modeling field has continuously adopted theories and methodologies from varying academic domains, and ABM is one of the latest infusions into urban modeling. Now it is gaining popularity in the urban modeling field, but fully-fledged generic models are not yet well developed (Parker et al., 2002, Matthews et al., 2007).

One of the most important challenges of developing an agent-based urban model concerns the specification of agents' behavior and their interaction with the environment. Although the ABM approach provides a useful framework for understanding the temporal dynamics of complex urban systems on a fine scale, it does not provide substantive knowledge about how urban systems change and evolve. In the past, these applications have been centered mainly on the study of self-organizing urban morphologies with a focus on generative knowledge discovery (Batty, 2009, Crooks et al., 2008, Matthews et al., 2007, Manson and O'sullivan, 2006, Epstein, 2007), and this has limited their applicability in real planning.

Recently, a new approach to integrating urban economic theories into ABM frameworks has emerged through the study of land-use change systems. The main benefit is not only stronger explanatory power from the perspective of ABM but also a greater behavioral/spatial heterogeneity with respect to how the urban economy is modeled and represented. Combined together, these developments potentially offer a new type of dynamic and operational spatial policy support system to planning practice.

The model in this research integrates the random utility theory (Mcfadden, 1973) into the ABM framework. Random utility theory explains the choice process of individual entities, such as households and businesses, on finite alternatives, and it sees that the utility is composed of an observable deterministic part and an unobservable stochastic part.

The utility that individual  $i$  is associating with alternative  $a$  is defined by:

$$U_{ai} = \sum_{s=1}^S \beta_s x_{ai} + \varepsilon_{ai},$$

Where  $S$  is a choice set,  $\beta_s$  is a vector of  $s$  estimable coefficient,  $x_{ai}$  is a vector of an observed independent attribute of individual  $i$  on alternative  $a$ , and  $\varepsilon_{ai}$  is an unobserved random disturbance that follows a Gumbel distribution.

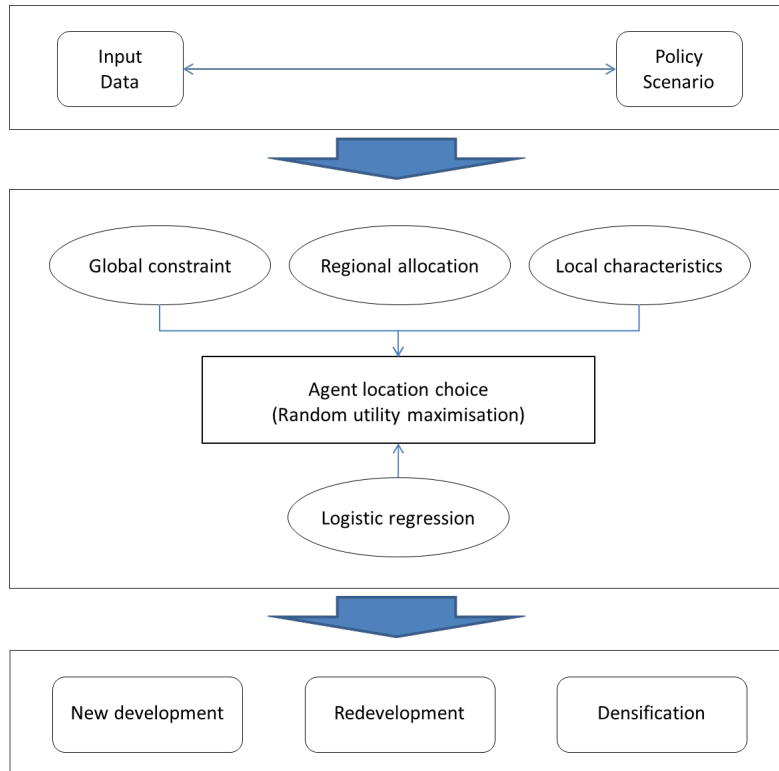
Assuming that the unobserved random part varies with the Gumbel distribution, we are led to the multinomial logit model for the probability of choosing an alternative  $i$  out of the choice set  $S_n$ .

$$P_{ai} = \frac{e^{x_{ai}}}{\sum_{k \in S_n} e^{x_{ki}}}$$

The basic spatial and behavioral configuration of the model to be developed here conforms to the fundamental assumptions of the random utility theory, which is used to model the location-choice behavior of spatial agents.

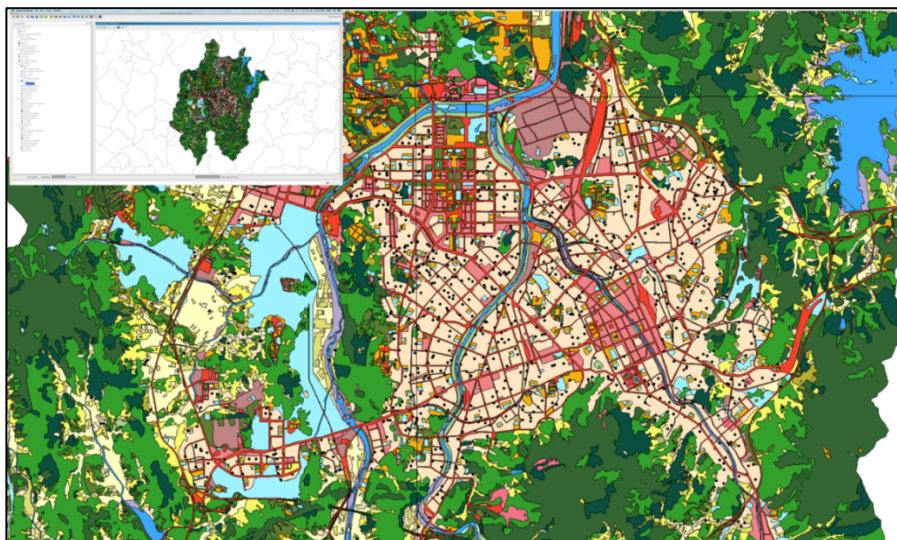
However, urban systems are affected not only by the location-choice behavior of individual agents but also by various socio-economic factors. Thus, in order to develop a spatially explicit dynamic urban model, multi-level modeling notions are further introduced into this study. Macro- and meso-scale socio-economic factors are considered in a micro-scale, agent-based model, on the one hand, and the agent-based location-choice model is integrated with other sub models, on the other hand. First of all, on a micro level, the model behavior is defined by the short-run, utility-maximizing location choice of spatial agents. Urban growth proceeds by a sequence of such decisions in an ABM framework. In addition to this, macro- and meso-level system behavior is also considered. On a macro level, an exogenous variable controls the total urban demand, and it is regionally allocated with reference to the ratio of regional population. This integration of a micro-level, location-choice model with meso- and macro-level factors offers an opportunity for introducing various socio-economic determinants of urban system changes into the ABM framework. In this study, we used simple variables for the meso- and macro-level factors, but these can be further extended in future research. The overall model structure is described in Figure 5.





**Figure 5. Conceptual framework of the proposed model**

We then developed a pilot model in Repast Symphony, a programming platform developed by researchers at the University of Chicago. In developing a computer-based agent-based simulation model, it helps to save time and money to use pre-defined libraries. The model running environment is presented in Figure 6.



**Figure 6. Initialization of the model**

### 3.3. Application to Daejeon, Korea

#### Input data

The model is designed to have a multi-level structure, and each level requires different types of input data. The macro level acts as a global constraint, and it defines a quantity of total urban demand at the target year. The total urban demand can be derived from an internal or external economic model, but this study used a number from a previous study,<sup>1</sup> which estimated the urban demand for Daejeon City by 2030 to be 22.1 Km<sup>2</sup>. We adopted that figure for this study as a macro-level constraint. The meso level provides a means to calculate sub-regional attractiveness or developmental potential. Total urban demand is not uniformly distributed for all of Daejeon, but differently allocated according to this factor. It can be also done by an external or internal model, but it is calculated by the ratio of population growth rate in each sub administration (Gu) of Daejeon. The micro level acts as a location-choice model, and under the influence of the total demand and regional attractiveness, individual spatial agents make a location choice by referring to their preferences concerning different factors. Geospatial input data to define local determinants of location choice are depicted in Figure 7.

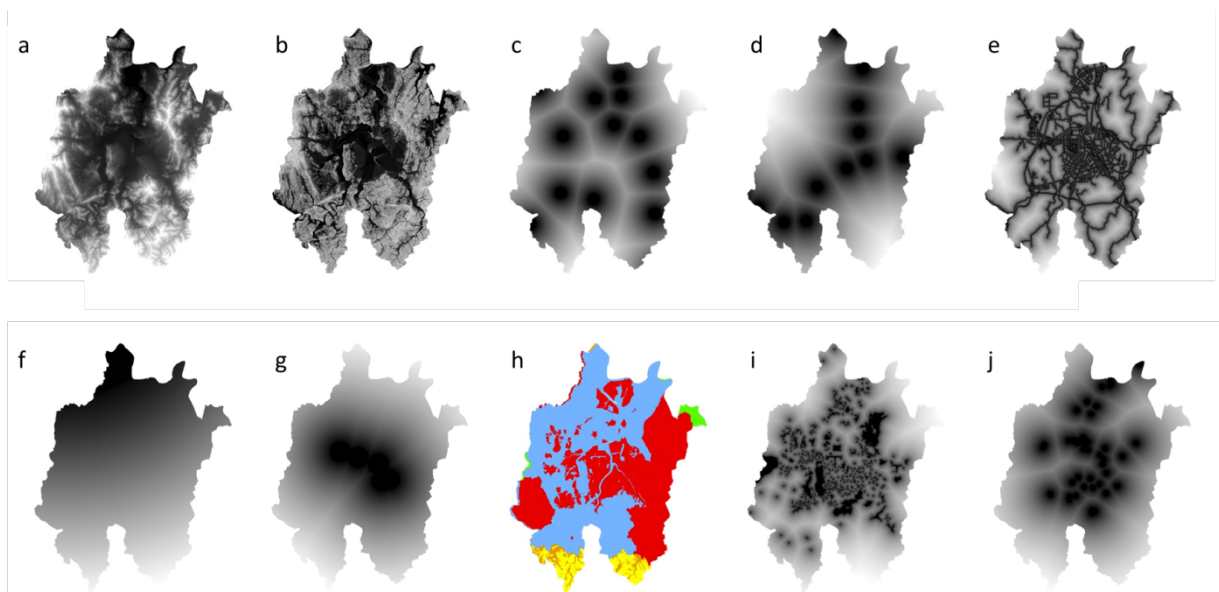


Figure 7. Input layers used for a micro-level location choice: a) elevation , b) slope, c) distance to nearest motorway junction, d) distance to nearest railway station, e) distance to nearest road, f) distance to Sejong City, g) distance to town centers, h) zoning, i) distance to nearest open space, j) distance to nearest cultural facility

<sup>1</sup> KRIHS. (2011). Land use change prediction based on urban policy scenarios.

## Scenarios

Like the simulations for Hwaseong, forecasts of future urbanization for Daejeon are also based on the two scenarios of business as usual and compact development. Whereas the first scenario focuses on the extension of current trends, the second scenario emphasizes the effect of a compact city policy. Unlike the compact development scenario for Hwaseong, we assume that urban redevelopment and densification will be promoted in Daejeon City. It is well argued that urban redevelopment and densification can reduce urban sprawl and loss of open space, and they are considered to be important characteristics of compact-city development. However, few urban models can simulate such urban redevelopment and densification practices. Thus, we introduce the notion of spatial redevelopment and densification into the ABM framework. Because an estimation of the amount of redevelopment and densification requires development of relevant empirical models, we simply used random stochastic effects to determine those. Nevertheless, this simulation will show how urban redevelopment and densification will change the overall urban structure. Table 5 shows the key assumptions in the two scenarios.

**Table 5. Alternative future scenario narrative for Daejeon City**

	Scenario 1: Business as usual	Scenario 2: A compact city with promotion of dense urban development
Assumptions	Assume no changes in policies or land use change drivers	1. Assume continued protection of all existing protected land 2. Assume no new roads in or near existing villages 3. Assume growth will occur near transportation networks such as primary roads or rail stations 4. Assume urban redevelopment around old town centre 5. Encourage urban development to occur near urban amenity such as cultural facilities 6. Assume high-density development 7. Retain existing population growth trends

### 3.4. Simulation and result analysis

#### Model calibration

The purpose of the model calibration is to find better fit parameters and hence to make the model work properly for a given study area. Different models adopt different calibration methods, and some models adopt a quantitative calibration method, whereas others use a qualitative one. Nevertheless, the model calibration requires analysis and examination of intensive empirical data, which is one of the most time-consuming parts of urban modeling. Moreover, the methodology for

calibrating microscopic urban models is not yet fully developed, and much more research effort is required in the future (Batty and Torrens, 2005).

To calibrate the pilot model we developed, we use quantitative and qualitative methods together. First, we conduct a binomial logistic regression to determine empirically justified model variables. Table 6 presents the results of the regression. Then, we form a utility function with the selected variables. Second, we run a simulation and qualitatively examine the results to see whether it matches the reality.

**Table 6. Result of logistic regression**

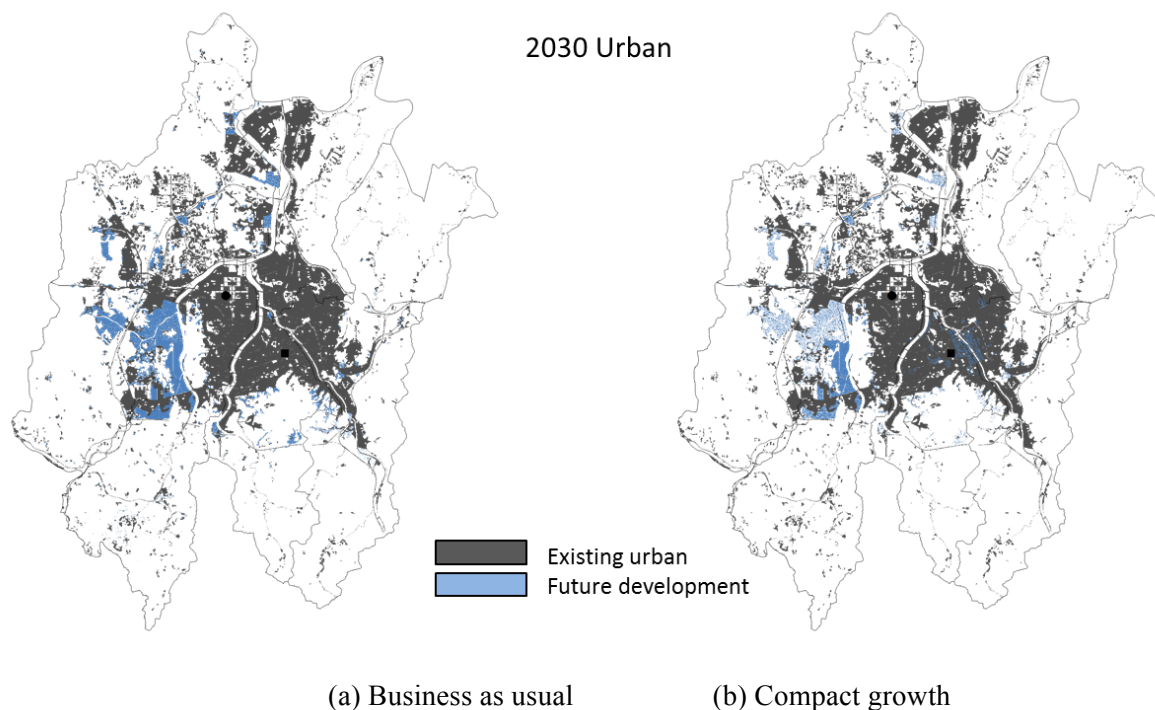
Variable		B	Sig.	exp(B)
Topography	Elevation	-.129	.000	.879
	Slope	-.794	.000	.452
Transportation	Distance to nearest motorway junction	-.113	.000	.893
	Distance to nearest railway station	-.349	.000	.706
	Distance to nearest road	-.530	.000	.589
Socio-economic	Distance to Sejong City	-.873	.000	.418
	Distance to town centers	-.696	.000	.499
	Zoning	-1.126	.000	.324
	Distance to nearest open space	-.038	.000	.963
	Distance to nearest cultural facility	-.362	.000	.696
Constant		26.576	.000	3.480E+11

### Simulation results

Figure 8 shows the urban development projected for 2030 in a comparison between the current-trends scenario and alternative scenarios for compact growth. Dajeon is not a rapidly growing city, but it will experience a certain degree of urban expansion and sprawl. The simulation result shows that the new urban growth will occur near existing urban areas in the business-as-usual scenario. Mid-to-large-scale new development will take place in the western part of the city, where most mid-to-large-scale developable lands are available. This simulation proves that residential development districts like Doan, Dukmyung, Gubong, and Hakha will be the areas of intensive new development. On the other hand, small-scale, spontaneous development will occur in the southwestern and southeastern part of the city, especially around the foot of Bomun Mountain. These areas are now filled mainly with detached and semi-detached houses, agricultural barns, and small manufacturing firms. These types of development are likely to expand in the future.

In the compact-growth scenario, urban redevelopment and densification will be pursued around the old town center. Generally, urban models assume that urban development is irreversible, and they tend not to account for redevelopment of these areas. This model, however, assumes the redevelopment of old town centers and accordingly reduces new development in the urban fringe areas. Certainly, this scenario will not remove the need for large-scale urban development; thus, the

overall spatial structure is similar to that of the business-as-usual scenario. Nonetheless, small-scale sprawling development is reduced in this scenario. Figure 9 and Table 6 present and compare the results of this simulation.



**Figure 8. Comparison of simulation results**

**Table 6. New urban areas under two scenarios**

	Business as usual	Compact development
Urban development within 2500m buffers between the new and old CBD	0.25 Km <sup>2</sup>	1.6 Km <sup>2</sup>
Urban development outside 2500m buffers between the new and old CBD	21.85 Km <sup>2</sup>	17.9 Km <sup>2</sup>

\* The location of new CBD is assumed at the point of Dajeon City Hall (upper left black point in Figure 10), and the location of old CBD is assumed at the point of Junggu Borough Hall (bottom right black point in Figure 10),

## 4. Discussion

### 4.1. Implications and Limitations

Scientific urban models, especially spatially explicit urban simulation models, play a valuable role in helping us understand the nature and impact of compact city development. Computer-based urban simulation models can act like a virtual laboratory that facilitates the building of various what-if scenarios and exploration of possible future states. Additionally, these models provide a variety of information and knowledge, and contribute to reducing uncertainty.

Many urban models have been developed to this end since the 1960s. Some models have been developed into a generic models, and many of these that focused on the interaction between land use and transportation blossomed in the 1970s and reflected policy needs for that era—the planned suburban development and the provision of transportation networks. On the other hand, urban models in and after the 1980s paid more attention to modeling unplanned urban sprawls with the CA and ABM approaches. Although some of these models can be useful for studying the compact city, the development of a dedicated urban model for compact city is a necessary quest if we are to understand the compact city better. In this regard, this research conducts urban simulations for two case study areas with a generic model and a purpose-built pilot model.

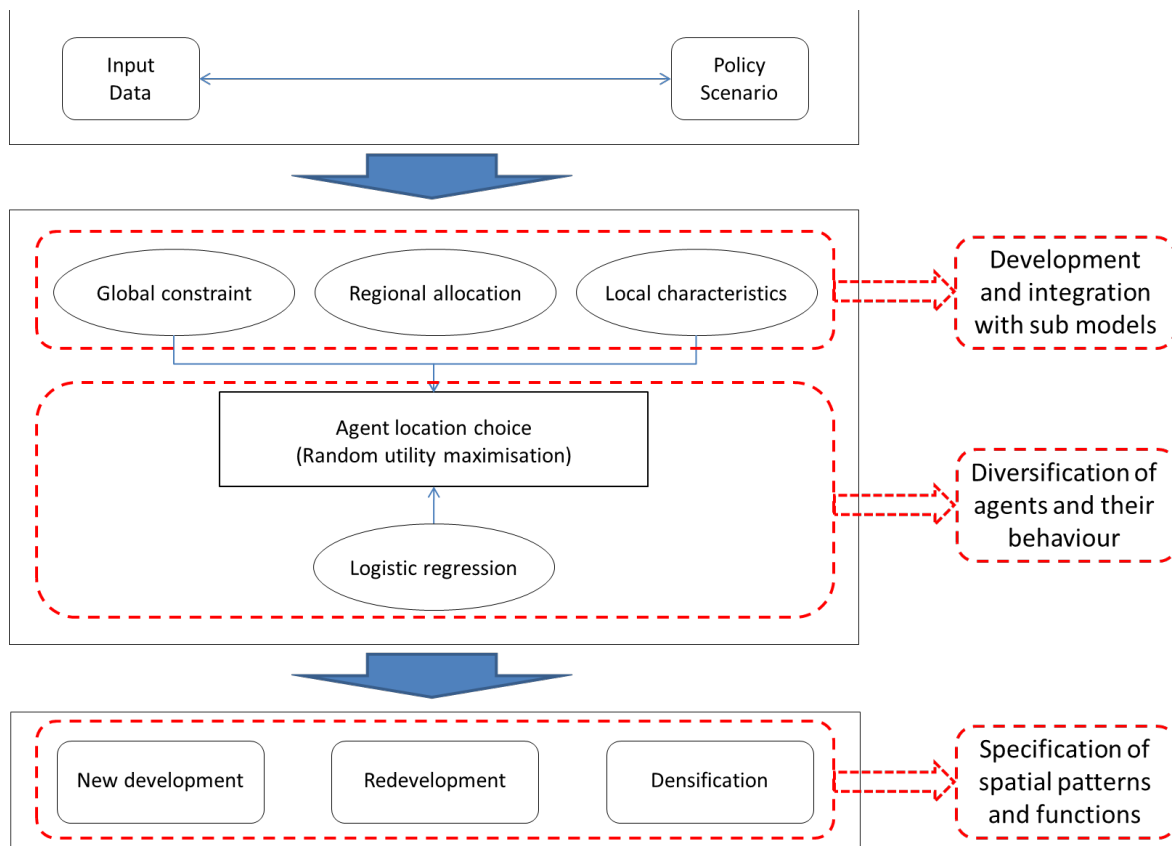
The results of urban simulation will never exactly predict the future. Rather, we use them to understand the possible urban future and to reduce uncertainty in the future, and the quality and plausibility of a simulation outcome can be improved if it is based on accurate data and austere analysis. This study has focused on demonstrating urban modeling for the study of the compact city and has paid less attention to producing well-refined simulation results with sufficient data analysis. This can be done with a different research focus in the future, but this research offers suggestions on how to improve further the pilot model for the study of the compact city.

## **4.2. Future Work**

This research demonstrates how urban models can empower urban planning and policy by providing alternative future development scenarios. The use of generic models and the development of dedicated models have their own merits in terms of studying urban systems. However, to understand better the nature and impact of compact city policies, it is more desirable to develop a dedicated model.

This study presented a pilot model and showed an innovative but feasible method to develop a compact city model. However, further research and development is necessary to make it as practical as possible. We identify three research and development agenda. First, development and integration with sub models is necessary. The model presented in this study is a location-choice model, which is intended to capture the nature of compact-city development. To understand the socio-economic, environmental, and cultural impact of the compact city, relevant sub models, such as population, employment, and transportation models should be developed and integrated with the location-choice model. Second, detailed specification of agents and their behavior is desirable. The model in this

research simplified the types of agents and preference factors. However, it is necessary to consider different types of agents, such as households and businesses, as well as relevant factors affecting their location decisions. Lastly, consideration of more urban forms and development patterns is needed. This study suggested new urban development, redevelopment, and densification as resulting spatial patterns. However, for a better understanding of the nature of the compact city, more urban development practices and resulting spatial patterns, such as mixed-used and transit-oriented development, should be modeled and produced. Figure 9 depicts such necessary improvement along with the model structure.



**Figure 10. Future development**

## 5. Conclusion

The overall results of the research demonstrate that dynamic urban models allow us to simulate changing urban form and the impact of compact city policy on it. The research not only shows the merits and limitations of generic urban models but also presents a feasible way of developing a dedicated compact city model. Besides, it suggests that the ABM approach offers a unique opportunity for the study of dynamic urban systems as well as the impact of compact city policies. Yet, ABM is not a well-established urban modeling methodology, and more research and development is necessary if it is to be used for purposes of policy support.

The development and success of the urban modeling field not only require a novel academic effort but also demand sound support from public sectors. Many generic urban models, including the SLEUTH model used in this research, are outcomes of these two elements. The development of a compact city model will also require academic research and institutional support.



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