Chapter 1
A Challenge to Configure Form Scenarios for Urban Growth Simulations Reflecting the Institutional Implications of Land-Use Policy

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Introduction

In planning practice, planners and policy makers frequently investigate urban forms, particularly urban growth boundaries (UGBs), using scenario analyses (SA) by regarding development policies as scenario conditions in urban simulations (i.e., Klosterman 1999; Landis 1994, 1995). Couclelis (2005), however, argued that routine land-use modeling has done little in the way of future-oriented research such as investigations of desirable or feared future conditions. This chapter uses planning alternatives, specifically UGBs, as scenarios to identify necessary spatial policies for planners. This is the inverse procedure of traditional urban growth SA. We propose the concept of "form scenario analysis" (FSA), which we employ to investigate relationships between planning alternatives and corresponding spatial policies. This chapter explains an FSA approach using constrained cellular automata (CA), a tool for matching planning alternatives with necessary spatial policies. We look in particular at form scenarios in order to present the institutional implications of different spatial land-use policy options. This novel exploration of FSA can identify necessary policies as well as policy variations required for different planning alternatives. This differs from traditional applications of constrained CA.

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Unlike in the West, Chinese urban planners, mostly working in government-held planning institutions, hold intrinsic notions from the planned economic system when devising alternatives, resulting in development potential factors not well being taken into account. Planners are accustomed to designing urban structure in master plans without sufficient deliberation on spatial policies that are required to realize the desired urban form. UGBs produced by planners cannot completely conform to the land-use development plan issued by the national land resource bureau, which is dynamically influenced by social, economic, political, technological, and environmental policies such as eco-sensitive land protection, infrastructure development, and other market economy factors. In planning practice, practical urban growth tends to depart from planned UGBs. An Investigation has shown that more than 35% of urban development occurring in Beijing exceeds the urban spaces defined in the original plan (Han et al. 2009). Appropriate policy guidance by planning authorities is necessary to make planned alternatives become reality in the process of urban development. From this point of view, the government is commonly concerned with spatial policies on spatial constraints that are consistent with planned UGBs. Therefore, FSA has significant practical promise as an approach to extract appropriate spatial policies from planning alternatives.

This chapter is organized as follows. In Sect. "What Is Form Scenario Analysis (FSA)?", conventional urban growth simulation and FSA are further introduced. In Sect. "Simulated UGBs Using Conventional Constrained CA", we employ conventional methods to simulate urban growth boundaries. In Sect. "The FSA Approach for Retrieving Policy Parameters that Fit Planned UGBs", we elaborate in detail on our new FSA approach using constrained CA. Section "Experiments in the Beijing Metropolitan Area" describes a case study in which we apply the FSA approach to four planning alternatives in the latest urban master plan for the Beijing Metropolitan Area. We also describe our research materials, including the study area, spatial constraints and planning alternatives. The form scenario analysis results are listed in Sect. "Conclusions and Next Steps". Finally, we give some discussion, a summary, and a description of the next steps of the FSA research.

What is Form Scenario Analysis (FSA)?

Cellular Automata for Simulating Urban Growth Boundaries (UGBs)

Recently, the process of simulating future urban forms using constrained cellular automata (CA) has attracted extensive attention. The results of such simulations, when viewed as alternative future urban forms based on specific assumptions of spatial constraints and policy environment, can be used as a basis for establishing UGBs.

Urban sprawl arising from rapid development is a great challenge in sustainable urban development. It is crucial to design appropriate methods for effective control of urban growth. Among various urban growth management policies, urban containment has been widely adopted to increase urban land-use density and protect open space (Nelson and Duncan 1995). Urban containment policies usually have three components: greenbelts, UGBs, and urban service boundaries (USBs) (Pendall et al. 2002). Through zoning, land development permits and other land-use regulations and methods, UGBs demarcate urban and rural land uses and aim to contain urban development within defined boundaries (Pendall et al. 2002).

In China, concepts resembling UGBs have just started to develop. These ideas are a precondition for land-use planning. The “Urban Planning Compilation Guideline”, issued by China’s State Ministry of Construction on April 1, 2006, requires that city master plans propose “development exclusion areas”, “development control areas”, and “suitable development areas”. Consequently, development exclusion areas and development control areas have become important references for identifying the boundaries of urban construction and have played a dominant role in controlling urban growth. In response to this guideline, Long et al. (2006) suggested a zoning method for the three types of areas, and established development exclusion and control areas in the Beijing Metropolitan Area (BMA). In addition, planned UGBs for urban growth management have became indispensable because the “People’s Republic of China Town and Country Planning Act” introduced on January 1, 2008 gave planned UGBs the legal authority to curb urban growth. The urban planning administrative department issues building permits based on the UGBs. Developments within the planned UGBs are legal, whereas those outside are illegal Therefore, how planners determine the urban growth boundaries is important.

The establishment of UGBs involves comprehensive consideration of various factors related to urban spatial development. In Chinese cities, traditional methods of establishing UGBs, mostly based on planners’ experience, often lack adequate scientific basis backed by quantitative analysis, and often fail to adequately control and regulate urban growth. Han et al. (2009) examined the effectiveness of the planned UGBs using multi-temporal remote sensing images and found that more new urban construction lay outside the UGBs than inside them in the case of the area within the sixth ring of Beijing from 1983 to 1993 and from 1993 to 2005. Moreover, Tian et al (2008) and Xu et al (2009) evaluated plan implementation in Guangzhou and Shanghai, respectively. Their results showed that a large number of urban developments were located outside UGBs specified in the urban master plan.

Cellular automata techniques can simulate UGBs and therefore have been widely used in modeling urban growth and as an analytical tool for complex spatio-temporal systems (Tobler 1970; White and Engelen 1993; Xie 1994; White and Engelen 1997; Clark and Gaydos 1998). Because of the complexity of urban growth, simulations of urban growth need to consider various factors that impact the urban growth process. Simple CA models only consider neighborhood effects, without taking factors the effects of planning policies into account. Therefore, many researchers have turned to constrained CA (CCA) models that allow the simulation to provide a more realistic model of urban growth (Engelen et al. 1997; Clark and Gaydos 1998; Wu 1998; Ward et al. 1999, 2000; Li and Yeh 2000; White et al. 2004; Guan et al. 2005). Institutional factors as well as development demands can be regarded as constraints in CCA simulations to model more reasonable future UGBs.

In this work, a constrained CA model incorporating macro socio-economic, locational, neighborhood, and institutional constraints is developed to simulate future urban growth as a basis for establishing UGBs. Because simulated UGBs involve various factors that impact urban growth process, stakeholders will wonder whether planned UGBs are reasonable or whether simulated UGBs are believable. For this, we suggest the use of FSA.

Form Scenario for Planned Urban Growth Boundaries

For finding spatial policy solutions for planning alternatives, particularly UGBs, two important steps are how to configure a scenario in an FSA and how to retrieve policy parameters using CCA. An FSA reflects a particular planning alternative, an urban master plan or land-use plan drawn by urban planners reflecting a planned UGB. To describe a planned UGB as a scenario, a dataset of spatial units and related attributes may be used to define an urban form as shown below:

$$Y = \Psi(U|y_{ij} \in Y, y_{ij} > p_{threshold}) \tag{1.1}$$

Y represents built-up and planned urban areas within the administrative district of city U, which is composed of developed spatial areal units y_{ij} that are assigned values over some constant, which represents a threshold of development potential in the CCA simulation. Ψ stands for the function used to determine places that will be developed based on development probability. y_{ij} stands for the land occupation status at space ij. $y_{ij}=1$ means that space ij is developed (built up), while $y_{ij}=0$ means undeveloped.

FSA, as a vision of future UGB, can be expressed as

$$\text{FSA} = f(X, A)\ x_{ij} \ \in\ X, \text{a}_{ij} \in A \tag{1.2}$$

In Equation (1.2), x and a are explicit spatial variables with ij subscripts representing spatial locations. A stands for the spatial constraints with respect to factors limiting urban sprawl, such as natural conservation areas, river buffer zones, steep slopes and others features. X, a temporal dynamic variable, is described as a "policy parameter", standing for the intensity of the impact that spatial constraints A exert when the corresponding policy is implemented.

We need affirm three basic premises to apply FSA to urban growth process, considering data availability and calculation time. First, the function f should be based on multi-criteria evaluation (MCE). Second, X and A should remain static from the initial step to the end of the simulation. Third, X is homogenous in the urban space.

In current research on urban growth scenario analysis, there are several competing models. For instance, Klosterman (1999) developed the planning support system "*What if?*" in which *A* represents spatial characteristics like soil conditions, flood control and transportation, and *X* stands for the force with which spatial policies related to *A* are implemented. Landis (1994, 1995) and Landis and Zhang (1998a, 1998b), respectively, developed the CUF (California Urban Future model) and CUF-2, in which *A* stands for spatial characteristics affected by governmental policies on location, environmental conditions, land-use control, zoning, existing development density, and accessibility to development land units (DLUs). *X* stands for the intensity of the effect of implementing related spatial policies. In our current way of thinking about urban growth scenarios, *X* and *A*, input together as one scenario, are used to estimate the corresponding UGB, *Y*.

Our FSA approach can be regarded as the inverse procedure of existing thinking about scenario analysis of urban growth. In FSA, the planned UGB is used as the base scenario. Urban planners are concerned with how to make planned urban forms become reality. From a planner's perspective, FSA is a method with the potential to identify policy solutions that can control urban growth boundaries to match reasonable planned alternatives. The impact of urban policies is their power to shape the future spatial features of an urban area. The FSA we propose can affirm what urban policies can make planning alternatives come to fruition. Before verifying a planned UGB based on FSA, we simulate the process of identifying UGBs in the Beijing Metropolitan Area using a conventional CCA process.

Simulated UGBs Using Conventional Constrained CA

Planners can gain insight on UGBs using the constrained CA model. First, spatial constraints considered by planners when establishing UGBs can be embedded as variables in the constrained CA. A CCA developed in that way will help planners to quantify the influence of these constraints on future urban forms. Second, planners also consider economic demands, which can be represented by land-use demand as a exogenous variable in the CCA simulation. Third, the constrained CA model can be applied for forecasting future urban growth based on historical trends, allowing planners to establish UGBs using the simulated results.

The basic concept of the CCA model as applied to practical urban development can be divided into two general steps. First, the government identifies total land-use demand and allocates that demand to an urban area. The constrained CA then simulates the probability of urban growth for all individual cells in different stages and identifies the spatial distribution of those cells that are predicted to become developed. Elements influencing the urban growth process in CCA models are selected to incorporate a hedonic model. They include the following:

1. Locational constraints: The attractiveness (potential force) of town centers at all levels the central city (*f_tam*), new city areas (*f_city*), towns (*f_town*), the attractiveness of rivers (*f_river*), and the attractiveness of roads (*f_road*). Locational constraints may vary depending on the study area and research purpose.

2. Neighborhood constraint: The development potential affected by the neighborhood (*neighbor*), identified as the ratio of developed cells within the neighborhood. The Moore neighborhood configuration is used in constrained CA, with each cell having nine cells in its neighborhood, including itself.
3. Institutional constraints: agricultural land use (*agri*), and development exclusion areas (*conf*). *agri* indicates suitability for cultivation and can be used to simulate the government's control on farmland to keep it from being encroached on by urban development. *conf* indicates spatial policy, where urban development is forbidden by eco-space protection or disaster prevention regulations.

Based on the above constraints, we use a multi-criteria evaluation (MCE) set of rules for status transition in the CCA as follows:

$$
\begin{aligned}
&1.\ LandDemand = \sum_t stepNum^t \\
&2.\ s_{ij}{}^t = w_0 \\
&\qquad + w_1{}^* f\_tam_{ij} + w_2{}^* f\_city_{ij} + w_3{}^* f\_town_{ij} \\
&\qquad + w_4{}^* f\_river_{ij} + w_5{}^* f\_road_{ij} \\
&\qquad + w_6{}^* conf_{ij} + w_7{}^* agri_{ij} \\
&\qquad + wN^{**} neighbor^t_{ij} \\
&3.\ p_g{}^t = \frac{1}{1 + e^{-s_{ij}{}^t}} \\
&4.\ p^t = \exp\left[\alpha\left(\frac{p_g{}^t}{p_g{}^t{}_{\max}} - 1\right)\right] \\
&5.\ \text{for } inStepID = 1 \text{ to } stepNum \\
&\qquad if p_{ij}{}^t = p^t{}_{\max} then V_{ij}^{t+1} = 1 \\
&\qquad p_{ij}{}^t = p_{ij}{}^t - p^t{}_{\max} \\
&\qquad p^t{}_{\max} \text{ update} \\
&\qquad \text{next } inStepID
\end{aligned}
\tag{1.3}
$$

where *LandDemand* is the total area to be developed in the future; *stepNum* is the number of cells to be developed in each iteration; $s_{ij}{}^t$ is suitability for development; w is the weighting coefficient for each constraint; $p_g{}^t$ is the initial transition probability; $p_g{}^t{}_{\max}$ is the maximum of $p_g{}^t$ in iteration t; α is the dispersion parameter, which ranges from 1 to 10, p^t is the final probability; *inStepID* is the ID of the sub-iteration; V_{ij} is the status of the cell; and $p^t{}_{\max}$ is the maximum p^t in iteration t. The cells to be developed in each iteration are those having the greatest development probability based on development suitability, which is determined by constraints and the weights they are assigned.

These status transition rules differ from those used by Wu (2002), which can be described by the equation $P_c{}^t = P_g{}^* con(s_{ij}{}^t = suitable)^* \Omega_{i,j}{}^t$. In Wu (2002), the user sets the neighborhood parameter Ω by the author's experience, rather than calibrated using historical observed forms. In this chapter, the role of the neighborhood constraint is included in the calculation of the land-use suitability, weighted together with other spatial constraints as in (1.3). This enables the comparison of the role of the neighborhood with other spatial constraints. The simulated urban form will be compared point-by-point with the observed urban form to obtain a *Kappa* index, which serves as a goodness-of-fit indicator. *Kappa* was initially introduced by Cohen (1960) and adapted for accuracy assessment in remote sensing applications by Congalton and Mead (1983). In this chapter, the *Kappa* index is calculated to analyze the similarity between observed and simulated urban forms.

The CCA simulation process shown in Fig. 1.1 is based on established status transition rules. First, the model sets the input variables and calculates the *stepNum* parameter based on the total land-use demand. Then land-use suitability, the initial transition probability, and the final transition probability are calculated. The cell with the maximum final transition probability is identified in space in the allocation process (Fig. 1.1, in grey). The model iterates until the entire simulation process is finally completed.

Constrained CA is used to estimate different future UGBs based on different scenarios devised by planners. The planners' perspectives and preferences can be embedded as constraints in the CCA model to establish UGBs. For instance, expected future urban growth rate and residential standard per capita can be represented as land-use demand in the socio-economic constraints in Fig. 1.1.

The results of the CCA simulation at some time (iteration or step), which are an estimate of that stage of urban growth, can be regarded as UGBs in the corresponding development period. The simulated UGBs, in raster format, can be converted into vector format consisting of many polygons. Small, non-compact polygons (<1 ha) should be first eliminated since they are not feasible for urban development. The remaining polygons can then be regarded as UGBs for different urban hierarchies (e.g., the central city, new cities, or small towns). The areas to be developed can be calculated by subtracting the existing urban construction areas from the UGBs thus established.

The FSA Approach for Retrieving Policy Parameters that Fit Planned UGBs

Policy Parameters and Constraints in Constrained CA

Whether the results of an FSA (a planned UGB) can be regarded as a scenario condition remains unexplored in recent literature on constrained CA. We attempt to follow the transition rules of conventional constrained CA when simulating urban growth with FSA. As usual, historical urban forms (*Y*) and constrained spatial features (*A*) are required to identify parameters (*X*) for the constrained conditions (*A*). In the routine model calibration process, historical urban forms are employed to

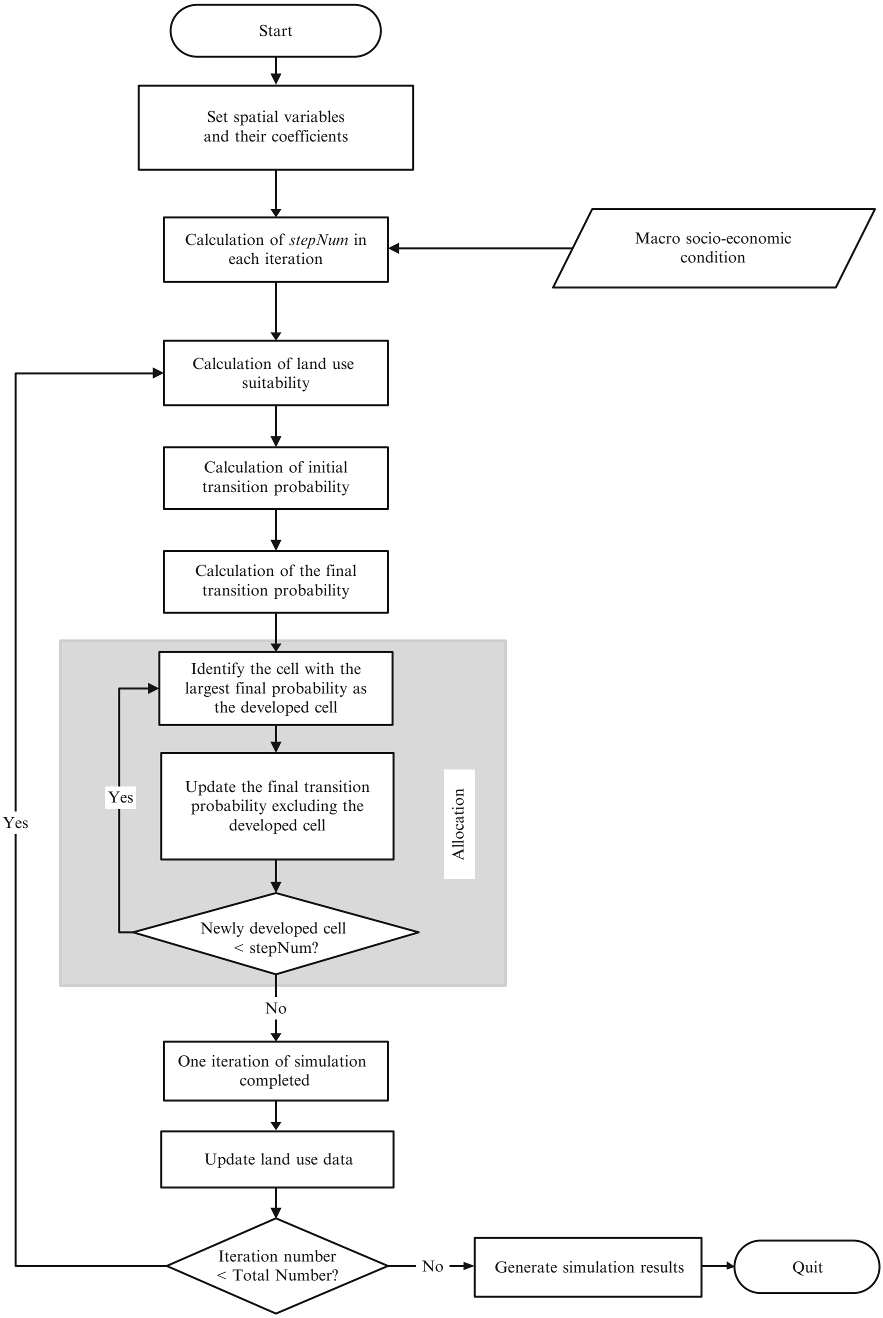

Fig. 1.1 The CCA flow diagram

retrieve X, while in FSA, retrieving X is done using the planned UGB. Therefore, identifying policy parameters (X) through FSA using constrained CA is possible.

Estimated parameters based on an historical urban form can be employed to conduct a simulation, and we can check whether the parameters can replicate the historical form. When the parameter X is positive, the corresponding spatial constrained form A should be encouraged, otherwise A should be rejected. Thus, policy implications can be drawn from the estimated parameters.

Policy Solutions for Planning Alternatives Using FSA

As mentioned above, identification of policy parameters X in an FSA can be used in model calibration for constrained CA simulations, where logistic regression, artificial neural networks (ANN), genetic algorithms (GA), and nested loops are widely employed. The evaluation indicator for the consistency of the form scenario (Y) and current spatial and institution constraints (A) should be established in the FSA. As input to the constrained CA, X is used to get the simulated UGB (Y'). The *Kappa* index, as an evaluation indicator, compares the simulated UGB Y' with the form scenario Y cell by cell and evaluates the goodness-of-fit. A *Kappa* of less than 80% stands for a no-solution condition, meaning that there are no policy parameters that can be used to realize the predefined form. Generally speaking, FSA solutions can be expressed as $\{X|Y' = f(X, A), Kappa(Y, Y') \geq 80\%\}$.

As general constrained CA simulation model, the conceptual constrained CA model for FSA can be shown as

$$y_{ij}^{t+1} = f(y_{ij}^t, G_{mac}, A, X) = f(y_{ij}^t, G_{mac}, A_{loc}, A_{ins}, A_n^t, X) \tag{1.4}$$

in which y_{ij}^{t+1} and y_{ij}^t, respectively, are the cell status at ij at times $t + 1$ and t, and f is the transition rule of constrained CA. There are four types of constraining conditions in the urban growth process. They are total land-use demand G_{mac} (which is a globally constraint, explicit non-spatial variable, with no corresponding policy parameter X), locational constraints A_{loc}, institutional constraint A_{ins}, and neighbor hood constraint $A^t{}_n$. Locational and institutional constraints are assumed to remain static during the urban growth process, and the total land-use demand reflects the total number of built-up cells to be developed. The neighbor hood constraint $A^t{}_n$, however, changes over model iterations during the constrained CA simulation.

For identifying policy parameters that fit a particular planning alternative, it is possible to retrieve the parameter set from a planned UGB y_e using MCE, just as is done when estimating parameters using historical urban forms in routine constrained CA. FSA, when used as a planned UGB, is a form predicted to develop from the current urban form. The total number of cells to be developed, compared to the current urban form, is defined as *LandDemand*, and $stepNum^t$ is the number of cells developed in iteration t reflecting the land-use demand. We assume that $stepNum^t$ is kept constant through the entire simulation period as follows.

$$\mathrm{stepNu}m^t = \frac{\mathrm{Y_e} - \mathrm{Y_s}}{\mathrm{t}} \tag{1.5}$$

In which Y_e and Y_s are, respectively, a scenario form and a current form, and t is the simulated time span. In our constrained CA, we integrate the methods of Wu (2002) and Clark and Gaydos (1998), combining their strengths, to identify the status transition rules. To reduce model estimation computation time, X is divided into two types of parameters, the temporal-dynamic neighbor hood parameter x_n and other temporal-static parameters x_k that represent spatial constraints. We can estimate x_k via logistic regression. Then, x_n can be estimated by finding the form scenario Y_e with the largest *Kappa*, compared with the simulated form Y' using the *MonoLoop* approach (details in Long et al. 2008).

In the following sections, the constrained CA will be applied empirically to the Beijing Master Plan of 2020 to examine the consistency of four planning scenarios and existing spatial policies as well as to identify required policy parameters.

Experiments in the Beijing Metropolitan Area

Study Area

Constrained CA has proven to be suitable to simulate the urban growth of the Pearl River Delta, where growth is quite rapid (Li and Yeh 2000, 2002). The Beijing Metropolitan Area (BMA) has experienced rapid urbanization since the 1978 Reform and Opening Policy was adopted by the central government regulating both GDP and population. The GDP in 2006 was 787 billion CNY, 83.7 times more than in 1976, which was 9.4 billion CNY. The population in 2006 was 15.81 million, 1.9 times the 1976 figure of 8.29 million (Beijing Statistical Yearbook 1987, 2007). Interpreted thematic mapper (TM) images show that the urban built-up area in 2006 was 1,324 km^2 (Fig. 1.2), nearly three times of that in 1976, which was 495 km^2. Moreover, urban growth is predicted to keep increasing for two decades according to the official report of the BMA government. Therefore, stakeholders and decision makers are concerned with how to make the planned UGB become a reality.

It has become necessary to alleviate urban sprawl by establishing UGBs for different city levels. A CCA with cell size of 100 m (a total of 1,640,496 cells in the whole BMA) is used to model the BMA. The model is developed using Python based on the ESRI Geoprocessing module and has a discrete temporal iteration corresponding to 1 month in the real world. The CCA used in the BMA can simulate urban growth based on various urban development spatial policies. The results of

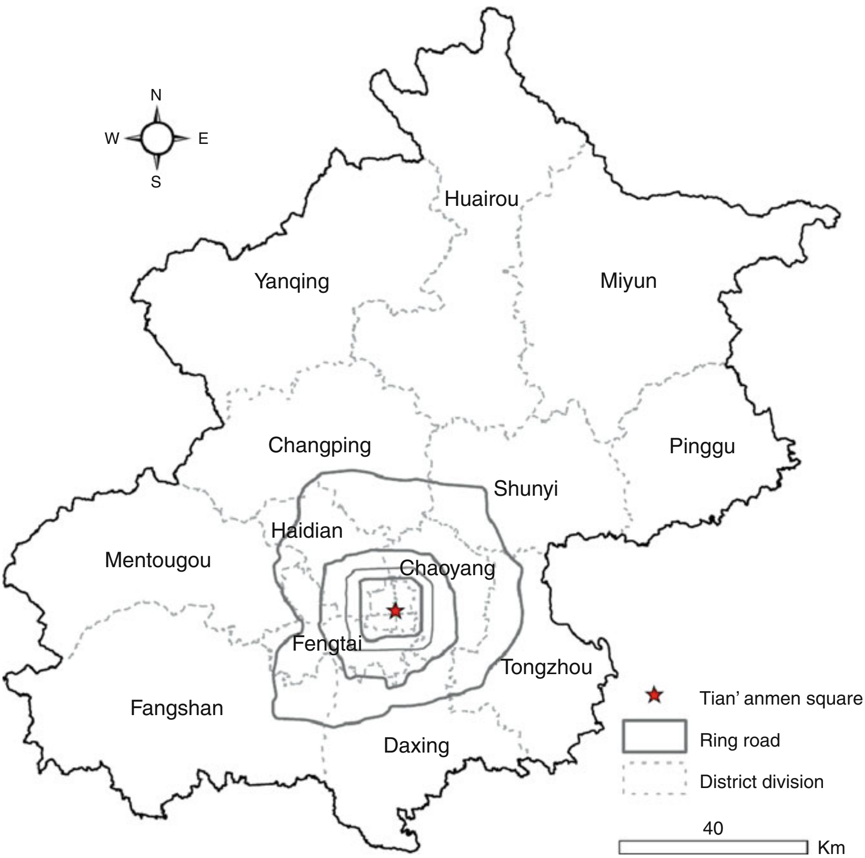

Fig. 1.2 The CCA study area

simulated BMA development can be used as a basis establishing UGBs. In the Beijing City Master Plan (2004–2020) (BCMP), the UGBs were determined by urban planners to meet the land-use demand for development, such as industrial development projects, population growth, and eco-space protection.

Data required for the CCA are shown in Table 1.1 and Fig. 1.3. In the table, the datasets *f_road* and *form* are interpreted from TM images. The locational constraints have been standardized to range from 0 to 1, with higher values representing greater development potential. The locational constraint a_k, which uses the corresponding spatial feature class as a data source, is processed using the "Distance/Straight Line" toolbox of the Spatial Analyst extension in the ESRI ArcGIS package to acquire $dist_k$, which is in turn $dist_k$ used to calculate the corresponding potential attractiveness. For institutional constraints, there are development exclusive policies a_6 and a_7, which describes how suitable an area is for the application of agricultural development policies. For institutional constraints, a value of zero for a development exclusion area means that all urban development is prohibited, and the land

Table 1.1 Statistical descriptions of CCA variables

Type	Variable	Name	Min	Max	Ave.	Std. D	Data source
Locational constraints	a_1	*f_tam*	0	1	0.037	0.091	Basic data spatial analysis using GIS
	a_2	*f_city*	0	1	0.214	0.196	
	a_3	*f_town*	0	1	0.531	0.198	
	a_4	*f_river*	0	1	0.789	0.162	
	a_5	*f_road* (1991)	0	1	0.818	0.187	1991-5-16 TM image interpretation
		f_road (2004)	0	1	0.827	0.190	2004-5-29 TM image interpretation
Institutional constraints	a_6	*conf*	0	1	0.570	0.495	Beijing Municipal Planning Commission (2007) (for details see Long et al. 2006)
	a_7	*agri*	0	1	0.418	0.237	Beijing Planning Commission (1988)
		form (1991)	0	1	0.050	0.216	1991-5-16 TM image interpretation
		form (2004)	0	1	0.080	0.266	2004-5-29 TM image interpretation
		form (planned)	0	1	0.150	0.353	Beijing Municipal Planning Commission et al. (2006)
Neighbor hood constraint	$a_n{}^t$	$Neighbor^t{}_{ij}$	0	1			Development intensity in neighborhood; calculated by CA
Macro constraint	*stepNum*	*LandDemand*					Socio-economic development plan

For details of the calculation approach, see Long et al. (2006)

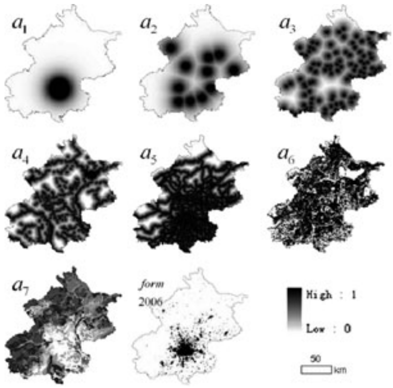

Fig. 1.3 Maps of spatial constraints and the 2006 urban form of the BMA

grade identifies how suitable areas are for farming, with larger values indicating lower cultivability. The institutional constraints are extracted from the planning drawings noted in Table 1.1.

Here, we first estimate the UGBs using constrained CA and compare it with the current planned and implemented UGBs in the BCMP. Second, we test the form scenario analysis approach on the BMA to identify policies will affect planning alternatives, in particular the current planned UGBs in the BCMP.

Simulated and Planned UGBs

Parameter Calibration

Historical data is used to retrieve information on urban transition in order to determine the parameter values to use for status transition. We use data from 1991 to 2004 as historical background information for parameter calibration. This requires three steps:

1. For 1991 and 2004 the numbers of developed cells are 80,343 and 125,928 respectively. There are 156 months in this period, and so developed cells is about 292 for each iteration (*stepNum*).
2. The weights of seven spatial variables $x_{0\text{–}7}$, excluding *neighbor* for 1991–2004 are calibrated using logistic regression. From the regression results (see Table 1.2), the significance levels for all variables are less than 0.001 the *Kappa* index is 43.427%.
3. The *MonoLoop* method is used to calibrate the weighting coefficient x_n for *neighbor* with the maximum *Kappa* index. Parameter x_n is set as 13 for the simulations. The *Kappa* index for this weight varies up to 81.419% due to the introduction of the neighborhood effect.

The calibration results are shown in Table 1.2. When the urban form in 1991 is used as the initial status of the model and the parameters in Table 1.2 are input to the

Table 1.2 Calibrated parameters for urban growth in 1991–2004

Name	Value
stepNum	292
x_0	−11.877
x_1	14.266
x_2	2.870
x_3	−2.595
x_4	1.149
x_5	6.743
x_6	1.084
x_7	−0.610
x_n	13.000

CCA, the resulting simulated urban form for 2004 is tested and found to be quite similar to the observed urban form in 2004. The results prove that the CCA is appropriate for simulating future urban growth in the BMA.

Urban Growth Simulation for 2020

The area of planned UGBs in the BCMP is 2388 km^2 expected to be developed till 2020. There are 192 months between 2004 and 2020, and so the *stepNum* value is 588. The baseline urban growth from 2004 to 2020 is continued development at the same rate as from 1991 to 2004. The weightings of all the spatial variables, including *neighbor*, are kept as the same as the calibrated historical values.

According to the simulated UGBs based on the assumption that urban growth will continue as it had up until 2004, UGBs for the central city and 11 new cities are shown in Fig. 1.5. The UGBs of the 142 small towns in the area are not listed here due to limited book space.

We compare the simulated and planned UGBs in the BCMP (see Table 1.3 and Fig. 1.4). The total areas of both versions for the central city and new cities are similar, and both are significantly larger than the 2004 area. If the historical development trend from 1991 to 2004 continues from 2004 to 2020 (the expected implementation period of the BCMP), urban land-use expansion in the southern parts of Beijing (such as Daxing and Yizhuang) will be much larger than planned in the BCMP. Meanwhile, expansion in the north (such as in Changping and Huairou) will be less than projected by the BCMP. The differences occur because the planned form reflects the Beijing government's policy trend toward development in the southern areas. Thus, it is important to take into account future urban development policies to predict the UGB.

The UGB simulated using constrained CA, with the urban form from 2004 as its initial condition and the calibration results from 1991 to 2004 as model inputs is illustrated in Fig. 1.4 (left). The *Kappa* index of the simulation results and planned UGBs is 68.309%, which means there is a relative high degree of difference between the simulation and the plan as can be seen in Fig. 1.4 (right). This also demonstrates that the future urban form and the planned UGBs will be somewhat

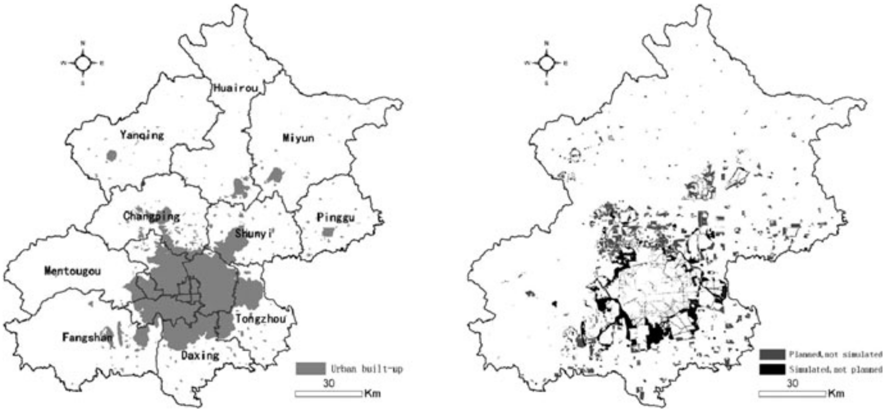

Fig. 1.4 Simulated UGB in 2020 (*left*), comparison with the planned UGB (*right*)

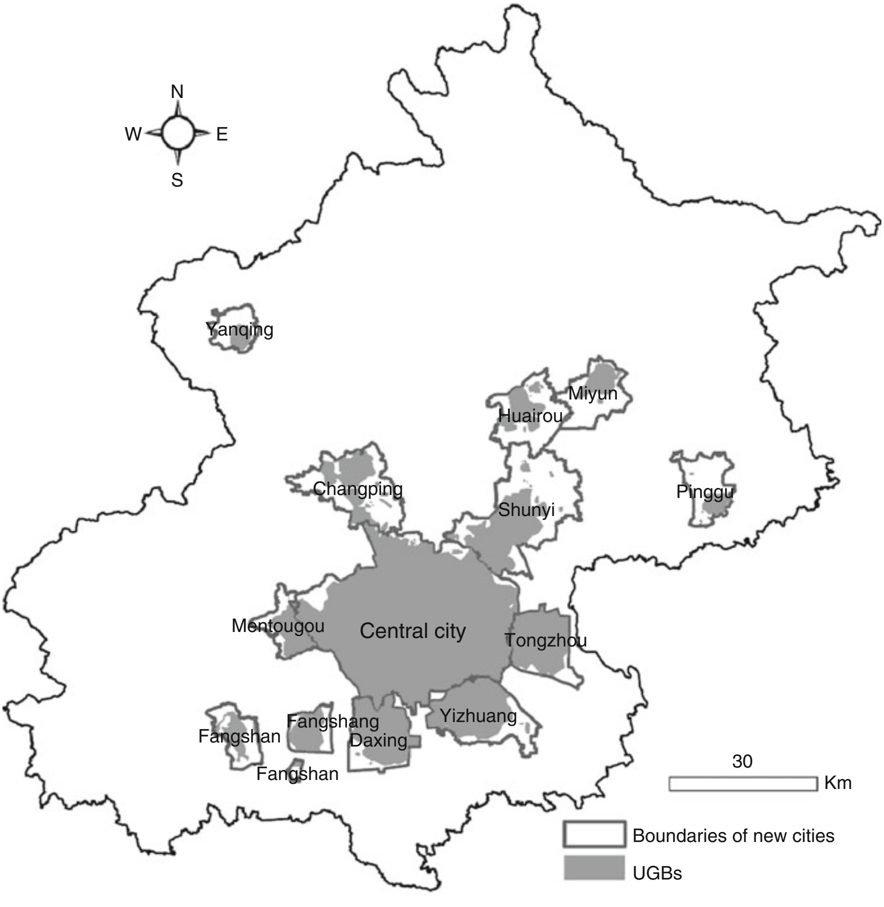

Fig. 1.5 Calculated UGBs for the central city and new cities using the simulated urban form

Table 1.3 UGB areas of the central city and new cities (area unit: km^2)

Name	Area (2004)	Simulated UGBs	Planne UGBs	Simulated-planned	$\frac{\text{Simulated}-\text{Planned}}{\text{Planned}}$ (%)
Central city	708.9	1033.0	984.2	48.8	5.0
1. Shunyi	50.2	157.2	180.2	−23	−12.8
2. Yizhuang	25.1	156.8	116.6	40.2	34.5
3. Tongzhou	42.7	133.6	109.5	24.1	22.0
4. Daxing	55.8	132.3	84.7	47.6	56.2
5. Fangshan	52.6	86.4	88.8	−2.4	−2.7
6. Chanping	35.7	82.0	109.8	−27.8	−25.3
7. Mentougou	21.2	52.9	35.5	17.4	49.0
8. Huairou	20.0	48.8	80.0	−31.2	−39.0
9. Miyun	18.9	34.8	46.9	−12.1	−25.8
10. Pinggu	13.1	19.8	31.0	−11.2	−36.1
11. Yanqing	7.3	17.3	20.2	−2.9	−14.4
Sum	1051.7	1954.7	1887.4	67.3	3.6

different, and reconfirms the current observation that partially planned UGBs tend to fail. Moreover, we assume that urban growth trends seen up to 2004 will continue. Thus, the simulated urban form will be different if growth differs during the simulated time period. From this viewpoint, how to set parameters based on future urban growth trends is a key point for identifying corresponding UGBs, for which we suggest employing FSA.

FSA Simulation and Policy Implications

How various constraints are distributed in the BMA influences the pattern of possible future urban growth (see Fig. 1.2). We can easily and directly recognize urban forms corresponding to every single constraint. Considering the combination of constraints and the currently existing urban form, which features central city sprawl, the BMA's future urban form tends to sprawl further around the central city in the plain area, with scattered developed patches in the mountain area. To obtain insight into the BMA's future urban growth pattern, we will set form scenarios (planning alternatives) and identify policy parameters required to produce those forms using constrained CA.

Planning Alternatives – Planned UGB as FSA

There have been five versions of urban master plans for the BMA since 1958. These were issued in 1958, 1973, 1982, 1992, and 2004 (Beijing Municipal Planning Commission et al. 1949). With respect to the 1992 version plan for 1991–2010, Han et al. (2009) argued that up to 51.8% of the urban development from 1991 to 2005 within the sixth ring road area was beyond the planned UGB. The actual urban developments were significantly inconsistent with the planned form in the BMA because urban development policies have been changing and land-use potential has not been taken into account.

The goal of the 2004 version for the BMA is to grow to a metropolis with a population of 18 million, and a developed land area of 2,300 km^2, with an urban spatial structure of "Two axes, two belts, and multi-sub-centers". This plan has four planning alternatives, as shown in Fig. 1.6. The alternatives have almost equal total demand for land-use development but different spatial layouts. During the constitution and approval of the plan, there was no means to efficiently determine the probability that each alternative would prove to be the eventual urban form.

The four planning alternatives (planned UGBs) in the BMA are as follows:

- Alternative A (Y_A), the alternative approved by the State Council of the P.R. of China (see Beijing Municipal Planning Commission et al. 2006), is

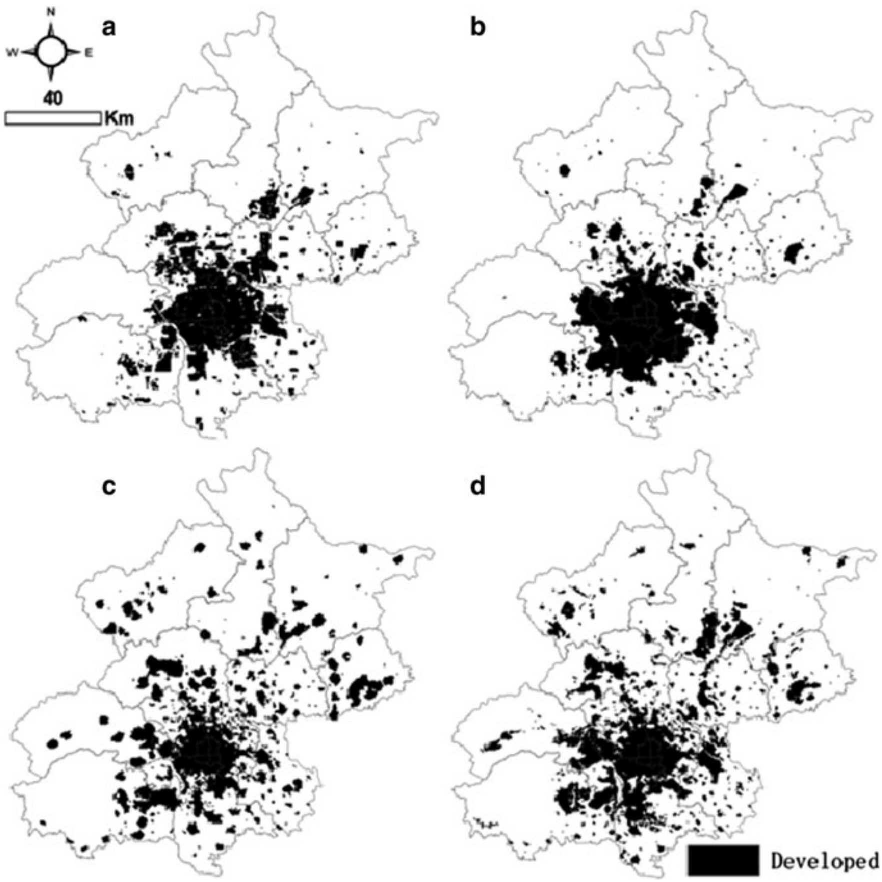

Fig. 1.6 Four planning alternatives in the BMA

characterized by a focus on preventing the central city from over-sprawling and on promoting the development of new cities.

- Alternative B (Y_B), the "sprawl" alternative, termed Tandabing (circle-spread) in Chinese, is characterized by promoting development in the central city and controlling development in new towns.
- Alternative C (Y_C), the "grape-cluster" alternative is characterized by promoting development both along transport corridors and around small towns.
- Alternative D (Y_D), the "sustainable" alternative, is characterized by preventing construction in forbidden areas and protecting high-quality farmland from been encroached upon, resulting in a more dispersed form.

We applied the FSA approach using a constrained CA model to find concealed trends in spatial policies necessary for the planned alternatives. The total number of iterations (*stepNum*) is 168 ([2,020-2,006]*12), with each iteration modeling 1 month. Y_s is equal to 5,011 if the urban form of 2006 (Y_{2006}) is used as the baseline year. In Alternative A, $Y_e = 9{,}254$ stands for the total number of developed cells in the year 2020, and *stepNum* is equal to 25 ([9,254 – 5,011]/168). The values of *stepNum* identified for the other planning alternatives are listed in Table 1.2. Parameter X is identified by applying an approach that integrates logistic regression and *MonoLoop*. For estimating x_i (x_0 to x_7) through logistic regression, we used the independent variables a_1 to a_7 in Table 1.1, excluding $a_n{}^t$. Via logistic regression x_i (x_0 to x_7), the regression coefficients are then identified. Using *MonoLoop*, x_n, the neighborhood effect parameter can be identified, and we can compare the planned UGBs A, B, and C with the simulated UGBs Y_A, Y_B, and Y_C using the *Kappa* index. The simulated urban form Y' can be generated using the constrained CA with the input parameters listed in Table 1.4, including *stepNum*, x_{0-7}, and x_n. When *Kappa* is greater than or equal to 80%, the planning alternative is deemed valid and the parameters identified can be used to realize the planning alternative. When *Kappa* is less than 80%, the planning alternative is deemed not to be validated.

Related Policy Implications

The results of the policy parameter identification, together with the *Kappa* index, are listed in Table 1.4. All the independent variables are significant at the 0.001 level. The *Kappa* indices for Alternatives B, C, and D are all greater than 80%. The cell-by-cell comparison of Y' and Y (the planning alternative) is shown in Fig. 1.7. The confusion matrix is shown in Table 1.5. As a result, the *Kappa* index for Alternative A is as low as 67.5%, indicating that alternative A cannot be achieved using constrained CA in the current policy context because of the effect of existing policies on spatial constraints. The reason alternative A cannot be realized using constrained CA may lie in the spatial distribution of the constraints imposed on the urban space.

Alternatives B, C, and D match relatively better with the simulated UGBs in the cell-by-cell *Kappa* validation. Policy implications for the validated planning

Table 1.4 Policy parameters identification results for four planning alternatives in the BMA

Variable	Alternative A	Alternative B	Alternative C	Alternative D	Historical form
Developed cells	9254	9270	9895	10,679	5011
stepNum	25	25	29	34	9
x_0	−8.700	−30.696	−63.599	−55.624	−12.263
x_1	15.268	54.558	15.106	20.849	11.782
x_2	3.575	10.294	10.046	9.701	2.490
x_3	−0.717	5.272	31.639	7.807	−1.872
x_4	4.105	8.765	24.348	11.622	7.574
x_5	1.368	6.027	7.627	8.113	0.917
x_6	1.193	3.672	4.078	23.000	1.535
x_7	−2.396	5.066	6.094	12.003	−1.179
x_n	15	17	9	7	20
Kappa (%)	69.4	91.8	85.0	85.8	67.5
Valid	False	True	True	True	False

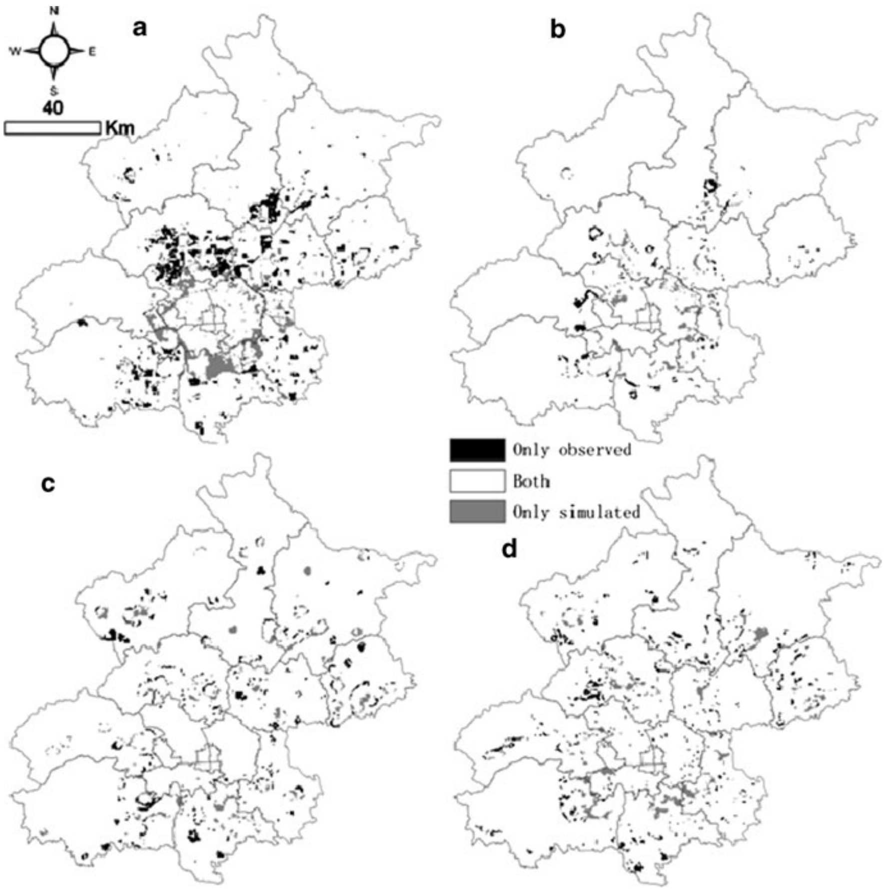

Fig. 1.7 Comparison of simulated urban forms with planning alternatives in the BMA

Table 1.5 Confusion matrix of planning alternatives and simulated urban forms

Alternative	Observed Planned	0	1	SUM	User accuracy (%)
A	0	53,919	2428	56,347	95.7
	1	2440	6826	9266	73.7
	SUM	56,359	9254	65,613	
	Producer accuracy (%)	95.7	73.8	Overall accuracy is 92.6%	
B	0	55,482	620	56,102	98.9
	1	793	8650	9443	91.6
	SUM	56,275	9270	65,545	
	Producer accuracy (%)	98.6	93.31	Overall accuracy is 97.8%	
C	0	54,391	1256	55,647	97.7
	1	1259	8639	9898	87.3
	SUM	55,650	9895	65,545	
	Producer accuracy (%)	97.7	87.3	Overall accuracy is 96.2%	
D	0	53,590	1273	54,863	97.7
	1	1276	9406	10,682	88.1
	SUM	54,866	10,679	65,545	
	Producer accuracy (%)	97.7	88.1	Overall accuracy is 96.1%	

alternatives can be presented based on the results of policy parameter identification. Three aspects of identifying policy implications are as follows:

1. Parallel comparison of parameters within a planning alternative: For Alternative B, built-up land is developed at a rate of $25 \times 12/4 = 75$ km^2/year from 2006 to 2020 according to *stepNum*. Therefore, assuming 100 m^2 of built-up land per capita, the population increase would be 750,000 people per year. Other parameters can also be compared in parallel, and larger parameters will require the implementation of more intense policies to realize the alternative. For instance, Alternative B suggests promoting the development of the central city, new cities, and riverside areas over other spatial policies.
2. Parallel comparison of parameters across planning alternatives: By comparing the same parameter in various planning alternatives, differences in necessary policy implementation of can be conveniently identified. For instance, x_1 of Alternative B is greater than that of Alternative C, meaning that to realize Alternative B, policies regarding the development of the central city will need to be implemented much more strenuously than to realize Alternative C. In the same way, much more intense protection against construction in prohibited areas will be needed to realize Alternative D than Alternative C since parameter x_6 in Alternative D is significantly greater than in Alternative C. The expansion of neighboring development should also be controlled to realize planning alternatives, especially Alternatives C and D.

The results of calibrating Alternative A, however, demonstrate that no policy parameter can be used to make this planned UGB become a reality. For this condition, either Y_A or A should be adjusted to align development policies with the predefined plan. By adjusting the spatial distribution of constraints affected by development policies such as the transportation network, or eco-space distribution, planners can experiment with the constrained CA model until the planned UGBs can be achieved.

This case study shows that a CCA simulation can be employed with FSA to determine required spatial policies for planned urban forms. In urban planning practices, UGBs tend to reflect the planners' preferences, knowledge, and possible urban development policy changes that may occur in the future, but lacking of consideration of land-use potential that geospatial policy analysis. Inconsistencies between planned urban growth patterns and practical development often imply that it is impossible to achieve the planned UGBs. FSA enables us to detect precautions that should be taken in planning practice.

Conclusions and Next Steps

In this chapter, we attempted to show how planning alternatives could be used as scenario conditions based on which discussions of whether UGBs developed by planners are feasible within the current framework of development policies regarding land-use, geographical conditions, and institutional controls. First, we proposed a method to establish UGBs using constrained CA. After calibrating the model using historical data, we simulated future urban forms based on current urban growth trends, and recommended new UGBs based on the simulations. The spatial distribution and UGBs estimated in the CCA simulation differ significantly from the UGBs specified in the Beijing City Master Plan (2004–2020). Our results reveal shortcomings in the CCA process of simulating urban form if it does not consider possible policy changes and planners' thinking about future urban development policies. Second, we incorporated constrained CA into the form scenario analysis approach, and successfully used four planning alternatives from the Beijing Metropolitan Area master plan as a case study to demonstrate our approach.

Combining FSA with constrained CA is a breakthrough in the application of CA. It can be employed to solve problems faced by planning departments and planners in China. Using FSA, planners can also evaluate how well planned UGBs and development policies fit together. Nowadays in China, planning implementation evaluation (PIE) is required in urban planning practice to examine how well real urban spatial developments agree with planned forms after several years of plan implementation. Existing PIE reports are not optimistic because development has sometimes broken out of the planned forms. Rather than PIE, FSA can be conducted at the very beginning of the planning process to examine the potential success of plan implementation under existing urban development policies and thus increase the likelihood that the planned form will become a reality.

We bring up three ways to simplify the FSA process in this chapter, including not taking into account spatial-temporal policy dynamics in the model parameters, as well as not separating development into various urban land uses, such as residential, commercial, and industrial types. To simulate urban growth much more factually, we suggest that further research focus on the current simplifications. The spatial and institutional constraints *A*, as well as the policy parameter *X*, can be included in FSA to identify not only how intense policy implementation must be, but how policies may need to vary in different areas. On the other hand, spatial heterogeneity of the policy parameter needs to be investigated since various studies show that the forces driving urban growth in China vary by sub-region in the metropolitan area (Liu et al. 2005; Li et al. 2008). Furthermore, we suggest that agent based modeling (ABM) be applied in FSA to represent planners' and other decision makers' preferences in another FSA research stream (Ligtenberg et al. 2001; Saarloos et al. 2005).

We did not investigate the sensitivity of policy parameters in FSA of this chapter. As our further research, we will undertake a global sensitivity analysis for FSA incorporating a regionalized sensitivity analysis approach called the HSY algorithm (Spear et al. 1994) that is more able to detect the parameters' global dynamics than local one-at-a-time (OAT) sensitivity analysis. Policy implications can meanwhile be identified in the global sensitivity analysis. Furthermore, with global sensitivity analysis it is possible to identify all the policy parameters that meet *Kappa* values over 80% instead of just finding the unique optimal solution described here.

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