Policy parameters identification and regional sensitivity analysis for predefined urban form incorporating constrained CA and HSY algorithm

Ying Long
School of Architecture, Tsinghua University
Beijing Institute of City Planning
Beijing, China
longying1980@gmail.com

Zhenjiang Shen
School of Environment Design, Kanazawa University
Kanazawa, Japan

Qizhi Mao
School of Architecture, Tsinghua University
Beijing, China

Abstract—The paper proposes an approach to identify the required policy parameters for the predefined binary urban forms. In current Chinese planning practices, planned forms were occasionally broken through by the practical urban growth driven by both institutional forces and market incentives. Few related researches pay attention to the developing pathways identification for the desired or feared urban form. Therefore, we aim to explore the problems faced by the planning practice and theory. A novel approach integrating constrained cellular automata (CA) and HSY algorithm is developed to identify policy parameters for predefined urban form as well as global sensitivity analysis of the model. The approach was firstly tested in a virtual space with four predefined forms and six constraints including point, line and polygon types, positive and negative respectively for each type. The approach was demonstrated to be capable to identify developing pathways for predefined forms respectively. Hereafter, the approach was also tested in the Beijing Metropolitan Area for four planned form scenarios with seven spatial policies. Through the introduction of parameter identification into planning practices, the impossible form can be eliminated at the very first of the urban plan to guarantee the implementation of the planned form. Moreover, the identified policy parameters can be used by decision makers to design the exact developing pathway towards the desired form.

Keywords- ***desired urban form, developing pathway, cellular automata, constraint, HSY algorithm***

I. INTRODUCTION

The paper aims to propose an approach to identify the required policy parameters for predefined form as the updated paper of Long et al (2009), which focused on the optimal parameters solution for the predefined form. Recently, the reports on the urban growth simulation using constrained CA (Wu, 1998; Ward et al, 2000; Yeh and Li, 2001; He et al, 2008) simulate urban sprawl phenomenon within an urban area, which is trying to predict a reasonable urban form. However, most of the impact factors are only the land use suitability and accessibility that are not enough to argue a reasonable urban form. For the sustainable development in the urban area, urban strategic policies such as the compact city (Breheny, 1992; Jenks et al, 1996; Gordon and Richardson, 1997; Kii and Koi, 2005), smart growth (Shen and Zhang, 2007; Howell-Moroney, 2008), and low carbon city (ISOCARP, 2009), also concentrate on the urban form, which cannot be simply generated by the land use suitability, accessibility and other factors in the existing constrained CA simulations. Otherwise, a reasonable urban form defined by the environmental impact and other disciplines is also in need. For an instance generally, diverse departments of the local government suggest the planned urban form in planning practices and a generated urban form using the routine constrained CA is difficult to be used directly as the plan.

The urban form is the carrier of many issues, especially sustainable and low carbon. The inappropriately urban form, such as the sprawling one, may induce many negative influences, such as land resources over consumption (Kahn, 2000; Landis, 1995; Johnson, 2001), increased working distance and traffic jam and air pollution (Newman, 1989; Kahn, 2000; Ewing et al, 2002), decreased affordable house provision ability (Danjelsen et al, 1999), increased urban infrastructure construction costs (Speir and Stephenson, 2002), less water supply (Otto et al, 2002), weaken neighborhood interactions (Ewing, 1997; Freeman, 2001), deteriorated public health (Ewing et al, 2003), as well as increased social inequity (Bullard et al, 1999). Therefore, the reasonable urban form can guarantee the sustainable city in distinguished aspects, and how to yield the predefined desired urban form is necessary to be explored.

This paper will focus on the quantitative relationship between a planned urban form proposed in planning practice and policy parameters, as well as all the solutions meeting the predefined form, namely near optimal solutions. In Long et al (2009), the term of form scenario analysis is brought forward as the reversed procedure of the routine urban growth or land use scenario analysis, in which the urban development policies are the spatial explicitly variables, such as natural environment constraints, transport accessibility, institutional and environmental policies and so on. The dataset of policy parameters is the implementation intensity respectively for the corresponding urban development policy. Long et al (2009) regards the spatial distribution of policies are fixed as exogenous variables, and identify the optimal policy parameters for four planned forms in the Beijing Metropolitan Area respectively using constrained cellular automata (CA) borrowing the method from the currently matured CA calibration method, the logistic regression, supported by historical observed forms. The urban growth phenomenon is the probability process rather than the deterministic process. We will come to discuss how to identify all the policy parameters for the predefined form, which maybe not an exclusive solution, instead of the optimal one in Long et al (2009).

In the context of current constrained CA simulation, the quantitative relationship between urban form and policy parameters is necessary to investigate but remained unexplored in existing literatures. On one hand, a number of literatures discuss how to measure the urban form using various spatial metrics or indicators, such as the patch numbers, mean patch area, mean patch compactness, edge length, and fractal dimension. To reflect the shape complexity across a range of spatial scales of the urban form, the fractal dimension is the most common metrics to evaluate the urban form (Batty and Longley, 1987; White and Engelen, 1993; Batty and Xie, 1996; Frenkel and Ashkenazi, 2008). On the other hand, some papers investigate the influence of policy parameters on the urban form using the scenario analysis approach in routine land use models, such as CUF, What If, CA-based models (Landis and Zhang, 1998ab; Klosterman, 1999; Li and Yeh, 2000; Yeh and Li, 2001; Long et al, 2008). Therefore, we can conclude that the existing papers only take into account single aspect, form or policy parameters, not both aspects and their inter-relationships, namely how spatial policies' spatial distribution (constraints) influence the urban form. Especially, in the related researches of constrained CA, the influence of constraints on the urban form, as the essence of constrained CA, however attracts less attention. In essence, the constraints compress the possible urban form generated by them comparing with the pure CA, which is not explored yet. The research of the influence of policies on the urban form will be helpful for investigate whether the form is possible to be achieved by the urban development policies.

There are also few previous studies for identifying policy parameters for the predefined form as the reversed process of routine urban growth models. Couclelis (2005) argued that little has been done by routine land use models to investigate the future-oriented research, such as desired or feared future. The benefits of identifying policy parameters for the predefined form are detailed in Long et al (2009) both in academic researches and planning practices.

In the second section, we will detail the methodology for policy parameters identification (PPI). The urban forms generated by various constraints are illustrated in the third section to evaluate the influence of constraints on the urban form. In the fourth section the method for PPI will be tested in virtual space, followed by the experiments in the Beijing Metropolitan Area in the fifth section. In Beijing case, four planned form scenarios together with seven spatial policies are the input variables to identify corresponding policy parameters meeting the planned forms. In the last section, we will come to the discussion of the PPI method and show the conclusions.

II. APPROACH

The heuristic approach for estimating earlier constrained CA can be borrowed to identify policy parameters for predefined form. CA based on complex adaptive systems is featuring in simulate complex phenomenon with simple rules. It has been a matured technique to modeling and simulating the urban growth process which is spatial and temporal dynamic. The issue for identifying required policy parameters for predefined form should therefore consider the spatiotemporal process of the urban growth. The calibration of constrained CA use heuristic approach with massive computation time consumed. Different parameter sets are tested and used as input of CA to simulate the urban form, followed by the comparison with observed historical one. The goodness-of-fit (GOF) indicators, such as edge length, patch size, are then calculated, and the parameter pair with the highest GOF is then regarded as the estimated parameters for the future urban growth simulation (Clark and Gaydos, 1998; Wu and Webster, 1998).

With respect to the method for PPI, the constrained cellular automata (CA) model is applied to simulate the urban form using policy parameters as the input. The CA simulation is repeated using the randomly sampled policy parameters sets by the Monte Carlo method to investigate the relationship between the policy parameters and simulated urban form. We can take the planned urban form and the current urban form as the observed historical forms. Moreover, each simulated form by CA is comparing with the predefined form using the *KAPPA* index for goodness-of-fit (GOF) test. If *KAPPA* is greater than 80%, then the policy parameters set is valid for the predefined form and can be used to realize the predefined form. Otherwise invalid and can not be used to generate the predefined form. As a result, all the sampled parameter sets can be then classified into two clusters, the valid cluster and invalid cluster. If any policy parameters set can not be used to realize the predefined form, the predefined is defined as the impossible form under the current policy environment in the paper.

Basing on the iterative simulation using Monte Carlo, HSY algorithm can be introduced into the PPI process for the regionalized sensitivity analysis (RSA) using the two clusters to evaluate the sensitivity of each policy parameter as policy implications in planning practices. HSY algorithm was firstly bought forward by Hornberger, Spear and Young in the late 1970s (Hornberger and Spear, 1980; Spear and Hornberger, 1980). HSY algorithm can be used to explore the uncertainty of the complex system, as well as analyze the sensitivity of parameters (Beck, 1987; Spear et al, 1994). In PPI, we can calculate the near optimal solutions using HSY algorithm, instead of the optimal solution using traditional regression, genetic algorithm approach. From the views of the theory and practice, it is of great significance to reflect the essence of urban growth system.

Following the procedures of HSY, the procedure of PPI using constrained CA and HSY algorithm are as listed below (also see Figure 1).

a) Define the initial distribution of each policy parameter x. To reflect the proportion relations, each x is log-uniform distributed ranging from 10-3 to 103;

b) Define the system behavior: the urban binary form F with KAPPA comparing with the predefined form Fd greater than 80% as valid and satisfied, or invalid and then rejected;

c) A sample of x is drawn from the parent distribution randomly;*

d) The constrained CA model with Multi-criteria Evaluation formatted status transition rule is run with x to obtain a sample realization of F;*

e) Calculate KAPPA of simulated F comparing with the predefined form Fd, and evaluate valid or invalid;

f) Classify F and x into FB, xB and FNB, xNB according to the classification result. xB is then the identified policy parameters for the predefined urban form Fd.

g) Repeat 3 to 5 until a sufficient large number of times (normally 5000 times) when KAPPA reaches convergence;

h) Assess the accepted parameter vectors xB to quantify parameter uncertainty;

i) Check the significance s whether the two distributions of xB and xNB are distinctly separated by K-S test;

j) Ranking the parameters s to assess the regional sensitivity of each parameter;

k) Assess whether to reject some of the model structure as insignificant.

From figure 1, we can see that calibrated parameters by HSY are a set of acceptable parameters, not a single point. HSY is for the probabilistic process, not the optimization methods for the deterministic process. Steps 8-10 are for the regional sensitivity analysis (RSA). Here we will explain its purpose. We do not know the parameters value, so we can not conduct the routine sensitivity analysis (SA) for PPI process to draw policy implications for decision makers, e.g. planners. Regarding SA of urban CA models, most of papers concern the uncertainties of the set of transition rules, neighbor types, cell size, and so on (Menard and Marceau, 2005; Kocabas and Dragicevic, 2006; Yeh and Li, 2006). Local SA, with the fixed base value point, is widely applied for the uncertainty analysis for urban CA models. Through the local SA, however, we can only understand the model at a fixed base point which is only one "tree" not "forest". In case we do not know the exact value of policy parameters during PPI, the local SA can not provide sensitivity analysis. Figure below is the show case for LSA varying from the selected base point. Therefore, we conduct regionalized sensitivity analysis (RSA) to calculate the sensitivity of parameters of constrained CA, which can solve the problem faced by LSA. K-S (Kolmogorov-Smirnov) test is used to calculate RSA by HSY algorithm in form of their significance. We use Kolmogorov-Smirnov Z as regionalized sensitivity value. We will introduce the regional SA for PPI to see the "forest" as for in-deep model understandings. HSY algorithm will be applied in this paper to calculate the distance of the valid and invalid clusters of policy parameters as for the calculation of the regional SA.

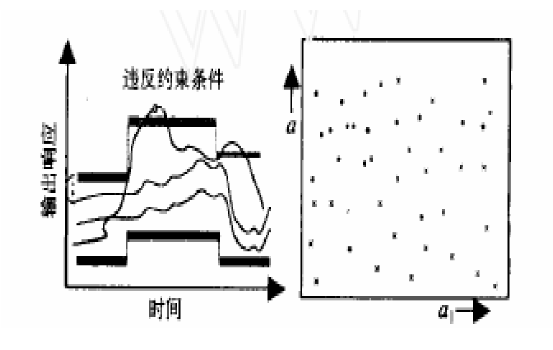


Figure 1. Comparison of HSY algorithm with normal parameter evaluation (Left: Specification of constraints on acceptable model responses; Right: Analysis of model parameter values (dots indicate values giving rise to acceptable behavior and crosses indicate values giving rise to unacceptable behavior) Source: Jining Chen at Tsinghua University, Beijing, China

III. CONSTRAINTS AND URBAN FORM TESTS IN THE VIRTUAL CITY

A. Constraints and urban form

The neighbor influence is the key element of CA, and pure CA only takes into account of neighbor effect without other factors. Constraints are introduced into the urban CA (namely constrained CA) since the urban form, originated from the infill, sprawl and frog-flip growth, is influenced by various natural, spatial and institutional constrained conditions (constraints), which has changed the complexity of simulated urban form. Each constraint can be regarded as a corresponding form with explicitly spatial distribution, which is actually the planned (refer to, e.g., eco-protected zones) or geometrically analyzed (refer to, e.g., the proximity of road networks) result. It has positive or negative effect (promoting of restricting the urban growth) on urban form, which has shaped the natural developing form without constraints effect by the pure CA, thus reducing the complexity of simulated urban form. In real cities, whether one constraint is positive or negative can be identified theoretically, where data mining, e.g. logistic regression, dominant component analysis, neural network, ant intelligence, can be employed to explore its effect

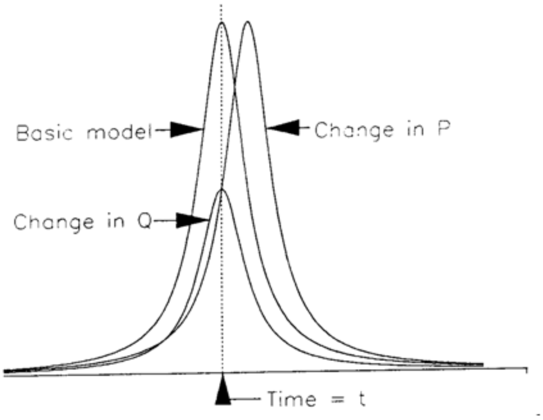


Figure 2. Defined local sensitivity analysis

quantitatively (Wu and Webster, 1998; Li and Yeh, 2002; Long et al, 2008; Liu et al, 2008).

We define the urban form as the geometry shape of the urban built-up space in the region, shown in Formula 1, where Ω is the whole region where cities lies in, P^t is the developing probability of one space (the superscript t is ignored for this variable), $P_{Threshold}$ is the developing threshold, and F^t is the urban form at time t. The urban form F^{t+1} at time t+1 can then be defined as shown in Formula 1.

$$F^{t+1} = F^t \bigcup \Omega(P \mid P \geq P_{Threshold}) \,. \qquad (1)$$

Constraints can be classified into the point constraints, line constraints and polygon constraints from the view of the geometric shape. With respect to the point and line constraints, the constrained effect decays with the increasing distance as known as the first law of geography, and the probability to be developed accordingly decreases. In this condition we set the probability threshold to constrain urban development. If the constraint is positive, the constrained urban form can be expressed as Formula 2, where n is the total number of constraints, C^{k+} is the positive constraint k, $dist^{C^{k+}}$ is the distance to the constraint k, λ is the distance decay coefficient, and P^k is the probability threshold for the constraint k. Within the distance of $dist^{C^{k+}}$, the urban development is completely promoted.

$$F^{t+1} = F^t \bigcup (\bigcup_{k=1}^{n} \{\Omega(P^k \mid P^k \geq e^{\lambda * dist^{C^{k+}}})\}) \qquad (2)$$

In condition of negative constraint of point or line types, the constrained urban form can be expressed as Formula 3, where C^{k-} is the negative constraint k, $dist^{C^{k-}}$ is the distance to the constraint k meeting the probability threshold. The area with the distance greater than $dist^{C^{k-}}$, without any constraint, is absolutely promoted to be developed.

$$F^{t+1} = F^t \bigcup (\Omega - \bigcup_{k=1}^{n} \{\Omega(P^k \mid P^k \leq e^{\lambda * dist^{C^{k-}}})\}) \qquad (3)$$

The polygon constraint, as the spatial entity, is different from the point or line constraint. The developing probability within the polygon is homogenously 100% for the positive type and 0% for negative type, which means that the polygon is absolutely promoted or forbidden as the developed area. As for the positive polygon constraint, the constrained urban form can be expressed as Formula 4, where m is the total number of the polygon constraints.

$$F^{t+1} = F^t \bigcup (\bigcup_{k=1}^{m} C^{k+}) \qquad (4)$$

In condition of the negative polygon constraint, the constrained urban form can be expressed as Formula 5. The area out of the polygon, without any constraint, is absolutely promoted to be developed.

$$F^{t+1} = F^t \bigcup (\Omega - \bigcup_{k=1}^{m} C^{k-}) \qquad (5)$$

If three types of positive or negative constraints are taken into account in constrained CA, the urban form can be respectively expressed as Formula 6 and 7.

$$F^{t+1} = F^t \bigcup (\bigcup_{k=1}^{n} \{\Omega(P^k \mid P^k \geq e^{\lambda * dist^{C^{k+}}})\}) \bigcup (\bigcup_{k=1}^{m} C^{k+}) \qquad (6)$$

$$F^{t+1} = F^t \bigcup (\Omega - \bigcup_{k=1}^{n} \{\Omega(P^k \mid P^k \leq e^{\lambda * dist^{C^{k-}}})\} - \bigcup_{k=1}^{m} C^{k-}) \qquad (7)$$

In the previous context, we discuss the possible urban form affected by various types of the single constraint, in which condition the single constraint is completely accepted. Generally the urban form is resulted from multi-constraints consisting of three above mentioned types, instead of solely yielded by a single constraint. In multi-constraints condition, we can not get the urban form meeting all the constraints, so the acceptance weights for the constraints are needed in this condition. For this reason, the multi-criteria evaluation (MCE) technique is frequently employed to analyze urban growth by constraints. In MCE, the weight of the constraint, namely the implementation intensity, is used to estimate the influence of the constraint on the urban form. The urban form affected by various constraints can be calculated via Formula 8. In the formula, X is for the constraint parameter standing for the implementation intensity of corresponding constraint, A is the constraint's spatial distribution, g is the developing probability (land use suitability) calculation function, and $P_{Threshold}$ is the probability threshold.

$$F^{t+1} = F^t \bigcup \Omega(P \mid P = g(X \bullet A) \geq P_{Threshold}) \qquad (8)$$

The transition rule of our proposed constrained CA for the urban form simulation and PPI is shown in Formula 9 as follow. In the formula, the point or line constraint will be expressed as the potential influencing layer using $a_k = e^{\lambda * dist^{C^k}}$ instead of directly as the proximity layer as for the normalization ranging from 0 to 1 in our paper. The distance decay coefficient λ is assumed to be -0.1. The weight of the constraint in practice can be regarded as the investment of cost of the corresponding policy.

$$\begin{aligned} s_{ij}{}^t &= x_0 + \sum_{k=1}^{m+n} x_k * a_k + x_N * a_N{}^t = s_0 + x_N * a_N{}^t \\ P_g{}^t &= \frac{1}{1+e^{-s_{ij}{}^t}} \\ P^t &= \exp\left[\alpha\left(\frac{P_g{}^t}{P_g{}^t{}_{\max}} - 1\right)\right] \\ F^{t+1} &= F^t \bigcup \Omega(P^t \mid P^t \geq P_{Threshold}) \end{aligned} \qquad (9)$$

The urban form, which can be evaluated using the fractal dimension indicator (FDI), is varied from the preference change of each constraint. That is to say, FDI is determined by X, and reflects the variation of X. For one predefined urban form, we can evaluate it using not only FDI but X. Therefore, it is possible to identify the constraints parameters X for every desired or feared urban form in theory. The difference between various urban forms can also be investigated from the view of X.

We will conduct several experiments in the virtual city to identify the relationship of constraints and the urban form using this constrained CA, and evaluate the simulated urban forms using FDI.

B. *Virtual city*

The virtual city for the relationship of constraints and urban form test has 400 square cells, and cell size is 100m*100m. Region width and length are identical, and equal to 2km. Three cells are developed in the initial form. In future we aim to develop 150 cells. Suppose 100 square meters for one person,

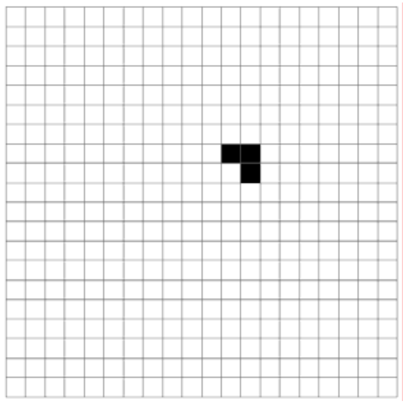


Figure 3. Initial urban form of virtual space

100 persons occupy one cell. As a whole, 15000 persons are forecasted to increase. Road width is 100 m, namely one cell size. In the virtual city, we conducted two types of tests, one for single constraint and the other for two combined constraints.

We set four predefined urban form scenarios (Form1 to Form4, see Figure 5) subjectively supposed as planned forms in the urban planning practice of the virtual city. The four forms, varying from each other greatly, will be used as form scenarios for the urban growth simulation with the single and combined constraints.

Regarding the constraints in the virtual city, we consider two point constraints PP, PL, two line constraints PL, NL, and four polygon constraints PG1, PG2, NG1, NG2 according to the polygon area. Table 1 is the list of all these possible constraints together with the descriptions. The spatial distributions of constraints are in Table 3.

C. *Design the tests*

To identify the influence of the constraint on the urban form, firstly we design one test with no constraint to simulate the urban form using constrained CA. In this case, the constrained CA is the pure CA. Since no constraint is taken into account, we can acquire the most complex urban form obeying the percolation theory shown in Figure 2.

We design 8 tests for 8 constraints respectively with the constrained CA considering the single constraint. In the constrained CA with single constraint, two factors control the simulation process and result, which are the neighbor influence and the introduced single constraint. The neighbor influence is the driving force of the indigenous growth, while the constraint will vary this process. The proportion between the constraint and the neighbor will be a key factor in influencing the simulated form. Therefore, to test the influence of the selected

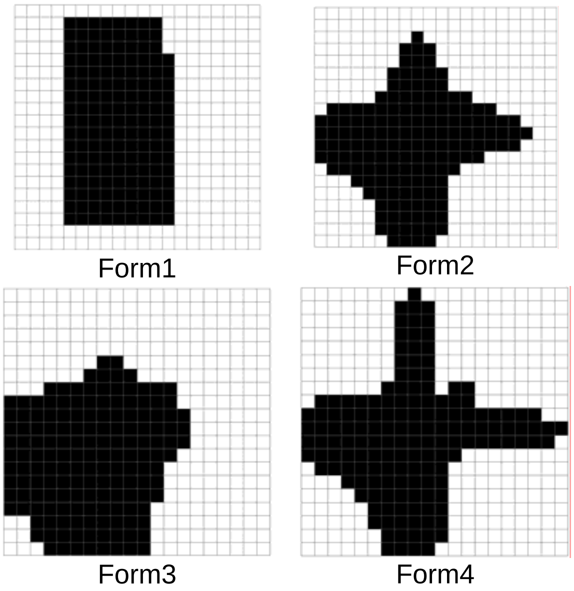


Figure 4. Form scenarios for PPL test

TABLE I. CONSTRAINT TYPES AND DESCRIPTIONS TABLE

Geometry type	Influence type	Name	Description
Point	Positive	PP	Promoting urban growth, such as town center, subway station, and public service center.
	Negative	NP	Excluding urban growth, such as geological disaster, pollution source, and solid waste/wastewater treatment facility.
Line	Positive	PL	Promoting urban growth, such as road, river.
	Negative	NL	Excluding urban growth, such as high-voltage power line, seism fracture, administrative division boundary
Polygon	Positive	PG1	Promoting urban growth, such as officially planned area, special policy zone.
		PG2	
	Negative	NG1	Excluding urban growth, such as agriculture land, ecological protected area, and steep area.
		NG2	

single constraint on the simulated form, we keep changing the proportion between the single constraint and neighbor effect using Formula 10, where x stands for the parameter for the single constraint, x_N stands for the parameter of the neighbor influence effect, and β is the ratio of x and x_N. To reflect the significant influence of the constraint on the simulated urban form, we respectively set β as 10^{-3}, 10^{-2}, 10^{-1}, 10^{0}, 10^{1}, 10^{2}, and 10^{3}.

$$\beta = x / x_N \tag{10}$$

D. *Simulation results*

The simulated results of various tests using the constrained CA (Threshold = 0.999) with different β values are illustrated in Table 2. We can conclude that the single constraint has

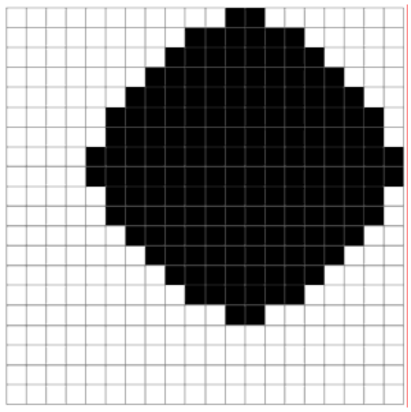


Figure 5. The simulated form with no constraint

TABLE II. FORM EVALUATION RESULTS (F) OF SINGLE CONSTRAINT TESTS

β	PP	NP	PL	NL	PG1	NG1	PG2	NG2
0.001	1.0873	1.0873	1.0873	1.0873	1.0873	1.0873	1.0873	1.0873
0.01	1.0762	1.0785	1.0886	1.0183	1.0808	1.0899	1.0556	1.0564
0.1	1.0847	1.0487	1.0873	1.0426	1.0801	1.0899	1.0847	1.066
1	1.1444	1.0698	1.1735	1.0564	1.0487	1.094	1.1703	1.1193
10	1.147	1.2136	1.1895	1.0665	1.0487	1.094	1.1703	1.0969
100	1.1444	1.2347	1.1601	1.0234	1.05	1.1047	1.1703	1.0883
1000	1.147	1.2347	1.1575	1.0234	1.0375	1.1047	1.1703	1.1294

accordingly changed the simulated urban form, and β has strong influence on the accordingly simulated urban form. Furthermore on the contrary, from one designated urban from we can also estimate the influence of the constraint, namely β.

E. *Simulated forms evaluation*

The fractal dimension index *f* is used to evaluate the simulated form. It overcomes one of the major limitations of the straight perimeter-area ratio as a measure of shape complexity. The fractal dimension index *f* is defined in Formula 11, where p_{ij} is the perimeter (m) of patch *ij*, and a_{ij} is the area (m^2) of patch *ij*. *f* greater than 1 for a 2-dimensional patch indicates a departure from Euclidean geometry (i.e., an increase in shape complexity). *f* approaches 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.

$$f = \frac{2\ln(0.25 * p_{ij})}{\ln a_{ij}} \qquad (11)$$

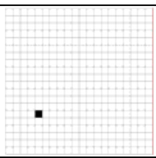
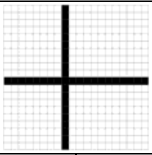
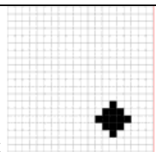
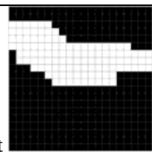
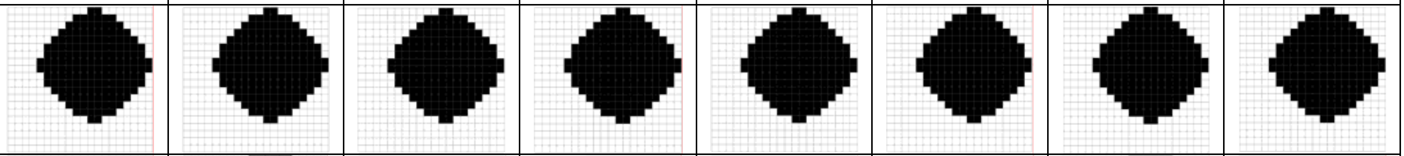
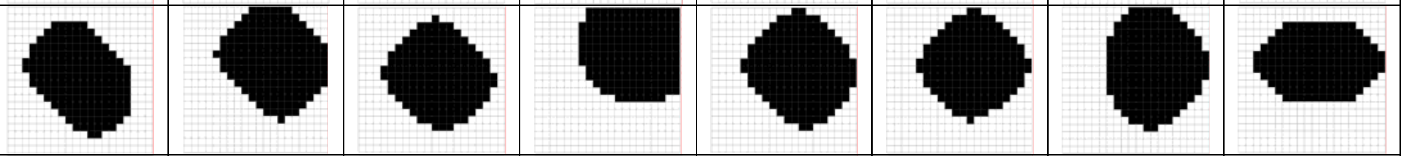
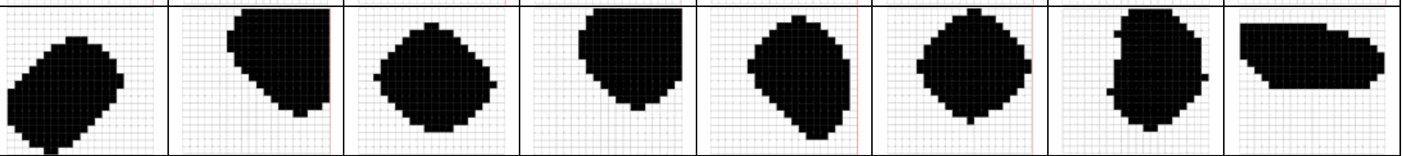
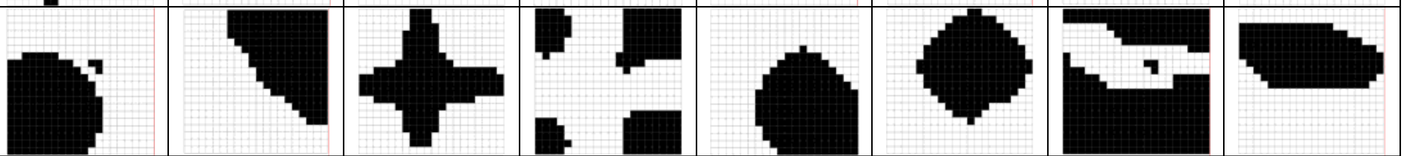
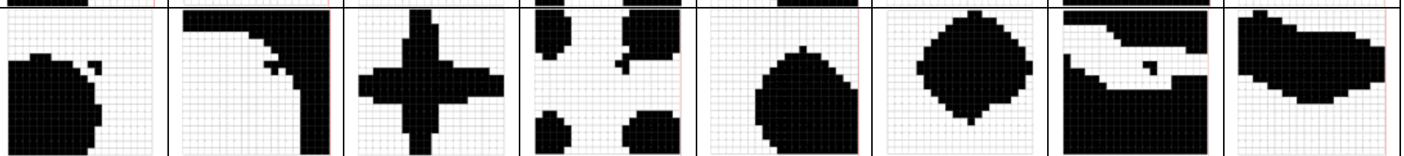
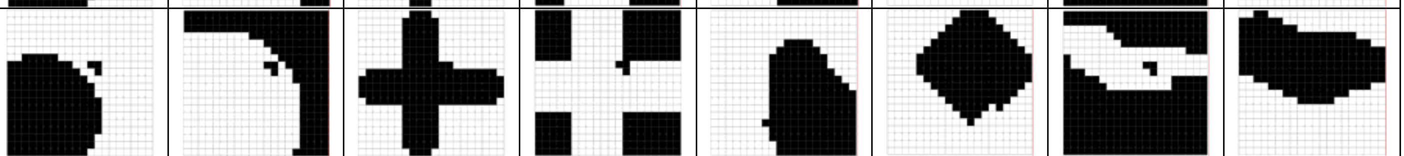
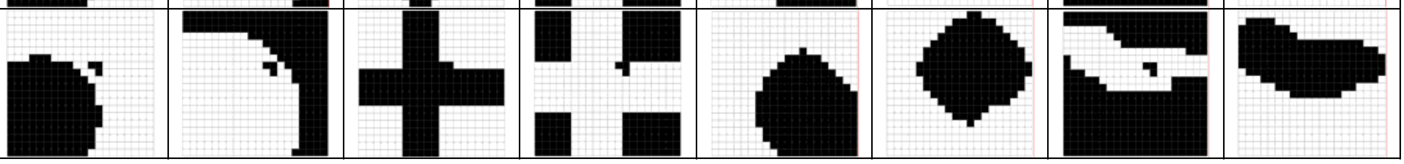
From Figure 6, when ß is 0.001 the *f* of all tests are identical standing for the influence of the constraint can be ignored comparing with the neighbor. For ß between 0.001 and 0.01, *f* decreases with the increasing ß, which denotes the shape complexity decreased when the constraint influence increases. Namely the simulated result is compressed by the constrained condition. The influences of the constraint and neighbor are the same when ß equals to 1, when *f* varies from the types of the constraints with different *f* values. When ß arrives at 100, the neighbor effect can be ignored comparing with the constraint influence. The *f* values keep stable when ß is greater than 100.

IV. PPI IN THE VIRTUAL CITY

A. *PPI for single constraint*

We use four previous predefined urban forms to respectively identify the policy parameters meeting 80%

TABLE III. RESULT OF TEST 2-9

β	**Point Constraint**		**Line Constraint**		**Polygon Constraint**			
Map (A)					Small constraint 		Large constraint 	
Constraint Type	PP	NP	PL	NL	PG1	NG1	PG2	NG2
0.001								
0.01								
0.1								
1								
10								
100								
1000								

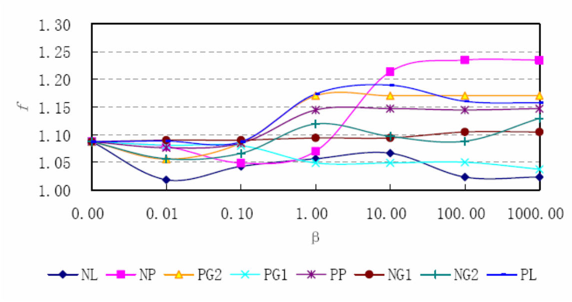


Figure 6. f- β curve

KAPPA restriction based on the constraint's influence on the urban form in the previous section. Three constrained conditions are tested for PPI respectively in the virtual city, the single constraint, the combined constraints, as well as the combined two constraints and *t*.

In PPI for the single constraint condition, PP is set as the constraint. Figure 7 is the PPI results for four forms. Only form3 can be achieved by the single constraint PP with its parameter ß (the parameter of PP divided by that of the neighbor effect) greater than 0.139 as the PPI result, while other forms can not be yielded whatever the value of ß is. Figure 4 also shows that ß with the value less than 0.01 or greater than 1 will lead to relatively steady *KAPPA* index for all forms.

Figure 8 is the calibration result for constraint PL of four forms, which shows that no valid value of ß can be identified for all forms. Figure 7 and 8 show that *KAPPA* is more sensitive to ß between 0.01 to 1, where the constraint influence and neighbor influence balance with each other. When ß is over 1, the constraint effect is then the dominating factor over the neighbor effect influencing the *KAPPA* as well as the simulated form.

The calibration for PP and PL demonstrates that the Monte-Carlo approach is applicable for PPI for predefined forms in the virtual city with single constraint, and the calibration results vary from urban forms and constraint types.

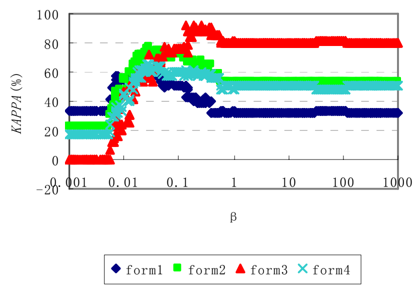


Figure 7. The scatter plot of KAPPA and ß of the PP constraint

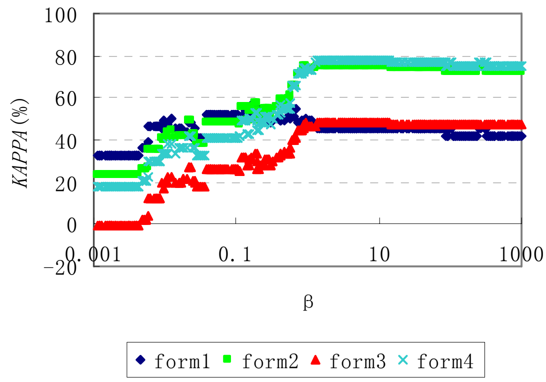


Figure 8. Figure 8 The scatter plot of KAPPA and ß of the PL constraint

B. *PPI for combined constraints and RSA*

In this section we conduct tests for combined constraints through adjusting the weight of each constraint. In view of the shape of constraint, the combined constraints may be Point & Line, Point & Polygon, Line & Polygon, and Point & Line & Polygon. To demonstrate how to conduct PPI for combined constraints, we herewith only select two constraints, one for positive point (PP) and the other for positive line (PL) in the experiments, defined as PPL test.

In PPL test, x_1 and x_2 standing for the parameters for PP (a_1) and PL (a_2) respectively are simultaneously adjusted using the HSY algorithm for 500 times (80 hours or so consumed). The validation results, varying from each other are shown in Figure 9 for the four predefined forms. With respect to Form1, no parameter pairs are valid, denoting the form can

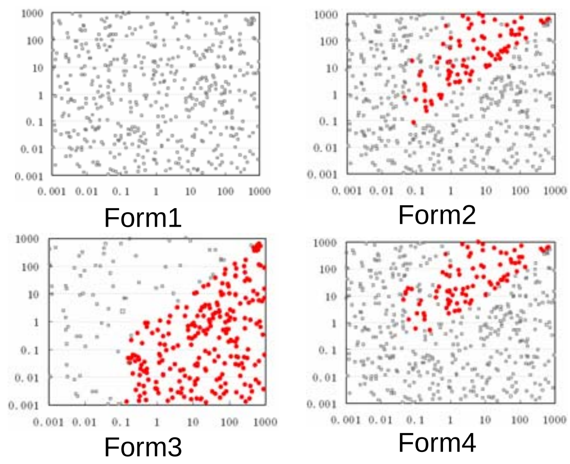


Figure 9. Form4 scenario analysis scatter plot (x axis x1, y axis x2, Accepted with KAPPA>=80%)

not be achieved by PP and PL constraints. If we hold on set it as the planned form, it will be definitely broken through with current polices environment. Regarding other form scenarios, valid parameter pairs, available for the desired form, can be identified. It shows that we can realize those predefined form by various pathways instead of solely by one.

The existing parameters pairs also demonstrate that the policies needed for the form scenario has its elasticity. Therefore, we will investigate the sensitivity issue of constraint parameter as for policy implication for valid forms. For four forms respectively, we conduct RSA for parameters x_1 and x_2 separately for four form scenarios. The RSA result is shown in Table 4. Since no parameters are detected for Form1, the RSA of Form1 is not available. With respect to Form2 and form4, x_2 is a more sensitive than x_1. For form3, however, the RSA result is in the inverse condition, which shows that regional sensitivity also depends on the defined form. Among the three valid forms, x_1 of Form3 and x_2 of form4 are of the most sensitive.

C. *PPI for combined constraints and* t *calibration and RSA*

Basically regarding 80% *KAPPA* restriction, the form with TDCN as 150 is not the unique one meeting the restriction. We define TDCN as a new constraint / parameter and incorporating its influence on *KAPPA*. We set x_1 as 0.1 for PP constraint, x_2 as 0.58 for PL constraint, and desired TDCN as 400 standing for the whole virtual space will be occupied. Then we run the model for 64 steps and calculate the *KAPPA* index. Figure 10 shows the dynamic variation of *KAPPA* with TDCN, from which the forms with TDCN ranging from 120 to 180, instead of only 150, all meet *KAPPA* restraint. Therefore, TDCN as 150 is not the peak of the *KAPPA*-TDCN curve, while 143 is the peak with the highest *KAPPA* value. The phenomenon demonstrates that to realize the predefined form, the TDCN value equaling to the predefined form maybe not the best condition. In some case, we can yield the predefined form before its TDCN. Therefore, *t* dimension also plays an important role in influencing the realization of the predefined urban form, and it should be taken into account in parameters list and parameter identification procedure.

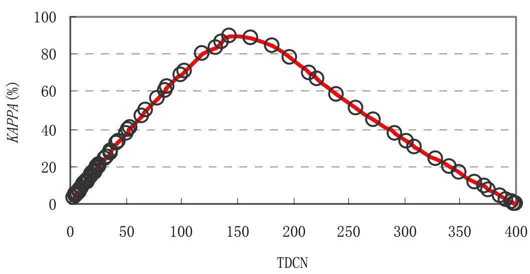


Figure 10. KAPPA changing with cell number (circles standing for simulation steps)

TABLE IV. RSA RESULT FOR FOUR FORMS

Regional Sensitivity Value	Form1	Form2	Form3	Form4
x_1	NA	3.169*	7.762*	2.872*
x_2	NA	4.161*	4.066*	5.080*

*Asymp. Sig. (2-tailed) at 0.001 level

Basing on previous combined constraints calibration (Section 3.2), we introduce TDCN as a new parameter to be identified. Its value is set ranging from 50 to 250 according to the analysis of above figure. In this test Threshold is 0.99 instead of 0.999 in Section 3.2 to save the computation time. We run the model for 2000 times, and the *KAPPA* indexes converge at near 500 times as shown in Figure 11.

Figure 12 is the identified parameter pairs for each predefined urban form. The red circle stands for the identified policy parameters x_1, x_2 and TDCN.

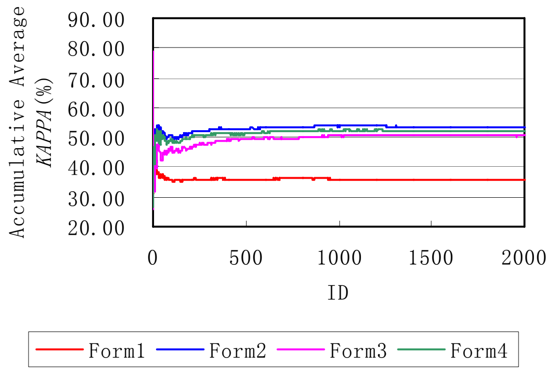


Figure 11. The convergence of the accumulative average KAPPA for four forms

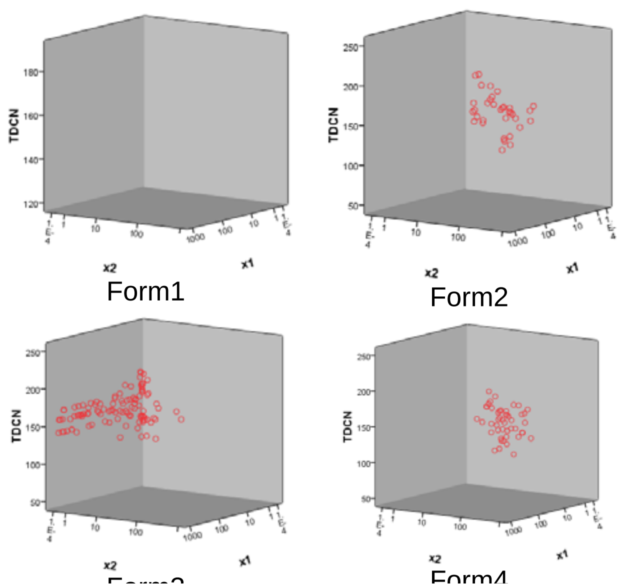


Figure 12. Valid solutions 3-D scatter plot of forms

TABLE V. DESCRIPTIVE TABLE OF VALID VARIABLES FOR THREE FORMS

Form	Name	N	Minimum	Maximum	Mean	Std. Deviation
Form 2	x1	34	.089	716.995	9.083	177.061
	x2		.501	855.844	13.916	233.920
	TDCN		127	188	156.210	16.756
	KAPPA		80.088	89.173	8.357	2.344
Form 3	x1	107	.228	971.997	16.456	246.434
	x2		.001	722.178	1.491	77.460
	TDCN		125	196	159.620	17.797
	KAPPA		80.416	95.816	8.321	3.192
Form 4	x1	47	.022	716.995	8.310	159.772
	x2		.911	969.423	170.283	263.144
	TDCN		117	191	149.040	17.757
	KAPPA		80.246	92.666	8.561	3.886

Table 5 is the statistic descriptive table for three valid predefined forms. Only 34 out of 2000 pairs are valid for Form2, with 107 and 47 for Form3 and Form4.

Table 6 are the RSA results of x_1, x_2 and TDCN. Comparing Table 6 with Table 4, the trend of the sensitivity of x_1 and x_2 remains the same although a new parameter TDCN is introduced into the process. However the RSA value of x_1 and x_2 respectively for each form is not the same with that in table3. It shows that the introduction of TDCN influences the parameters' sensitivity with the model structure changed.

V. PPI IN THE BEIJING METROPOLITAN AREA

The PPI approach proved in the virtual city is then applied in the Beijing Metropolitan Area (BMA) with an area of 16,410 km2, which lies in northern China. Beijing has experienced a rapid urbanization period together with GDP and population amount since Reform and Opening was firstly advocated in 1978 by the central government. Therefore, the planning scheme is challenged by the rapid urban growth, and whether the latest planned urban form for the BMA is valid under current policy environment is also widely concerned by the decision makers.

We set four predefined forms shown in Figure 13. Form A is the approved urban form by State Council of P. R. China with characteristics of preventing central city from over-sprawled and promoting the development of new cities. Form B is the sprawl scenario. Form C is the grape-cluster scenario. Form D is the sustainable scenario.

TABLE VI. RSA RESULT OF COMBINED CONSTRAINTS AND TDCN FOR FOUR FORMS

Regional Sensitivity Value	Form1	Form2	Form3	Form4
x_1	NA	1.875**	4.127*	2.439*
x_2	NA	2.658*	2.880*	3.640*
$TDCN$	NA	2.207*	3.729*	2.891*

*Asymp. Sig. (2-tailed) at 0.001 level

** Asymp. Sig. (2-tailed) = 0.002

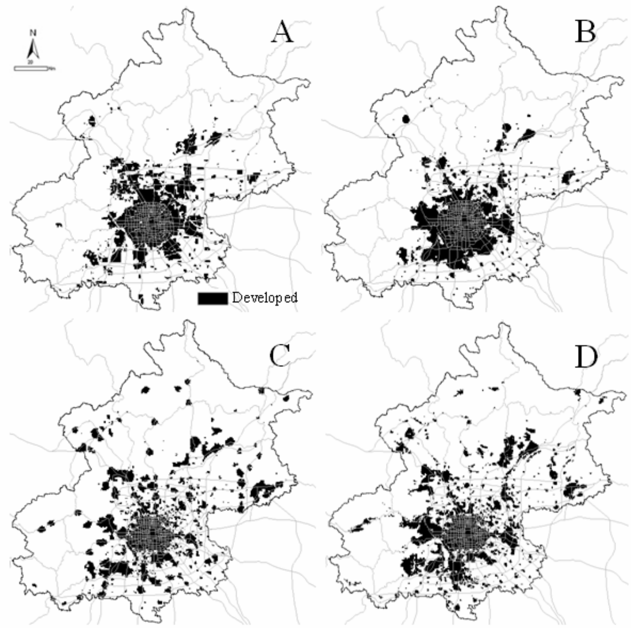


Figure 13. Four planned forms in BMA

We set four predefined forms shown in Figure 13. Form A is the approved urban form by State Council of P. R. China with characteristics of preventing central city from over-sprawled and promoting the development of new cities. Form B is the sprawl scenario. Form C is the grape-cluster scenario. Form D is the sustainable scenario.

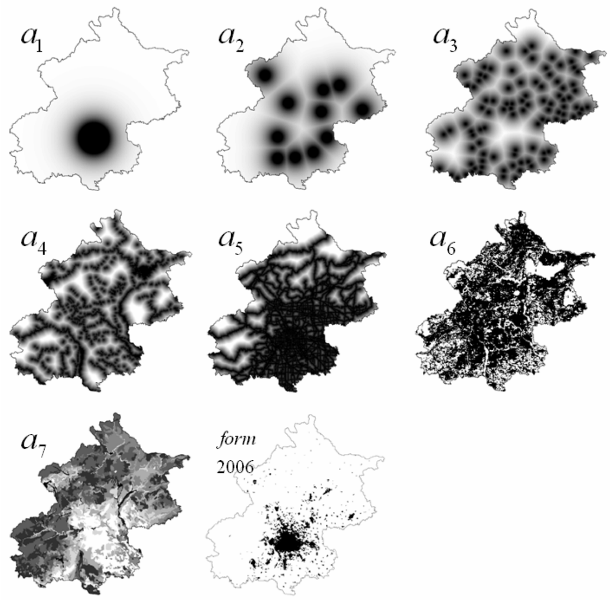


Figure 14. Constraints and the urban form in 2006

TABLE VII. DATASET IN CONSTRAINED CA

Type	Variable	Description	Value range	Data source
Spatial constraints	a_1	Tian'anmen (city hierarchy)	0-1	Derived from spatial dataset
	a_2	New city (city hierarchy)	0-1	Derived from spatial dataset
	a_3	Town (city hierarchy)	0-1	Derived from spatial dataset
	a_4	River (Flood control)	0-1	Derived from spatial dataset
	a_5	Road of 2006 (Transport development)	0-1	Interpreted from TM image of 2006-11-01
Institutional constraints	a_6	Development exclusive area (Ecological protection, disaster prevention)	0, 1	Beijing Municipal Planning Committee, 2007 *
	a_7	Suitability for agriculture development (farm protection)	0-1	Beijing Planning Commission et al, 1988

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

In BMA we select seven constraints including five spatial constraints and two institutional constraints except the neighbor effect. The constraints are shown in Table 7, and their spatial distributions are illustrated in Figure 14 as well as the current urban form in 2006.

The PPI results for the four planned forms in BMA listed in Table 8 can be referred as the policy implications for the decision makes from various aspects. Firstly, each pair of policy parameter calibrated is available for decision makers for designing the future developing pathway or adjusting the currently implemented one. Secondly, Form A is tested to be invalid under current policy environment. That is to say that the current implemented planned urban form for the BMA will be broken through by the practical urban growth. The other three predefined urban form are all valid with distinguished developing pathways. Form C with the greatest mean *KAPPA* has the highest probability to be realized accordingly. Thirdly, the policy parameters with the greatest *KAPPA* (e.g. 91.671 for Form B) could be the ideal developing pathway to implement the corresponding urban form, and the policy parameters with the least *KAPPA* can be referred to avoid the undesired development. Lastly, the policy parameters can compare across the predefined forms to further understand the differences of the needed policies to realize the corresponding urban form.

The regional sensitivity analysis is also conducted for the BMA, and the results are shown in Table 9. Similar with RSA for the virtual city, the sensitivity for the policy parameters also varies from each other. For Form B and Form D, x_1 is most sensitive, and x_3 for Form C. The more sensitive for the policy parameter, the more should be paid attention to the corresponding policy parameter in planning practices. In this condition, the little variation of the policy parameter, the *KAPPA* would be influenced greatly and the future urban form will deviate from the predefined one.

TABLE VIII. DESCRIPTIVE TABLE OF VALID VARIABLES FOR THREE VALID FORMS

Form	Name	N	Minimum	Maximum	Mean	Std. Deviation
Form B	x1	305	0.011	98.617	30.215	28.928
	x2		0.010	41.068	3.626	6.666
	x3		0.011	14.588	0.730	1.600
	x4		0.010	53.106	2.760	6.658
	x5		0.010	17.248	1.207	2.608
	x6		0.010	47.064	3.319	6.642
	x7		0.010	16.740	1.214	2.265
	KAPPA		80.027	91.671	82.492	1.921
Form C	x1	258	0.010	86.744	6.681	12.025
	x2		0.010	43.076	4.835	7.391
	x3		1.111	99.855	32.160	28.975
	x4		0.010	83.237	8.599	15.735
	x5		0.010	77.594	3.726	8.163
	x6		0.014	92.885	10.203	15.277
	x7		0.010	27.362	1.444	3.424
	KAPPA		80.023	88.940	81.896	1.558
Form D	x1	4	0.014	1.791	0.461	0.887
	x2		0.059	2.682	0.926	1.236
	x3		0.013	2.076	0.774	0.965
	x4		0.068	6.143	3.466	2.661
	x5		0.098	1.202	0.479	0.507
	x6		1.433	9.703	3.661	4.031
	x7		0.550	4.313	1.618	1.803
	KAPPA		80.135	81.216	80.824	0.486

VI. CONCLUSIONS

In this paper, we mainly conduct three aspects of works. Firstly, the relationships between constraints and urban form are dynamically investigated using a constrained CA model in the virtual city. The fractal dimension index is used to evaluate the urban form and then the relationship between the index and the policy parameters are tested. This work can be regarded as the base for policy parameters identification for the predefined form. Secondly, policy parameters identification is successfully conducted separately in the virtual city and the Beijing Metropolitan Area using Monte Carlo based approach. The results can be referred as the policy implications for the decision makers in planning practices to design the appropriate developing pathways for the planned form as well as remove the impossible planning scenarios. Thirdly, the regional sensitivity analysis is developed following the policy parameters identification respectively for the two tests in the virtual space and the Beijing Metropolitan Area. The policy implications can also be drawn from the RSA result in planning practices. Moreover, the regional sensitivity analysis is proved to be more effective and general than the routine local sensitivity analysis for cellular automata models.

Nowadays in China, the planned form evaluation results show that more than 35% urban development was beyond the planned form in Beijing and Shenzhen (Han *et al*, 2009; Tian *et al*, 2008). Planning departments, lacking of policy guidance,

TABLE IX. RSA RESULT OF COMBINED CONSTRAINTS AND TDCN FOR FOUR FORMS

Form	RSA result	x1	x2	x3	x4	x5	X6	x7
Form B	Z	7.771	3.185	6.778	3.281	5.291	2.224	4.838
	Asymp. Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Form C	Z	1.472	2.617	8.246	1.359	2.801	5.089	4.616
	Asymp. Sig. (2-tailed)	0.026	0.000	0.000	0.050	0.000	0.000	0.000
Form D	Z	1.351	0.857	0.930	0.747	0.984	1.117	0.866
	Asymp. Sig. (2-tailed)	0.052	0.455	0.353	0.631	0.287	0.165	0.441

have little knowledge of the exact policies for the planned form and their differences from current policies. From this point of view, urban policies required for planned urban form are widely concerned by the government, and therefore, FSA has important practical significance in China.

REFERENCES

[1] Batty M, and Longley P A, "Fractal-based description of urban form," Environment and Planning B: Planning and Design, vol. 14, pp. 123-134, 1987.

[2] Batty M, and Xie Y, “Preliminary evidence for a theory of the fractal city,” Environment and Planning A. vol. 28,pp. 1745-1762, 1996.

[3] Beck M B, “Water quality modeling: A review of the analysis of uncertainty,” Water Resources Research. vol. 23, pp. 1393-1442, 1987.

[4] “Ecologically limited land-use planning in Beijing (2006-2020),” (in Chinese) Beijing Municipal Planning Committee. 2007.

[5] “Beijing land resource,” (in Chinese) Beijing Planning Commission, Beijing SciTech Press. Beijing, 1988.

[6] Breheny M, “The compact city,” Alexandrine Press. Oxford1, 992.

[7] Bullard R D, Johnson G S, and Torres A O, “Sprawl Atlanta: social equity dimensions of uneven growth and development,” Clark and Atlanta University, The Environmental Justice Resource Center. Atlanta, and GA,1999.

[8] Clark K C, and Gaydos L J, “Loose-Coupling a Cellular Automation Model and Gis: Long-Term Urban Growth Prediction for San Francisco and Washington/Baltimore,” Geographical Information Sciences. vol. 12, pp. 699-714, 1998.

[9] Couclelis H, “Where has the future gone? Rethinking the role of integrated land-use models in spatial planning,” Environment and Planning A. vol. 37, pp. 1353-1371, 2005.

[10] Danielsen K, Lang R, and Fulton W, “Retracting suburbia: Smart growth and the future of housing,” Housing Policy Debate. vol. 10, pp. 512-40, 1999.

[11] Ewing R, “Is Los Angeles style sprawl desirable?,” Journal of the American Planning Association. vol. 63, pp. 107-126, 1997.

[12] Ewing R, Pendall R, and Chen D, “Measuring sprawl and its impact,” The Smart Growth America. Washington, DC, 2002..

[13] Ewing R, Schmid T, Killingsworth R, Amy Zlot and Stephen Raudenbush , “Relationship between urban sprawl and physical activity, obesity, and morbidity,” American Journal of Health Promotion. vol. 18, pp. 47-57, 2003.

[14] Freeman L, “The effects of sprawl on neighborhood social ties: an exploratory analysis,” Journal of the American Planning Association. vol. 67, pp. 69-77, 2001.

[15] Frenkel A, and Ashkenazi M, "Measuring urban sprawl: how can we deal with it?," Environment and Planning B: Planning and Design. vol. 35, pp. 56–79, 2008.

[16] Gordon P, and Richardson H W, “Are Compact Cities a Desirable Planning Goal?,” Journal of the American Planning Association. vol. 63, pp. 95-106,1997.

[17] Han H, Lai S, Dang A, Tan Z, and Wu C, “Effectiveness of Urban Construction Boundaries in Beijing: An Assessment,” Journal of Zhejiang University: SCIENCE A Forthcoming.2009.

[18] He C, Okada N, Zhang Q, Shi P, and Zhang J, “Modelling dynamic urban expansion processes incorporating a potential model with cellular automata,” Landscape and Urban Planning.vol. 86, pp. 79-91, 2008.

[19] Hornberger G M, Spear R C, 1980 “Eutrophication in Peel Inlet, I: Problem-defining behavior and a mathematical model for the phosphorus scenario” Water Resources, 14 29-42

[20] Howell-Moroney,M, “A description and exploration of recent state-led smart-growth efforts,” Environment and Planning C: Government and Policy. vol. 26, pp. 678-695, 2008.

[21] “The official website of 45th ISOCARP International Congress,” http://www.isocarp.org/index.php?id=409, ISOCARP, Accessed on 30 July 30, 2009.

[22] Jenks M, Burton E, and Williams K, “The Compact city: a sustainable urban form? E & FN Spon,” London,1996

[23] Johnson M P, "Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda," Environment and Planning A .vol. 33, pp. 717–735, 2001.

[24] Kahn M, “The environmental impact of suburbanization,” Journal of Policy Analysis and Management. vol. 19, pp. 569-586, 2000.

[25] Klosterman R E, “The What if? Collaborative planning support system,” Environment and Planning B: Planning and Design.vol. 26, pp. 393-408, 1999.

[26] Kii M, and Doi K, "Multiagent land-use and transport model for the policy evaluation of a compact city," Environment and Planning B: Planning and Design. vol. 32, pp. 485– 04, 2005.

[27] Kocabas V, and Dragicevic S, “Assessing cellular automata model behavior using a sensitivity analysis approach,” Computers, Environment and Urban Systems. vol. 30, pp. 921-953, 2006.

[28] Landis J D, “Improving land use futures: Applying the California urban model,” Journal of the American Planning Association. vol. 61, pp. 438-457, 1995.

[29] Landis L D, and Zhang M, “The second generation of the California urban future model, Part1: Model logic and theory,” Environment and Planning B: Planning and Design.vol. 25, pp. 657-666, 1998.

[30] Landis L D, and Zhang M, “The second generation of the California urban future model, Part2: Specification and calibration results of the land-use change submodel,” Environment and Planning B: Planning and Design. vol. 25, pp. 795-824, 1998.

[31] Li X, and Yeh A G O, “Modeling sustainable urban development by the integration of constrained cellular automata and GIS,” International Journal of Geographical Information Science. vol. 14, pp. 131-152,2000.

[32] Li X, and Yeh A G O, “Neural-network-based cellular automata for simulating multiple land use changes using GIS,” International Journal of Geographical Information Science. vol.16, pp. 323-343, 2002.

[33] Liu X, Li X, Liu L, and He J, “A bottom-up approach to discover transition rules of cellular automata using ant intelligence,” International Journal of Geographical Information Science. vol. 22, pp. 1247-1269, 2008.

[34] Long Y, He Y, Liu X, and Du L, 2006 “Planning of the controlled-construction area in Beijing: Establishing urban expansion boundary,” (in Chinese) City Planning Review. vol. 30, pp. 20-26, 2008.

[35] Long Y, Shen Z, Du L, Mao Q, and Gao Z, “BUDEM: an urban growth simulation model using CA for Beijing metropolitan area,” Proceedings of the SPIE. 71431D-1-15, 2008.

[36] Menard A, and Marceau D J, “Exploration of spatial scale sensitivity in geographic cellular automata,” Environment and Planning B: Planning and Design. vol. 32, pp. 693-714, 2005.

[37] Newman P a J K, “Gasoline consumption and cities: a comparison of U.S. cities with a global survey,” Journal of the American Planning Association. vol 55, pp. 24-37, 1989.

[38] Shen Q, and Zhang F, “Land-use changes in a pro-smart-growth state: Maryland, USA,” Environment and Planning. vol. A39, pp. 1457-1477, 2007.

[39] Spear R C, Grieb T M, and Shang N, “Parameter uncertainty and interaction in complex environment models,” Water Resources Research. vol. 30 ,pp. 3159-3169, 1994.

[40] Spear R C, and Hornberger G M, “Eutrophication in Peel Inlet, II: Identification of critical uncertainties via generalized sensitivity analysis,” Water Resources, vol.14 pp. 43-49, 1980.

[41] Speir C, and Stephenson K, “Does sprawl cost us all? Isolating the effects of housing patterns on public water and sewer costs,” Journal of the American Planning Association. vol.68, pp. 56-70,2002.

[42] Tian L, Lv C, and Shen T, “Theoretical and Empirical Research on Implementation Evaluation of City Master Plan: A Case of Guangzhou City Master Plan (2001-2010),” (in Chinese) Urban Planning. vol. 5, pp. 90-96, 2008.

[43] Otto B, Ransel K, Todd J, Lovaas D, Stutzman H, and Bailey J, “Paving our way to water shortages: how sprawl aggravates drought,” The American Rivers, The Natural Resources Defense Council, and The Smart Growth America (Washington D C). 2002.

[44] Ward D P, Murray A T, and Phinn S R, “A stochastically constrained cellular model of urban growth,” Computers, Environment and Urban Systems. vol. 24, pp. 539-558.

[45] White R, and Engelen G, “Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land-use patterns,” Environment and Planning. vol. A25, pp. 1175-1199, 1993.

[46] Wu F, “Simland: a prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules,” International Journal of Geographical Information Science. vol. 12, pp. 63-82, 1998.

[47] Wu, F, and Webster C J, “Simulation of land development through the integration of cellular automata and multicriteria evaluation,” Environment and Planning B: Planning and Design. vol. 25, pp. 103-126, 1998.

[48] Yeh A G-O, and Li X, "A constrained CA model for the simulation and planning of sustainable urban forms by using GIS," Environment and Planning B: Planning and Design. vol. 28, pp. 733-753, 2001.

[49] Yeh A G-O, and Li X, “Errors and uncertainties in urban cellular automata,” Computers, Environment and Urban Systems. vol. 30, pp. 10-28, 2006.

Acknowledgment: We would like to thank for the financial support of National Natural Science Foundation of China (50678088) and National Project of Scientific and Technical Supporting Programs Funded by Ministry of Science & Technology of China (NO.2006BAJ14B08).