Chapter 5
Reaching Consensus Among Stakeholders on Planned Urban Form Using Constrained CA

Ying Long and Zhenjiang Shen

Introduction

In this chapter, we propose an approach for negotiation between planners and developers by identifying the required spatial policies for predefined alternative plans. Recently, the constrained cellular automata (CA) method has been extensively applied to simulate urban growth for predicting future urban forms (Wu 1998; Ward et al. 2000; Yeh and Li 2001; He et al. 2008). However, an alternative plan, which is prepared by planners during the plan compilation process, has been used in the decision-making process of the urban master plan worldwide. In China, practical urban growth often deviates from the planned urban form, resulting in the planned urban form being broken. Local planning authorities who lack policy guidance have little knowledge of the exact policies related to the planned form and their differences with current policies. Given this situation, urban policies required for the planned urban form are a governmental concern. If the simulated urban form using constrained CA can be accepted as a reasonable form by planners, then the simulated results can be possibly used for the deliberation in the local planning committee among planners, developers, and other stakeholders.

Urban form must be given ample attention because it guarantees sustainable development. Inappropriate urban forms such as sprawled urban forms may have negative effects on society, including overconsumption of land resources (Kahn 2000; Landis 1995; Johnson 2001); increased commuting distances and traffic jams (Newman 1989; Kahn 2000; Ewing et al. 2002); decreased availability of affordable housing (Danielsen et al. 1999); increased urban infrastructure construction costs (Speir and Stephenson 2002); reduced water supply (Otto et al. 2002);

Y. Long (✉)
Beijing Institute of City Planning, School of Architecture, Tsinghua University, Beijing, China
e-mail: longying1980@gmail.com

Z. Shen
School of Environmental Design, Kanazawa University, Kanazawa, Japan

Z. Shen, *Geospatial Techniques in Urban Planning*, Advances in Geographic Information Science, DOI 10.1007/978-3-642-13559-0_5,

poor neighborhood interaction (Ewing 1997; Freeman 2001); poor public health (Ewing et al. 2003); and increased social inequity (Bullard et al. 1999). The policy parameter regulates and controls the impact of the corresponding spatial constraint on urban growth. Long et al. (2009) proposed the term "form scenario analysis" to identify optimal policy parameters through a logistic regression-based approach for four planned forms in the Beijing Metropolitan Area using constrained CA. However, the optimal solution of policy parameters for a predefined alternative plan is not unique. Therefore, in this chapter, we focus on all the policy parameters required to satisfy an alternative plan.

The simulated urban form using constrained CA is only reasonable from the viewpoint of history. All parameters in the transition rule of CA simulation are estimated using a historical dataset, which can be recognized as an optimal solution for simulating the future urban form. However, if the historical trend cannot be replicated in the future, then the estimated parameters cannot be used to simulate the future urban form. In this sense, if the future development is considered to be different from the historical trend, then the estimated parameters will not be useful. Thus, knowing how to define parameter sets becomes a precondition for simulation.

In planning practice, planners should consider all possible factors for drawing an urban form. These factors are actually proposed and prepared in different sections of the local government. If the planners have different opinions on the future urban form, then there will be numerically possible parameters for those factors. Defining the parameters of a form is possible via negotiation among planners, developers, and other stakeholders. Thus, this chapter focuses on how to retrieve all parameters for a future form through negotiation, supposing that planners opt to use CA simulation. This remains unexplored by existing research.

A number of studies have investigated the impact of policy parameters on the urban form using a scenario analysis approach in traditional land-use models, such as the California Urban Future model (CUF) (Landis and Zhang 1998a, b), *What If?* (Klosterman 1999), and CA-based models (Li and Yeh 2000; Yeh and Li 2001; Long et al. 2008). In previous studies, less attention has been given to identify the types of spatial policies that are available for the planned alternative. In essence, the impact of constraints on the possible urban form has yet to be investigated, and research into the impact of constraint parameters on urban form will be useful for investigating whether an alternative plan can be achieved. Therefore, identifying appropriate policy parameters for the alternative plan is necessary, which can be done via negotiation between planners and stakeholders.

We describe a methodology for the policy parameter identification (PPI) process in Sect. "Approach". The resulting urban forms from various constraints are illustrated in Sect. "How to Present the Negotiation Process Among Stakeholders Using CA", in which the impact of constraints on the resulting urban form is evaluated. The PPI method will be tested in a virtual city in Sect. "Presenting the Negotiation in the Virtual City", and we discuss the PPI method and present some concluding remarks in Sect. "Conclusion".

Approach

We assume that planners are making an urban master plan in a city, for which they have prepared an urban form based on their preferences. On the other hand, planners in the environmental department have established some environmental conservation areas, and some developers are considering the locations of their development projects. Thus, they need to cooperate with each other when making an urban form that meets their distinct requirements. The CA method is employed to combine their requirements by simulating the spatiotemporal dynamic urban growth process.

First, we retrieve all the parameters that match an urban form as suggested by an urban planner. A CA approach is then used as follows:

$$\{X^*|F = f(X, A), X^* = X_{\max(\mathrm{GOF}(F_h, F))}\}, \tag{5.1}$$

where f is the transition rule of the constrained CA; A is spatial constraints; X is the intensity of spatial policy on spatial constraints; F_h is the planned urban form; F is the simulated urban form using A and X as the parameters of constrained CA; and X^* is the estimated policy parameter after a calibration process with the maximum goodness-of-fit (GOF) between F_h and F. Each simulated urban form generated by constrained CA is compared to the predefined urban form using the *KAPPA* as a GOF indicator. A benchmark is required to evaluate the degree of matching between the simulated and predefined urban forms. We set an 80% benchmark in this chapter based on our experiences, that is, two urban forms can be regarded as being quite similar when their *KAPPA* value approaches 80%. Consequently, all the sampled parameter sets can be classified into two clusters, namely, the valid cluster and invalid cluster for a predefined alternative plan.

In this chapter, we can generate a valid cluster that includes all possible solutions for the policy parameters through the following steps.

1. Define the initial distribution of each policy parameter x in X. To reflect the proportional relationship among policy parameters, each x is assumed to be uniformly log-distributed from 10^{-3} to 10^3.
2. A sample policy parameter x is randomly drawn from its parent probability distribution.
3. The constrained CA model is run with x to obtain a simulated urban form F.
4. The *KAPPA* of the simulated urban form F and its predefined form F_d is calculated, and F is evaluated as being valid or invalid.
5. Repeat steps 3 through 5 until *KAPPA* reaches convergence.
6. Classify F and x into F_B and x_B and F_{NB} and x_{NB} based on the validation results, where x_B is the identified policy parameter for the predefined urban form F_d.
7. Assess the accepted parameter vector x_B to quantify the parameter uncertainty.
8. Check the significance s to determine whether the two distributions of x_B and x_{NB} are distinctly separated by the K-S (Kolmogorov–Smirnov) test using its Z value.
9. Rank the parameters according to significance s to assess the global sensitivity of each parameter.

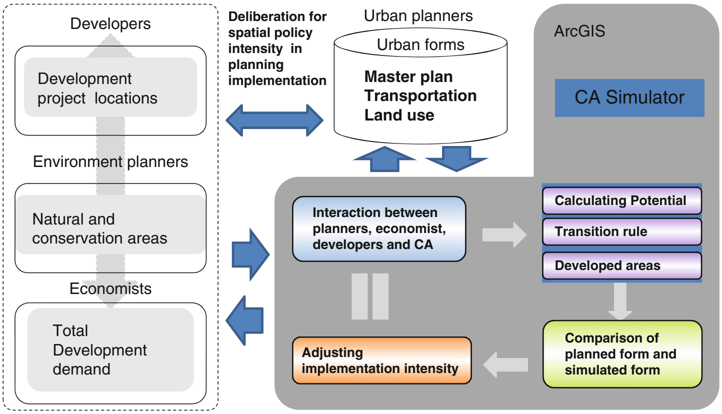


Fig. 5.1 Framework of our approach using the CA simulator

Second, we need to let the planners and stakeholders select their parameters from the identified solution space in the previous process (steps 1–9). In the present work, we define the negotiation process among stakeholders as the adjustment of parameters in CA simulation (Fig. 5.1), which is a negotiation or cooperation process used to reach a consensus on the planned urban form among stakeholders. The planned urban form is assumed to be a goal expected to be realized in the planning period. For implementing the planned form, various stakeholders, including urban planners, developers, economists, and environment planners in the local government, can ask for their respective policy intensities to be strengthened or weakened by comparing the planned and simulated urban forms.

We only investigate the possibility of solutions of the different parameters of spatial constraints for negotiation among stakeholders; the practical negotiation process among them is not discussed in this chapter. In the next section, we describe a virtual city and the corresponding spatial constraints for retrieving all solutions of the policy parameter sets that match the planned urban form.

How to Present the Negotiation Process among Stakeholders Using CA

Planned Urban Form and Spatial Constraints in a Virtual City

The virtual city has 400 square cells, where the size of each cell is 100 m × 100 m (Fig. 5.2). The virtual city is 2 km wide and 2 km long. Three cells are developed in the initial urban form of this virtual city, and we expect to develop 150 cells in the future. For the constraints in the virtual city, we consider two point constraints: PP and NP; two line constraints: PL and NL; and two polygon constraints: PG and NG. Table 5.1 lists these constraints in the virtual city together with their detailed descriptions and

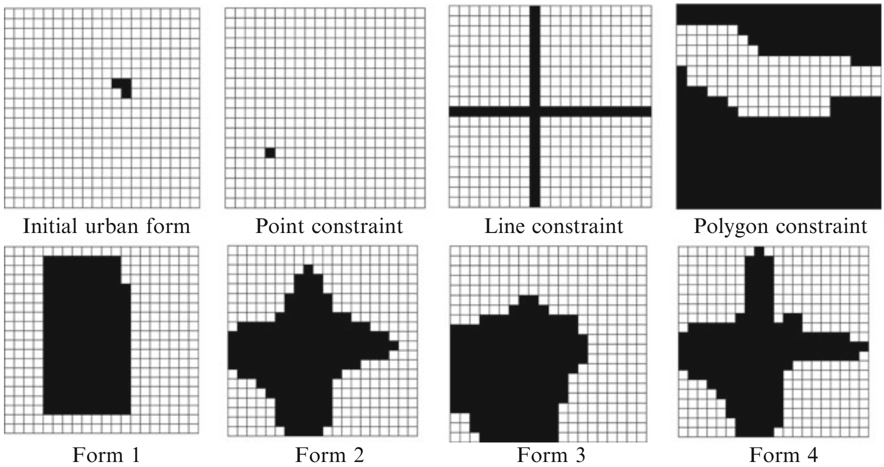


Fig. 5.2 Predefined urban forms in the virtual city

spatial distributions. Each constraint has a corresponding spatial distribution, which largely originates from natural land use, planning, or policy files (e.g., eco-protected zones) or the results of spatial analysis (e.g., proximity of road networks). Table 5.1 shows that these constraints have positive or negative effects (promoting or restricting urban growth) on the future urban form, thus shaping the future urban form due to dynamic interactions with the neighbor effect in the simulation process.

We set four predefined urban forms (Forms 1–4, Fig. 5.2), which are intended as alternative land-use plans in the virtual city. The four urban forms, which vary greatly from each other, will be used as various future images in the virtual city for urban growth simulation with single and multiple constraints.

Policy Intensity for Spatial Constraints Reflecting Negotiation Among Various Stakeholders

Urban form is defined as the geometric shape of the built-up urban space. The urban form at time $t + 1$ can be generated based on the urban form at time t, as follows:

$$F^{t+1} = F^t \bigcup \Omega(P^t | P^t \geq P_{Threshold}), \tag{5.2}$$

where F^{t+1} is the urban form at time $t + 1$; F^t is the urban form at time t; Ω is the entire region; P^t is the probability of development in the region at time t; and $P_{Threshold}$ is the development threshold (0–1) as the lowest allowed development suitability above which urban development will occur. $\Omega(P^t | P^t \geq P_{Threshold})$ stands for the region in which the urban development probability is greater than or equal to the development threshold.

Table 5.1 Constraints in the virtual city

	Type	Name	Description	Stakeholder(s)
Global	Total number of developed cells	TNDC	Total urban development demand	Economist
Point	Positive	PP	Promoting urban growth, such as town centers, subway stations, and public service centers	Private or public developers
	Negative	NP	Restricting urban growth, such as geological disaster sites, pollution sources, solid waste/wastewater treatment facilities, and other not-in-my-backyard facilities	Environment planner
Line	Positive	PL	Promoting urban growth, such as road networks	Transportation planner
	Negative	NL	Restricting urban growth, such as high-voltage power lines, seismological fault lines, and administrative division boundaries	
Polygon	Positive	PG	Promoting urban growth, such as officially planned areas and special policy zones	Land use zoning planner
	Negative	NG	Restricting urban growth, such as agricultural land, ecologically protected areas, and steep areas	Environment planner

In CA simulation, the urban form generally results from multiple constraints rather than a single constraint (Wu and Webster 1998; Li and Yeh 2002; Liu et al. 2008). A multi-criteria evaluation (MCE) approach can be applied for identifying the influence of each constraint. In the MCE, the weight of a constraint is used to estimate the effect of constraint on the urban form. The status transition rule for the proposed constrained CA for urban growth simulation is expressed as follows:

$$\begin{aligned} s^t &= \sum_{k=1}^{m+n} x_k{}^* a_k + x_N{}^* a_N^t \\ P_g{}^t &= \frac{1}{1+e^{-s^t}} \\ P^t &= \exp\left[\alpha\left(\frac{P_g{}^t}{P^t{}_{g\max}} - 1\right)\right] \\ F^{t+1} &= F^t \bigcup \Omega(P^t | P^t \geq P_{Threshold}), \end{aligned} \tag{5.3}$$

where x_k is the policy parameter of constraint a_k (x_k can be regarded as the policy impacts on constraint a_k); ${a_N}^t$, which ranges from 0 to 1, is the number of developed cells within the neighborhood of the cell, excluding the cell itself, divided by 8 (we used the Moore neighborhood with a 3×3 cell configuration for the constrained CA); x_N is the parameter for the neighbor constraint that is set to 1 and remains static across repeated simulations (because x_k is assumed to be log-uniformly distributed to reflect the proportional relationship between the constraint parameters in the parameter identification process); s^t is the development suitability of the cells at time t; ${P_g}^t$ is the development potential of the cells at time t; ${P_g}^t_{\max}$ is the maximum ${P_g}^t$ across the entire lattice space at iteration t; and α is the dispersion parameter, which ranges from 1 to 10, indicating a rigid level of development that regulates urban growth speed. The value of α is herein set to 2. In addition, the positive and negative point and line constraints are assigned effect values using $a_k = e^{-\lambda * dist^{{a_k}^+}}$ and $a_k = 1 - e^{-\lambda * dist^{{a_k}^-}}$ for the positive and negative constraints, respectively, to normalize the constraint values to range from 0 to 1. For the positive polygon constraint, the value of the cell is set to 1 within the constraint and 0 outside the constraint. For the negative polygon constraint, the value of the cell is set to 0 within the constraint and 1 outside the constraint.

Presenting the Negotiation in the Virtual City

Concept of Negotiation While Considering the Neighbor Effect

The negotiation process in the planned urban form among various stakeholders (Fig. 5.3) includes the following: (1) the economist sets the total development demand as the total number of developed cells (TNDC); (2) planners argue for spatial policy intensity in planning implementation, such as the planning policy on road networks and environmental conservation areas that are defined as certain spatial constraints; (3) developers argue for the development policy on their selected locations, which can be defined as a point constraint. Therefore, we consider that changing policy parameters on spatial constraints in simulation can reflect negotiation among stakeholders who are concerned with the different kinds of spatial constraints.

In the following context, we focus on the relationship between spatial constraints and their parameters to gain some insights on the negotiation among stakeholders. Given that the neighbor effect is an important factor in CA simulation, we cannot check the simulation results without considering the neighbor effects. In the virtual city, we conducted two types of experiments: one with no constraints and the other that considers single constraints. In the no-constraint scenario, the development suitability in (5.3) is expressed as $s^t = {x_N}^* {a_N}^t = {a_N}^t$ (as described in (5.3), where x_N is set to 1). See Fig. 5.4 for the results of the no-constraint scenario.

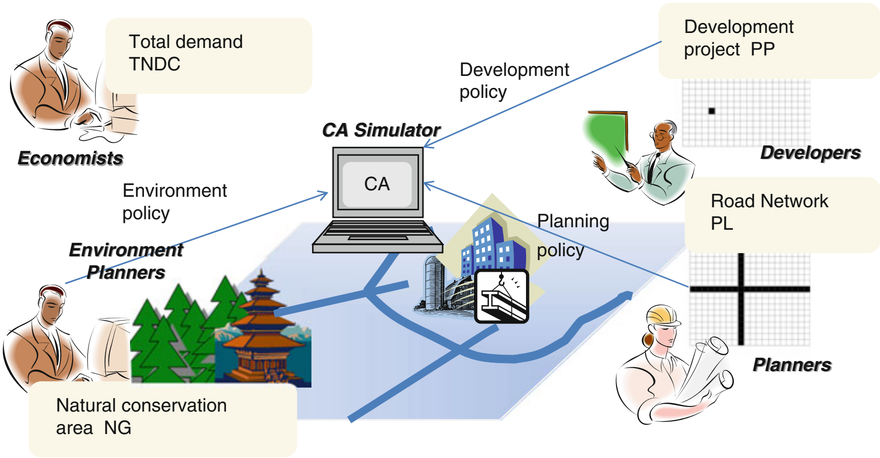
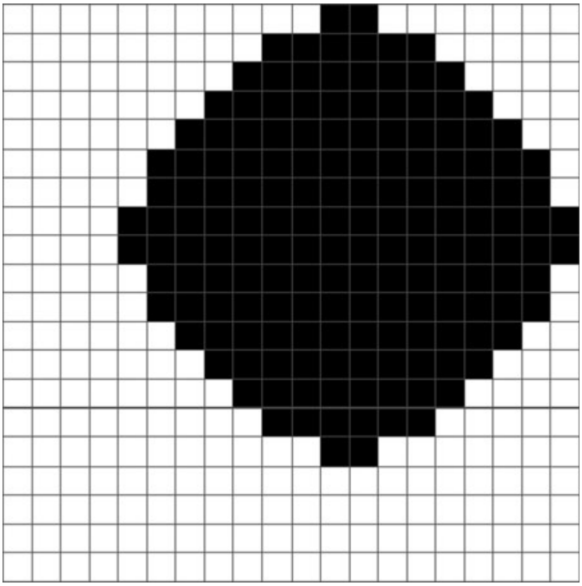


Fig. 5.3 Negotiation process among stakeholders in CA

Fig. 5.4 Simulated urban form with no constraints in the virtual city



For a single constraint, the suitability obtained is calculated using $s^t = \beta^* a_1 + {a_N}^t$, where a_1 is the single constraint. We herein consider the constraint PP as the single constraint. The proportion between the constraint and neighbor parameter is a key factor that influences the simulated form. Therefore, the proportional relation between the single constraint parameter and the neighbor parameter is employed using $\beta = x/x_N = x$, where x is the single constraint parameter, x_N is the parameter of the neighbor effect (set to 1), and β is the reflection of the effect of the single constraint compared with the neighbor effect. To identify the effect of the

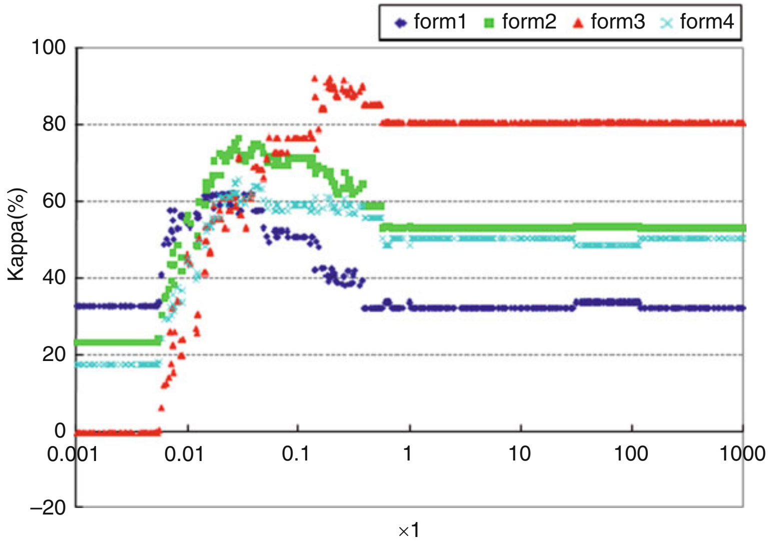


Fig. 5.5 Scatter plots of *KAPPA* and β for constraint PP in the virtual city

constraint on the simulated urban form, we set β to 10^{-3}, 10^{-2}, 10^{-1}, 10^0, 10^1,10^2, and 10^3, respectively, thereby obeying the log-uniform distribution as described in the approach section.

Figure 5.5 shows whether the urban forms simulated using the single constraint PP can be fitted to the four predefined forms in terms of the *KAPPA* indicator. Form 3 is the only form that can be achieved by the single constraint PP when its β value ranges from 0.1 to 0.6, whereas the other three forms cannot be achieved with the single constraint PP, regardless of the β value. For β values less than 0.01 or greater than 1, a relatively steady *KAPPA* value will be achieved for all predefined forms. Thus, *KAPPA* is sensitive when β is between 0.01 and 1, where the effect of the constraint becomes larger and closer to the neighbor effect. When β is greater than 1, then the constraint effect becomes the dominant factor during simulations.

One Planning Policy for Single Spatial Constraint

We ran six single-constraint tests for the six constraints using constrained CA, respectively. In the constrained CA with a single constraint, the simulation process runs while considering the dynamic interactions between the neighbor effect and single constraint. Table 5.2 shows the simulated results of various experiments using constrained CA ($P_{Threshold}$ was set at 0.999) with different β values. Based on the simulated urban forms, we find that single constraints can change the simulated urban form and that β has a strong effect on the simulated urban form.

We can conclude that different spatial constraints have different significant impacts on urban growth. Table 5.2 shows that we only checked the one-policy parameter on one spatial constraint, which highlights the importance of checking the interaction among multi-policy parameters on different spatial constraints. We then assume that the one planning policy represents one planner. Thereby, if more than two policy parameters are taken into account, then there should be a negotiation among the planners who will argue for policy intensity in planning practice. When a consensus is reached on an alternative plan during the plan compilation process, decision makers would find it helpful once they understood the potential effects of the policies on the planned urban form during the planning implementation process.

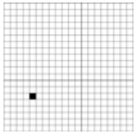
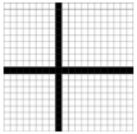
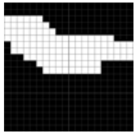
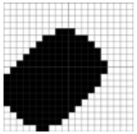
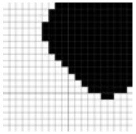
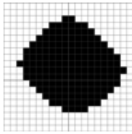
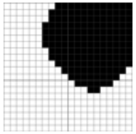
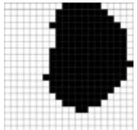
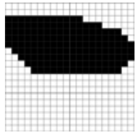
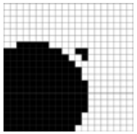
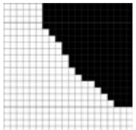
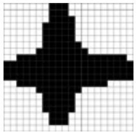
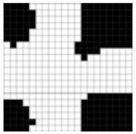
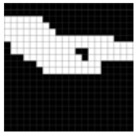
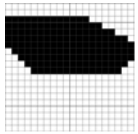
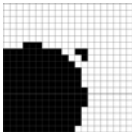
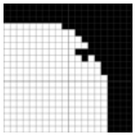
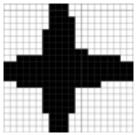
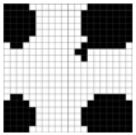
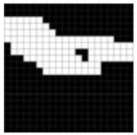
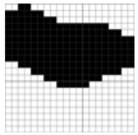
Two Planning Policies for Two Spatial Constraints

In this subsection, we test the effects of two combined spatial constraints by adjusting the policy parameters of each constraint simultaneously to demonstrate how the parameters of the combined constraints are retrieved. We use two constraints, namely, the positive point constraint (PP) and the positive line constraint (PL), in computer simulations. PP can be a location of a development project (as a starting project in a region) and PL can be a road planned by one urban planner.

In the present test, the development suitability is calculated using $s^t = x_1{}^*a_1 + x_2{}^*a_2 + a_N{}^t$, where x_1 and x_2 are the policy parameters for PP (a_1) and PL (a_2), respectively, which are simultaneously adjusted 500 times randomly. The PPI results for the four predefined forms, which vary from each other, are plotted in Fig. 5.6. For Form 1, no parameter pairs are valid, indicating that this urban form cannot be achieved with the combined PP and PL constraints. If Form 1 is set as the planned form, then practical urban spatial development will deviate from the planned form within the context of the current spatial development polices. For the other three urban forms, valid parameter pairs can be applied to realize the corresponding urban form. Considering that Form 1 cannot be archived, there is no negotiation between the planner and the developer. For Forms 2 and 4, strong policy on PP leads to strong policy on PL, which makes the balance and cooperation between the planner and developer necessary. Form 3 cannot be archived without a strong policy on PP, whereas the planner of PL has more alternatives for cooperation with the developer of PP.

Table 5.3 shows that the difference between valid and invalid parameter sets is significant as verified by the K-S test. The *Z* value for each policy parameter of various planned urban form stands for the sensitivity of the policy parameter. That is, a small change of a policy parameter with a high *Z* value will lead to a great change of the simulated urban form in terms of the *Kappa* indicator between the simulated and predefined urban forms.

Table 5.2 Simulation results of various single constraint tests in the virtual city

	Point constraints		Line constraints		Polygon constraints	
Map (A)					 (black)	
Constraint type	PP	NP	PL	NL	PG	NG
Practical meanings	Development project	Pollutant area	Transportation plan	River	Develop promote area	Conservation area
$\beta = 0.1$						
$\beta = 1$						
$\beta = 10$						

Note: In some forms with constraint PG, the number of developed cells exceeded 150 because the number of promoted cells for PG exceeded 200

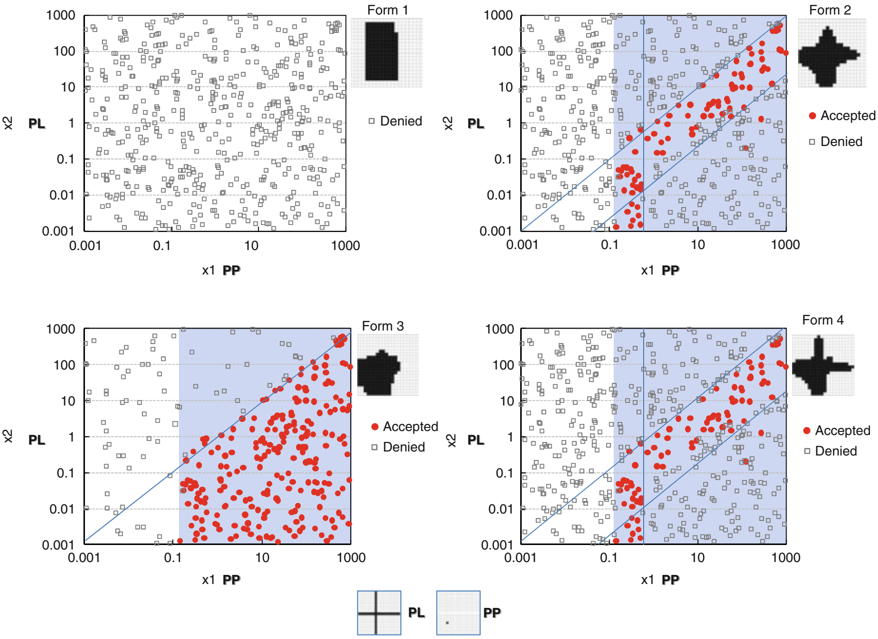


Fig. 5.6 Scatter plots of constraint parameters identified for two combined constraints in the virtual city

Table 5.3 The K-S test for four forms in the virtual city

Z value	Form 2	Form 3	Form 4
x_1	3.169[a]	7.762[a]	2.872[a]
x_2	4.161[a]	4.066[a]	5.080[a]

[a]Significant at 0.001 level (two-tailed)

Economist for Controlling the Total Number of Developed Cells (TNDC)

In this sub-section, we introduce the TNDC as the requirement of an economist in the local government, which is used for controlling the total development demand in the negotiation process among stakeholders. We argue that total development demand will have a significant impact on urban form; thus, the TNDC claimed by the economist may change the extent and shape of the future urban form. Thereby, the TNDC will change the *KAPPA* value between the simulated and planned urban forms. That is, urban forms with a TNDC of less than or greater than 150 may also be similar to the planned urban form in terms of the 80% *KAPPA* restriction.

In the test with the TNDC, we set x_1 as 0.1 for the PP constraint, x_2 as 0.58 for the PL constraint, and the desired TNDC as 400, which represents that the entire virtual city is developed as urban. For each TNDC value from 0 to 400, we run the model

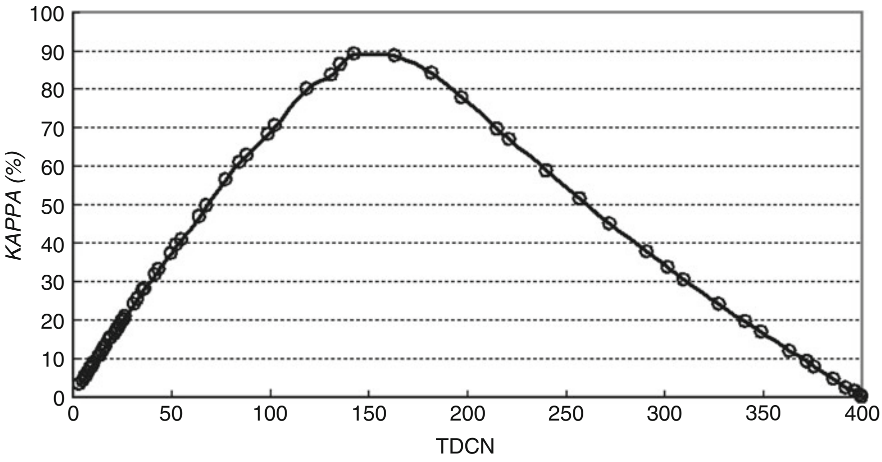


Fig. 5.7 Variations in *KAPPA* with the TNDC in the virtual city

multiple times until the accumulative average Kappa value reaches convergence. Figure 5.7 shows the dynamic variation of *KAPPA* with the TNDC during simulation, where the simulated forms with the TNDC ranging from 120 to 180 all satisfy the *KAPPA* 80% restriction. A TNDC of 150 does not represent the peak of the *KAPPA*-TNDC curve, but rather, a TNDC of 143 has the highest *KAPPA* value. This result indicates that to realize a predefined form, a TNDC value that is the same as the planned form may not be the best condition. Therefore, the TNDC is also an important parameter and should also be argued for realizing the planned urban form.

Figure 5.8 shows the identified parameter pairs for each planned urban form. Circles represent the identified constraint parameters of x_1, x_2, and the TNDC. There are also no constraint parameters available for Form 1, and we have identified numerous parameter pairs for other predefined forms. Table 5.4 presents the descriptive statistics for the three valid predefined forms, which show the overall characteristics of the identified parameters. Only 34 out of 2,000 pairs are valid for Form 2 (we ran the model for 2,000 times, which is enough for model output convergence), whereas there are 107 and 47 valid pairs for Forms 3 and 4, respectively. As a result, if an economist argues for the total demand of development in the planning process, the solution space of policy intensity on spatial constraints will be limited to smaller extent than those without the TNDC. Therefore, more meaningful and available planning policies can be reached with consensus through the cooperation among planners, developers, and economists.

As a result of the K-S test (see Table 5.5), the TNDC, as a new indicator, has a significant impact on the valid and invalid parameter groups.

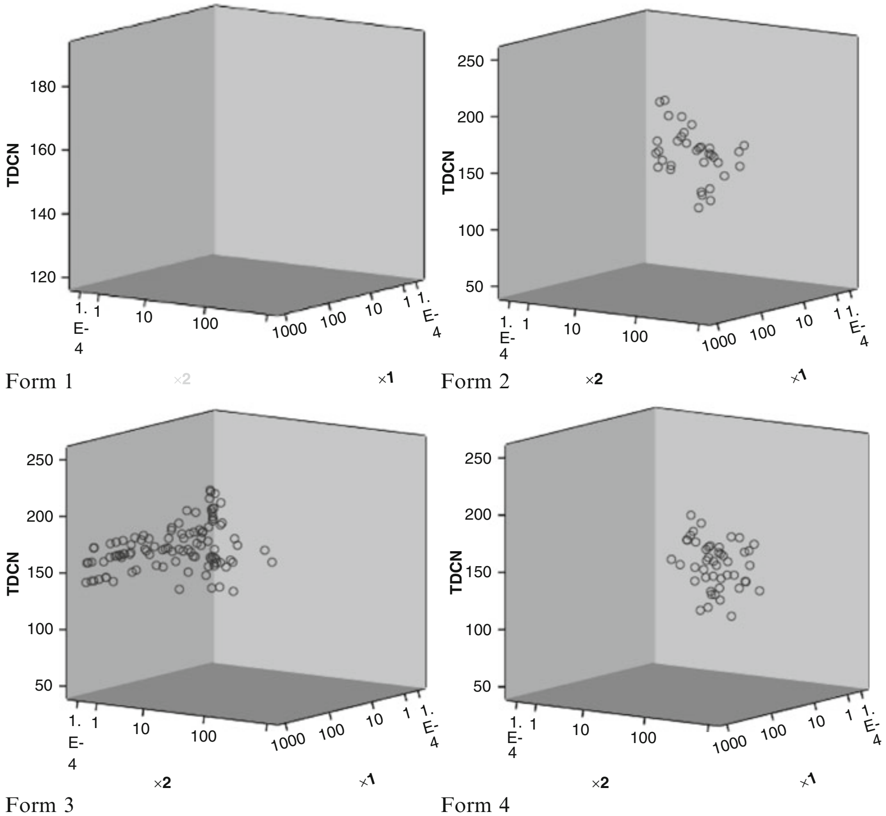


Fig. 5.8 Valid parameter pairs of four predefined urban forms in the virtual city

Table 5.4 Variables for three valid predefined urban forms in the virtual city

Form	Name	Parameter sets	Minimum	Maximum	Mean	Standard deviation
Form 2	x_1	34	0.089	716.995	9.083	177.061
	x_2		0.501	855.844	13.916	233.920
	TNDC		127	188	156.210	16.756
	KAPPA		80.088	89.173	8.357	2.344
Form 3	x_1	107	0.228	971.997	16.456	246.434
	x_2		0.001	722.178	1.491	77.460
	TNDC		125	196	159.620	17.797
	KAPPA		80.416	95.816	8.321	3.192
Form 4	x_1	47	0.022	716.995	8.310	159.772
	x_2		0.911	969.423	170.283	263.144
	TNDC		117	191	149.040	17.757
	KAPPA		80.246	92.666	8.561	3.886

Table 5.5 The K-S test including the TNDC for four forms in the virtual city

Z value	Form 2	Form 3	Form 4
x_1	1.875[a]	4.127[b]	2.439[b]
x_2	2.658[b]	2.880[b]	3.640[b]
TNDC	2.207[b]	3.729[b]	2.891[b]

[a]Significant at 0.002 level (two-tailed)
[b]Significant at 0.001 level (two-tailed)

Conclusion

In this chapter, we proposed an approach for building consensus between planners and developers for identifying the required spatial policies for planned urban form using a CA simulator (constrained CA). We focused on the relationship between spatial constraints and their parameters to gain insights on the negotiation among stakeholders using the CA simulator. We assumed that one planning policy represents one planner. Thereby, if more than two policy parameters are taken into account, then there should be a negotiation between the planners who will argue for policy intensity for their policy in planning practice. The simulated urban form using CA can reflect the policy intensity on spatial constraints, which allows the simulated results to be possibly used for deliberation in the local planning committee among planners, developers, and other stakeholders. Point, line, and polygon constraints with positive and negative effects on urban development are considered in tests in a virtual city. In addition, we also introduce the total number of developed cells (TNDC) as a requirement of economists in the local government, which is used for controlling the total urban development demand in the negotiation process among stakeholders.

In summary, our proposed approach applies to the desired urban form in the foreseeable future by combining various stakeholders in an integrated CA simulator. This tool, as a planning support system (PSS) in planning practice, enables these stakeholders involved in urban development negotiating with each other for realizing a planned urban form.

Acknowledgments We would like to thank the National Natural Science Foundation of China (No. 51078213) for the financial support.

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