Chapter 14
An Urban Growth Control Planning Support System for the Beijing Metropolitan Area

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Introduction

This chapter is a case study of a planning support system (PSS) for urban growth control, in which the Beijing Metropolitan Area is used as an example to demonstrate the implementation of the planning support system. Generally, encroachment on open space and natural resources caused by urban sprawl has drawn worldwide attention and posed enormous challenges to sustainable human development. The possible negative impacts of urban sprawl include increased land consumption, infrastructure construction costs, commuting distance, traffic congestion, energy consumption, and air pollution (Burchell 1998; Anas and Rhee 2006). However, little attention has been paid to urban growth control planning (UGCP), considering various control factors and their indicators, or the possible application of PSS to these problems.

Currently, PSS is regarded as the latest form of computer-aided planning system (Klosterman and Richard 1997; Brail and Klosterman 2001; Stillwell 2002; Geertman and Stillwell 2004). It was initially proposed by Harris (1960). Several books have been edited in recent years regarding the most frequently discussed PSS (Brail and Klosterman 2001; Geertman and Stillwell 2002; Stillwell 2002; Brail 2008; Geertman and Stillwell 2009). The fundamental characteristics of PSS include its systematic, dynamic and interactive nature. It has been mainly applied in spatial plans (Kammeier 1999; Geneletti 2008), urban environment improvement plans (Edamura and Tsuchida 1999), industrial location choices (Piracha and

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Kammeier 2002), and land-use plans (Klosterman 1999). Typical PSSs currently used in urban planning are INDEX for land-use planning, *What If*? for land-use and urban planning, CommunityViz for community planning, CITYgreen for evaluating the ecological value of urban green space, GB-QUEST for future development prediction, NatureServe Vista for biodiversity protection, WEAP for water resource evaluation and planning, AEZWIN for land resource evaluation, RAMCO for coastal management, and BLM ePlanning for planning information sharing (Long 2007). However, there are no existing PSS packages related to urban growth control. Because the spatial distribution of control factors and the specific content of control indicators can all be temporally dynamic in UGCP, UGCP planning schemes need to be adjusted occasionally. Therefore, we construct the urban growth control planning support system (UGC-PSS), a planner-oriented system, so that it can adapt to these practical requirements by interacting with urban planners, re-calculate the planning scheme, and output the planning drawings with high efficiency.

To address UGCP issues, land-use suitability analysis for urban growth was first proposed by McHarg (1969). It has become a mature method in the field of land-use planning, used to identify appropriate regions for feasible urban land use (Diamond and Wright 1988; Carver 1991; Thill 1999; Sui 1993). To conduct land-use suitability analysis, overlay functions and multi-criteria evaluation (MCE) are commonly combined to create suitability maps for various land uses. The land-use suitability analysis approach, however, has its limitations in simultaneously taking into account numerous control factors (CFs) together with their multiple control indicators that are involved in UGCP. For this purpose, we developed a specific urban growth control planning support system, rather than employing the land-use suitability analysis directly, that supports the whole planning compilation process, including displaying control factors and automatically calculating and exporting the UGCP scheme.

In urban planning practice, urban growth control aiming to alleviate the negative effects of urban sprawl is needed in many urban areas in Europe, the USA, Japan, and China. In Europe and the USA, urban growth control toolkits can be classified into four types: neotraditional development, urban containment, compact city, and eco-city toolkits. Recently, urban containment policies, targeting improved development density and open space protection, have been extensively applied to control urban growth (Nelson and Duncan 1995). They usually include three forms: greenbelts, urban growth boundaries (UGBs), and urban service boundaries (USBs), all of which are designed to contain the future urban form within pre-defined boundaries in order to control urban sprawl and encourage “infill development”. Urban planners have also advocated the adoption of the compact city model and other intensive forms (Echenigue 2005). In America, more than 100 metropolitan areas, together with their sub-regions, have adopted urban containment policies to control urban growth by 2004 (Nelson and Dawkins 2004). The main purposes of those policies were to protect open space and improve the efficiency of urban land development (Nelson and Dawkins 1999; Pendall and Martin 2002). In Japan, the “Planned Urban Area” policy is applied in land-use planning to regulate urban growth. During periods of rapid growth, urban growth has not been effectively controlled in Japan, resulting in over-scattered urban forms. Meanwhile, in China, construction-forbidden areas and UGBs need to be established to control urban sprawl according to the latest "Urban and Rural Planning Act" that took effect on January 1, 2008. In addition, green belt policies have also been implemented in some cities, such as Beijing and Shenzhen. Generally speaking, according to European and American experience, as well as practices in China, urban planners should view urban growth control as a critical element during the process of creating urban plans.

In Chinese urban planning and management practice, however, these borrowed urban containment policies, especially green belts and UGBs, that aim to determine rigid control boundaries for urban growth cannot control it effectively because China's over-abstracted control means that "development permitted" and "development not permitted" rules can only be applied in absolutely controlled areas, not in relatively controlled areas. In the relatively controlled areas, urban development may be permitted subject to some development requirements, such as maximum (protecting the perspective of old buildings) or minimum (preventing flood inundation) building heights, constrained land-use types, or constrained urban activities. Therefore, urban growth control can be divided into two classes, absolute control (forbidding all types of urban developments and activities), and relative control (allowing development meeting some designated requirements). To address this objective issue, we propose the concept of "urban growth control planning" and apply it to solve the comprehensive problem of urban growth control. In contrast to existing urban containment policies, UGCP requires not only the establishment of absolute boundaries restricting urban growth, but also specific control requirements based on various control aspects in regions where urban growth is relatively controlled.

In this chapter we discuss how to deal with absolute and relative control using the UGC-PSS and introduce the theoretical methodology, key techniques, and dataset requirements, as well as documenting one case of UGC-PSS implementation. To begin with, we discuss our approach to urban growth control planning in Sect. "Research Approach", and investigate how to establish UGCP planning using spatial control factors and their indicators in Sect. "Spatial Factors Related with Urban Growth Control". In Sect. "The System Framework of UGC-PSS", we analyze and discuss UGC-PSS implementation, and in Sect. "UGC-PSS in the Beijing Metropolitan Area" we report the application of UGC-PSS in UGCP in the Beijing Metropolitan Area. Finally, in Sect. "Conclusions and Discussion", we draw conclusions and offer further discussion about UGC-PSS.

Research Approach

In considering urban growth control, urban planners first want to know what control factors are available. For this, UGS-PSS should provide a well-structured menu of numerous control factors and corresponding control indictors, thus enabling planners to organize a dataset using the PSS to support their ideas in the planning process. UGC-PSS should take all possible control factors, together with their control indicators, into account to show their comprehensive and combined effects. Planners will continue to work out planning rules for urban growth control, and so UGC-PSS must be capable of not only calculating planning schemes using numerous control factors and their control indicators, but also of automatically exporting the calculated planning scheme. Moreover, UGC-PSS output is also expected to set conditions on other spatial plans for the built-up urban space layout at the various levels of the entire city, urban districts, or blocks in order for developers and urban planners to be able to understand the control conditions at their project sites.

To meet these system requirements, we choose the uniform analysis zone (UAZ) scheme, a vector dataset of irregular polygons, as the basic UGC-PSS data model to express control cells (in the following context, a UAZ can be regarded as a control cell). The UAZ scheme was first proposed by Klosterman (1999) and introduced into his WHAT IF? planning support system. In WHAT IF?, the UAZ is the fundamental analysis unit of modules, such as Land Suitability Evaluation and Land-Use-Demand Allocation. In the California urban future model (CUF) proposed by Landis (1994, 1995) for simulating urban development, the fundamental modeling unit is the developing land unit (DLU), which is similar to the UAZ in that they are both based on irregular polygons. Unlike WHAT IF? and CUF, the proposed UGC-PSS emphasizes natural resource protection and risk prevention in urban growth control, rather than analyzing and predicting urban growth.

In view of the large number of control factors located in a control cell, the GIS spatial analysis toolbox UNION can be employed to generate the UAZ dataset. UGC-PSS generates the UAZ layer based on different sets of control factors (see Fig. 14.1). The UAZ dataset denotes the spatial distribution of the control cells as the basic system input to UGC-PSS. The UAZ attributes, namely T, H, A, and U control indicators, can be calculated to generate planning rules for UGCP. The control cells, together with planning rules, are used to produce the UGCP planning scheme based on different spatial partitions.

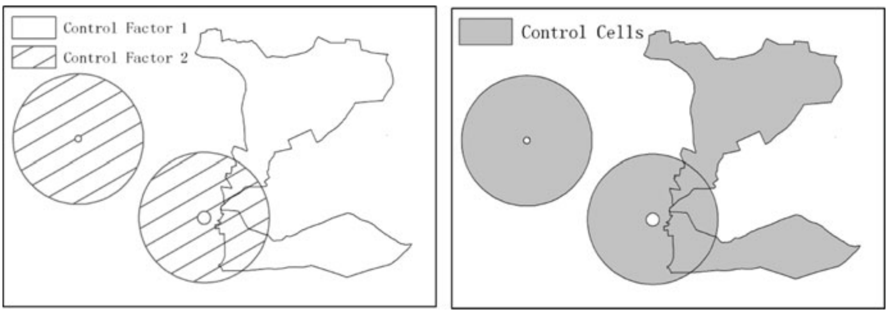


Fig. 14.1 Diagrams of control factors and corresponding control cells in a small part of the Beijing Metropolitan Area

In the next section, we discuss how to generate planning rules based on the UAZ dataset in UGC-PSS. Most of our control factors are prepared and edited in vector format. However, if a raster dataset is chosen for UGC-PSS, all the vector-based planning drawings should be converted into raster formats, which should be saved in the same grid size. This may reduce the data precision. In addition, compared with the regular rectangle raster, the irregular polygon-based UAZ dataset is more capable of recording numeric attributions for further calculations. However, one disadvantage of the UAZ data model is that it takes more computation time than a raster data model using map algebraic operators. Therefore, the arithmetic in UGC-PSS still requires further optimization.

Spatial Factors Related with Urban Growth Control

Spatial Factors

UGCP is based not only on the spatial distributions of factors that curb urban growth, but also on their control indicators determined by existing materials, including laws, codes, regulations, technical standards, research results, international treaties, and agreements, as well as already approved plans. The approved plans may consist of rules for geological hazard prevention, water resource protection, cultivated land protection, and ecological space protection, for example. UGCP can be regarded as "a plan of the plans" or a combination of the plans. Generally, UGCP's foundamental inputs are control factors and corresponding control indicators, as distinguished from land-use suitability analyses based on natural elements such as terrain, geological conditions, climatic conditions, and soil types.

On the basis of the processes and nature of the urban growth, it can be divided into urban developments and urban activities. Urban developments can be divided into the above-ground and underground types. Accordingly, the essence of UGCP in this chapter includes not only above ground urban development, but also underground development and the corresponding urban activities. This view of urban growth control is multi-dimensional in practice and includes controls on development type, building height, and city activities, as well as on underground development. The tasks involved in UGCP are to demarcate control zones (*Z*) as control indicators so as to distinguish between rigid absolute control areas and flexible relative control areas, and then carry out more detailed controls from a multi-dimensional perspective, utilizing the other four control indicators: land-use type control (*T*), construction height control (*H*), urban activities control (*A*), and underground development control (*U*) (see Long et al. 2006; He 2008).

The five control factor indicators, reflecting the various essential means of controlling an urban form, can be defined as the term of the negative form (NF) in this study in that every control indicator plays a role in modelling the urban form by controlling development types, building height range, urban activities, or underground development. In contrast to other studies on the urban form, a NF does not recommend types of urban forms to be developed, but rather defines the urban forms that are forbidden or restricted to control growth. In the process of urban growth, such forms should be controlled, so as to avoid encroaching on ecological resources or incurring other risks. The NF, as the final, multi-dimensional product of the UGCP, can be applied to guide the determination of urban forms in land-use planning, urban master planning, or detailed regulatory planning.

To conduct UGCP, it is first necessary to identify the spatial distribution of control factors (CFs). The spatial distribution of the CFs can be obtained from various local government departments. The CF control indicators, a primary basis of UGCP compilation, include the following main aspects:

Control zones (*Z*): divided into absolute control (AC) and relative control (RC) classes.

Absolute control (AC):

In this zone all types of urban construction, urban activities, and underground developments are forbidden. The absolute control zone, as the rigid control limit on urban growth (the other four indicators are irrelevant here), is identical to the currently existing plan drawings based on policies forbidding construction in certain areas in China.

Relative control (RC):

In this zone, there are strict constraints on urban construction, urban activities, and/or underground developments. Special requirements for other control indicators (such as *T*, *H*, *A*, and *U*) need to be met to permit urban growth within this zone. Relative control is identical to the existing policy governing construction-limited areas in China. The other four indictors are not required to be simultaneously active for the construction-limited policy, which, in practice, considers only the boundaries of the limited construction areas.

Land-use type control (*T*): Forbidden urban land-use types. If there is no limitation, then the value of *T* is null.

Construction height control (*H*): Specifies the forbidden building height in meters. If there is no height limitation, the value of *H* is null.

Urban activities control (*A*): Refers to controlled urban activities. If there is no limitation on this indicator, the value of *A* is null.

Underground development control (*U*): Indicates whether underground development is controlled; if yes, $U = 1$, otherwise *U* is null.

Detailed descriptions of the control indicators are shown in Table 14.1 ("AC" stands for the absolute control zone, and "RC" for the relative control zone).

We define the detailed content of each control indicator of every control factor as shown in Table 14.1. For instance, the control elements of indicator *T* are "R", "C", and "M". The relationship between control elements and control indicators is

Table 14.1 Descriptions of control indicators for urban growth control

Control indicators	Z = "RC"				Z = "AC"
	T	H	A	U	
Description	Regulations for different types of land use	Regulations on building height	Regulations for different types of urban activities	Whether underground development is permitted	No construction will be permitted
Sample control elements	Residential (R)	>27	Control of facilities destruction (a)	1	
	Commercial (C)	<9	Control of pollutant emissions (b)		
	Industrial (M)	9–27	Control of resource exploitation (c)		
			Control of site occupation (d)		

illustrated in (14.1), where t_m, h_p, a_q, u_r are, respectively, the control elements of control indicators T, H, A, and U and m, p, q, and r are, respectively, the total numbers of control elements in the corresponding control indicator sets, K_T, K_H, KA, and K_U are the control element sets, i is the control factor ID, I is the total number of control factors, j is the control indicator ID, l_{ij} is the value of the control indicator j for control factor i, and L is the set of all control indicators for all control factors. From (14.1), we can see that the control indicator of a given control factor may include more than one control element. If $l_{ij} = \Phi$ (the empty set), control factor i is not controlled by control indicator j. On the other hand, if it includes all the control elements of the control indicator, namely $l_{ij} = K_j$, the control factor i is absolutely controlled by the control indicator j. Moreover, if all the control indicators are absolutely controlled, namely, $l_{iT} = K_T, l_{iH} = K_H, l_{iA} = K_A$ and $l_{iU} = K_U$, the Z indicator of control factor i is "AC", which stands for absolutely controlled.

$$
\begin{aligned}
K_T &= \{t_1, \ldots.t_m\} \\
K_H &= \{h_1, \ldots.h_p\} \\
K_A &= \{a_1, \ldots.a_q\} \\
K_U &= \{u_1, \ldots.u_r\} \\
L &= \{l_{ij} | i = 1, 2, \ldots, I, j \in \{T, H, A, U\}\} \\
\mathit{where}\ l_{iT} &\subseteq K_T, l_{iH} \subseteq K_H, l_{iA} \subseteq K_A, l_{iU} \subseteq K_U
\end{aligned}
\tag{14.1}
$$

The control factor with all its control indicators corresponds to one NF. For example, Z denotes whether urban developments are allowed. If $Z =$ "AC", then urban developments are absolutely forbidden, and the NF should be a purely natural landscape. H and T play roles controlling the aboveground urban form. A controls urban activities within the urban form and is related to the social space rather than the physical space. U controls the underground development of the urban form. Equation (14.2) expresses the relationship between these indicators and NF, where F is all the possible urban growth patterns within the whole study area, UF is the urban form, and NF is the negative form. We divided all the possible urban growth patterns from aspects of T, H, A, and U within the whole study area into two parts, the negative form (NF) and the urban form (UF), based on T, H, A, and U.

$$
\begin{aligned}
F &= \{UF \cup NF\} \\
UF &= \{x | x \in F, x \notin NF\} \\
NF &= \{(T, H, A, U)\}
\end{aligned}
\tag{14.2}
$$

To address the issue of multiple overlapping control factors, we propose using the control cell to stand for the combination of control factors in the same geographical space. Since each control factor corresponds to one NF, every control cell also stands for one NF, which integrates the NFs of the control factors, and is the basic unit of the UGCP analysis. The calculation method for the control cell using the control factors will be investigated in detail in the next section.

Calculating Planning Rules for Urban Growth Control

In view of the complexity of factor composition and the spatial distribution of control cells (being the basic UGCP analysis unit), a planning support system based on GIS has been developed to assist in compiling the UGCP, in which the NF of every control cell is calculated according to the UGCP scheme.

In this chapter, the term "planning scheme" is defined as the control cells, together with their planning rules, as generated from the control factors and their indicators. Equation (14.3) shows how to calculate the planning scheme using different control factors' indicators. In (14.3), UAZ stands for the generated control cell dataset using UNION, x for its ID, uaz^x for a control cell, $R(uaz^x)$ for the planning rule for control cell uaz^x, ${uaz_j}^x$ for the planning rule j for control cell uaz^x, s_x for the control factor set contained in uaz^x, $\bigcap_{i \in s_x}^{spt}$ for the overlapping space of control factors s_x (the spatial intersection set), and f^j for the function to calculate the planning rule j.

$$
\begin{aligned}
UAZ &= \{uaz^x | x = 1, 2, 3, \ldots, X\} \\
R(uaz^x) &= ({uaz_T}^x, {uaz_H}^x, {uaz_A}^x, {uaz_U}^x) = l^{s_x} = \bigcap_{i \in s_x}^{spt} l_i \\
{uaz_j}^x &= \underset{i \in s_x, j \in \{T,H,A,U\}}{f^j} (l_{ij})
\end{aligned}
\tag{14.3}
$$

The planning rules can be calculated from the control factors contained in the control cell. However, methods of calculating the (f^j) of the planning rules may vary.

The System Framework of UGC-PSS

Urban Planners and UGC-PSS

UGC-PSS is important in the current planning practice requirements in Beijing. Given the spatial extent of particular developing sites, the system will be helpful in developing many urban and rural spatial plans to be implemented in Beijing, such as the respective coordinated planning of the eastern and western parts of Beijing, zoning of the central city, and master plans for nine new cities and 12 towns and the Badaling-Ming Tombs scenic area plan. Most of these spatial plans are at the master plan level.

For spatial planners with an urban planning background who are not very familiar with the regulations or standards related to urban growth control, UCG-PSS should be a comprehensive tool covering all the other fields, such as forests, environment protection, water resources, and earthquake prevention, adhering to all the *relevant* urban growth control regulations or standards, such as land-use control and building height control, thus making it possible for urban planners with better understanding to accept their urban growth control ideas and formulate better spatial plans meeting urban growth control requirements.

To present the results of the comprehensive urban growth control system in the negative form for spatial planners, all possible control factors for controlling the urban forms of land-use, building height, urban activities, and underground development in the spatial plan should be listed in the UGC-PSS.

To present the spatial distribution of the control cells and the planning rules for each cell, it is necessary to present the GIS dataset in terms of control cells and to print it out at different map scales. Since the combination of control factors and the massive number of control cells generated make it difficult to express the planning scheme in a single page, we partition the UAZ layer of the whole study area into multiple partitions according to the requirements of the result display. For instance, partitions can be generated by dividing the whole study area into several rows and columns, or according to standard Chinese map scales, such as 1:25,000, 1:10,000, 1:5,000, 1:2,000, and 1:500, for various purposes. Generally, to support the master plan, the UGCP scheme should be at the scale 1:25,000, the detailed plan at 1:2,000, and the architectural construction projects at 1:500. Thus, in checking development conditions, planners and developers can understand the objective conditions for urban growth control by reading the hardcopy of the scheme or querying the UGC-PSS.

This indicates that the main challenges in UGC-PSS implementation are the process for retrieving the spatial patterns of the urban growth control using UAZ and presenting the results for urban planners.

Development of UGC-PSS for Urban Planning and Design

The UGC-PSS system that we developed consists of six modules: the system configuration, spatial dataset display, comprehensive query, control cell generation, automatic planning scheme calculation, and automatic planning scheme output. The last three modules make up the core of the UGC-PSS.

The UGC-PSS operating procedure is as follows:

1. Users log in to the system through the common user interface, which has access control.
2. Users set system configurations, including defining the workspace for the input and output datasets, selecting the control factors to be involved in the planning scheme calculation, setting the scheme partitioning, and modifying the users' privilege levels, using the "System configuration module".
3. Users load the corresponding required datasets, including control factors and other base layers, and set the display parameters using the "Spatial dataset display module". The spatial distribution of control factors can be browsed by users along with basic feature classes, such as road networks, rivers, and residential areas, as spatial location references.
4. Using the "Control cell generation module", the control cell feature classes (planning rules are not calculated yet) can then be generated based on selected control factors and their indicators using the spatial analysis settings. The control factors are stored in the Geodatabase as feature classes, and the indicators for all the control factors are stored as an info table in the same Geodatabase.
5. The "Control cell generation module" can be employed to calculate planning rules for those control cells already generated by the "Control cell generation module". The results of the calculation can be regarded as the planning scheme, which can be accessed in two ways.

   - Users can conduct comprehensive queries of the planning scheme from aspects of the spatial distribution of control cells and their planning rules, and can analyze the construction conditions objectively within a given yet-to-be-developed area using the "Comprehensive query module". The module is developed especially for spatial planners to use when they query the urban growth control conditions for the designated planning area.
   - The planning scheme can be exported automatically using the "Planning scheme automatic output module" in the form of many digital figures, which can also be printed as one collection of figures for decision makers' creating the UGCP.

The fundamental structure and workflow of the UGC-PSS are as shown in Fig. 14.2.

Based on the diagram above, a UGC-PSS was developed using the ESRI ArcGIS Engine 9.0 by Visual Basic 6.0, while the automatic planning scheme calculation module was developed in Visual C++ for computational efficiency. We used the ESRI Personal Geodatabase based on Microsoft Access. As shown in Fig. 14.3, the main interface of the system is composed of seven parts: the title bar, menu bar, toolbar, map window, layer control window, thumbnail window, and query results output panel. It is possible to perform data browsing, queries, and other related functions through the main graphic user interface, while further system functions can be accessed through the menu bar.

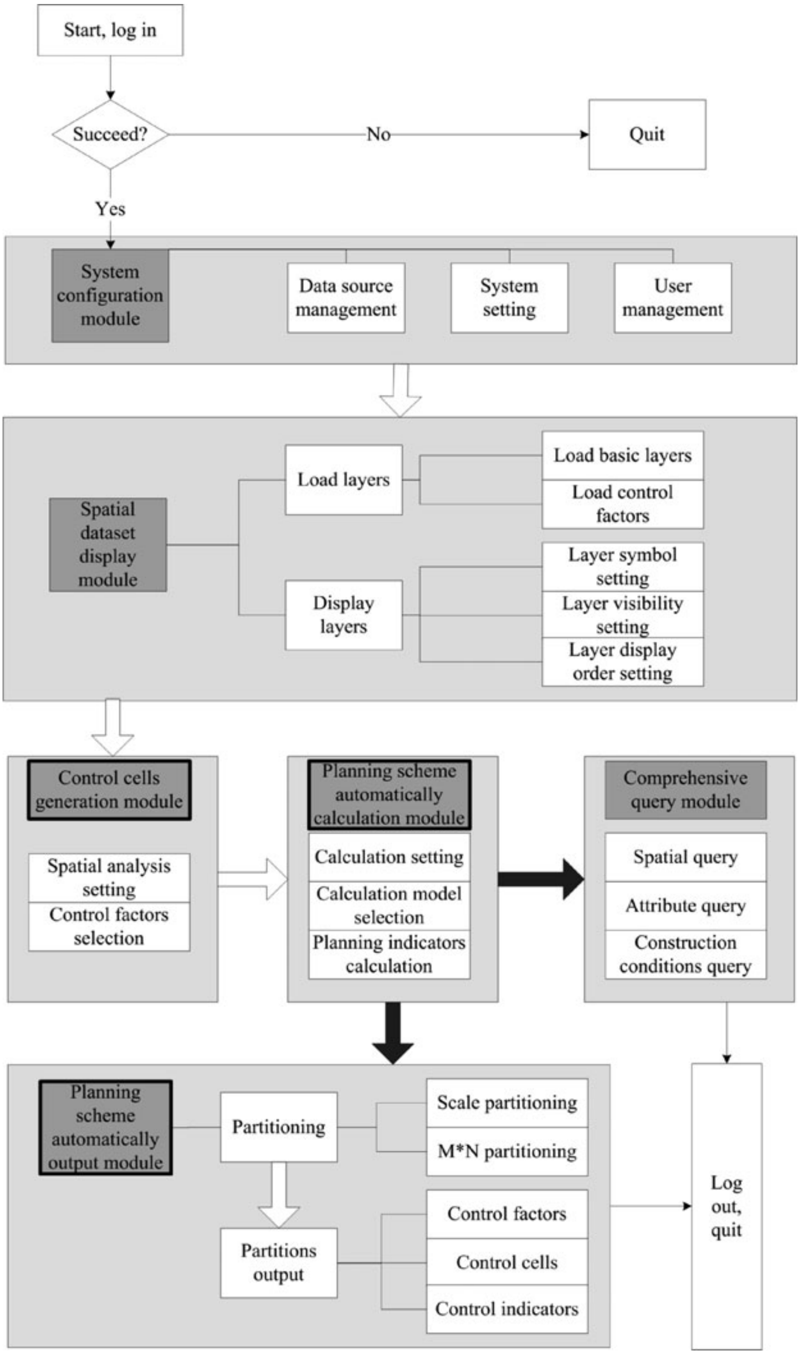


Fig. 14.2 Framework and flow diagram of the UGC-PSS (The modules with the thick frames are the three key modules of the UGC-PSS)

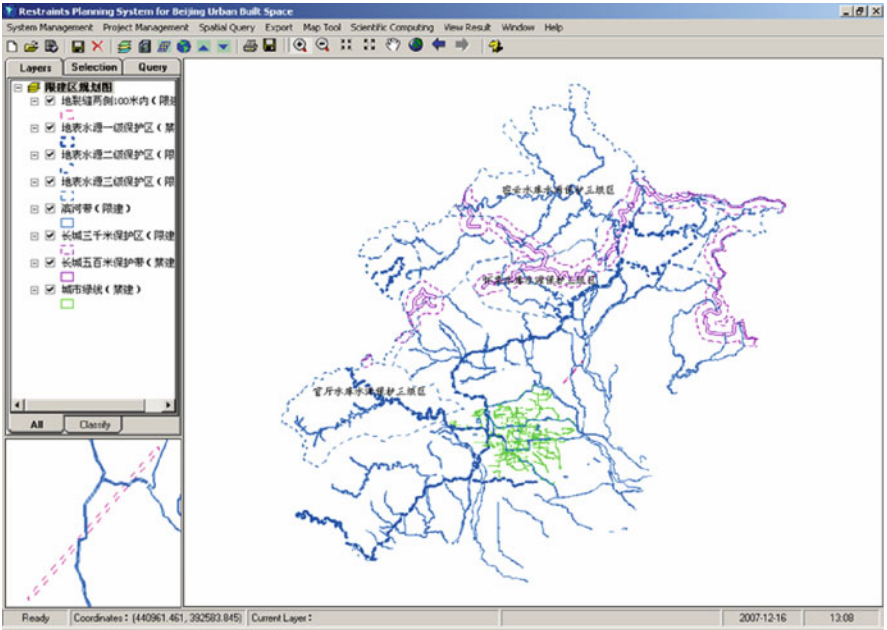


Fig. 14.3 Main UGC-PSS graphic user interface

UGC-PSS in the Beijing Metropolitan Area

Study Area: The Beijing Metropolitan Area

During the process of rapid development in Beijing, the tendency to disorderly urban expansion has not yet been effectively controlled. Within the Beijing Metropolitan Area, urban growth is restricted by many control factors. Urban growth control planning in Beijing has been conducted to solve the problems caused by urban growth in the mega-metropolis, and UGC-PSS played an essential role in planning support. The spatial extent of the planning region is the Beijing Metropolitan Area (see Fig. 14.4) with an area of 16,410 km^2. It lies in northern China, to the east of the Shanxi altiplano and south of the Inner Mongolia altiplano. The southeastern part of the study area is a plain about 150 km from the Bohai Sea. Mountains cover 10,072 km^2, 61% of the area.

Integrating All Control Factors and Indicators Using UGC-PSS

The basic datasets used in UGC-PSS include fundamental terrain datasets, administrative division boundaries, and control factors. The fundamental terrain datasets

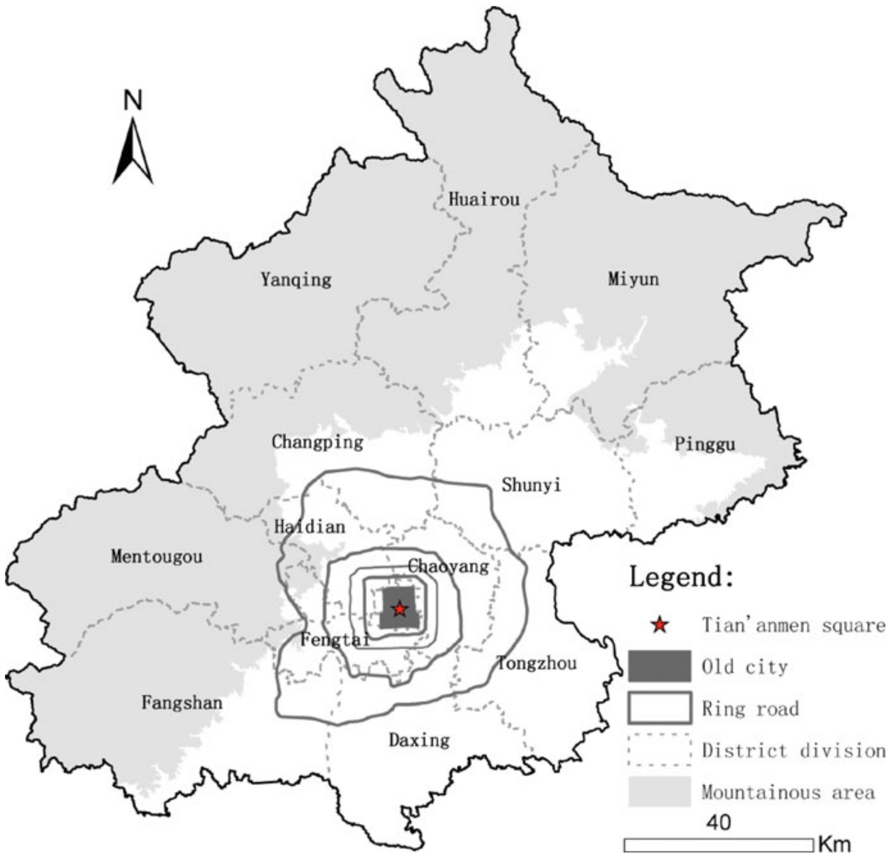


Fig. 14.4 Spatial structure of the Beijing Metropolitan Area

are topographic maps of different scales, aerial maps with 1 m resolution, digital elevation models (DEM), existing roads, existing wetlands, current land-use maps, and the urban master-planning scheme. There are administrative division boundaries at the district, town, and ward levels. The first two datasets, which are not involved in the calculations of the UGCP scheme, mainly aid in expressing the planning scheme spatially in terms of the base map and assist with spatial queries.

Control factors are among the most important datasets in the UGC-PSS. Within the study area, there are 60 control factors controlling urban growth, including water conservation, biodiversity conservation, agricultural land protection, flood control, geological disaster prevention, steep slope areas, and pollution source protection. Four of Beijing's control factors are displayed in Fig. 14.5. Within the spatial distribution of each control factor, control guidance remains the same, or must be subdivided into new control factors.

In the Beijing Metropolitan Area, the elements of each control indicator are, respectively, $K_T = \{``R", ``C", ``M"\}$, $K_H = [0, 1000)$, $K_A = \{``a", ``b", ``c", ``d"\}$, and

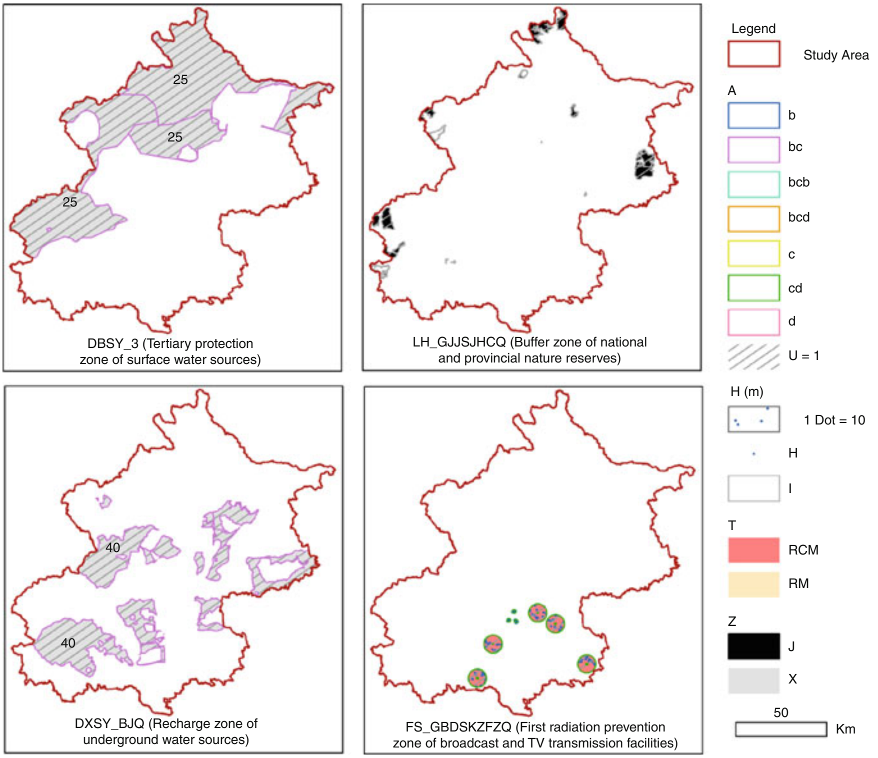


Fig. 14.5 Negative urban forms for four control factors (DXSY_3, LH_GJJSJHCQ, DXSY_BJQ, and FS_GBDSKZFZQ denote the control factors, and a, b, c, and d are control elements of the indicator *A*. *R*, *C*, and *M* are elements of the control indicator *T*. In the control indicator *H*, one dot stands for a maximum building height of 10 m)

$K_U = \{1\}$. The names and control indicators of all control factors are listed in Table 14.2, and the spatial distribution of every control factor is available from the Beijing Municipal Planning Commission (2007). For instance, one control factor in Table 14.2 stands for the secondary protection zone of surface water sources, which belongs to the relative control level, and urban activity with pollutant emissions is forbidden. Within the spatial extent of it, moreover, residential, commercial, and industrial land uses are not permitted. Another control factor denotes the first protection zone of surface water resources, where all urban activities and developments are absolutely forbidden.

All the planning rules are calculated using the same function, namely the union of sets, in this model. That is to say, the value of the planning rule equals the union of the corresponding control indicators of the factors contained in the control cell. In terms of planning practice, this means that the control cell obeys all the control rules of the factors within the control cell.

Table 14.2 Inventory of control factors and corresponding control indicators

Description	*Z*	*H*	*U*	*A*	*T*
Secondary protection zone of surface water sources	RC			b	R C M
Tertiary protection zone of surface water sources	RC			b c	
Area of over-exploited underground water	RC			c	R M
Recharge zone for underground water sources	RC		1	b c	
Protected zone of underground water sources	RC		1	b c	
Area with poor engineering geology	RC	>45			R C M
100 m to 500 m buffer zone around ground fissures	RC				RM
Secondary radiation prevention zone for broadcast and TV transmission facilities	RC			c d	
Primary radiation prevention zone for broadcast and TV transmission facilities	RC	>120		c d	R C M
Zone forbidding night soil treatment plants	RC				R C M
Zone forbidding waste compost plants	RC				R C M
Zone forbidding waste incineration plants	RC				R C M
High-risk flooding area	RC			d	
Existing forests in the second greenbelt	RC				R C
First greenbelt	RC	>18			
Secondary scenic spot protection area	RC	>9		b c d	
Tertiary scenic spot protection area	RC	>18		b c d	R M
Planned scenic spots	RC	>27		b c d	
Experimental zone of national and provincial nature reserves	RC			b c	
Forest parks	RC	>21		b c	
County-level nature reserves	RC			b c	R M
Other existing scenic spots	RC	>21		b c d	R CM
General ecological forests	RC			c d	RM
General cultivated lands	RC			c	RC
General farmlands	RC	>9	1	b c d	
River buffer zone	RC			a b c d	R C M
Reservoir buffer zone	RC			a b c d	
Piedmont ecological protection zone	RC			b c	R
Protection zone for south-to-north water diversion infrastructure	RC			d	
Secondary protection zone for oil/gas pipelines	RC			d	
3 km buffer zone for the Great Wall	RC	>9			
Protection area for underground cultural relics	RC	>15			
Historical culture protection area	RC	>15			
Secondary noise prevention zone around city roads	RC				R C
Secondary noise prevention zone around light railways	RC				R C
Tertiary noise prevention zone around Beijing Capital International Airport	RC				R M
Primary protection zone for surface water sources	AC				
Radiation prevention zone near 110 KV power stations	AC				
Radiation prevention zone near 220 KV power stations	AC				
Radiation prevention zone near 550 KV power stations	AC				
Flood diversion gates	AC				

(continued)

Table 14.2 (continued)

Description	*Z*	*H*	*U*	*A*	*T*
Flood detention area in central city	AC				
Green wedges	AC				
Planned green lands within the first greenbelt	AC				
Primary scenic spot protection area	AC				
Special grade protection area for scenic spots	AC				
Buffer zone around national and provincial nature reserves	AC				
Core zone for national and provincial nature reserves	AC				
Green spaces in central city	AC				
Key ecological forests	AC				
Basic farmlands	AC				
River-type wetlands	AC				
Pond and reservoir-type wetlands	AC				
Steep areas with slopes greater than 25°	AC				
Prevention zone around 110 KV transmission lines	AC				
Radiation prevention zone around 220 KV power transmission lines	AC				
Radiation prevention zone around 500 KV power transmission lines	AC				
Primary protection zone around oil/gas pipelines	AC				
500 m buffer zone around the Great Wall	AC				
Protected historical units	AC				

Presenting Planning Scheme Using UGC-PSS

In the Beijing urban growth control planning, UGC-PSS has played a supporting role in plan compilation from the beginning. Most importantly, UGC-PSS can perform the functions of calculating and outputting the planning scheme, tedious tasks in routine planning practice. Control cells are created based on control factors (Fig. 14.6), and 60 control factors generate 356,689 control cells using the UNION function. Based on the generated control cells, the UGCP scheme for Beijing was then calculated, which took 9.5 h.

The resulting planning scheme can be expressed and exported as digital pictures or paper drawings for decision makers, planners, or the public. The spatial distribution, calculated control cell attribution table, and base map, were utilized to express the planning scheme. Due to the complexity of urban growth conditions in the study area, we partitioned the whole study area into 213 partitions using a scale of 1:25,000. The basic partitioning method was as follows. First, a polygon dataset was created based on partitioning parameters to record the distribution of various partitions. Each polygon represented the spatial boundaries of a partition. Second, in accord with the boundaries, map control limits were determined by the boundaries of spatial datasets within the partition, and certain control cells within the partition were selected using spatial analysis functions. The attribute table of selected control cells within the partition was output as the planning rules table.

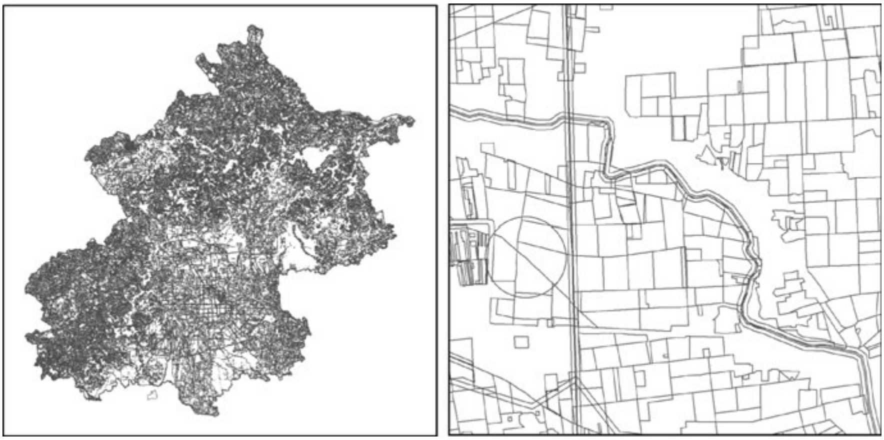


Fig. 14.6 Spatial distribution of control cells in the Beijing Metropolitan Area (*left*: the entire study area; *right*: the partial zoomed-in area)

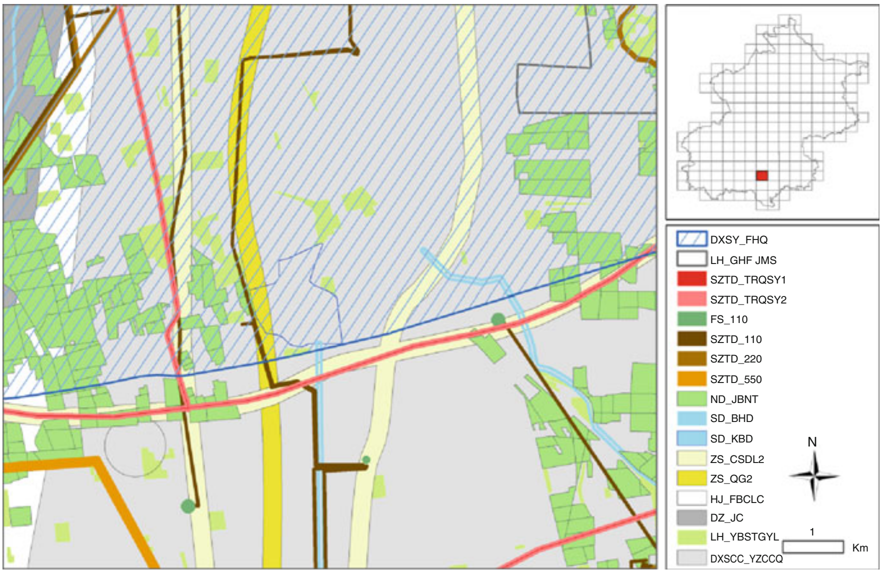
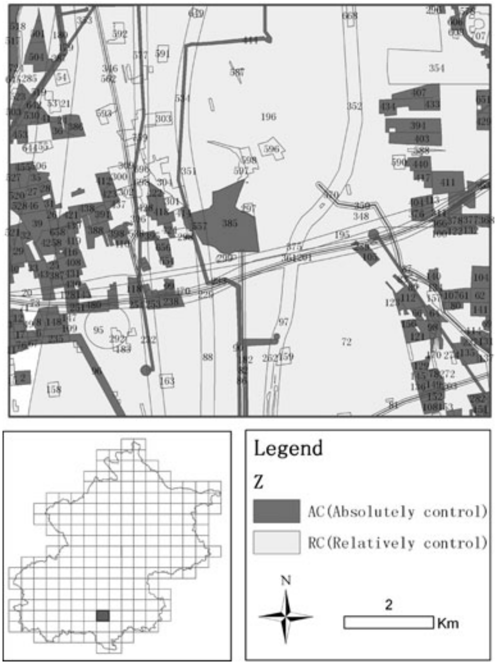


Fig. 14.7 Spatial distribution of control factors of a partition (The main map is an enlarged view of the red polygon shown on the mesh in the upper right corner)

Third, auxiliary map elements were added to the map, such as the title, legend, compass, scale bar, and partitioning index map. Finally, the print configurations were set, so the partitions could be printed on paper or exported as JPEG digital files.

The planning maps exported by UGC-PSS are illustrated in Figs. 14.7 and 14.8. In Fig. 14.7, the control factors in the partition were rendered and displayed



FID	Z	H	U	A	T
1	AC				
2	AC				
3	AC				
4	AC				
5	AC				
6	AC				
7	AC				
8	AC				
9	AC				
10	AC				
11	AC				
12	AC				
13	RC			cd	RCM
14	RC			cd	RCM
15	RC			cd	RM
16	AC				
17	AC				
18	AC				
19	RC			cd	RM
20	RC		1	bc	
21	RC		1	bc	
22	AC				
23	AC				
24	AC				
25	AC				
26	AC				
27	AC				
28	AC				
29	AC				
30	AC				

FID	Z	H	U	A	T
31	AC				
32	AC				
33	AC				
34	AC				
35	AC				
36	AC				
37	AC				
38	AC				
39	AC				
40	AC				
41	AC				
42	AC				
43	AC				
44	AC				
45	AC				
46	AC				
47	AC				
48	AC				
49	AC				
50	AC				
51	AC				
52	AC				
53	RC		1	bcd	RCM
54	RC		1	bcd	RCM
55	RC		1	bcd	RCM
56	AC				
57	AC				
58	AC				
59	AC				
60	AC				

Fig. 14.8 Control cell distribution map and the first page of the planning rules

together with their legends. The control factor map can be used to gain an understanding of the basic urban growth control situation. In Fig. 14.8, the spatial distribution of control cells and the corresponding planning rules are shown, which can also be viewed as the NF information within the partition. If there are excess control cells that make it impossible to list all the planning rules on one page, UGC-PSS can export the planning rules information automatically in multiple pages. The application of UGC-PSS improved the efficiency with which the UGCP was compiled considerably, and reduced the time necessary to establish and express the planning scheme by over 90%.

Conclusions and Discussion

The UGC-PSS proposed in this chapter offers a platform for urban growth control analysis that can consider large numbers of control factors in a synthetic framework and use them to calculate and automatically output a planning scheme. For the Beijing Metropolitan Area, 60 control factors, together with their indicators, were included to reflect urban growth conditions in the study area. The PSS enables complex urban growth control problems to be solved in the mega-metropolitan area by using multi-disciplinary knowledge, such as flooding control, eco-zone protection, noise prevention, and disaster prevention. The UGC-PSS can integrate all these urban growth control-related factors in one platform, which has not previously been possible for a single urban planner with limited knowledge on various control factors. Therefore, the UGC-PSS can also be regarded as a knowledge base for urban growth control in planning practice.

Planners, decision makers, and citizens can benefit from the use of the UGC-PSS. First, for urban planners, the precision and efficiency of UGCP can be significantly improved by using the PSS to integrate all possible control factors and their indicators, which would be quite complicated using routine means. Furthermore, spatial planners can refer to the outcome of the UGCP stored in the UGC-PSS as a precondition for spatial plans. Second, decision makers in the municipal government or the planning department can query and check the objective construction constraints in their concerned areas using the UGC-PSS as a decision support system. Lastly, the UGC-PSS has the potential to let *citizens* participate in urban development by monitoring illegal development conflicting with the UGCP if the PSS is upgraded to be web-based. The application of the UGC-PSS in the Beijing Municipal Area has proven the benefits noted above.

In the UGC-PSS, the method of calculating the planning scheme using UAZs with several planning rules is not only suitable for research regarding urban growth control, but can also be applied to urban growth research on the condition that more factors that promote urban growth are also included, such as institutional factors and accessibility factors (a preliminary attempt has been conducted in Long et al. 2008). The prototype of UGC-PSS may also be applied to other geographic analysis and geocomputing fields where various spatial factors with multi-indicators are required.

Due to the limited availability of datasets, some control factors were not included in the empirical PSS implemented described herein, such as protected cultural & historical sites in the central city, environmental capacity, and resource carrying capacity. Therefore, the UGC-PSS needs to be improved in future to more objectively and comprehensively reflect the state of urban growth control in Beijing. Moreover, we also intend to upgrade the UGC-PSS to a web-based PSS to accommodate more stakeholders in public participation in the planning of urban growth control.

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