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An urban containment planning support system for Beijing

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A B S T R A C T

Urban containment policies, including urban growth boundaries, urban service boundaries and greenbelts, have been extensively discussed worldwide for managing urban growth. This paper focuses on the issues associated with supporting an urban containment plan and its application in China using a planning support system. The background is that the urban containment plan has been enacted as a new component of the urban plan under the City Planning Law of the People's Republic of China. In China, the accommodating or restrictive features are integrated as control factors (CFs), which include control indicators for land-use type control, urban activity control, building height control, as well as underground development control. This paper proposes an urban containment planning support system (UC-PSS) based on ArcGIS for automatically compiling the Beijing urban containment plan considering 60 control factors with various control indicators. The compiled plan was also applied for reviewing urban master and district detail plans in Beijing supported by the UC-PSS. The effectiveness of UC-PSS was comprehensively evaluated from the perspectives of planning compilation and planning review via interviewing urban containment planners (main users of the UC-PSS) in Beijing.

1. Introduction

This paper is a case study of a planning support system (PSS) for the Chinese termed "Xianjianqu plan" (hereafter the "urban containment plan"), of the Beijing Metropolitan Area (BMA). The urban containment plan is required as a precondition of urban spatial developments for both urban master plans and district detail plans under the City Planning Law of the People's Republic of China, which was issued by the National People's Congress of China, and enacted on January 1, 2008. In China, an urban containment plan categorizes areas into two zones: areas where urban developments are partially controlled, and areas where urban developments are totally controlled and prohibited (He, 2008). Factors regarding partial control in urban containment plans include constrained land-use types, building height, urban activities, as well as underground developments. In this paper, an urban containment planning support system (UC-PSS) is developed according to the framework of the Beijing urban containment plan based on various local plans and regulations.

The UC-PSS, which borrows ideas of uniform analysis zones (UAZs) from the planning support system *What If?* proposed by Klosterman (1999), is developed on an ESRI's ArcGIS platform to support the compiling of an urban containment plan. An urban containment plan may involve urban development policies such as natural resource protection and risk prevention. The concept of "planning support system", initially proposed by Harris (1989), is considered to be the latest form of computer-aided planning system (Geertman & Stillwell, 2004; Klosterman, 1997) and has mainly been applied in spatial plans (Geneletti, 2008; Kammeier, 1999), urban environment improvement plans (Edamura & Tsuchida, 1999), industrial location choices (Kammeier, 1999), and land-use plans (Klosterman, 1999). Most existing PSSs focus on future land-use patterns, and few PSSs are related to urban containment. The UC-PSS is constructed to adapt to the practical requirements of the urban containment plan in China based on a rule-based approach and the proposed UC-PSS can be applied for generating the urban containment plan.

Urban growth management policies, targeting increased development density and protection of open spaces, are widely required in various parts of the world to alleviate negative effects of urban development. Negative impacts of disordered urban growth range from excessive land reclamation and energy consumption, to traffic congestion and air pollution (Anas & Rhee, 2007; Burchell, 1998). Urban containment policies including urban growth boundaries (UGBs), urban service boundaries (USBs), and greenbelts are intended to contain the specified types of future urban development (e.g. high-rise residential buildings), within pre-defined boundaries to curb urban sprawl and encourage "infill development". For instance, greenbelts have been adopted in London,

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and the adoption of the compact city model and other intensive urban forms are also advocated in Europe (Echenique, 2005). In the USA, more than 100 metropolitan areas, together with their sub-regions, have adopted UGBs to curb urban growth (Nelson & Dawkins, 2004). The main purpose of those policies is to protect open space and improve the efficiency of urban land developments (Pendall, Martin, & Fulton, 2002). In Japan, the policy of strict urban development control areas has been applied in land-use plans to regulate urban sprawl (Millward, 2006). In China, numerous policies on urban growth management are now being implemented and viewed as critical elements and preconditions for urban spatial development. As mentioned above, according to the City Planning Law of the People's Republic of China, the urban containment plan, as a novel planning practice in China, is required to present boundaries of total and partial control areas as well as detailed urban containment conditions within partial control areas. The use of the urban containment plan in China, however, is different from existing urban containment policies in Europe, the USA and Japan.

In terms of the planning practices in the BMA, extensive domestic laws, local regulations, normative documents and international conventions regarding urban containment should be taken into account. Each urban containment regulation contains one or more control factors. In general, those factors can be classified into two types in terms of urban development controls: total control and partial control. For instance, The "Regulations on Protecting Beijing Great Wall Management (enacted on May 22, 2003)" forbids residential and commercial developments within the 500–3000 m buffer zone of the Great Wall, and other types of developments should not exceed 9 m in building height. The "Law of the People's Republic of China on Prevention and Control of Water Pollution (amended on May 15, 1996)" forbids all urban developments and activities in the core protection zone of surface water sources. The "Forest Law of the People's Republic of China (amended on April 29, 1998)" and "Regulations on Forest Park Management (enacted on January 22, 1994)" forbid residential and commercial developments. In addition, the maximum building height within forest parks is 21 m. Therefore, it is important to integrate those existing related urban containment policies issued by various departments into a single urban containment plan. Furthermore, it is urged that the urban containment plan also should be referred to in other various urban spatial plans, for which the UC-PSS can better facilitate the review of urban plans, designs and policies.

In this paper we will discuss how to design and develop the proposed UC-PSS to operationalize the urban containment plan of the BMA, and introduce the methodology, implementation and application of the UC-PSS. This paper is organized as follows. In Section 2, we discuss the framework of the BMA urban containment plan, and illustrate the system development based on this framework in order to match the requirements of planning compilation and management in planning practice. In Section 3, the use the UC-PSS for compiling and presenting the urban containment plan of the BMA is elaborated in detail. In Section 4, we discuss user evaluation and feedbacks regarding the proposed UC-PSS from the perspective of planning compilation and management. Finally, we end paper with concluding remarks and discussion of the UC-PSS.

2. System framework and development for supporting urban containment plan

2.1. System users

The potential users of the UC-PSS are planners and officers of the urban containment plan, urban master and district detail plan, and citizens. Urban containment planners directly use the UC-PSS to compile and present the urban containment plan. Local officers, responsible for the specification of specifying urban containment conditions, work in various departments of local government (not including the planning commission), such as the forest bureau, water bureau, earthquake bureau and environment protection bureau. Urban master and district detail planners (hereafter urban planners) refer to the results of the urban containment plan in order to match multi-discipline requirements. Local officers reviewing urban master and district detail plans (hereafter urban plans) are in the planning commission of local government, whose routine work is to check urban development applications from stakeholders/developers, and to offer or reject applications for development permits. Citizens take care of the future of their properties and neighborhoods. They can monitor illegal developments (e.g. excessively-high buildings, or inconsistent land-use type) by accessing the urban containment plan results. Citizens can also be involved in the compilation process of the urban containment plan by accessing planning results to evaluate the plan and promote public participation.

Among all users, urban containment planners will be the key users of the UC-PSS: They use this tool to generate the urban containment plan. The UC-PSS should be a comprehensive tool for these planners to cover all related professional fields, such as forest management, environment protection, water resources, and earthquake prevention, in accordance with all of the related urban containment regulations. In addition, urban containment planners can derive different scenarios by combining various sets of control factors. Therefore, the implementation of the urban containment plan should be a cooperative process between planners and officers in local government. Urban planners will negotiate with urban containment planners and local officers in other departments for urban plan compilation. Local officers in the planning commission can use the UC-PSS to search urban containment conditions and to check the consistency between development projects and these conditions.

2.2. Spatial distributions and control indicators of control factors

To support the urban containment plan in the BMA, spatial distributions and indicators of control factors (CFs) are the key concepts of this paper. CFs are spatial features that are spatially related to policy measures that control urban development or activities. The spatial distribution of a CF stands for the spatial extent of the corresponding urban containment policy enacted by the local or central government. Control indicators are the attributes of control factors used to reflect the policy measures and are determined by existing official documents including laws, codes, regulations, technical standards, research results, international treaties and agreements, as well as previously approved plans. Related documents consist of many types of plans including geological hazard prevention plans, water resource protection plans, cultivated land protection plans, and ecological space protection plans. Therefore, the urban containment plan is described as "the plan of plans", or the combination of plans in China. Because the spatial distributions of CFs and their control indicators are all possibly temporally dynamic within an urban containment plan, the plan needs to be updated and amended frequently.

The tasks of the urban containment plan are to demarcate control zones (Z) so as to distinguish the total control zone and partial control zone, and then to carry out four detailed control indicators from a multi-dimensional perspective: land-use type control (T), construction height control (H), urban activity control (A), and underground development control (U) (for more see He, 2008; Long, He, Liu, & Du, 2006). In the total control zone (Z = "Total Control"), all types of urban construction activities, and underground developments are forbidden. In the partial control zone (Z = "Partial Control"), there are strict constraints on urban construction activities, and underground developments. Special requirements in terms of control indicators (T, H, A, and U) of all control factors need to be described in the urban containment plan for the partial control zone as follows:

- Land-use type control (T): This indicator refers to the forbidden urban land-use types. If there is no restriction on this indicator, then the value of T is null;
- Construction height control (H): This indicator refers to the forbidden building height in meters. If there is no restriction on this indicator, the value of H is supposed to be ranging from 0 to 1000 (here we use 1000 m as the highest possible building);
- Urban activity control (A): This indicator refers to the controlled urban activities. If there is no limitation on this indicator, then the value of A is null;
- Underground development control (U): This indicator refers to whether underground development is forbidden; if yes, U = 1, otherwise U is null.

Moreover, we term control alternatives as the optional value(s) of CFs' control indicators. For instance, the control alternatives of the control indicator T in one control factor are "R", "C" and "M"; the control alternatives of the control indicator H in one control factor are ">27 m", "9–27 m", and "<9 m". Regarding each control indicator of every CF, we define its alternatives as illustrated in Table 1, which is edited as an example. The relationship between control alternatives and control indicators can be expressed as follows:

$$\begin{aligned} &K_T = \{t_1 \ldots t_m\} \\ &K_H = \{h_1 \ldots h_p\} \\ &K_A = \{a_1 \ldots a_q\} \\ &K_U = \{u_1 \ldots u_r\} \\ &L = \{l_{ij} | i = 1, 2, \ldots, I, j \in \{T, H, A, U\}\} \end{aligned}, \quad (1)$$

where K_T, K_H, K_A and K_U are the control alternative sets, m, p, q and r are, respectively, the total numbers of control alternatives in the corresponding control indicator and they may vary with the planning area, t_m, h_p, a_q and u_r are, respectively, the control alternatives of the control indicator T, H, A and U, i is the ID of CF, I is the total number of CFs within the planning area, j is the control indicator's name, l_{ij} is the value of control alternative of the control indicator j for the CF i, and L is the set of all control indicators for all CFs. Generally, $l_{iT} \subseteq K_T, l_{iH} \subseteq K_H, l_{iA} \subseteq K_A,$ and $l_{iU} \subseteq K_U$.

The multi-dimensional urban containment conditions in terms of land-use types, urban activities, underground developments, as well as building height can be established accordingly (see Table 1). For instance in regulations related to water supply facilities, scenic zone management, and mineral resource protection, the forbidden land-use types are described. In addition, related official documents of each control indicator are also indicated in Table 1, and control alternatives are retrieved from those documents.

2.3. Generating control cells based on spatial features of control factors

As mentioned above, the spatial distribution of CFs and their indicators are of the most important datasets for compiling the urban containment plan, and can be obtained through various related local government departments. CFs are prepared and edited in geographical information systems (GIS), and stored as polygon layers in vector format while control indicators are prepared as attributes of CFs in GIS. The unified spatial-overlapped features of multi-CFs in a map are defined as control cells (CCs) in this paper, and are generated with the Union function in GIS. Each CC contains at least one CF, and is the basic planning unit of the urban containment plan. The urban containment context within each CC is homogenous in terms of the composition of control factors. For this, we define CCs as the uniform analysis zones (UAZs), the vector irregular polygon datasets, as the basic data model for the UC-PSS. The term "UAZ", initially proposed by Klosterman (1999), was applied in his planning support system *What if*? in which the UAZ is the fundamental analysis unit of modules including Land Suitability Evaluation and Land-Use-Demands Allocation. In addition, the basic spatial unit of the California Urban Futures (CUF) model and its updated version CUF-2, aiming to replicate realistic urban growth patterns and evaluate the impacts of urban development policy for the San Francisco Bay Area, is the developable land unit (DLU), which is also similar with the concept of UAZ (Landis, 1994; Landis, 1995).

The generated CCs are spatial features associated with control indicators as their attributes. In contrast to a regular square raster,

Table 1
Exemplified control indicators and their control alternatives of CFs in the BMA.

Control alternatives of control indicators	Z = "Partial Control"				Z = "Total Control"
	T	H	A	U	
Description	Regulations for different types of land-use	Regulations for building height	Regulations for different types of urban activities	Underground developments are permitted or not	All control alternatives are forbidden, and no urban development or activity will be permitted
Exemplified control alternatives of control indicators			The control of facilities destruction (a),		
	Residential (R),	>27 m,	the control of pollutant emission (b),		
	commercial (C),	9–27 m,	the control of resource exploitation (c),	1	
	industrial (M)	<9 m	the control of site occupation (d)		
Related official documents of the BMA	Water supply facilities, scenic zone management, mineral resources	Protection of cultural relics, flood control, forest park management	Prevention and control of water pollution, urban greening	Groundwater exploitation and utilization, geological disasters prevention	Basic farmland protection, wetland management

the irregular CC polygon is capable of recording multi-attributes for further calculating the urban containment plan. For instance, the layer "Control Cells" in Fig. 1 has seven control cells generated by combining the two CFs, "Control Factor 1" and "Control Factor 2". The control indicators of both CFs are then stored as the attributes of the CCs dataset and there will be ten attributes of "Control Cells" if each CF has five control indicators. The approach for calculating control indicators of CCs is detailed as follows:

$$CC = \{CC^x | x = 1, 2, 3, \ldots, n\}$$
$$R_j(CC^x) = \underset{i \in s_x}{f^j}(l_{ij}), \quad j \in \{T, H, A, U\} \tag{2}$$

where CC is the set of all generated control cells, x is the control cell ID, CC^x is the control cell x, n is the total number of CC within the planning area, $R_j(CC^x)$ is the control indicator j of the control cell x, S_x is the CFs set contained in CC^x, l_{ij} is the value of the control indicator j for the CF i, and f^j is the rule-based reasoning function to calculate the control indicator j CC^x (see Table 2 and Formula 3 for more). Formula 2 shows that the control indicator j of a control cell is determined by the control indicator j of CFs within this control cell. For instance, the control indicator T of the control cell labeled "5", CC^5 in Fig. 1, composed by CF1" and "CF2", can be calculated by the control indicator T of "CF1" and "CF2" using the function f^T. Since the control cell labeled "3" CC^3 only contains "CF2", the control indicators of this control cell are the same with those of "CF2".

The number of CFs included in the UC-PSS is generally required to be as large as possible to reflect complete urban containment conditions within the planning area. Partial CFs may lead to a unilateral and incomplete scenario for urban containment. Therefore, it is important to clarify the framework of urban containment plan of the BMA in order to integrate all control indicators of CFs within the planning area.

2.4. System development

The UC-PSS, as a rule-based reasoning tool, will be mainly used by urban containment planners to derive the urban containment plan and apply it in the urban master and district detail plans and development projects. Therefore, the proposed system structure is depicted in Fig. 2. It is developed based on ESRI's ArcGIS Engine 9.0 using Visual Basic 6.0. The Active Report 2.0 is introduced as a third party component for generating the partition scheme automatically in the "Planning scheme automatic output module" of the UC-PSS. The database platform used is ESRI's Personal Geodatabase.

The UC-PSS consists of six modules (see Fig. 3), and urban containment planners can access the system via a Graphical User Interface. The "Control cells generation module" and "Planning scheme automatic calculation module" are set for urban containment planners to compile the urban containment plan. Urban planners, local officers and citizens can access the urban containment plan and study development permission conditions for planning review through the "Comprehensive query module" and "Spatial dataset display module". The functions of each module are as follows:

(1) System configuration module. Users set system configurations, including defining the workspace for the input and output datasets, selecting CFs to be involved in the planning calculation process, setting the scheme partitioning means, and modifying users' privileges.

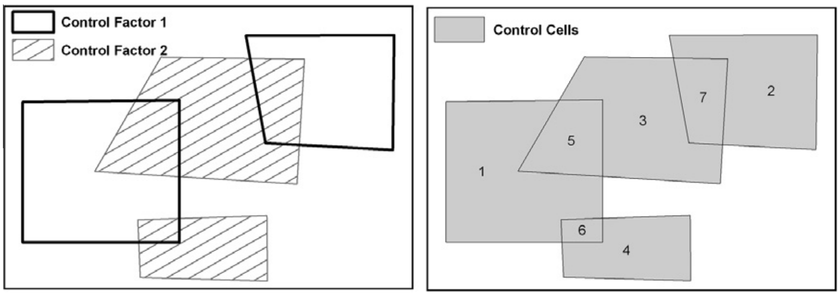


Fig. 1. Exemplified CFs and corresponding control cells diagrams.

Table 2
Partial CFs and their control indicators in one exemplified control cell CC^x of the BMA.

ID	Description	Control Zone (Z)	Control Indicator l_{ij}			
			$l_{iT} = \{t_m\}$, $t_m \in K_T = \{R, C, M\}$	$l_{iH} = \{h_p\}$, $h_p \in K_H = [0, 1000]$	$l_{iA} = \{a_q\}$, $a_q \in K_A = \{a, b, c, d\}$	$l_{iU} = \{u_r\}$, $u_r \in K_U = \{1\}$
1	Secondary protection zone of surface water sources	Partial control	R,C,M		b	
2	Area with poor engineering geology		R,C,M	>45		
3	High-risk area of flooding				d	
4	The first greenbelt			>18		
5	Nature reserves of county level		R,M		b,c	
6	General farmlands			>9	b,c,d	1
7	Protected area of historical culture			>15		
Results saved in the control cell CC^x as attributes $R_j(CC^x)$ in control cells.			$R_T(CC^x)$	$R_H(CC^x)$	$R_A(CC^x)$	$R_U(CC^x)$
			{R, C, M}	(9, 1000]	{b, c, d}	{1}

Note: Control alternatives of each control indicator for CFs are explained in Table 1.

(2) Spatial dataset display module. Users load corresponding required datasets, including CFs & other base layers, and set the spatial data's rendering parameters as a preparation step for planning compilation. The spatial distribution of CFs can be browsed by users together with the base maps as the spatial location references, such as road networks, rivers, and residential areas.
(3) Control cells generation module. The CCs dataset is generated using selected CFs (by "System configuration module") and their control indicators, which is indispensable for planning compilation.
(4) Planning scheme automatic calculation module. This module can be employed to automatically calculate control indicators for CCs as the compiled urban containment plan.
(5) Comprehensive query module. Users can conduct comprehensive queries of the compiled urban containment plan from aspects of the spatial distribution of CCs and their control indicators, and analyze the construction conditions objectively within a given yet-to-be-developed or concerned area. This module is set particularly for planning reviewing based on the compiled urban containment plan.
(6) Planning scheme automatic output module. The urban containment plan can be exported automatically in the form of many digital figures, which can also be printed as one collection of figures for the application of urban containment plan for planning review.

The main interface of the UC-PSS is composed of seven parts, including the caption bar, menu, toolbar, map content, table of content (TOC), thumbnails, and query results output panel (see Fig. 3). It is possible to perform planning compliance, data browsing, query and other related functions through the main Graphic User Interface for planning compilation and planning review.

3. Compiling urban containment plan using the UC-PSS

3.1. Study area – the Beijing Metropolitan Area (BMA)

The BMA (see Fig. 4), with an area of 16,410 km^2, has experienced rapid urbanization in terms of GDP and population growth since the Reform and Opening Policy in 1978 by the central government of China. The GDP in 2006 was 787 billion CNY, 83.7 times that of 1976. The population in 2006 was 15.81 million, 1.9 times that of 1976 (Beijing Municipal Statistics Bureau and NBS Survey Office in Beijing, 1987 and 2007). From the interpreted TM images, the urban built-up area in 2006 was 1324 km^2, nearly three times the area in 1976. In addition, as expected by the local government, urban expansion in the BMA is predicted to keep increasing in the coming two decades. During the process of rapid urbanization in Beijing, the tendency for disordered urban expansion has not yet been effectively controlled. Within the BMA, urban growth is constrained by many CFs, which make urban containment conditions very complicated. Therefore, the urban containment plan in the BMA urgently needs to be conducted for regulating urban developments and managing urban growth. The UC-PSS plays an essential role in supporting urban containment planning compilation and planning reviewing.

3.2. Control factors and their control indicators of the BMA

In total, there are 60 CFs in the BMA and the spatial distribution of each CF is explained in and approved by the Beijing Municipal Planning Commission (2007). They can be classified into two clusters: natural resource protection and disaster prevention. The natural resource protection cluster includes seven types of CFs, namely the wetland, water resource protection, bio-diversity space protection, cropland protection, historical relic protection, geological vestige protection, and greenbelt protection. The disaster prevention cluster includes nine types of CFs, namely the groundwater over-exploitation prevention, flood control, geological disaster prevention, seismic prevention, geological condition for engineering, pollutant centralized treatment facility prevention, environmental radiation prevention, municipal infrastructure protection, and environmental noise prevention.

The control indicators of these 60 CFs are retrieved from official files, including 18 laws, 50 state administrative regulations, 33 local administrative regulations, six international conventions, 11 normative documents, as well as 24 standards and technical specifications. Among all CFs, 24 CFs are totally controlled, and 36 are partially controlled. In the BMA, the control alternatives of each control indicator are, respectively, $K_T = \{R, C, M\}$, $K_H = [0, 1000]$, $K_A = \{a, b, c, d\}$ and $K_U = \{1\}$ as described in Table 1. The name and control indicators of exemplified CFs are listed in Table 2. For instance, the CF "Secondary protection zone of surface water sources" in Table 2 stands for the secondary protection zone of surface water sources, which belongs to the partial control level, and pollutant emission namely alternative "b" is forbidden. Moreover, within the extent of this CF, residential, commercial and industrial land uses are not permitted.

3.3. Combining all control factors into control cells to compile the urban containment plan

For the control cell CC^x control indicators, $R_T(CC^x)$, $R_H(CC^x)$, $R_A(CC^x)$, and $R_U(CC^x)$ are, respectively, calculated using a rule-based process as follows:

$$\begin{aligned} R_T(CC^x) &= \underset{i \in s_x}{f^T}(l_{iT}) = \bigcup_{i \in s_x} l_{iT} \\ R_H(CC^x) &= \underset{i \in s_x}{f^H}(l_{iH}) = \bigcup_{i \in s_x} l_{iH} \\ R_A(CC^x) &= \underset{i \in s_x}{f^A}(l_{iA}) = \bigcup_{i \in s_x} l_{iA} \\ R_U(CC^x) &= \underset{i \in s_x}{f^U}(l_{iU}) = \bigcup_{i \in s_x} l_{iU} \end{aligned} \quad (3)$$

where i is the CF ID, l_{iT}, l_{iH}, l_{iA} and l_{iU} are, respectively, the control indicators T, H, A and U for the CF i, S_x is the CFs set contained in the control cell CC^x, and $\bigcup$ is the simplified rule-based function standing for the union of sets. Formula 3 indicates that the calculation functions for all control indicators of CC^x are identical to the union of sets meaning the CC obeys all the control requirements of the CFs within the CC (see the last row of Table 2). For instance, a CC contains two CFs "CF1" and "CF2", CF1's control indicator T is $l_{1T} = \{\mathrm{R}, \mathrm{C}\}$, which signifies that residential and commercial types of urban developments are forbidden within CF1. CF2's control indicator T is $l_{2T} = \{R, M\}$, which signifies that residential and industrial types of urban developments are forbidden within CF2. The control indicator T of the CC will be the union of control indicator T of CF1 and CF2, $\bigcup(l_{1T}, l_{2T}) = \bigcup(\{R, C\}, \{R, M\}) = \{R, C, M\}$, signifying that residential, commercial and industrial types of urban developments are forbidden for this control cell according to official files related to urban containment.

Although this ruled-base reasoning process is simple, it is tedious work to calculate control indicators of all CCs without using the UC-PSS. In total, 333,564 CCs are created based on 60 CFs using the UC-PSS. Based on the generated CCs dataset, the urban containment plan in the BMA was then calculated and compiled, taking 9.5 h. In the results, an area of 7203 km^2, 43.9% of the BMA, is totally controlled, and 8420 km^2 (51.3% of the BMA) partially controlled. Only 4.8% area of the BMA is free of urban containment conditions. That is, no restrictions on urban growth exist in this

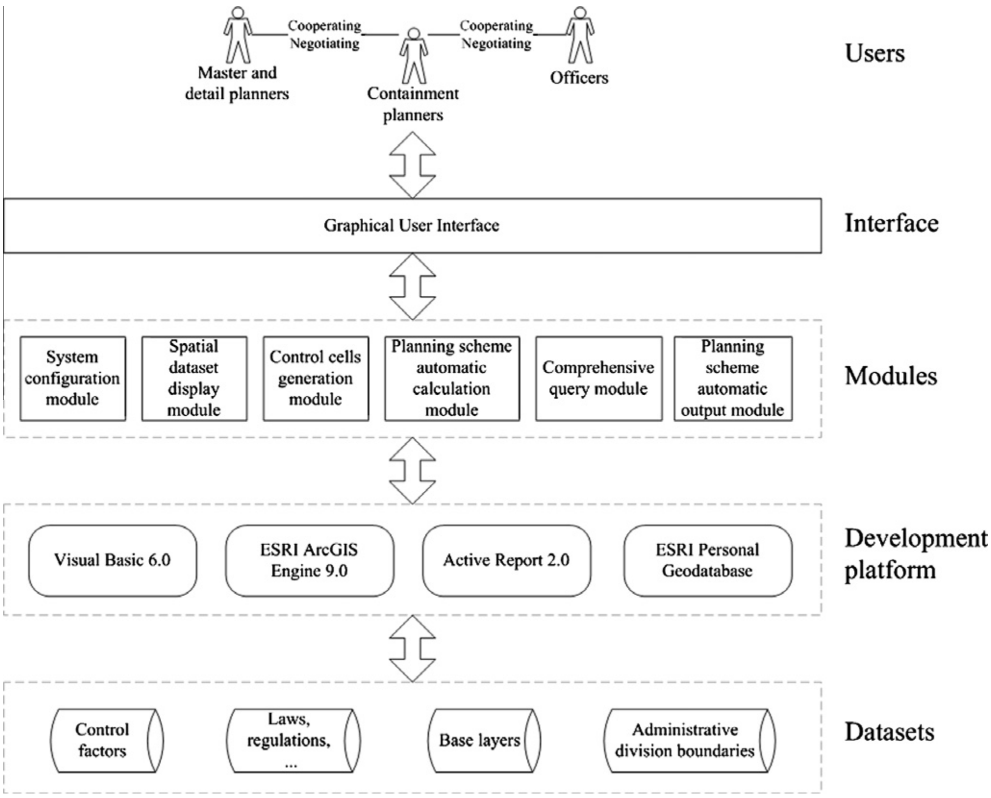


Fig. 2. The system structure diagram of the UC-PSS.

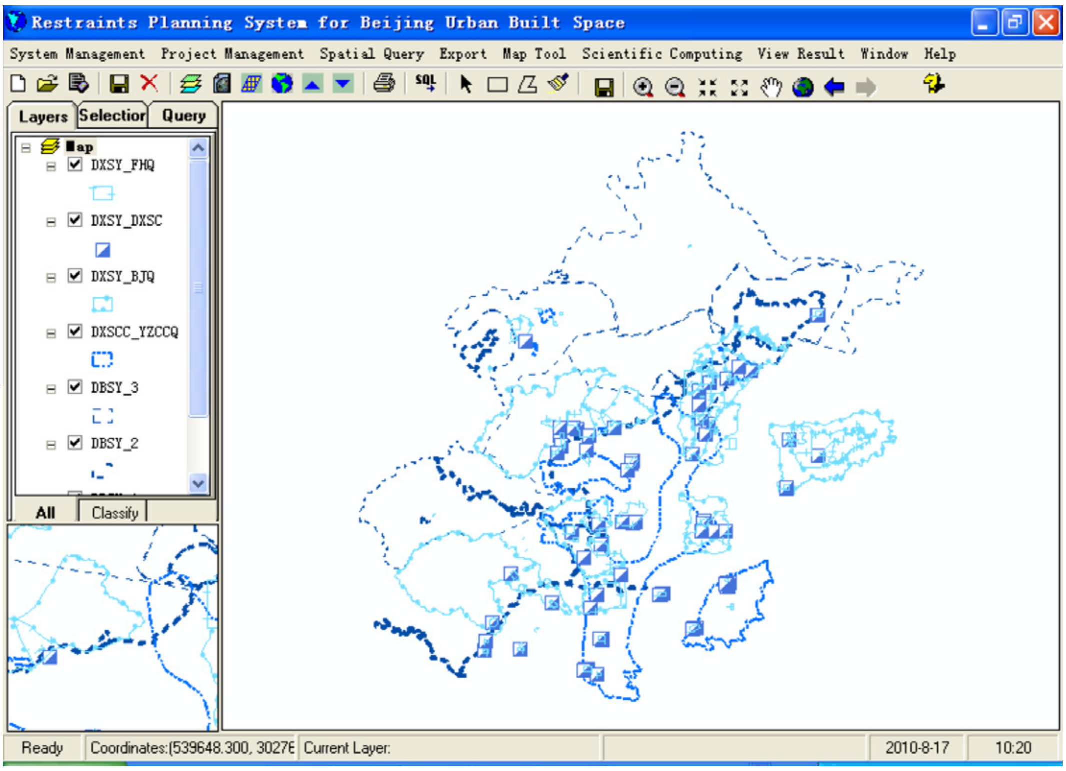


Fig. 3. The main graphic user interface of the UC-PSS.

area. Within the partial control zone, regarding the control indicator *T*, the residential urban development is uniquely forbidden in 567 km^2, both residential and commercial types are forbidden in 209 km^2, both residential and industrial types are forbidden in 4505 km^2, and all three types of urban developments are forbidden in 1572 km^2. Regarding the control indicator *H*, urban developments are restrained in height within 4149 km^2 (25.3% of the BMA). Regarding the control indicator *A*, urban activities are

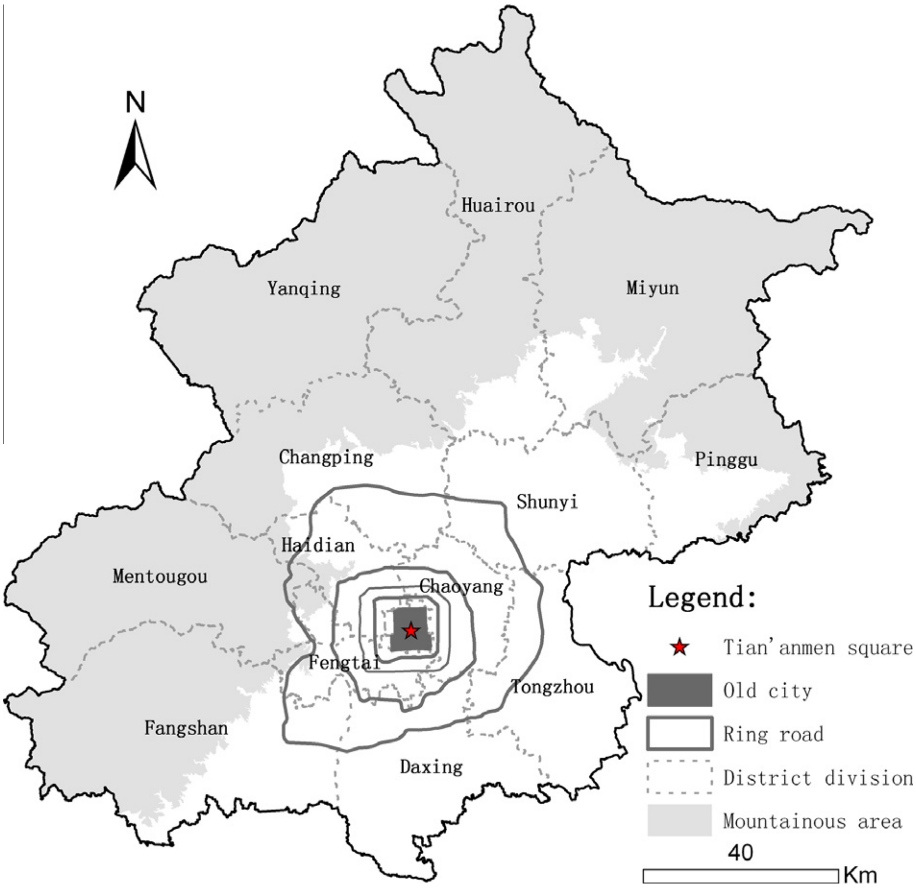


Fig. 4. The spatial structure of the Beijing Metropolitan Area.

restrained in 8266 km^2 (50.4% of the BMA). With respect to the control indicator *U*, 3117 km^2 (19.0% of the BMA) are forbidden for underground developments.

3.4. Partitioning the planning area to present the urban containment plan

Since the tremendous amount of CCs makes it difficult to present the urban containment plan in a single page, the whole planning area should be divided into multiple partitions. For instance, partitions can be generated by dividing the whole planning area into grids of numerous rows and columns, or according to the standard map scale of planning drawings in China, such as 1:25000, 1:10,000, 1:5,000, 1:2000, and 1:500, for various purposes. Partitions can also be generated by urban containment planners' delineation in addition to regular grids. Generally, to review the urban master plan, the urban containment plan should be presented at the scale of 1:25,000, 1:2000 for the district detail plan, and 1:500 for the building site plan.

We present two types of figures here as an example of applying the compiled urban containment plan in a planning review, namely: the CFs spatial distribution (illustrated in Fig. 5 for an exemplified scheme partition), and the CCs distribution and their control indicators (illustrated in Fig. 6 with the same partition as Fig. 5). In the illustrated partition, 17 CFs are screened from all 60 CFs in the BMA, and displayed in the figure with explicitly spatial distribution. Thus, it is possible for the basic urban containment conditions within the partition to be checked by urban planners or corresponding officers when conducting a planning review.

The spatial distribution of CCs and their partition indicators are illustrated in Fig. 6. The spatial distribution of CCs is shown in the upper-left of Fig. 6, and each CC is labeled with its unique ID (FID) and themed with different colors to show its control zone. Users can first locate the concerned location in this map, check its control zone from the rendered color, and then gather more detailed development permission conditions from the control indicators table, in the right of Fig. 6 according to the CC's FID. If there are too many CCs in one partition that make it impossible to list all the control indicators of CCs in this partition within one page, the UC-PSS can export the CCs' control indicators automatically in multiple pages.

The UC-PSS can also export the statistical information on control factors and control cells within a partition. For instance, Fig. 7, which corresponds to the same partition with Figs. 5 and 6, shows the area for each control factor, the area for each control zone, as well as the area for the region controlled by each control indicator. This figure provides an overall urban containment condition for this partition.

In sum, the developed UC-PSS has achieved the system requirements proposed in Section 2.1 in terms of both compiling and presenting an urban containment plan for urban containment planners in Beijing. In addition to calculating and presenting the urban containment plan of the BMA, the UC-PSS is also expected to be used to update the plan every 5 years due to varied policy contexts. As it is not easy to compile and present the urban containment plan manually, the application of UC-PSS improved the compilation efficiency of the urban containment plan significantly.

4. User evaluations on the UC-PSS

For the purpose of user evaluation of the UC-PSS tool, we interviewed urban containment planners in the Beijing Institute of City Planning (BICP) who used the UC-PSS for compiling the Beijing

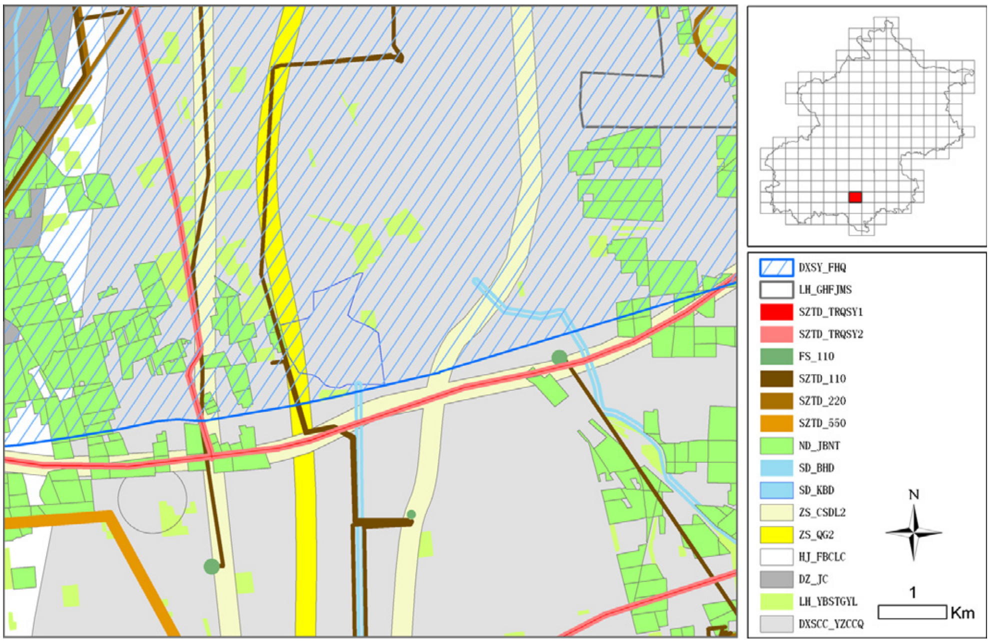
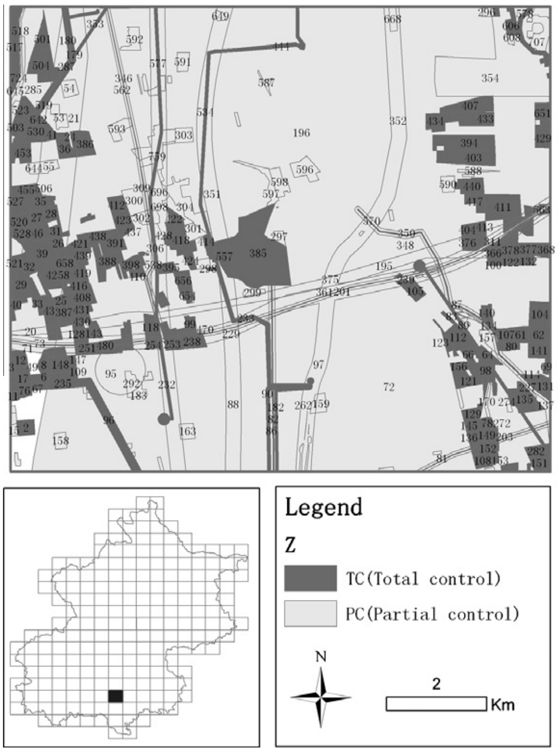


Fig. 5. Spatial distribution of CFs of the illustrated partition (the main map is the enlarged red polygon in the upper-right map, which is the 213-partition map of the BMA. Note that the largest irregular polygon in the partition map is the administrative boundary of the BMA). (For interpretation of the references to colors in this figure legend, the reader is referred to the web version of this paper.)



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

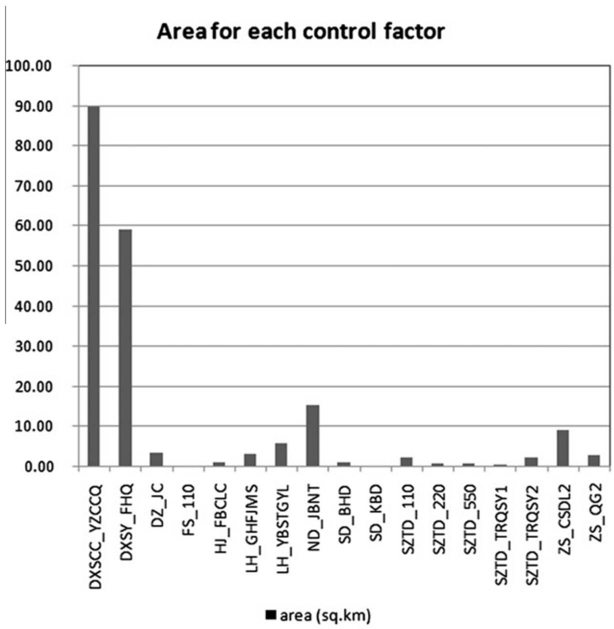
FID	Z	H	U	A	T
31	TC				
32	TC				
33	TC				
34	TC				
35	TC				
36	TC				
37	TC				
38	TC				
39	TC				
40	TC				
41	TC				
42	TC				
43	TC				
44	TC				
45	TC				
46	TC				
47	TC				
48	TC				
49	TC				
50	TC				
51	TC				
52	TC				
53	PC		1	bcd	PCM
54	PC		1	bcd	PCM
55	PC		1	bcd	PCM
56	TC				
57	TC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

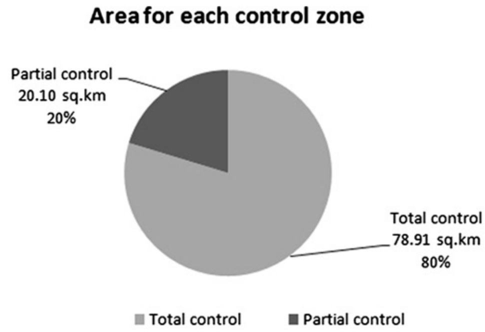
Fig. 6. The CCs distribution map and the first page of the control indicators table of the illustrated partition. (Occasionally, the control indicator *H* is null in the first page of the control indicators table. Note that this partition is the same one with the Fig. 5, and control indicators of the control cell with "Z = Total Control" are blank in this table to save space.)

urban containment plan and applied the compiled urban containment plan for planning review in October and November 2010. The detailed analysis regarding the contents i.e. control factors and control indicators of the urban containment plan, however, was not conducted because we focused on the effectiveness of the UC-PSS on planning compilation and management.

4.1. Evaluation of planning compilation functions

Two urban containment planners are employed at BICP. They apply the Beijing urban containment plan in various urban master and district detail plans (46 from October 2007 to August 2010) and development projects (62 from October 2007 to August





Details of planning scheme in the partition

Control Zone (Z)	Control Indicator	CC count	area(sq.km)
Total control		435	78.91
Partial control		797	20.10
Within the partial control zone:	*H*	27	4.12
	U	244	48.62
	A	433	78.77
	T	422	76.65
The whole partition		1232	99.80

Fig. 7. Statistical information for control factors and control cells of the illustrated partition.

2010) (partial applications listed in Table 3). Prior to the UC-PSS, urban containment planners "paid a lot of time collecting data, overlaying factors, checking regulations, and drawing plan alternatives". Now, with the support of UC-PSS, they can "conveniently find out all urban containment conditions". Accordingly, their working efficiency has been greatly enhanced compared to the period when the UC-PSS was not available. Therefore, although there are a limited number of urban containment planners in BICP, turnaround time is significantly reduced. In addition, the two planners judged the UC-PSS to be easy to use thanks to the user-friendly GUI.

In addition, urban containment planners received the dataset of various control factors from local officers outside the planning commission of the Beijing municipal government, and the dataset was the key component of the UC-PSS for compiling the urban containment plan. In our interview with the urban containment planners, we gathered that "the attitude of officers was quite positive since their specifying of control factors can be guaranteed to be implemented in planning practice through the UC-PSS". Prior to UC-PSS deployment, "the planning drawings of urban master & district detail plans drafted by the planning commission of Beijing were sent to those officers for reviewing in the printed form before finally issued". "Officers cannot easily identify the consistency between urban plans and their related control factors via merely checking the printed plan materials". In the case of urban master plan regarding the Beijing mountainous areas, "local officers also liked to provide an updated dataset of control factors to urban containment planners, which assisted to guarantee that the UC-PSS can maintain the latest urban containment information related to their department". Furthermore, "officers in the water bureau of

Table 3
Some applications of the UC-PSS in BMA.

	Planning site	Planning type	Year	Planning improvement using UC-PSS
Planning compilation	Yangfang Town	Urban master plan	2007	A high-voltage power line was moved to another route after negotiation among urban planners, containment planners and local officers.
	Badaling Scenic Reservation	District detail plan	2007	Urban planners commented that the urban containment plan provided more information than the results of conventional planning works.
	Changping Tistrict	Urban master plan	2008	Planners improved the framework of land-use zoning through confirmation of containment conditions for residential development.
	Qiaozi Town	Urban master plan	2009	The urban containment planners required urban planners to negotiate with local officers in the water department for improving urban master plan.
	Zhangshanying Town	District detail plan	2009	District detail plan was improved through referring to the detailed urban containment conditions. However, the spatial resolution of some control factors need to be improved.
	Mountainous Areas of the BMA	Urban master plan	2010	Local officers outside the planning commission provided an updated dataset in order to update the urban containment plan.
Planning management	Shidu Town	District detail plan	2007	Officers in the planning commission commented that they were in great need of mastering the specific development conditions within the project area. For improving the efficiency of urban management, urban planners suggested that urban plan need to be added as additional control indicators to the urban containment plan.
	Yanqing District	Urban master plan	2008	The water protection zones of river Gui were adjusted by the local government after checking the urban containment conditions.
	Yanfang Education Park	District detail plan	2010	An existing development project was found to be not consistent with the containment conditions in the urban built-up spaces.

Beijing also tested the impact of the updated surface water protection law of China on urban development using the UC-PSS".

Thirdly, the Beijing urban containment plan generated by the UC-PSS has been widely used for compiling urban plans located in different areas of Beijing. In our interviews of urban containment planners, we also understood that "compared with conventional land-use suitability analysis, the Beijing urban containment plan can provide more information for the partial control zone in terms of different control indicators (*T*, *H*, *A* and *U*)", which coincides with land-use types, building height and floor-area-ratio (FAR) in urban plans. For example, in the case of the Badaling Scenic Reservation as shown in Table 3, district detail planners working to compile the district detail plan for a block assign the land-use type for each parcel within the block in the plan. These planners commented that the urban containment plan provided more information than the results of conventional planning work, such as a land-use suitability analysis which was firstly proposed by McHarg (1969) and has become a popular analysis method in land-use plans (Thill, 1999) by providing information regarding whether an area is suitable for urban development. Because the forbidden land-use types for each parcel have been already described in the urban containment plan, planners can assign a proper land-use type for each parcel according to the urban containment plan. For example in the exercise of their planning duties, "urban planners in the town of Zhangshanying can conveniently compile plans fed by the detailed urban containment conditions described in the urban containment plan". With the support of UC-PSS, planners can easily find the urban containment condition in the plan area. In the case of the master plan in Changping District, "planners also confirmed the reasons why some areas are forbidden for some types of urban development and improved the framework of land-use zoning for residential development". The UC-PSS provides detailed control factors and related regulations information to assist urban planners to easily find out necessary planning information accordingly.

Conflicts can be detected by comparing the urban containment plan and urban master and district detail plans. In some cases, urban planners may also question the results provided by the UC-PSS. For instance, "an area is set as a development forbidden area where a high-voltage power line is located". Urban planners argued that "they will move the power line to another route in order to allocate development projects more reasonably" and they argued in support of revising the urban containment plan in Yangfang Town. In this case, "they will not accept the result of urban containment plan based on existing control factors". In another case such as Qiaozi Town, "urban planners did not agree with control indicators of a control factor, such as surface water protection zone; thus the urban containment planners required them to negotiate with related officers directly". "If the officers could agree with urban planners' opinions, the urban containment plan would be updated accordingly". Otherwise, urban planners should accept the original urban containment plan. With the UC-PSS, better urban plans were generated according to interviewees who co-worked with many urban planners.

4.2. Evaluation of planning management functions

Through interviews conducted with urban containment planners regarding the decision-making process of urban plans, the officers working in the planning commission of BMA also discovered the UC-PSS as a tool that provides accurate information regarding urban containment policies. For instance, in the case of reviewing a district detail plan of an urban development project in Shidu Town, when officers needed to make a decision on whether to permit a development application, they turned to urban containment planners to check urban containment conditions of this project site using the UC-PSS. As commented by the officers, "we are in great need of mastering the specific allowed development conditions in terms of land-use type, building height and underground development within an area as the partial control zone". Regarding the case in Yanqing District, local officers in the planning commission of BMA found the UC-PSS helpful in their routine urban management work. They have been accustomed to checking urban containment conditions with UC-PSS before issuing a development permit or an urban plan, since "the UC-PSS does this in a very convenient manner". This made them "confident their development permit will not conflict with the urban containment conditions provided by other related departments of local government". If conflict occurs, they are able to explain to developers by directly referring to the urban containment conditions. However, these officers found that there are conflicts between the previously compiled urban containment plan and existing urban development projects permitted before the use of UC-PSS. This problem remained unsettled in Beijing until now. An example of such as a project located in the Yanfang Education Park is shown in Table 3.

Citizens are also involved in urban management process in China, with public participation having been recently introduced into the urban planning compliance and implementation process. Urban containment planners have shared drawings of the compiled urban containment plan generated by the UC-PSS with citizens, who are asked to review a digital map of their area of concern. The majority of citizens are most concerned with detail plans or urban redevelopment projects within a small-scale location in or around their neighborhood. Therefore, urban containment planners attempted to enable citizens to prosecute illegal development in or around their neighborhood. Little feedback was received from citizens in Beijing. Unfortunately, public participation is not easily improved upon because citizens cannot use and evaluate the UC-PSS directly. An important next step of this research is to develop an online system that will enable the public to access the UC-PSS.

5. Concluding remarks and discussion

The contribution of this paper is to propose a planning support system using a straightforward rule-based approach to tackle a very comprehensive urban containment issue. The developed UC-PSS can take numerous control factors and their control indicators into account in a framework, which can be used to automatically compile and present the urban containment plan as well as query the plan for reviewing urban planning and design. From the perspective of planning theory, we adapted urban containment as a multi-dimensional planning measure, which integrates land-use type control, building height control, urban activity control as well as underground development control. From the perspective of planning support system, the UC-PSS is also capable of enabling numerous related urban containment policies to be visualized in a digital map in order to explore their impacts.

In our case study of UC-PSS applied to the BMA, 60 control factors, together with their control indicators, are included to reflect comprehensive urban containment conditions of the BMA, involving multi-disciplinary professional knowledge such as flooding control, eco-zone protection, noise prevention, and disaster prevention. Therefore, the UC-PSS can integrate all the control factors in one platform, which has not previously been possible for a single urban containment planner with a limited professional background.

The practices in the BMA have proved the applicability of the UC-PSS. Planners and officers, as well as citizens can benefit from the implementation of the UC-PSS. Firstly, for urban containment planners, the UC-PSS tool can improve the precision and working efficiency of compiling the urban containment plan, which would otherwise be too difficult to be conducted manually. Local officers can employ the tool to protect their spaces of concern from being encroached upon by unwanted urban developments. Secondly, it is possible for urban planners to refer to the urban containment plan generated by the UC-PSS as a precondition for planning reviews. Officers in the planning department can query and check the development conditions in a site area using the UC-PSS before issuing a development permit. Lastly, the UC-PSS provides the potential for citizens to monitor urban development projects by identifying illegal urban developments which conflict with the urban containment plan.

The UC-PSS differs from other existing PSSs. Firstly, unlike *What If*? and CUF/CUF-2, the UC-PSS emphasizes urban containment, rather than forecasting or simulating future urban land-use patterns. Secondly, the UC-PSS can be applied in not only compiling the urban containment plan, but also in urban planning management. This differs from other PSSs that mainly focus on how to compile the plan itself. Thirdly, the UC-PSS has significant cartographic features for presenting the urban containment plan. In our case study, there were a total of 1015 pages of the partitioned scheme for the 213-partitions in the BMA, which would obviously be tedious work to process without use of the UC-PSS. In considering the benefits of the UC-PSS, as urban containment conditions are occasionally modified, the urban containment plan still needs to be updated accordingly in this rapid growing area of China due to changes in the spatial distribution of control factors or variation in control indicators.

There are still several aspects needed be further investigated in the next step of our research. One of the further improvements of the UC-PSS is how to organize more accurate and comprehensive control factors that faithfully reflect the urban containment policies of the BMA. We also intend to adapt the UC-PSS into a web-based PSS to facilitate more end-users for improving public participation in the urban containment plan compilation process as well as applying the urban containment plan not only in the review of urban plans, but also in exploring effectively policy impacts. In addition, the urban containment plan generated by the UC-PSS can advantageously be incorporated to land-use models, which lack consideration of comprehensive urban containment conditions. Through consideration for the urban containment conditions generated by the UC-PSS, land-use models can be expected to generate more conform land-use patterns.

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References

Anas, A., & Rhee, H. (2007). When are urban growth boundaries not second-best policies to congestion tolls. *Journal of Urban Economics, 61*, 263–286. doi:10.1016/j.jue.2006.09.004.

Beijing Municipal Planning Commission (2007). *Urban containment plan of the Beijing Metropolitan Area (2006–2020)* (In Chinese).

Beijing Municipal Statistics Bureau, & NBS Survey Office in Beijing (1987). *Beijing statistical yearbook 1987*. Beijing: China Statistics Press.

Beijing Municipal Statistics Bureau, & NBS Survey Office in Beijing (2007). *Beijing statistical yearbook 2007*. Beijing: China Statistics Press.

Burchell, R. (1998). *Cost of sprawl revisited*. New York: Rutgers.

Echenique, M. (2005). Forecasting the sustainability of alterative plans: The Cambridge futures experience. In Mike. Jenks & Nicola. Dempsey (Eds.), *Future forms and design for sustainable cities*. Oxford: Elsevier.

Edamura, T., & Tsuchida, T. (1999). Planning support system for an urban environment improvement project. *Environment and Planning B-Planning & Design, 26*, 381–391. doi:10.1068/b260381.

Geertman, S., & Stillwell, J. (2004). Planning support systems: An inventory of current practice. *Computers, Environment and Urban Systems, 28*, 291–310. doi:10.1016/S0198-9715(03)00024-3.

Geneletti, D. (2008). Incorporating biodiversity assets in spatial planning: Methodological proposal and development of a planning support system. *Landscape and Urban Planning, 84*, 252–265. doi:10.1016/j.landurbplan.2007.08.005.

Harris, B. (1989). Beyond geographic information systems. *Journal of the American Planning Association, 55*, 85–90. doi:10.1080/01944368908975408.

He, Y. (2008). Planning in restrictions for Beijing urban and rural development. In *Proceedings of 44th ISOCARP Congress*. <http://www.isocarp.net/Data/case_studies/1185.pdf> Accessed 25.12.10.

Kammeier, H. D. (1999). New tools for spatial analysis and planning as components of an incremental planning-support system. *Environment and Planning B: Planning & Design, 26*, 365–380. doi:10.1068/b260365.

Klosterman, R. E. (1997). Planning support systems: A new perspective on computer-aided planning. *Journal of Planning Education and Research, 17*, 45–54. doi:10.1177/0739456X9701700105.

Klosterman, R. E. (1999). The what if? Collaborative planning support system. *Environment and Planning B: Planning and Design, 26*, 393–408. doi:10.1068/b260393.

Landis, J. D. (1994). The California Urban Futures Model: A new generation of metropolitan simulation models. *Environment and Planning B: Planning and Design, 21*, 399–420. doi:10.1068/b210399.

Landis, J. D. (1995). Imagining land use futures: Applying the California Urban Futures Model. *Journal of American Planning Association, 61*, 438–457. doi:10.1080/01944369508975656.

Long, Y., He, Y., Liu, X., & Du, L. (2006). Planning of the controlled-construction area in Beijing: Establishing urban expansion boundary. *City Planning Review, 30*, 20–26 (In Chinese).

McHarg, I. L. (1969). *Design with nature*. Garden City, New York: Natural History Press.

Millward, H. (2006). Urban containment strategies: A case-study appraisal of plans and policies in Japanese, British, and Canadian cities. *Land Use Policy, 23*, 473–485. doi:10.1016/j.landusepol.2005.02.004.

Nelson, A. C., & Dawkins, C. J. (2004). *Urban containment in the United States: History, models and techniques for regional and metropolitan growth management*. Chicago, IL: American Planning Association.

Pendall, R. J., Martin, J., & Fulton, W. (2002). *Holding the Line: Urban Containment in the United States Washington, DC*. Brookings Institution Center on Urban and Metropolitan Policy.

Thill, J. C. (Ed.). (1999). *Multicriteria decision-making and analysis: A geographic information sciences approach*. Aldershot: Ashgate.