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Urban growth boundaries of the Beijing Metropolitan Area: Comparison of simulation and artwork ☆

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ABSTRACT

Urban growth boundaries (UGBs) have been extensively studied and applied in the USA as an effective tool to curb urban sprawl. The "People's Republic of China Town and Country Planning Act" requires the establishment of urban construction boundaries (UCBs) in Chinese city master and detail plans. We consider planned UCBs in China to be Chinese UGBs, as they have similar implementation mechanisms to their counterparts in the USA. However, different from UGBs in the USA, Chinese UGBs often resemble "artwork" by urban designers. Accordingly, they lack sound analytical basis and fail to sufficiently accommodate market mechanisms of land use. When measured by the criterion that the UGB should result in a spatial pattern that corresponds to its map, the Chinese UGBs are not well implemented. In this paper, we propose a method to support establishing UGBs through constrained cellular automata (CA). Our approach takes into account influence factors related to urban growth and generates UGBs based on spatiotemporally dynamic simulations. This method is applied to establish UGBs for the central city, new cities and small towns in the Beijing Metropolitan Area. The results indicate that there are significant differences between the UGBs based on constrained CA simulations and those in the previously established city master plan. We argue that our method could be a helpful planning tool for the establishment of UGBs in Chinese cities.

Introduction

Urban sprawl and some other urban deficiencies arising from the rapid development of cities are a major challenge for sustainable urban development. Consequently, it is crucial to design appropriate methods to establish effective control of urban growth. Among the various urban growth management policies, urban containment policies have been widely adopted to increase urban land use density and protect open space from being developed (Long, Shen, & Mao, 2011; Nelson & Duncan, 1995). An urban containment policy usually has three components – greenbelts, urban growth boundaries (UGBs), and urban service boundaries (USBs) (Pendall, Martin, & Fulton, 2002). UGBs are currently the most widely discussed tool in academia. Through zoning, land development permits and other land-use regulations, UGBs demarcate urban and rural uses and aim to contain urban development within the predefined boundaries (Pendall et al., 2002).

In China, concepts similar to UGBs have recently begun to develop. The "Urban Planning Compilation Guideline", which was issued on April 1st, 2006, by the former Ministry of Construction (the current name is Ministry of Housing and Urban–Rural Development), requires that city master plans propose "development exclusion areas", "development control areas" and "suitable development areas". Such development exclusion areas and development control areas help to confirm the planning boundaries of urban construction areas (Long et al., 2011), which have been defined by the most recent "People's Republic of China Town and Country Planning Act" as the legal boundaries to distinguish urban areas from rural areas (Han, 2009). Planning UCBs (urban construction boundaries) are applied by the urban planning administrative department as the basis for issuing building permits, and they have played a crucial role in containing urban growth in China. In terms of urban containment, development

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exclusion areas, development control areas, and planned urban construction areas in China have a similar mechanism to UGBs in the USA and other Western countries in that they are operated by delineating the boundaries between urban areas and rural areas, zoning, development permit controls, and other land-use regulations. Therefore, in a broad sense, the boundaries of these areas can be considered as Chinese UGBs, and the planned UCBs, which are the most explicit legal urban containment boundaries, can be narrowly defined as Chinese UGBs (the terms "Chinese UGBs" and "planned UCBs" are used interchangeably in this paper).

The establishment of UGBs involves the comprehensive consideration of various factors related to urban spatial developments. In Chinese cities, conventional methods of delineating UGBs are based on planners' personal experiences; thus, they lack an adequate scientific basis and quantitative support. Consequently, the UGBs often fail to contain urban growth. According to Han, Lai, Dang, Tan, and Wu (2009)'s study on the examination of the implementation of planned UGBs within the sixth ring road of Beijing using multi-temporal remote sensing images, more urban land development was found outside than inside the UGBs during the two previous planning periods (1983–1993 and 1993–2005). Tian, Lv, and Shen (2008) and Xu, Shi, and Fan (2009) also suggest that substantial urban development occurred outside of UCBs in Guangzhou and Shanghai in recent years. The reason for the inconsistencies between the predefined UGBs and the practical urban developments was assumed to be the lack of market incentives in the UGBs due to the planners' conventional methods, which were primarily based around Chinese architecture of the last several decades. In addition, the conventional approach to establishing UGBs is not appropriate when taking into consideration the comprehensive forces that quantitatively influence urban growth process. Therefore, new methods that can account for all of the forces driving urban growth are necessary for improving the development of UGBs.

In China, urban planners, most of whom work in state-owned planning institutions, tend to retain the notions of the planned economy before the reform and opening-up policy of 1978 when they propose spatial urban plans (Gu, 2011). This approach has resulted in wide-spread ignorance with respect to market factors (such as locations of commercial centers and roads). The normal procedure for urban planning is to propose the desired planned form first and to consider the required spatial policies to implement the desired urban form second. The planned urban form proposed by planners cannot be implemented solely by enforcing land use plans (or zoning), as it is also influenced by other related urban spatial policies, such as eco-sensitive land protection, infrastructure development, and other market factors. In Chinese cities, actual urban growth often departs from planned forms. Planning departments tend to neglect policies in support of planned forms of growth while also disregarding the coherence of policies over time. Therefore, there is an urgent need to develop a method to link supporting policies to the desired urban forms (Gu, 2011; Long, Shen, & Mao, 2012).

Cellular automata (CA), which can simulate the form and pattern of urban growth, has been extensively applied in modeling urban growth and used as an analytical tool for complex spatio-temporal systems (Clark & Gaydos, 2008; Tobler, 1970; White & Engelen, 1993; White & Engelen, 1997; Xie, 1994). Due to the complexity of urban growth, urban growth models should consider various factors that influence urban growth process. The pure CA model only considers neighborhood effects, setting aside important factors such as policy and geographical constraints. Therefore, many researchers have introduced constraints into the CA model—constrained CA—thereby rendering the simulation of urban growth closer to real world outcomes (Clark & Gaydos, 2008; Engelen, White, & Uljee, 1997; Guan, Wang, & Clark, 2005; Li & Yeh, 2000; Ward & Murray, 1999; Ward, Murray, & Phinn, 2000; White, Straatman, & Engelen, 2004; Wu, 1998). Institutional factors and market incentives can be regarded as constraints in constrained CA to simulate future urban forms while taking into account comprehensive urban development considerations.

Planners can use constrained CA as a planning support system (PSS) to establish planned urban forms, in particular UGBs. The constrained CA simulation results—as an alternative future urban form or a possible land use scenario—can be applied as the basis for Chinese UGBs, as there are usually more explicit policy constraints in Chinese cities than in cities with mature market economies. Constrained CA can be conveniently applied to predict future urban forms if future development policies are known (Li & Yeh, 2000; Long, Mao, & Dang, 2009; Wu, 1998). In addition, the impact of the policies related to the control and guidance of urban growth can be simulated as different scenarios in constrained CA. The planners' particular visions can be embedded as the constraints of constrained CA. However, to our knowledge, little literature to date has addressed using constrained CA simulation to establish UGBs although there are extensive publications on urban growth simulation using constrained CA. This paper aims to bridge this gap.

In the present paper, a constrained CA model that considers macro-level socio-economic constraints, locational constraints, neighborhood effect and institutional constraints is developed to simulate future urban growth and establish the UGBs for the Beijing Metropolitan Area. The "Urban growth simulation using constrained cellular automata" section introduces the methodology to establish UGBs through constrained CA in detail. The "Case study in the Beijing Metropolitan Areas (BMP)" section shows how to use constrained CA to establish UGBs in the Beijing Metropolitan Area. The "Conclusion and discussion" section presents and concludes our findings.

Urban growth simulation using constrained cellular automata

Constrained cellular automata

The conceptual model of the constrained CA is shown as follows:

$$V_{ij}^{t+1} = f(V_{ij}^{t}, A_{mac}, A_{loc}, A_{ins}, A_{nei}^{t}) \quad (1)$$

where V_{ij}^{t+1} and V_{ij}^{t}, respectively, are the cell status at ij of time $t + 1$ and t and f is the transition rule of the constrained CA model. In this paper, the cell status represents 0 for no development or 1 for developed from rural to urban. Constrained conditions in the urban growth process, namely, development policies, consist of four types, which include the macro socio-economic constraint A_{mac} (a non-spatial explicit variable), locational constraints A_{loc}, institutional constraints A_{ins}, and neighborhood effect A_{nei}^{t}. Locational and institutional constraints are assumed to remain static during the future urban growth process, and they do not change across simulation iterations, a condition that is widely adopted by constrained CA studies. The macro-level socio-economic constraint reflects the total number of built-up cells to be developed in the future. The neighborhood effect, however, continues to change with simulation iterations of the constrained CA. To differentiate the neighborhood effect from other constraints, we consider locational and institutional constraints to be spatial constraints in this paper.

The status transition rules in constrained CA are illustrated in Formula (2) (Wu, 1998):