Landscape and Urban Planning 177 (2018) 47–63

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Delineating multi-scenario urban growth boundaries with a CA-based FLUS model and morphological method

Xun Liang[a], Xiaoping Liu[a,*], Xia Li[b,a,*], Yimin Chen[b,a], He Tian[a], Yao Yao[c]

[a] Guangdong Key Laboratory for Urbanization and Geo-simulation, School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, PR China
[b] School of Geographic Sciences, Key Lab. of Geographic Information Science (Ministry of Education), East China Normal University, 500 Dongchuan Rd, Shanghai 200241, PR China
[c] School of Information Engineering, China University of Geosciences, Wuhan, Hubei 430074, PR China

ARTICLE INFO

Keywords:
Urban growth boundaries (UGBs)
UGB-FLUS model
Planning scenarios
Cellular automata
Erosion and dilation

ABSTRACT

Urban growth boundaries (UGBs) have been commonly regarded as a useful tool for controlling urban sprawl. There is a need to create models that can establish plausible UGBs for fast growing regions. Previous methods have merely focused on establishing a single UGB scenario over different time intervals, but rarely considered the influences of macro policy (e.g., future urban demand) and spatial policy (e.g., master plan) for regional planning. However, the spatial patterns of urban expansion are significantly affected by regional planning. In this paper, a CA-based method called the future land use simulation (FLUS) is applied to the delineation of UGBs. We argue that the delineation needs to integrate the top-down approach with CA for projecting complex land use changes under designed scenarios. The system dynamics model (SD) and cellular automaton model (CA) were interactively coupled in the FLUS model during the projection period. The top-down SD is used to project scenarios that relate to macro policy and socioeconomic status, and the bottom-up CA accounts for urban growth simulations under the influence of different driving factors and spatial planning policies. A morphological technology based on erosion and dilation is further proposed to generate the UGBs from the FLUS model's simulated urban forms. The proposed UGB-FLUS model was applied to the establishment of UGBs in the Pearl River Delta region (PRD) from 2020 to 2050. The results demonstrate that the method can support urban planning by generating feasible patterns for UGBs under different planning scenarios.

1. Introduction

Urban sprawl, which arises from the rapid growth of the economy and population, has become a major challenge for sustainable urban development worldwide (Yao et al., 2016, 2017; Hashem & Balakrishnan, 2015; Liu et al., 2014). For assisting urban planning, methods or models are required to guide and constrain urban area growth (Long, Han, Lai, & Mao, 2013). Urban growth boundaries (UGBs) have been a common tool used by planners to control urban development in open spaces, protect superior rural areas that make significant contributions to the urban environment from development, and promote efficiency in urban management, especially where there is residential development in established and planned suburban areas (Gennaio, Hersperger, & Burgi, 2009). Moreover, this planning tool is also important for increasing the density of urban services and reducing urban infrastructure costs (Tayyebi, Perry, & Tayyebi, 2014). A recent study was carried out by Long, Han, Tu, and Shu (2015) regarding planner designed UGBs, and they reported that UGBs were effective in containing human mobility and activity. In addition, the control function of UGBs increases over time during urban development, and the effect of UGBs is clearly stronger in exurban areas than in central urban (Long, Gu, & Han, 2012). Therefore, the UGBs will play an increasingly important role in the future of new urban land management.

UGBs are most often established in high growth areas such as metropolitan areas. The earliest UGB can be traced back to the green belt in London in the 1930s (Nelson & Moore, 1993). In recent decades, UGBs were first adopted widely in the United States (Hepinstallcymerman, Coe, & Hutyra, 2011; Jun, 2004) and then, they were gradually brought into other countries such as China (Han, Lai, Dang, Tan, & Wu, 2009), India (Venkataraman, 2013), Canada (Gordon & Vipond, 2005), Albania (Carter, 1992), Australia (Coiacetto, 2007), Switzerland (Gennaio et al., 2009), etc. To date, UGBs are being used by

* Corresponding authors at: Guangdong Key Laboratory for Urbanization and Geo-simulation, School of Geography and Planning, Sun Yat-sen University, Guangzhou 510275, PR China (X. Liu) and School of Geographic Sciences, Key Lab. of Geographic Information Science (Ministry of Education), East China Normal University, 500 Dongchuan Rd, Shanghai 200241, PR China (X. Li).
E-mail addresses: liangxunnice@foxmail.com (X. Liang), liuxp3@mail.sysu.edu.cn (X. Liu), lixia@mail.sysu.edu.cn (X. Li).

https://doi.org/10.1016/j.landurbplan.2018.04.016
Received 23 September 2017; Received in revised form 8 February 2018; Accepted 30 April 2018
0169-2046/

an increasing number of local governments in various countries around the world to direct urban growth (Ma, Li, & Cai, 2017). As UGBs attract an increasing amount of attention, there are also a growing number of requirements to develop efficient and feasible techniques to define those boundaries for different applications. However, many UGBs are delineated by conventional methods that are only based on the personal experience of planners, which may lead to the lack of an adequate scientific basis and quantitative support (Long et al., 2013). Land use suitability evaluation models used to evaluate UGBs based on a series of spatial factors, e.g., topography and traffic conditions (Cerreta & Toro, 2012) have also been widely used in previous studies (Bhatta, 2009). Although easy to implement, these methods ignore the urban landscape characteristics, which will have negative effects for establishing elaborate urban boundaries (Cao, Huang, Wang, & Lin, 2012; Ma et al., 2017). Moreover, many geographic factors that drive urban change operate across different spatial and temporal scales in a very complex way (Tayyebi, Pijanowski, & Pekin, 2011; Tayyebi, Pijanowski, & Tayyebi, 2011). Suitability evaluation models commonly fail to reflect these relationships and interactions, which may result in UGBs failing to realistically accommodate future urban expansion (Tayyebi, Pijanowski, & Pekin, 2011; Tayyebi, Pijanowski, & Tayyebi, 2011).

To overcome the disadvantages of the abovementioned studies, many researchers have established UGBs by adopting the cellular automaton (CA) model. The CA model differs from previous models (manual method and suitability evaluation model) in its ability to represent spatial interactions implemented in the immediate neighborhood or the hierarchical structure of the neighborhood (Li et al., 2017a). CA can simulate the dynamics of urban growth at the landscape level (Verburg & Overmars, 2009). Through iterations and updates, CA can efficiently incorporate the interactions between urban growth and its corresponding geographic driving factors (Clarke & Gaydos, 1998). Thus, by using the CA model, UGBs can be generated from the simulation results in these studies. For example, Tayyebi, Pijanowski, & Pekin, 2011; Tayyebi, Pijanowski, & Tayyebi, 2011 proposed two rule-based CA models for the Tehran metropolitan area, which can directly predict the size and shape of urban boundaries. Long et al. (2012) delimited UGBs for the Beijing region using a constrained CA and compared the results to those established in the city master plan. The results show that CA is a helpful planning tool for the establishment of UGBs. Some of the researchers have tried to combine CA with intelligent algorithms such as logistic regression (Hu & Lo, 2007), artificial neural networks (Tayyebi, Pijanowski, & Pekin, 2011; Tayyebi, Pijanowski, & Tayyebi, 2011), particle swarm optimization (Feng, Liu, Tong, Liu, & Deng, 2011), and ant colony optimization algorithms (Ma et al., 2017). In addition, a recent study also proposed CA models based on partial least squares (PLS-CA) regression or generalized pattern search (GPS-CA) which can better explain the dependent variables and reduce simulation uncertainties. These CA models also have great potential to improve the CA-based UGB delineating method (Feng, 2017; Feng, Liu, Chen, & Liu, 2016). In summary, the use of these intelligence algorithms allows CA models to simulate the local interaction between land use patterns and various driving factors (Li & Yeh, 2002; Lin, Chu, Wu, & Verburg, 2011; Liu, Xia, Shi, Zhang, & Chen, 2010).

CA-based UGB models have made superior progress compared to previous UGB methods. However, the spatial patterns of urban expansion are significantly affected by regional planning on both regional and local scales (Lu, Wu, Shen, & Wang, 2013; Tian & Shen, 2011). Most of the previous UGB models only focused on the local “bottom-up” effect of the CA model but ignored the “top-down” effect at the regional scale. The large-scale influences usually refer to the future demand for economic development and population increase that determine the future amount of urban land in a region (Verburg & Overmars, 2009). The local effects are indicative of interactions and feedback between land use patterns and multiple spatial driving forces, which include the road network, geographical locations, terrain conditions, etc. (van Asselen & Verburg, 2013; Verburg, 2006; Verburg, Ellis, & Letourneau, 2011). On both scales, these effects are influenced by the development policies of a region (Gao, Wei, Chen, & Chen, 2014), and the urban area dynamics are largely determined by forces that are exogenous to land allocation. Therefore, the influence of regional planning on both scales should be considered by coupling the “bottom-up” CA model with a ‘top-down’ approach (Verburg, van de Steeg, Veldkamp, & Willemen, 2009; Xiang & Clarke, 2016). However, there are no previous studies that attempted to build a UGB model by integrating both the macro urban demand and local dynamics.

Additionally, the ways in which different planning policies influence the spatial patterns of urban areas and future UGBs under various scenarios is of great importance for decision makers to assess the outcome and impact of different policies (Chen, Li, Liu, & Ai, 2014). For example, Long et al. (2012) incorporated urban planning to simulate a planning-strengthened scenario in Beijing to help illustrate the impact of urban planning on urban expansion. In addition, considering planning factors in the urban simulation can be employed by decision makers in the early stages of policy making; this operation provides an inexpensive and effective way for planners to obtain helpful information about the influences of different development policies or planning scenarios on urban development, which may prevent poor urban designs (Clarke, 2014). With this information, planners can better adjust the direction of urban development by modifying corresponding planning factors and planning policies, as well as delineating more appropriate UGBs. Most of the previous research only attempted to build UGBs under a single scenario, in specific time nodes or by a set of model parameters (Ma et al., 2017; Tayyebi et al., 2014; Inkoom, Nyarko, & Antwi, 2017). However, a very limited number of studies have tried to establish UGBs for large-scale and fast-developing areas under various planning scenarios. Another challenge in delineating UGBs is that some cities with amazing development speed show fractal characteristics in urban land forms, spatial form and landscape organization (Yuan, 2005). An example of this is the Pearl River Delta area in China. This results in UGBs in these areas potentially comprising numerous polygons and even showing a dispersed form. When delimiting the UGBs, polygons with low compactness and a small area should be eliminated, as they are not feasible for urban development. This indicates that the results of the simulation model cannot be directly used as final UGBs. Previous studies established UGBs based on CA simulation, which was mainly through manual modification (Long et al., 2013). Such modification is quite subjective and inconvenient to use. The effective establishment of UGBs from the CA model simulation results remains unresolved for practical problems.

In this paper, a novel UGB delineation framework is presented, in which UGB-FLUS is proposed to tackle these problems. This framework is implement by two steps: 1) urban growth simulation with a future land use simulation (FLUS) model and 2) delineating UGBs based on the simulated urban growth. The FLUS model is a CA-based method that is integrated with a top-down approach to solve UGBs problems. This FLUS model has been proven effective for projecting complex land use changes under various design scenarios (Liu, Liang, Li, & Xu, 2017). By using this FLUS model, the visions of planners can be embedded as the constraints or drivers for creating UGBs. In the second step, we proposed a component based on the theory of erosion and dilation to improve the effects of generating plausible UGBs from the simulation results, because traditional methods cannot effectively remove the small and dispersed urban patches. This method is used to merge and connect the cluster of urban blocks into one large area and simultaneously eliminate the small and isolated urban patches. The application of this proposed framework is carried out in the Pearl River Delta (PRD), which is one of the fastest growing regions in China.

2. Methods

The UGB-FLUS framework involves several techniques. First, a spatial simulation model based on the theory of cellular automaton