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Beijing Urban Development Model: Urban Growth Analysis and Simulation*

LONG Ying (龙 瀛)[1,2,**], MAO Qizhi (毛其智)[1], DANG Anrong (党安荣)[2]

1. School of Architecture, Tsinghua University, Beijing 100084, China;
2. Beijing Institute of City Planning, Beijing 100045, China

Abstract: Urban growth analysis and simulation have been recently conducted by cellular automata (CA) models based on self-organizing theory which differs from system dynamics models. This paper describes the Beijing urban development model (BUDEM) which adopts the CA approach to support urban planning and policy evaluation. BUDEM, as a spatio-temporal dynamic model for simulating urban growth in the Beijing metropolitan area, is based on the urban growth theory and integrates logistic regression and MonoLoop to obtain the weights for the transition rule with multi-criteria evaluation configuration. Local sensitivity analysis for all the parameters of BUDEM is also carried out to assess the model's performances. The model is used to identify urban growth mechanisms in the various historical phases since 1986, to retrieve urban growth policies needed to implement the desired (planned) urban form in 2020, and to simulate urban growth scenarios until 2049 based on the urban form and parameter set in 2020. The model has been proved to be capable of analyzing historical urban growth mechanisms and predicting future urban growth for metropolitan areas in China.

Key words: cellular automata; policy simulation; logistic regression; planned urban form

Introduction

Along with the prosperity of Beijing macro-economy, especially as a result of the Olympics, the future form of the Beijing metropolitan area needs to be analyzed in the post-Olympic games period in 2009, at the end of the urban master planning in 2020, and for the 100th anniversary of the founding of the P. R. China's capital in 2049. Furthermore, long-term forecast of the urban form is essential for the next round of urban master planning. Comprehensive urban models have been developed to simulate urban systems for some major metropolitan areas, such as the London metropolitan area, the San Francisco Bay area, and the California area. However, there is no urban model for Beijing or most other cities in China.

Urban models, which were developed in the early years of the twentieth century, have progressed from structural models to static models to dynamic models. Traditional urban models, based on differential equations or quasi dynamic equations, usually simulate the urban system at a macro level, so they cannot accurately reflect the dynamic, self-organizing, or emerging characteristics of urban systems. The development of GIS and other complex adaptive models has led to urban models based on artificial life or discrete dynamics. In recent years, urban growth models have used the cellular automata (CA) approach which is based on self-organizing theory. The CA models are composed of a series of basic rules instead of strictly defined physics equations or functions. The discrete character

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** To whom correspondence should be addressed.
E-mail: longying1980@gmail.com; Tel: 86-10-88073660

is a key characteristic of the time and space and status in CA. CA has been adapted to simulate the emergence, self-organizing, and chaos phenomena in urban systems.

CA is now a practical tool for simulating urban growth, which is the main field using CA. Tobler[1] initially simulated urban expansion in the Great Lakes region of the United States. Couclelis[2-5] claimed that CA with simple rules can be applied to generate complex urban forms in a virtual city, with great potential to simulate urban growth. White and Engelen[6] applied CA to urban planning and White and Engelen[7] simulated the land use patterns in Cincinnati, Ohio, United States. Clark and Gaydos[8] developed the SLEUTH model to simulate long-term urban growth in the San Francisco Bay area and the Washington-Baltimore area in the United States, like some of the earliest applications of CA which simulate urban growth in the real cities. Batty et al.[9-16] conducted several studies using fractal and CA to study urban formation and expansion. Xie[17] simulated the land use changes in Buffalo, NY, United States. Wu and Webster[18-20] used the multi-criteria evaluation (MCE) method to find the status transition rules in CA and applied the model for urban expansion simulations of Guangzhou, China.

In China, Li and Yeh[21-27] used various intelligent methods to identify the CA transition rules, with a constrained CA model to simulate sustainable urban growth in the Pearl River Delta and analyzed the uncertainty of CA. Others have used CA to simulate urban growth in Haikou[28], Wuhan[29], Fuzhou[30], Xi'an[31], Northern China[32], and part of the Beijing metropolitan area[33]. Thus, there have been many applications of CA to simulate urban growth in China. However, there are no studies using CA to simulate urban growth in the Beijing metropolitan area.

The Beijing urban development model (BUDEM) was developed to support urban planning and policy evaluation. This spatio-temporal dynamic model simulates urban growth for the Beijing metropolitan area using the CA approach. The model was developed for the Beijing metropolitan municipal government and planning committee with an area of 16 410 km^2 and with a spatial resolution of 500 m, including computer simulations using CA of the Beijing metropolitan area. The BUDEM urban form simulation platform was specially developed for Beijing urban planning in a mega-city. BUDEM integrates logistic regression and MonoLoop to identify the CA transition rule to realize the desired urban form. The model uses environmental constraints and urban planning conditions to reflect China's urban development characteristics. Then it is used to simulate the planned urban form of Beijing in 2020 and to predict the long-term unknown urban form of Beijing in 2049. Therefore, the paper presents a historical analysis of the different phases of Beijing's urban growth and model estimates for Beijing in 2020 (BEIJING2020), and then predicts the Beijing form in 2049 (BEIJING2049) based on the urban form and parameter set of Beijing in 2020.

1 BUDEM: CA-Based Urban Simulation Model

1.1 Spatial factors selection

Macro level urban growth research, which does not consider urban spatial distribution, regards the urban system as one whole entity. The driving forces for urban growth consist of population changes, economic changes, political structure, etc.[34]. However, we prefer the self-organizing process research within the urban system. Urban development is influenced by location and geographic conditions in a classical urban land use model. Alonso[35] pointed out that the distance to the urban center is the principal factor controlling the urban land use structure in his single center urban location theory. The optimum land type will change according to the distance to the urban center, which affects the accessibility and transportation cost. In addition, Doxiadis, who founded human settlement science, concluded that the distances to the present urban center, to the main road, or to the natural landscape are the main forces for human settlement[36]. The Hedonic model provides a clearer framework, which assumes that commodity prices are determined by the total utility of the different properties and depend on the number and composition of the commodity's properties[37]. For example, Butler[38] held that residential prices are affected by location, architectural structure, and neighborhood, and that the prices reflect the total preferences of the consumer. Urban development is related to residential prices and its probability reflects developer's preferences for the lot or block. Therefore, the spatial variables in the CA were chosen as shown in Table 1 based on Hedonic theory and the possibility of