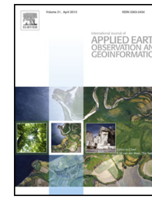
International Journal of Applied Earth Observation and Geoinformation 52 (2016) 380–389

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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



# The simulation and prediction of spatio-temporal urban growth trends using cellular automata models: A review

Maher Milad Aburas [a,b], Yuek Ming Ho [a,*], Mohammad Firuz Ramli [a], Zulfa Hanan Ash'aari [a]

[a] *Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*
[b] *The High Institution for Engineering Vocations Almajori, Almajori, Benghazi, Libya*

ARTICLE INFO

*Article history:*
Received 25 April 2016
Received in revised form 9 July 2016
Accepted 11 July 2016

*Keywords:*
Simulation
Prediction
Urban growth
Spatio-temporal
Cellular automata

ABSTRACT

In recent years, several types of simulation and prediction models have been used within a GIS environment to determine a realistic future for urban growth patterns. These models include quantitative and spatio-temporal techniques that are implemented to monitor urban growth. The results derived through these techniques are used to create future policies that take into account sustainable development and the demands of future generations. The aim of this paper is to provide a basis for a literature review of urban Cellular Automata (CA) models to find the most suitable approach for a realistic simulation of land use changes. The general characteristics of simulation models of urban growth and urban CA models are described, and the different techniques used in the design of these models are classified. The strengths and weaknesses of the various models are identified based on the analysis and discussion of the characteristics of these models. The results of the review confirm that the CA model is one of the strongest models for simulating urban growth patterns owing to its structure, simplicity, and possibility of evolution. Limitations of the CA model, namely weaknesses in the quantitative aspect, and the inability to include the driving forces of urban growth in the simulation process, may be minimized by integrating it with other quantitative models, such as via the Analytic Hierarchy Process (AHP), Markov Chain and frequency ratio models. Realistic simulation can be achieved when socioeconomic factors and spatial and temporal dimensions are integrated in the simulation process.



**Contents**



## 1. Introduction

Urban growth has become a global issue, resulting in the heightened concern among planners and decision makers over the future impacts on the ecosystem (Bihamta et al., 2014; Liu and Phinn, 2004). Simulating and predicting urban sprawl patterns has become essential to ecosystem protection and sustainable development (Yao et al., 2015). In addition, the complex structure of the urban environment must be understood to simulate urban dynamics correctly (Dahiya, 2016). Urban growth simulation needs to consider the chronology of the issue of sprawl and wide historical information to understand spatial and temporal relationships

* Corresponding author.
*E-mail address:* yuekming@upm.edu.my (Y.M. Ho).

http://dx.doi.org/10.1016/j.jag.2016.07.007

accurately (Sudhira et al., 2004). Hence, simulation techniques can be improved by obtaining the true knowledge of driving forces of urban growth that affect future land uses. (Pijanowski et al., 2002). The understanding of spatial and temporal changes, as well as all effective elements, are facilitated using remote sensing (RS) and geographic information system (GIS) techniques (Punia and Singh, 2012).

The Cellular Automata (CA) model has an open structure and can be integrated with other models to simulate and predict urban growth patterns (Clarke, 1997). Flexibility, intuitiveness, and the ability to integrate the spatial and temporal dimensions of the processes, as well as the capability to model complex dynamic systems are major reasons for the widespread application of the CA model to stimulate urban growth patterns and future land use changes in recent years (Santé et al., 2010). Tobler (1979) first proposed the application of cellular space models to geographic modeling. In the 1980s, the first theoretical approaches of CA-based models to simulate urban growth appeared (Couclelis, 1985; Batty and Xie, 1994; White and Engelen, 1994).

Conceptual growth in CA studies and the evolution of computing capability contributed to the first operational urban CA model used on real-world urban systems in the 1990s. The capability of the urban CA model to simulate and predict land use changes is based on the assumption that the previous urban growth affects the future patterns through local and regional interactions among different types of land uses (Santé et al., 2010). Moreover, the urban CA model can be easily integrated with the GIS environment (Al-sharif and Pradhan, 2013); thus, the CA model has a high spatial resolution with computational efficiency because models of these kinds have the capability to simulate according to the assumption that past urban growth affects future trends of urbanization based on local interactions between land uses (Santé et al., 2010; Wagner, 1997; Batty and Longley, 1994).

The other key fields of urban CA models considered as powerful spatial dynamic modeling techniques that represent a major development over previous conventional models are: (i) spatiality, (ii) the linking macro to micro approaches, (iii) the integration between GIS and RS techniques, (iv) dynamics, and (v) simplicity and visualization (Batty and Xie, 1994; White and Engelen, 1994, 2000; Clarke, 1997; Wu, 1998). In order to implement a realistic simulation process which takes into account social, economic, dynamic and spatio-temporal dimensions, this study provides a critical review of the CA model in detail, including describing the integration approach among the CA model and other models, techniques, and approaches. The results can be used to determine future pillars of development, and can significantly address any limitations and defects. The main contribution of this study is the suggestion of a novel approach to improve the prediction and simulation capability of the CA model.

## 2. Overview of simulation and prediction models within the GIS and RS

RS and GIS techniques are commonly used to monitor and control urban growth patterns (Al-shalabi et al., 2013a; Dezhkam et al., 2014). Currently, modeling urban growth patterns and simulating land use changes generally employ various types of models and methods within the RS and GIS techniques (Amato et al., 2014; Mohammad et al., 2013; Arsanjani et al., 2013). Studies have used traditional models that depend on the assessment of the dynamic growth of urban areas, such as the CA models (Clarke, 1997). Some of these studies have relied on quantitative models, such as the Logistic Regression (LR), for simulation and prediction (Alsharif and Pradhan, 2014). Other studies have relied on the integration of the different types of models, such as the Markov Chain (MC) and CA, to achieve accurate and realistic results (Al-sharif and Pradhan, 2013). Modeling urban growth patterns based on RS and GIS techniques is used to understand the spatial process for the urban movement within a specific time toward the creation of future policies of sustainable development.

Based on the advantages and disadvantages of the models (Table 1) and the comparison among previous publications on simulation models, this study confirms that the CA is an effective and reliable model commonly used in spatial and temporal simulation studies. The findings of the Land Transformation model (LTM) showed a high capacity of prediction with high resolution. However, this model requires complex operational steps, making it one of the least preferred models in terms of application. While, Conversion of Land Use and its Effects (CLUE) model, which depends on several parameters, such as case study, data availability, and dominant land use change processes, is not completely specified. Jokar Arsanjani et al. (2013) used integration Logistic Regression LR based CA-MC model for simulating urban growth trends. The accuracy of simulation has been improved using this model. Meanwhile, Amato et al. (2014) used the Weights of Evidence model (WE). This model will not be successful without rich data and detailed maps for simulation.

On the other hand, Pijanowski et al. (2014) utilized integration LTM, Land Use and Land Cover Change (LUCC) and ANN approach. This integrated model is still under development and needs a wide range of raw data to generate accurate simulation. Park et al. (2011) used the Frequency Ratio (FR) model, Analytical Hierarchy Process (AHP), Logistic Regression (LR) model, and ANN. These models achieved good comparison using multi-criteria and different types of growth factors, such as dynamic and quantitative factors. Finally, SLEUTH and Urban Growth Potential (UGP) models have been successfully applied worldwide over the last 16 years to predict land use and land cover change. However, the disadvantage of the SLEUTH model is that the simulation operation is restricted by specific factors that cannot change and evolve.

Based on the comparison among previous publications on simulation models (Fig. 1), CA models have the highest number of publications in recent years. The number continues to increase because of the following reasons: CA models are easy to apply, can simulate any complex pattern, have an open structure, can be integrated with other models, and can simulate spatial and temporal patterns (Clarke, 1997; He et al., 2008). However, CA models are limited in the inclusion of driving forces of urban growth for urban simulation, which is difficult for these models to process (Al-sharif and Pradhan, 2013). This issue can be resolved by integrating the CA model with other quantitative and spatio-temporal methods, such as the Analytic Hierarchy Process (Mohammad et al., 2013) and Logistic Regression (Liu and Feng, 2012). According to the literature reviews, including 181 publications that have been published in the last 10 years, the CA model is one of the strongest models for simulating and predicting the urban growth phenomenon.

## 3. Designing urban CA model

Designing an urban CA model can be done by following multiple phases, namely, (i) data collection phase, which requires different types of data according to the type of model, data availability, and the existence of a type of integration with other models (Dietzel and Clarke, 2004; Oguz et al., 2007; Bihamta et al., 2014; Dezhkam et al., 2014); (ii) selection of the influencing factors on urban growth patterns and future land use changes based on data availability and the method of study (i.e., whether it is a quantitative or spatio-temoral study) (Al-Kheder et al., 2008; Al-shalabi et al., 2013b); (iii) identification of the characteristics of CA that are used for simulation, such as defining the lattice, determining cell state, identifying the neigh-