Towards a cellular automata based land-use transportation model

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1. Introduction

Cellular automata (CA) models were introduced to Urban Studies by Waldo Tobler [1], starting a period of intensive development that gave birth to the first applications of CA for simulating both theoretical and real-world urban systems [2, 3, 4]. The foundations set in this period boosted numerous variations and improvements to CA models that are now widely used for simulating increasingly more complex spatial systems [5, 6, 7]. The vast majority of the applications rely on regular cells derived from remote sense imagery, but more attention is progressively being given to use irregular cellular fabrics [8, 9, 10].

Accessibility has long been seen as a major driver of urban growth. A significant number of urban simulation models incorporate accessibility and its interdependent effects with a series of other factors such as land price or household and activity location. The same occurs with CA models, where accessibility is included as one of the components in the formulation of transition rules, which drive the evolution of CA [11]. However, these models typically consider accessibility in a very simplistic way, mainly defined as the linear distance from a cell to the nearest transport infrastructure [12, 13, 14]. This way of characterizing accessibility discards the effects that infrastructure capacity and travel demand has on the performance of transportation systems and their consequences on land use. In this paper we present a CA model where accessibility is characterized in a more sophisticated manner, which can be seen as a first step towards the development of CA-based land-use transportation model.

2. Model Description

A CA model comprises five main components: cells, cell states, neighborhoods, transitions rules, and time. In our model, the cells are irregular, to simulate real-world irregular spatial partitions, such as census blocks. Cell states are the possible land uses each cell may have. We consider aggregate land uses: urban low density (UL) and urban high density (UH); industry (I); expansion areas for urban (XU) and for industrial (XI) land uses; and areas where construction is highly restricted (R). Neighborhoods, i.e. the geographic scope of land use interactions between cell states, are defined as radial distances calibrated by the model. Transition rules play a key role as they represent the way the system evolves throughout time. We use the concept of transition potential to select which cells will change state at each simulation step. This potential is a weighted value of land use suitability, neighborhood effects, and accessibility, taking into consideration a stochastic perturbation. Accessibility is measured by a function of the travel time between cells and the main functional centers (central areas and industrial districts) through the road network, considering its hierarchical structure and using an impedance function (typically an exponential function or a power function) of an aggregate value of travel time. Land use demand is proportional to the increase of population and employment, as well as to the variation of construction density throughout time. The performance of the model is assessed through contingency matrices and a modified version of the *kappa* index, k_{mod}, in which cells that cannot change state are not considered. Parameters are calibrated using a particle swarm algorithm to maximize the value of k_{mod}. Previous versions of the model were applied to a group of different cases [9, 15, 16] and proven to give good results in comparison with other CA models. For detailed information about this CA model and all model features see Pinto and Antunes [9].

3. Model Application

The CA model was applied to the city of Coimbra, Portugal, to simulate the impacts of the construction of a ring road – Anel da Pedrulha – on urban change. The main goal was to demonstrate the use of the model to evaluate planning scenarios. The model was calibrated for a set of reference data that included census data on population and employment for the years of 1991 and 2001, considering the Municipal Master Plan legally in force. Land use maps for the reference data are depicted in Figure 1(a) for 1991 and Figure 1(b) for 2001. The model achieved a k_{mod} value of 0,767, which indicates its high capacity to simulate reality, as depicted in Figure 1(c). Two very simple future scenarios were designed, one 'Baseline' which did not consider any change in the road network and the other called ‘Anel da Pedrulha’ considering the construction of the ring road, both assuming the same values for population and employment growth rates. The model was able to clearly identify areas of larger demand for urban development around the area directly served by the new ring road, reflecting the increase of accessibility from/to this area, as seen in Figure 2.

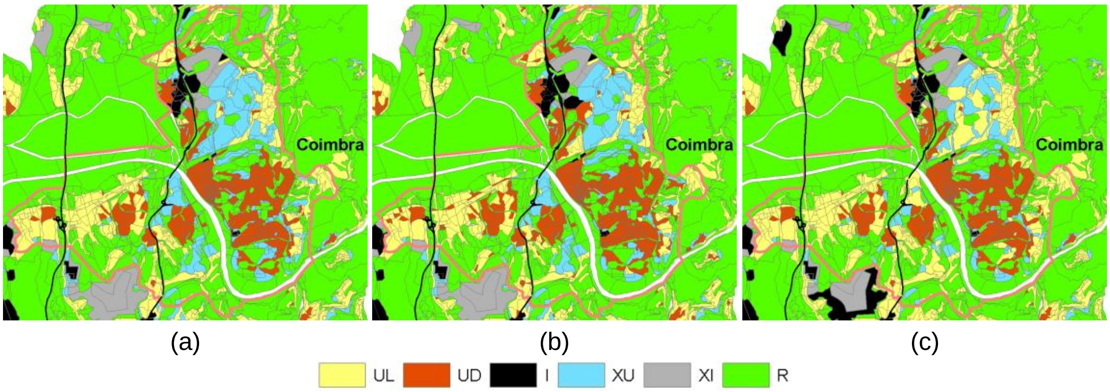

Figure 1 Land use maps for the municipality of Coimbra: (a) reference data for 1991, (b) reference data for 2001 and (c) simulation results for 2001

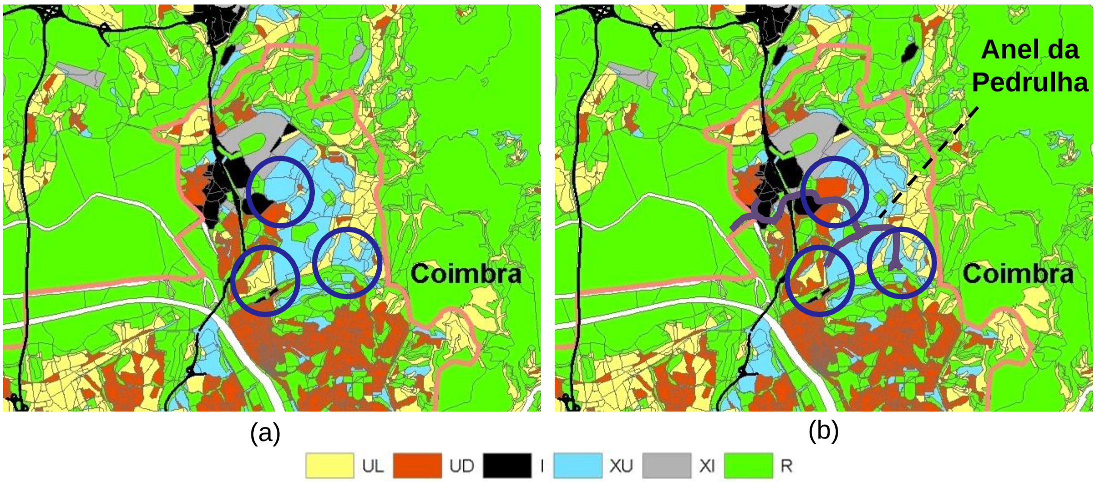

Figure 2 Comparison of the land use maps for the area directly served by the new ring road for (a) the ‘Baseline’ scenario and (b) the ‘Anel da Pedrulha’ scenario

4. Concluding Remarks

The scenarios designed for the application described above are quite simple, but they were useful to exemplify how the CA model can be used in the assessment of different planning choices. Its results were already presented in a meeting with elected and appointed public administration officials – including the Mayor of Coimbra and several representatives of national agencies with competences in spatial and transportation planning – where the land-use impacts of Anel da Pedrulha were thoroughly discussed. In the future, we plan to continue improving the accessibility component of the CA model, to end up with a model that is capable of dealing properly with complex land-use transport interactions.

References

[1] Tobler, W., “Cellular geography” IN GALE, S. & G. OLSSON (Eds.) Philosophy in Geography. Boston, D. Reidel, 1979.

[2] Couclelis, H., “Cellular worlds - a framework for modeling micro-macro dynamics” Environment and Planning A, 17(5), 585-596, 1985.

[3] White, R. & G. Engelen, “Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land-use patterns”, Environment and Planning A, 25(8), 1175-1199, 1993.

[4] Batty, M. & Y. Xie, “From cells to cities”, Environment & Planning B: Planning & Design, 21(Celebration Issue), 531-548, 1994.

[5] Wu, F. & C. J. Webster, “Simulation of land development through the integration of cellular automata and multicriteria evaluation”, Environment and Planning B: Planning and Design, 25(1), 103-126, 1998.

[6] Silva, E. & K. C. Clarke, “Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal”, Computers, Environment and Urban Systems, 26(6), 525-552, 2002.

[7] Liu, X., X. Li, X. Shi, S. Wu & T. Liu, “Simulating complex urban development using kernel-based non-linear cellular automata”, Ecological Modelling, 211(1-2), 169-181, 2008.

[8] O'Sullivan, D., “Exploring spatial process dynamics using irregular cellular automaton models”, Geographical Analysis, 33(1), 1-18, 2001.

[9] Pinto, N.N. and A.P. Antunes, “A cellular automata model based on irregular cells: application to small urban areas”, Environment and Planning B-Planning & Design, 37(6): p. 1095-1114, 2010.

[10] Stevens, D., S. Dragicevic & K. Rothley (2007) “iCity: A GIS-CA modelling tool for urban planning and decision making”, Environmental Modelling & Software, 22(6), 761-773, 2007.

[11] Santé, I., A. M. García, D. Miranda & R. Crecente, “Cellular automata models for the simulation of real-world urban processes: A review and analysis”, Landscape and Urban Planning, 96(2), 108-122, 2010.

[12] Clarke, K., S. Hoppen & L. Gaydos, “A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area”, Environment and Planning B: Planning and Design, 24(2), 247-261, 1997.

[13] Li, X. & A. G. O. Yeh, "Modelling sustainable urban development by the integration of constrained cellular automata and GIS", International Journal of Geographical Information Science, 14(2), 131-152, 2000.

[14] He, C., N. Okada, Q. Zhang, P. Shi & J. Li, "Modelling dynamic urban expansion processes incorporating a potential model with cellular automata", Landscape and Urban Planning, 86(1), 79-91, 2008

[15] Pinto, N., A. Antunes & J. Roca, "Application of a cellular automata model to the Metropolitan Area of Barcelona", In ROCA, J. & R. BIERE-ARENAS (Eds.) Proceedings of the 5th International conference on Virtual Cities and Territories. Barcelona, Spain, Center for Land Policy and Valuation, 2009.

[16] Pinto, N., A. Antunes, J. Roca, "Cellular Automata in Urban Simulation: Basic Notions and Recent Developments", In BAVAUD, F. and C. MAGER, Handbook on Theoretical Quantitative Geography, FGSE, University of Lausanne, Lausanne, Switzerland, pp 365-402, 2009.