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Educational infrastructure and its impact on urban land use change in a peri-urban area: a cellular-automata based approach

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ABSTRACT

Educational infrastructure plays a crucial role in shaping urban tissue and this holds true mainly in informal neighborhoods of developing countries, where land use dynamics are constantly evolving. This paper is committed to analyze trends of land use change in a peri-urban area in the vicinities of a unified educational center (in Portuguese, *centro educacional unificado* — CEU) named Paz, built in 2004, in the northern sector of Sao Paulo city (southeast of Brazil). A cellular automata-based spatiotemporal model was used to simulate land use change in time spans before and after its construction: 2000—2004 and 2004—2010. The model, which comprises 10 types of land use classes and multiple transitions, was run in a high performance computing platform and its parameterization was based on the Bayesian weights of evidence method. Urban landscape dynamics were analyzed with the aid of land use transition rates, the cells transition probabilities and morphological metrics of the land use patches. The results revealed that the yearly growth rate of informal urban settlements increased 27% after the CEU-Paz start-up; the transition rate to formal residential areas was eight times greater in the second time span, and the rate of unoccupied lands (vacant plots) decreased 37% between the given periods. Considering that the cells transition probabilities presented a strong spatial dependence with the distance to CEU-Paz, an unbalanced urban growth pattern was though observed in the studied area, which gathered informal settlements in physically vulnerable areas, although close to CEU-Paz, and drove the expansion of formal urban settlements to safe sites in its surroundings and predominantly close to previously existing transport infrastructure.

1. Introduction

Urban cellular automata (CA) models are mostly designed for both retrospective and prospective analyses of urban land use change as well as for detecting the evolving pattern of urban structure components and its spatial arrangements (Herold et al., 2005; Batty, 2012). In other words, urban simulation models are not only built for the purpose of predicting future patterns, but also for simulating past and present conditions as a means to assess and analyze the intervening factors in urban dynamics as a whole. Several urban CA models have been conceived to cope with the influence of infrastructure on urban form and dynamics (Blecic et al., 2004; Kumar et al., 2009; Puertas et al., 2014; Wray et al., 2015; Wahyudi and Yan, 2016). Urban form is the outcome of economic, social, political, legal, institutional and environmental drivers, which actuate in a concurrent, and sometimes conflicting, way.

There is an inherent complexity in the emergence of urban form and in the urban dynamics itself, since housing choice, physical infrastructure (transport, sewers, water, energy provision), social infrastructure (schools, health care, shops, housing, recreation and green areas), natural characteristics of physical sites (relief, soil type, hazard-prone areas), legal restrictions (right-of-way of transmission lines, railways and highways; zoning; environmental laws) and alike are closely interrelated in the webs of local and metropolitan life and policy (McLoughlin, 1991). As stated by Batty (2012), "*the functioning of cities in space and time is based on multiple processes of spatial choice in which individuals and groups in the population locate with respect to one another and their wider activities in the form of land use types*".

Urban interventions, like the implementation of educational facilities, usually affect social structures and promote improvements in the spatial patterns of social relations reproduction, driving the demand for new areas of urban expansion (Thisse and Wildasin, 1992; Kowarick, 1996). For Ghosh et al. (2017), CA-based simulations must lay greater emphasis on the skills to relate socioeconomic factors, so as to refine the analyses on such interventions.

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The aim of this article is to assess the influence of Paz Unified Educational Center (CEU-Paz), built in 2004, in variations of urban land use change trends in a particular peripheral area in the northern sector of Sao Paulo city, characterized by both formal and informal (illegal) residential settlements. A CA-based model was designed to simulate land use change for two transition periods: 2000—2004 and 2004—2010, namely before and after its implementation.

2. Brief literature overview: Urban CA models approaching educational infrastructure

Infrastructure provides a crucial support for the several activities of people and communities, which promote urbanization (PPIAF, 2007). In other words, technical and social infrastructure underpins the basic livelihood of citizens and their businesses (Kim, 2015). Infrastructure development, on its turn, has direct impacts on urban growth, and consequently, on urban land use change both in legal and illegal settlements (Torres, 2008; Otsuki, 2016). Particularly with respect to social infrastructure equipments, they are often regarded as inducing poles of urban expansion and/or urban change.

Several researchers worldwide have acknowledged the strategic role of social equipments in urban expansion processes and urban land use dynamics. Haase et al. (2008) state that modified social spaces deriving from modified accessibilities of social infrastructure (green and technical ones) present close connections with land use changes. Prasad and Shankar (2013) argue that the shaping of the city character is determined by the degree of provision of infrastructure and that social infrastructure contributes to the local urban structure and impacts land values and economic aspects of its catchment area.

Further authors highlight as well the role of social infrastructure in urban development (Braimoh and Onishi, 2007). Le Berre et al. (2016), when conceiving a probabilistic model of residential urban development along the French Atlantic coast between 1968 and 2008, listed the proximity to technical and social infrastructure, including educational infrastructure, as determinants of urban land use change associated with housing expansion undertakings.

Researchers, town planners, local managers and consultants have often tried not only to understand the relations between infrastructure and urban dynamics, but rather simulate such changes as a result of infrastructure implementation. CA models relating urban land use change and social infrastructure are manifold.

One of the earliest urban cell-space based models (Chapin and Weiss, 1968) created in the 1960s already acknowledged the importance of social infrastructure, and specifically educational infrastructure, for residential growth, and hence, urban land use change. Along this line of research, Blecic et al. (2004) developed a model for simulating urban dynamics in the city of Heraklion, Crete, subdividing the drivers of land use change into dynamic and auxiliary ones, in which the former comprised land use, social quality, density and real estate values, and the latter contained the traffic system, social infrastructure (including educational facilities) and technical infrastructure.

Kumar et al. (2009), when conceiving a CA model in order to assess the effect of land use policies on urban dynamics, stated that simulation results of urban growth should be accurate and represent the actual local site specific patterns close to reality. These authors demonstrated the close linkages between the urbanization process and the level of services and infrastructure in general.

Okwuashi et al. (2012) developed a GIS loosely-coupled CA model for simulating land use change in Lagos, Nigeria. The model is parameterized by support vector machine, and the authors laid great emphasis on the proximity to technical and social infrastructure as drivers of land use change. The technical infrastructure comprised major roads, railway, seaport, and the international airport, while the social infrastructure concerned commercial centers, residential structures and educational institutions of great magnitude, like the campi of the University of Lagos and Lagos State University. Further works reinforced as well this stream of thought also by means of urban modeling experiments (Xie, 1996; Pinto, 2006; Van Delden et al., 2011; Wray et al., 2015; Amujal, 2015; Wahyudi and Yan, 2016).

Urban models embrace distinct categories, which may focus on process or agent-related aspects of urban dynamics and may approach or not the spatio-temporal dimensions of such changes. According to Braimoh and Onishi (2007), several predictive modeling techniques have been used to model urbanization and land use change. One example in this sense is the spatial statistical model, which is process-based and essentially not dynamic, consisting in a cross-sectional representation of the land use change potential of an urban system in a given time. It comprises three components: multi-temporal land use maps, a multivariate function of the hypothesized driving factors of change, and the resulting prediction map of change (JRC, 1994).

Another modeling technique refers to the so-called multi-agent systems (MAS), which focus on the collective behavior of agents and the interaction, among themselves and may deal or not with spatio-temporal aspects. MAS enable the simulation of land-use decisions of smallholders at an individual level (micro scale) and allow to differentiate between how an individual agent perceives its environment and the 'full-information' system response (Haase et al., 2008). When the interaction between the agents and their environment is taken into account, the model will certainly cope with space and time.

A further well known technique for modeling changes in the urban environment is the cellular automata (CA) approach. CA can be either process-based or agent-based and fundamentally consist in a spatio-temporal paradigm. They represent systems as a cellular grid, in which the state of the cells, i.e. their attributes, are discrete (one state per cell at a time), and changes in the state of a given cell occur throughout discrete time steps as a function of the states in its neighboring cells and according to universal transition functions, which are invariably applied over the whole cellular space. CA deal with deterministic or probabilistic transition rules and can generate stationary and non-stationary predictive scenarios. This latter category involves exploratory ("what-if") and prescriptive (regulatory) scenarios, which are those that comply with legal or institutional constraints.

The present work aims at conceiving a process-based CA model meant to simulate urban land use change in the vicinities of Paz Unified Educational Center (CEU-Paz), located in a particular peripheral area in the northern sector of Sao Paulo city in 2004, in response to its implementation. Although this modeling experiment is not focused on agents, we will approach in a succinct way the strategies and roles of social actors underlying the observed processes of land use change in our discussions.

Finally, we ought to mention that our choice towards the use of a CA model lies on the fact that they can explicitly handle spatial and temporal dimensions, are not overburdened with theoretical assumptions, besides being tractable in the sense that they can generate a dynamics able to replicate traditional processes of change through diffusion, but contain at the same time enough complexity to simulate surprising and unprecedented change as observable in emergent phenomena (Almeida et al., 2003).

3. Material and methods

3.1. Study area

The study area is located in the northern sector of Sao Paulo city, capital of Sao Paulo State and seat of Sao Paulo municipality, in a municipal administrative district known as Brasilandia (Fig. 1). This is a place characterized by a remarkable social vulnerability and exclusion, presenting environmental risk areas and where most of its population shows varying degrees of poverty (Sposati, 1996; Preteceille and Valladares, 1999; Gamba and Ribeiro, 2012).

The Brasilandia administrative district sheltered the fourth greatest share of Sao Paulo municipality´s population in 2010 (280,069