Accessibility-based simulation of urban expansion in Brazil

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Summary

This work proposes an urban growth simulation model based on a weighted accessibility measure, which is calculated based on the characteristics of the landscape surrounding the city. Two types of features were considered: natural and human-made. The model was tested for the city of Bagé, in the Southern Brazil. The model was largely able to replicate the urban expansion pattern of the case study, suggesting that the proposed weighted accessibility measure is a suitable way to capture the impact of surrounding areas in the process of urban expansion.

KEYWORDS: urban growth, accessibility, natural environment, transport system, urban modelling.

1. Introduction

Accessibility measures have been largely used in urban studies, mainly for urban transportation (Ritsema van Eck & Geurs, 2001), and natural environment studies (Bunn et al., 2000). The present study proposes a simple model for simulating urban expansion based on accessibility. It assumes that the relationship between an urban area and its surroundings (natural and human-made features) is an important aspect of urban growth. The relationship between natural environment and urbanization has been demonstrated by Alberti et al (2003) who have called for more studies integrating urban and natural environments. This study assumes that urban expansion is partially influenced by the characteristics of the surrounding area, which may attract urban development (river, beach or proximity to existing transport network) or offer resistance to urbanization (flooding places or lack of infrastructure). In the present work, the proximity to such features is quantified using an accessibility measure.

2. Method

In this study, accessibility is used to consider the characteristics of the natural and urban environment as a single spatial differentiation measure. Urban expansion is then simulated assuming that areas with higher accessibilities are more likely to be urbanized. In the model the rate of urban expansion is an exogenous variable, which can be defined by the user. The same applies for the amount of randomness in the selection of areas to convert process. The model is recursive and accessibility is recalculated every iteration taking into consideration the newly converted urban areas.

Accessibility can be defined as the property of a particular element to be closest to all other elements of the network, considering minimal (or preferred) paths between them (Ingram, 1971). For this work, the measure will be calculated in a grid space. Mathematically, the cellular accessibility described here is defined in Equation 1.

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$$AC_i = \Sigma\ (1/d_{ij}) \quad (1)$$

That can be read as: the cellular accessibility of cell i equals to the sum of the inverse of the distances between cells i and j, for each j cell that has attributes of attraction to urbanization. Figure 1 shows the resulting accessibility patterns for two scenarios: two urban areas, and multiple urban cells scattered by the grid.

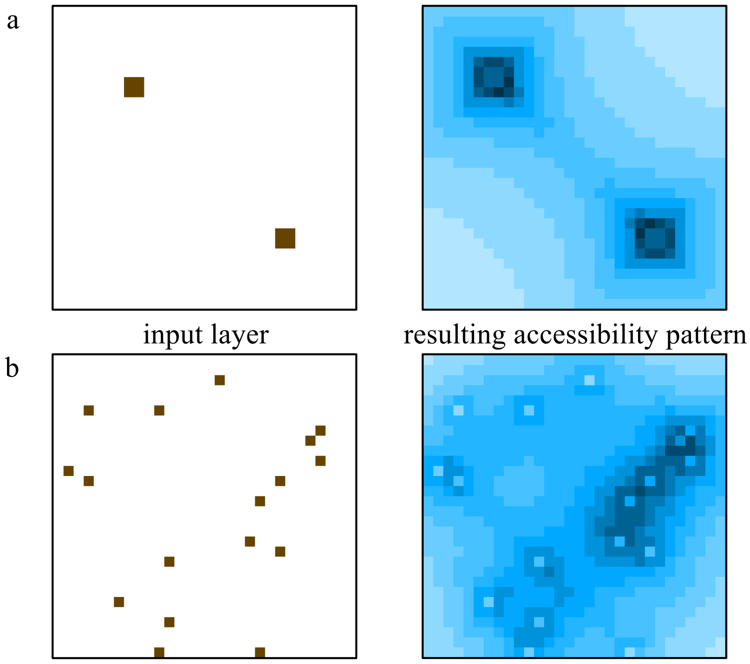

Figure 1: (a) accessibility pattern (represented in tones of blue) was calculated between the two urban areas (in brown); (b) accessibility pattern based on multiple urban cells.

The measure of accessibility used in the model extends the one above by including different aspects of the space surrounding urban areas, including features of the natural environment (such as topography, swamps, lakes and streams) and human-made features such as the transportation system (roads, railroads and waterways) as well as land-use zoning policies. These are included by using a weighted accessibility measure, in which each cell receives a different weight based on the features it contains. Different weights are given to natural and human-made features.

The effects of environmental and human factors weighting on accessibility are shown in Figure 2, below.

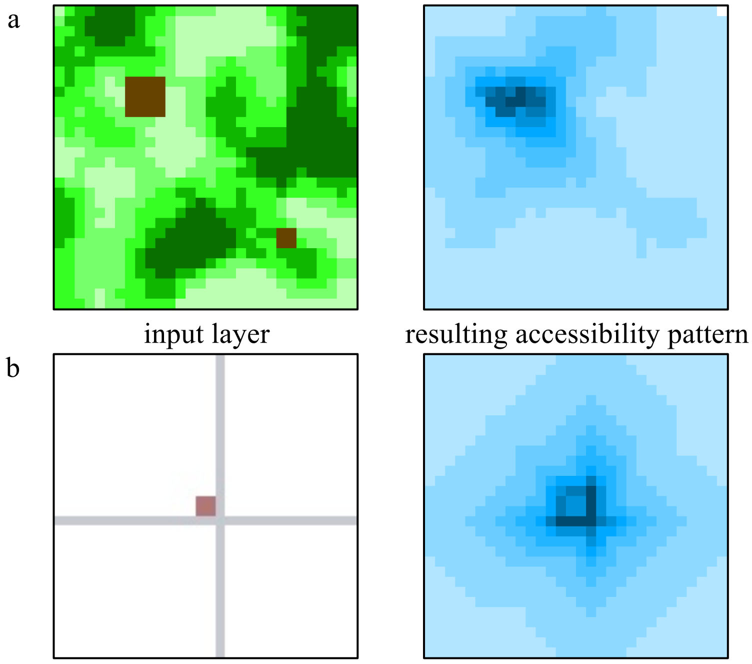

Figure 2: effects of weighting in cellular accessibility. (a) urban cells in brown and the intensity of environmental resistance in tones of green. (b) urban cells in brown and roads in grey.

As shown in Figure 2, the weighted cellular accessibility measure is able to capture the structure of the system, presenting variation in response to changes in the input data.

Mathematically, the cellular accessibility measure represents each cell's probability of ground conversion. The actual cells to be converted are selected randomly among the most accessible cells based on a random variable and urban expansion rate, both user-defined parameters.

3. Case study

The model was applied to the city of Bagé, a medium-sized city in the south of Brazil with 116.794 inhabitants. The study area was represented using a grid of square cells with a resolution of 200m. Figure 3 shows the city in the years 1974 and 2012, which have been set as the start and end times of the simulation. During the 38 years period, the city grew 326%, at an average rate of 3,2% per year. The input data used in the simulation is shown in Figure 4, and is composed by: a) the urban area in 1974; b) current road system; c) a military zone (not available for urbanisation); d) a grid derived from topography and hydrology via interpolation, assuming that better drained areas attract urbanization.

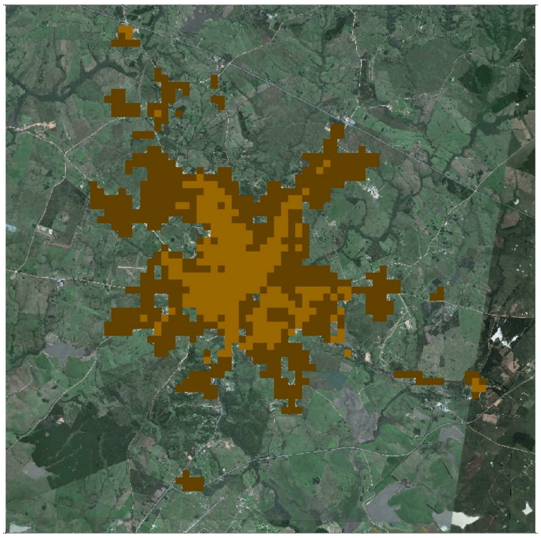

Figure 3: urbanized area of Bagé in 1974 (light brown, 262 cells) and 2012 (dark brown, 855 cells).

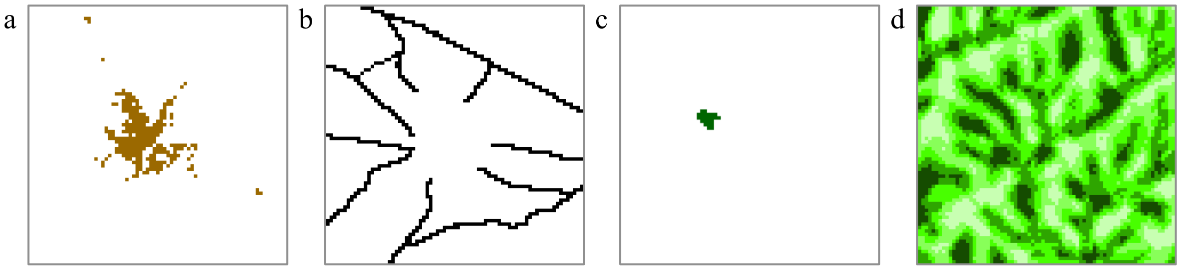

Figure 4: Input data for the model: (a) urban area in 1974, (b) road system, (c) military field, and (d) topography and hydrology grid, with areas more suitable to urbanization in light green.

Figure 5 shows the outputs of the urbanized area and cellular accessibility in three partial states of the simulation, representing iterations (t) 1, 20 and 40. For this simulation the following parameters were used: randomness = 50%, urban growth rate=3.2%.

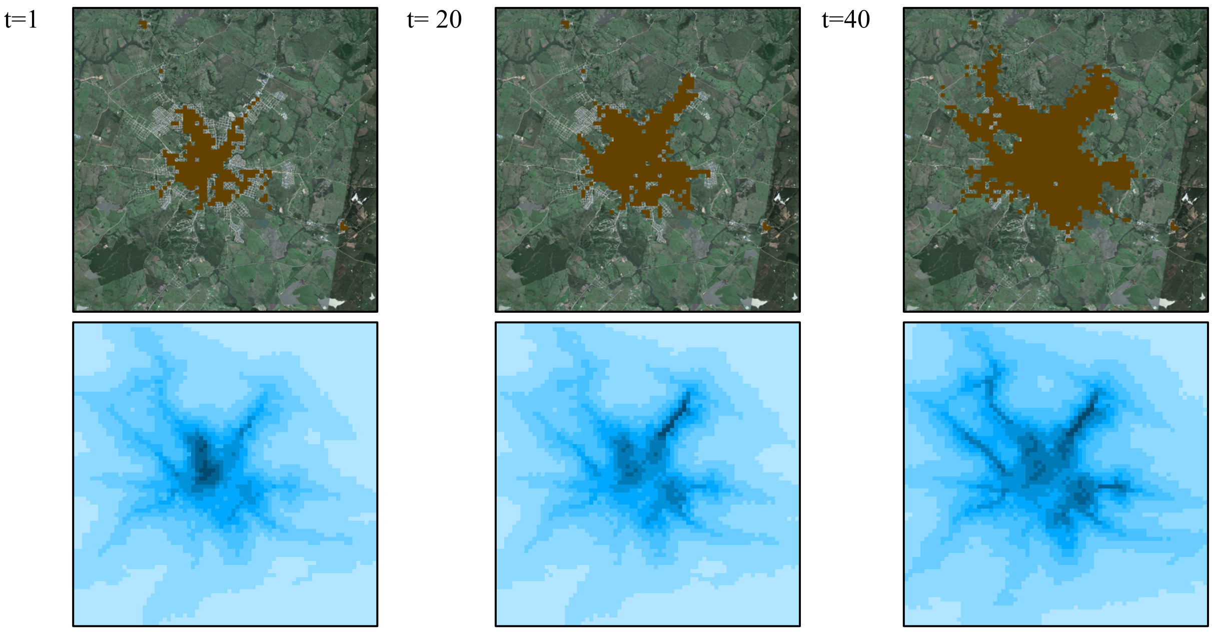

Figure 5: Outputs of the simulation, showing the urbanized area in brown and the corresponding weighted accessibility in tones of blue.

Results show visual similarities between the real and the simulated cities. The city of Bagé has an urban form predominantly compact in the centre and axial towards the city's borders and both of these characteristics could be replicated by the model. The accessibility distribution also shows a strong axial pattern in this scenario. The road system influence heightens the accessibility of distant places, facilitating the land conversion of these cells and generating the axial form of the city.

Figure 6 shows the comparison between the final state of the simulation and the city of Bagé in 2012. The image overlaps the satellite image of the city with the model's output. In order to aid comparison, the figure shows three versions of the model's output. On the first (Figure 6a), it shows the simulated urbanised area in brown, on the middle image (Figure 6b), the cells in which there is a match between simulated and real urban areas are represented in brown and the cells where there is no match are represented in red; in the last image (Figure 6c), matching cells are represented in dark green, non-matching cells in red and 'near-miss' cells in light green. Near-miss cells are a result of the calculation of fuzzy similarity between the two maps following Hagen's (2002) approach.

When analysing the results in Figure 6b, it is clear the non-matching cells (in red) are mainly concentrated in the borders of the city. On Figure 6c, which was calculated with fuzzy similarity, shows that the majority (76%) of the non-matching simulated cells (in red in Figure 6b) are located next to urbanised cells in reality. These are represented in light green in Figure 6c and indicate the formal structure of the city has been successfully captured.

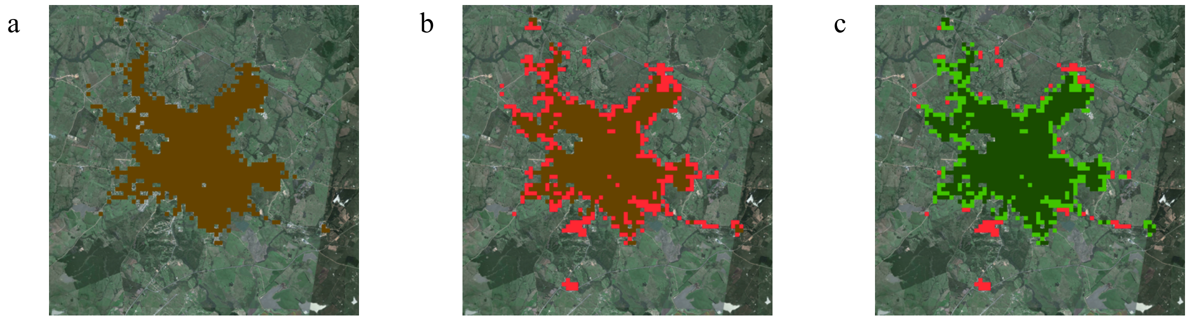

Figure 6: a) urbanized area in brown; b) correct cells in brown and wrong cells in red; c) correct cells in dark green, wrong cells in red and near-miss cells in light green.

4. Conclusions

The model was able to largely replicate the urban expansion pattern of the city of Bagé for a period of 38 years (from 1974 to 2012). Thus, the weighted accessibility measure seems to be a suitable way to capture the impact of surrounding areas in urban expansion, integrating natural and human factors. However, in the case study, small settlements located in the outskirts of the city were not captured by de model. This is due to the pattern of the accessibility measure, which values are higher close to the urban areas and decrease slowly towards the borders of the work area. The next step of this research is to attempt to mitigate this effect.

5. References

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7. Biography

Marcus Saraiva is a PhD student interested in computational models of urban dynamics, more specifically cellular automata models extended with techniques of graph theory and artificial intelligence.

Joana Barros is a lecturer in GI Science at Birkbeck, University of London and Marcus' supervisor. Her areas of expertise are urban planning and modelling, more specifically agent-based and cellular automata models applied to urban systems and urbanisation in developing countries.

Mauricio Polidori is an academic in the Federal University of Pelotas / Brazil. His interests include: urban and regional planning, urban simulation models, urban morphology, and the natural environment.