Hybrid cellular automaton – agent-based model of informal peripheral development in Latin American Cities

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Abstract

The study of the complex dynamics that engage urban form presents powerful instruments to understand the driving forces of contemporary urban development. This research intends to test traditional urban growth tendencies against informal development mechanisms and decision-making behaviors of competition in geosimulated environments. The empirical objectives are the investigation of the morphological patterns of peripheral poverty and its interactions with urban form, in which accessibility has played important parts sided by informal processes from Latin-American contemporary cities. The paper will present a theoretical review of agent-based models in cellular environments stressing urban growth and decision-making processes as basis for a proposal of a hybrid agent-based model in cellular space.

The contemplated model expands the cellular automata approaches by including the interpretation of the model's landscape by heterogeneous collective agents that settle and promote growth in competitive dynamics according to preferences and hierarchy. The expected result is an urban development intensities landscape, natural features and agent-types concentration, which should allow one to analyze urban form expansion and fragmentation, socioeconomic segregation and urban policies effects.

This work succeeds the research by the LabUrb/UFPEL based on the CityCell modelling framework, which has yielded insights on the linkages between urban morphology, social and environmental attributes through emergent urban phenomena simulation focused on temporal and spatial dynamics.

Key words:

Urban Morphology Urban Growth; Social Process Dynamic Simulation; Cellular Automata; Agent-Based Models.

Peripheries, urban form and contemporary urban development

Cities make up the largest artifacts made by man and have structured human organizations since the first agricultural sedentary societies 6,000 years ago in Mesopotamia (Portugali 2000).Over history, humanity has become dependent on cities for its subsistence and as cities developed and evolved the growing integration of its inner and outer expansion converged. In contemporary urban development dynamics, important economic and social feedback mechanisms reinforce this bond. Urban form is, therefore, composed through interactive cycles in which both the peripheries and its centers have active roles (Barros 2004; Abramo 2012).

By end of the 20th Century, the urban development process, propelled by economic and cultural globalization, has led the peripheries to the forefront of urban development research. The transition processes that had started in the Industrial Revolution consolidated by changing morphological patterns worldwide and cities could no longer be defined as the compact *intramuros* built mass that exercised absolute contrast with the country surrounding it. Modernity brought about the progressive dissolution of the urban block (Panerai et al. 2004), while post-modernity intensified the dispersal of the urban tissue, its hybridization and the introduction of diverse intermediate stages of urbanization (Chin 2002; Ascher 2010).

The fringes of cities were the stages where sizeable part of this processes took place. The disperse outskirts and the *terrains vagues* from the *arrebaldes* were gradually settled in, assimilated by the overall urban form and overcome in cyclic expansion waves. From the centers outward, city form blended with rural and semi-rural forms, discontinuities and low densities. It was crossed by vast transportation networks and divided in extensive poly-nucleated urban areas. The city limits became less clear with the stretching of urban form, as if the city was distended to the point of being penetrated by less dense land uses so that towns begun to blend with one another, forging continuous occupation gradients of varied densities (Chin 2002).

These changes endowed contemporaneity with great diversity of urban forms that elude apprehension and classification. On developed countries, specialized urban nuclei organize vast mono-functional suburban networks. This sprawling urban form expands into very low density and extends as far as the fuel price allows, while urban inhabitants gradually abandon the inner city districts (Berube & Kneebone 2006).

South of the Equator, immense informality and poverty areas are interspersed with industrial facilities and high income enclaves (Davis 2004); social inequality soars and informality is incorporated as the main alternative to access urban land for poor families (Bógus & Taschner 1999). A true urban development kaleidoscope (Abramo 2012) is formed and redefined in continuous cycles, without ever solidifying and keeping permanent impetus towards expansion (Barros 2004).

In this fractured urban condition, the informal settlements scale is such that they start amassing relative autonomy from the regular urban processes controlled by regulations and promoted trough the market. They create para-formal logics that escape the normative discipline of the rule of law and work around environmental and infrastructural constraints. Their urban interventions are brought about through family savings, reciprocal relationships and local trust networks (Davis 2004; Abramo 2012). This process establishes a peripheral condition: the co-existence of opposites with little compatibility; the interspersing of compact and disperse urban forms; the connection of specific sites to the global scale and the segregation between adjacent territories based on class; overall low densities; close relation to informality and blatant illegality; and settled extensions that converge to the regional scale (Walker 1978; Polidori 2004).

This spatial differentiation presents the close combination between the formal market and widespread informality. The stock market bound real state is associated with land grabbing practices, with self-help housing in *favelas*, with the popular occupation of urban voids and derelict inner buildings. Since the externalities of one process is captured by the other, the interaction between space and social processes driven by diverse rationalities imposes antagonistic, but reciprocally determined tendencies. Dispersion and concentration of urban form occur in alternate cycles propelled by the land market's logic as well as by necessity's vigor (Abramo 2012). They reveal important systemic ties between the urban territory and multi-scale heterogeneous agent and process networks (Barros 2004).

Global and urban peripheries

In contemporary urban growth processes, cities serve as conduits and motors to globalized capital so that the capitalist processes at work over land and places (Harvey 1978) include the cities as translators of global dynamics to the diversity of local reality (Scott & Storper 2003; Sassen 1999). The contrast between global city-regions and global peripheries is reinforced under global stimuli and in response to local characteristics. The world-economy capitals are organized around their specialized and increasingly anti-human Central Business Districts (Davis 2006) and diametrically oppose immense portions of territory excluded from the capitalist mode of production and its control (Davis 2004). The latter lie on the extreme end of civilization: they are relegated to material inferiority, absence from rule of law and to the deprivation of means for their autonomy.

In the middle ground to these extremes, human societies are pushed towards polarization. While some of its members increase their specialization, others have to make the best of informal labor as the only available route for inclusion (Bógus & Taschner 1999). In Latin-American cities, in the decades of 1950-1960, informal areas were ignored and if possible removed (UN-Habitat 2010). More recently, though, one can see the resurgence of informal peripheries as majoritarian form of urbanization and shelter for most of the population, especially from the 1990s onwards (Bógus & Taschner 1999; UN-Habitat 2003). What remained was the overall state of incomplete infrastructure, lack of basic services and opportunities, portraying a second-class urbanization (Davis 2004).

In the last two decades, the urban outline is defined: more than half of the world population becomes urban, largely due to the contributions of the borders of urbanization on the edges of cities of peripheral countries in globalized economy (UN-Habitat 2010). These sites, in dual peripheral condition (both global and local), become the object of renewed interest as a tool for explaining the urban question integrally through the provision of intermediate and varying tones of a continuous spectrum of urbanization (Chin 2002).

The role of the peripheries

In third-world cities, the phenomenon of social inequality proliferates fueled by segregation based on spatial disintegration (Bógus & Taschner 1999). This happens not as a secondary consequence of the capitalist development of cities, but as a central mechanism of its reproduction (Harvey 1978). The expansion of cities according to economic and productive stimuli occurs on alternate surges of rapid, disorganized and seemingly chaotic expansion, which are followed by slow, gradual consolidation. In these cyclic processes of capitalist urban development, poverty areas act as compensation valves to cities' expansion mechanisms. They dampen tensions, absorb environmental impacts and infrastructure costs while maintaining flexibility to change according to the settlement evolution. Thus, it can be argued that the precarious and unstable occupations "[…] actually absorb part of the existent social instability […] in unstable pockets within the city" and that "[…] they are necessary for the structural stability of the global system." (Barros 2004, p.180).

The actual development of Latin American cities is connected to socio-economic inequality. It reinforces it, but is also fueled by it. From colonial times the political and legal frameworks have privileged landowners, which in turn heavily influences the locational process and has pushed the larger part of the population into the informal land market. Contemporarily, capitalism is interwoven with these traditions and composes a complex system of competition, complementation and superimpositions between the legal and informal land markets. While the individual location decision from a family may target the optimization of its choices, the aggregate effect is a conflicting tendency among similar families: while searching for unique opportunities, they drive the market towards homogeneity, which narrows their choices. On the bottom of the social scale, poor families are driven outwards towards the cheaper lands of the peripheries and lesser opportunities, or have to improvise ever-denser inner-city settlements. The conflicts are broadened by social segregation resultant from the “urban convention” that draws middle-class families towards places occupied by families of similar, or higher, social standing, leaving the poor to fend for themselves in self-help, informal support circles (Abramo 2012).

This rationale seeks to expose non-aggregate behaviors that are relevant in the modes of production and occupation of the urban form, acting either in coordination or in competition with the general market mechanisms. The reciprocal influences between formality and informality are based on local externalities and logics of interpersonal knowledge and trust, which add up in consecutive cycles of valuation and de-valuation of urban form (Abramo 2012). This shapes cities through inter-representation networks (Portugali 2000) between urban morphology and socio-economic processes that reveal emerging patterns of "peripherization", which is the alternation between compact and diffuse urban form. These processes increase contrast between city center and periphery and stress the marked social differences of Latin American societies: the poor end located in the expansion edges or in dense favelas, while the better off live near the city center and public services.

Urban periphery models

Geosimulation supports an embryonic “science of cities” (Batty 2012) that seeks to reveal patterns of order that emerge from actions and decisions where individuals interact with their environment and to each other in collaboration or competition, from the bottom of the systems up (Batty 2007). Urban models in cellular environments have relevant capabilities in describing city growth under these premises (Batty 2007) and urban Cellular Automaton (CA) models allow to coherently articulate the effects of urbanization on the natural environment (Polidori & Krafta 2005), on informality and on poverty formation (Barros 2004; Patel et al. 2012). The simulation of urban dynamics can be achieved through the interaction of adjacent cells in grids that changes states following simple rules, applied locally and in repetition, under stochastic *disturbances*. The accretion of these neighborhood relations is capable of producing order states that emerge from the bottom up, correlating basic elements from the urban environment that shape overall system order (Batty 2007).

Cellular models of urban growth can be further complemented by the explicit inclusion of social agents as these may simulate the decision-making capacity of rationally autonomous entities with limited knowledge. Agent-based models (ABM) bring the detailing of each agents characteristics to enable the modeling of particular behaviors and attributes such as motivation, objectives, goals, decision-making and learning. The combination of cellular environments based on CA and autonomous decision making from ABM may be used to represent social processes articulated to morphological dynamics (Heppenstall et al. 2012).

Agent-based model of peripheral growth

This paper proposes a model that aims to answer questions of location choice, competition and exercise of power in decision-making processes. These processes are executed by non-coordinated social actors during urban external growth in dynamics that put relate urban form to social interests, as demonstrated by image 1.

This research is supported by the CityCell modeling framework, through which initially Polidori (2005) and more recently Saraiva and others (2013) have produced several urban growth simulation models on cities from southern Brazil. Following to the frameworks' structure, the modeling environment is defined by urban, natural and institutional attributes (image 2). They are represented in different intensities on a grid of square cells and can have behaviors of attraction or resistance to urbanization, interacting in accordance with local rules to simulate urban growth processes (Polidori & Krafta 2005).

Image 1: General model flowchart.

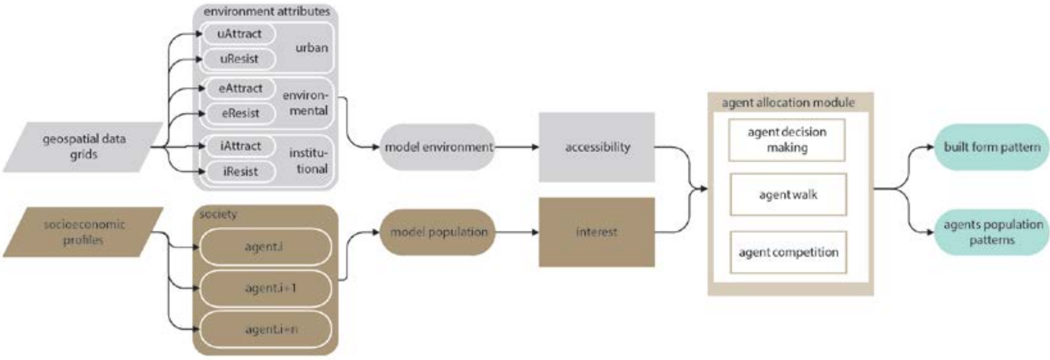
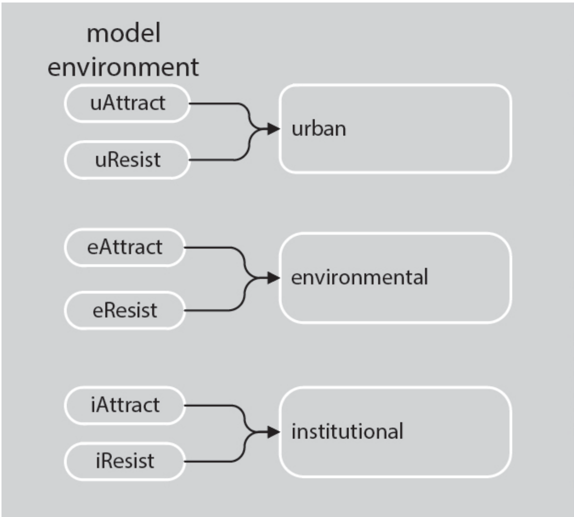
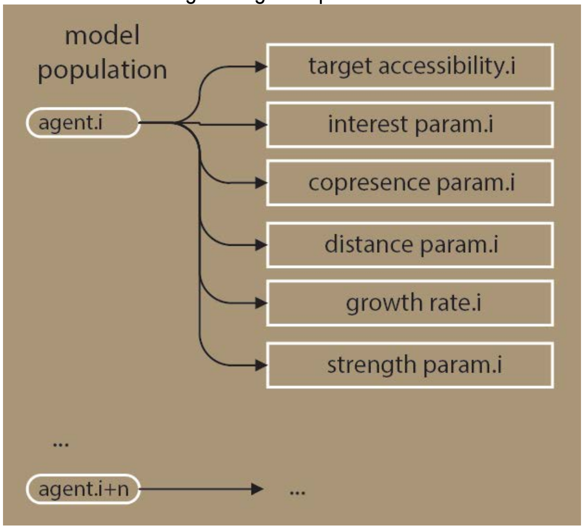


Image 2: Modeling environment structure consisting of urban, environmental and institutional attributes, which offer attraction or resistance to urbanization.



The society that populates the model consists of autonomous agents capable of decision-making. The agents' categories represent social groups defined by socioeconomic profiles such as social classes. These agents dwell exclusively on urban cells, and may choose to move according to their preferences. This model constitutes a hybrid approach between the fully explicit individual ABM and the implied social behavior contained in traditional CA models.

Image 3: Agents' parameters.



To determine the agents' evaluation of the environment, movement and competition dynamics, as depicted in image 3, agents have the following parameters:

a) *target accessibility* (Av): is the value of relative accessibility (see below) considered optimal by the agent. In its evaluation of environment cells, the agent checks the available range of relative accessibility (from cells in its neighborhood) and chooses the cell that most closely matches its *target*;

b) *interest parameters* (w): are the stated preferences for each agent in relation to the environment attributes and accessibility. They take the form of multipliers to be applied when composing the *Interest Matrix* (below);

c) *interest matrix* (T): is the combination of interest parameters for each agent and attributes of the model. It is calculated in every cycle, being sensitive to variations from unstable attributes, accessibility and urban area growth;

d) *copresence parameters* (c_p): indicate the tolerance to different agent populations in the same cell as a given agent. These parameters are the base for the copresence threshold on each cell, concerning each pair of agent settled on it. They increase the tolerance to different agents' populations in direct proportion to its value;

e) *strength parameter* (s_p): implies the ability of an agent to exercise power in the competition process. It influences in determining the expulsion of agents when the copresence threshold is overcome in a cell as the "leverage" each agent can use against its opponent. The parameter influences disputes in direct proportion to its value;

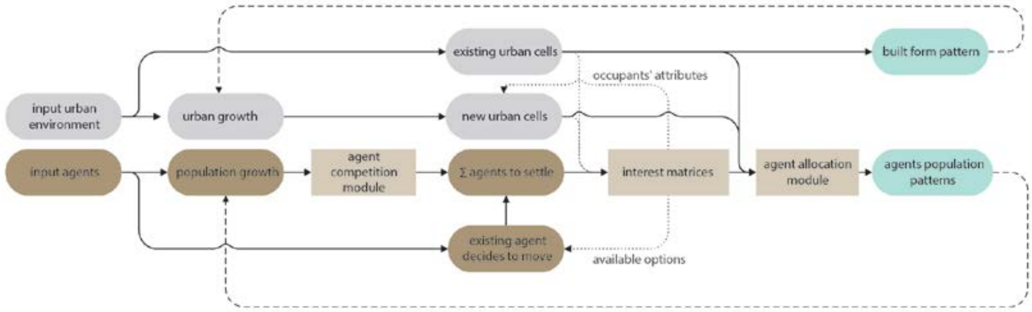
f) distance parameter (d_p): is the maximum distance, in number of cells, that an agent is able to go (or see);

g) growth rate (θ): is the growth rate per cycle of each agent. By default, equals the growth rate of urban cells, but can be specified for each agent separately.

Model dynamics

The overall dynamic structure of the model starts with the entry of environmental and social data in the model. This includes the input of urban areas, the initial distribution of agents' and other attributes in the form of two-dimensional data grids, as seen on image 4.

Image 4: Model dynamic structure.

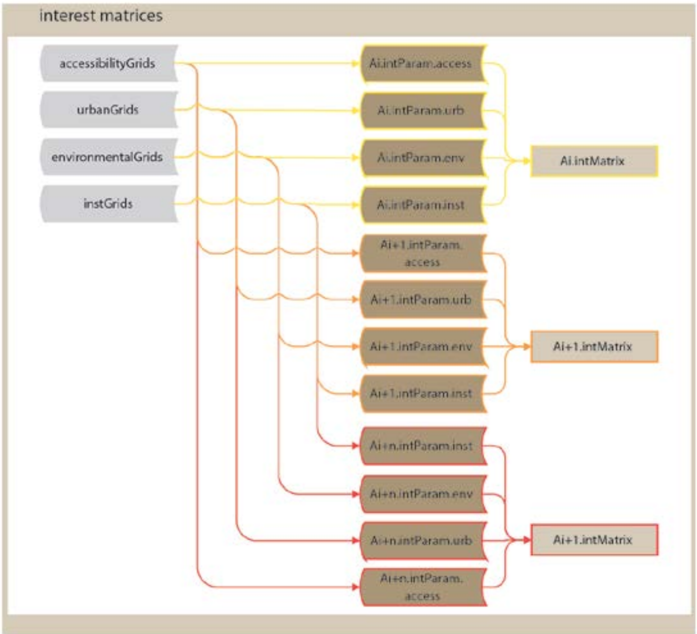


The first step after initialization is urban growth, which derives from a weighted accessibility measure from Saraiva (2013). In this model, it acts as a subroutine that determines distances among cells loaded with urban attraction that receive "resistances" from environmental attributes (increasing relative distances) to generate an global accessibility pattern. This pattern is then normalized and used as the base for a combination of deterministic and random mechanisms that distribute fixed rates of urban growth, as expressed in equation 1.

Equation 1: Cell i accessibility.	
$$AC_i = \sum_{(j \neq i) \in \cup} \frac{1}{d_{ij}}$$	Where: $AC_i =$ cellular accessibility from cell i $d_{ij=}$ distance between cells i and j $\cup =$ cell set loaded with urban attraction attributes
$$d_{ij} = \sum_{c \in C_{ij}} Env_c$$	Where: $d_{ij=}$ distance between cells i and j $Env_c =$ cell c weight for the weighted accessibility measure $C_{ij=}$ =preferential path cell set between i and j
$$Ar_i = \frac{AC_i}{ACmax}$$	Where: $Ar_i =$ relative accessibility from cell i $AC_i =$ cellular accessibility from cell i $ACmax =$ maximum *grid* cellular accessibility
Source: Saraiva (2013).	

The main stage of the agents decision-making process depends on the intersection of agent's preferences with the modeled environment. The agents' potential choices are represented in the *interest matrix (T),* determined from each agents' interest parameters (w) related to the model attributes (A).

Image 5: Modeled attributes and relative accessibility form the *interest matrix* for each agent



For urban, institutional and natural attributes to be included in the *interest matrix*, they need only to be informed and have their weights defined during input. Accessibility, however, must be checked against the economic power of the agent, comparing *target accessibility* (Av) to *relative accessibility (Ar)* in tandem with the agent's interest on accessibility. The highest values of relative accessibility are close to 1, while the lowest approach 0. The target-accessibility varies within the range of Ar, and therefore has values ranging from 0 (the least economic power) to 1 (the highest economic power). The relationship between the target accessibility of the agent and relative accessibility of each cell is given by the *particular accessibility (Ap)* measure, as expressed in equation 2.

Equation 2: *Particular accessibility* for the agent i in cell $(\boldsymbol{x}, \boldsymbol{y})$.	
$A\mathrm{p}_{\mathrm{i,x,y}} = 1 - \lvert(Av_i - Ar_{x,y})\rvert$	Where: $A\mathrm{p}_{i,x,y} =$ Particular accessibility for the agent i in cell $(\boldsymbol{x}, \boldsymbol{y})$ and $(\mathrm{x}, \mathrm{y}) \in \mathrm{Cd_i}$ $\mathrm{Ar}_{x,y}$ = relative accessibility of cell $(\boldsymbol{x}, \boldsymbol{y})$ Av_i = target accessibility from agent i

The sum of all preference measures (t_i) compose the interest matrix (T_i) for the i agent, as in equation 4.

Equation 3: Agent i interest matrix.	
$\mathrm{T_{i=}} \sum_{(\mathrm{x,y}) \in \mathrm{Cd_i}} t_{\mathrm{ix,y}}$	Where: $\mathbf{T}_{\mathrm{i}}$ =is the interest matrix for agent i, drawn from the t_{i} parameters for every $(\boldsymbol{x}, \boldsymbol{y})$ cell, and $(\mathrm{x}, \mathrm{y}) \in \mathrm{Cd_i}$
$t_{\mathrm{i,x,y}} = \sum_{j=1}^{m} w_j A_{j,x,y} \Big/ max\left(\sum_{j=1}^{m} w_j A_{j,x,y}\right)$	Where: $A_{j,x,y}$ = model attributes present in (x, y) cell w_j = each attribute's weight set by the equivalent *interest parameter* m = number of attributes taken into account.

Each agent's decision to move for can take two forms: voluntary or due to competition for a certain space. In the first case, the *interest matrix* subsidizes the decision-making of agents, defining a "topography" of its preferences in the system´s cells that is compared with the cell the agent occupies in each iteration. If the current cell is below the average, the agent then decides to move.

In the second case, it is assumed that even if the urban form does not impose a settlement limit to the agents (such as a finite urban form stock to be allocated), there is constant contention over urbanization. The occupation tolerance of each agent's surroundings to different categories of agents is geared to this contention. The limit for this "tension" between the agents is defined (for each of them) by its copresence parameter. This parameter enlarges or reduces the quantity of different agents to be tolerated in the same cell, as shown in equation 4. It should be noted that the co-presence factor is directional, i.e., there may be differences between the parameter of agent i to agent j to the parameter of agent j to agent i, indicating asymmetry in co-presence relations.

Equation 4: Co-presence test from agent i to agent j.

$$Cf_{i,j,x,y} = \frac{P_{j,x,y}}{Cp_{i-j} \times P_{i,x,y}}$$

$$Cpres_{x,y}\left(Cf_{i,j,x,y}\right) = \begin{cases} true, & Cf_{i,j,x,y} \leq 1 \\ false, & Cf_{i,j,x,y} > 1 \end{cases}$$

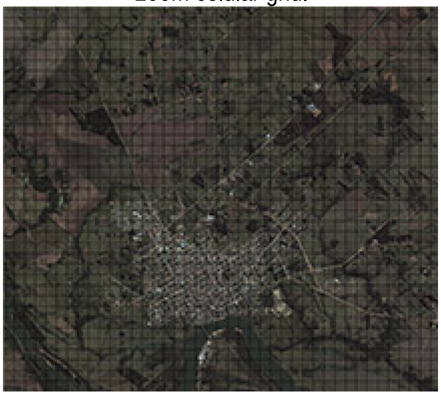
Where:
$Cf_{i,j,x,y}$ = copresence factor from agent i to j in (x, y) cell
$Cp_{i,j}$= copresence parameter from agent i to j
$P_{i,x,y}$ = agent i population in (x, y) cell
$P_{j,x,y}$ = agent j population in (x, y) cell

Experiment for Jaguarão/RS/BR

Jaguarão, in the Rio Grande do Sul state of southern Brazil has been studied by the Laboratório de Urbanismo[1]/UFPel in recent years. Outreach initiatives, undergraduate education and research have been conducted in a systematic manner and have provided important data on the municipality. Therefore, in continuity to some of this research, this experiment is set to verify the following hypothesis: is there influence from disaggregate decision in settlement patterns, especially when poverty is considered?

[1] Urbanism Lab in the Federal University of Pelotas.

Image 6: Modeling environment. Jaguarão/RS/BR urban área Quickbird image from 2009 superimposed by 200m celular grid.



This issue serves as a base for future investigation and model development. To address it and to verify the viability of the current proposal, the experiment is outlined as follows:

1. to simulate urban growth in the CityCell framework making use of agent-based model over the weighted accessibility from Saraiva (2013);
2. to consider the agents distribution from urban, natural, and institutional attributes and accessibility influence as a result from agent allocation decision making;
3. to verify the selected attributes influence, seeking evidences of the linkages between morphological attributes and social subjects.

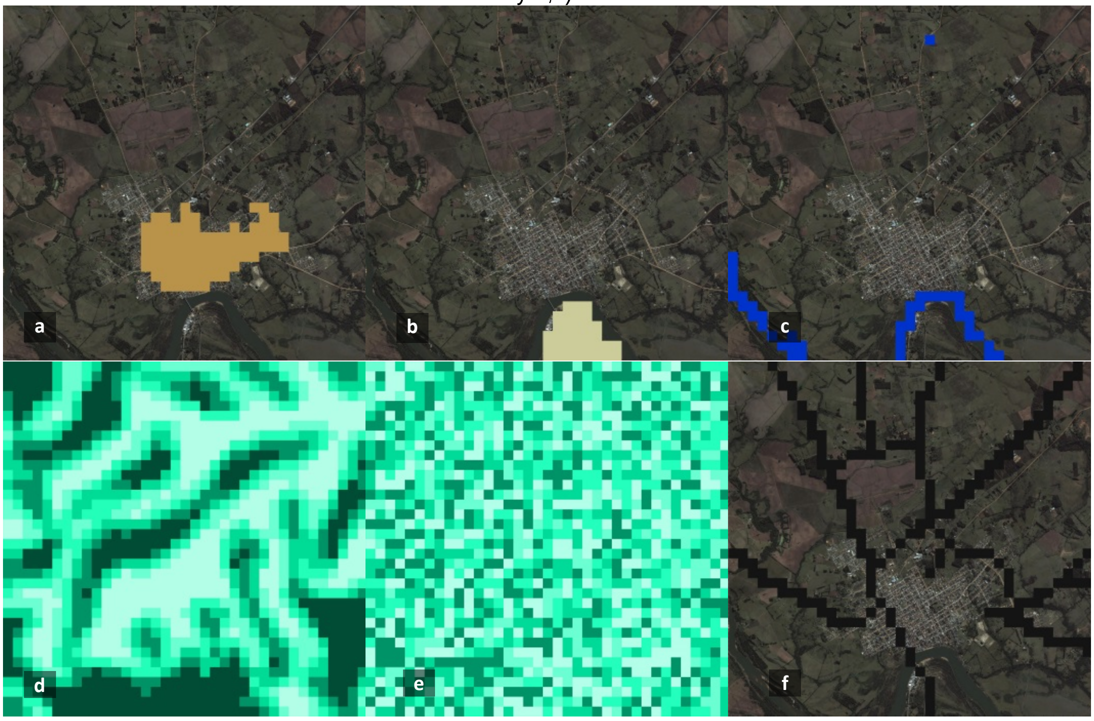
The parameter set for the urban growth dynamics can be found in table 1.

Table 1: atributos de entrada do modelo de acessibilidade ponderada por fatores ambientais

Atribute	Type	Weight
1947 urban nucleus	urban/attraction/mutable	1,0
Rio Branco (UY) municipality	urbano/attraction/freezing	0
Jaguarão river	urbano/attraction/freezing	0
Watersheds	natural/resistance/mutable	0,7
random layer	natural/resistance/mutable	0,3

Source: Saraiva (2013).

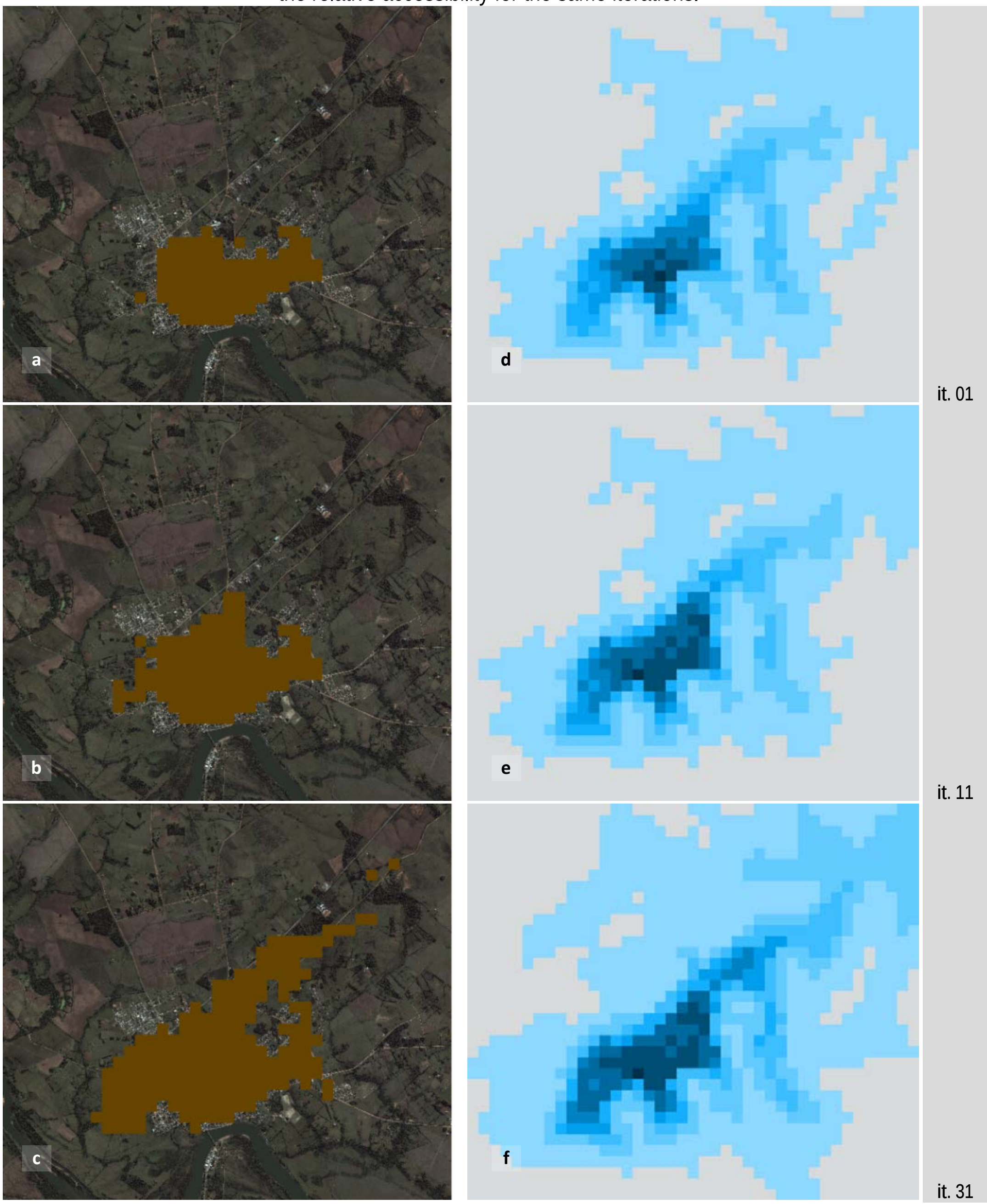
Image 7: model attributes; a) effectively urbanized area in 1947; b) the territory of Rio Branco, Uruguay; c) Jaguarão river; d) watersheds (dark values are the valley bottoms and clear values the watershed limits); e) random layer; f) roads..



Source: Saraiva (2013).

The modeling environment was established in a GIS in the UTM geographical coordinates system, zone 22 south. It encompasses the extended surroundings of Jaguarão urban area in 2009. It results in the rectangular area shown in Image 6, which is divided into 1,476 cells of 200x200m. The growth simulation attributes are shown in Image 7 and its results are the growth patterns illustrated in Image 8, for iterations 01, 11 and 31 (corresponding to the 62 years from 1947 to 2009). On the left column is the resulting urban form for each iteration, while on the right, there is the relative accessibility patterns.

Image 8: model outputs. From (a) to (c), urban form corresponding to iterations 01, 11 and 31; from (d) to (f), the relative accessibility for the same iterations.



Source: author simulation based on Saraiva (2013).

Interest matrix

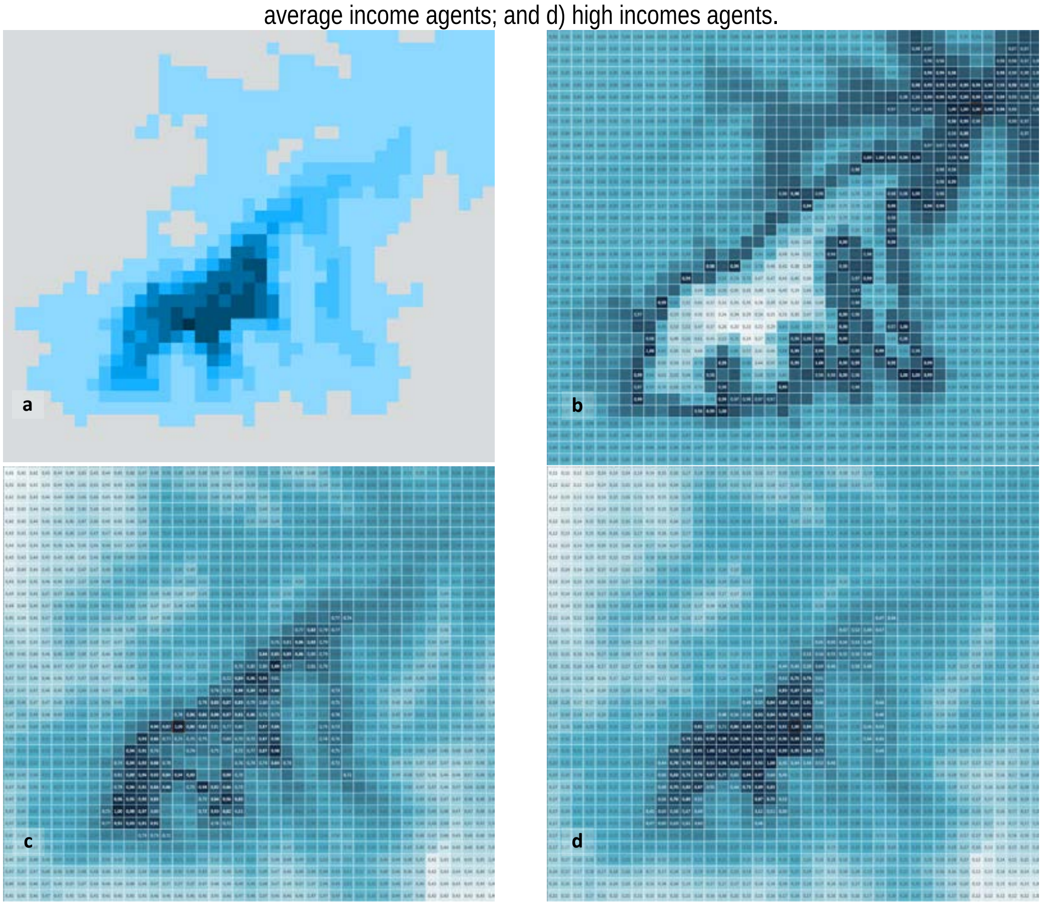
Three agents' categories are set for the model population. They represent the high, middle and low-income populations on the city and to each a parameter set was assigned, as shown in table 2. For this experiment, their preferences were determined by the modeler according to relevant cases from the literature, considering income stratification, the road system influence, as well as relationships with environmental attributes, topography and non-urban land use (Sietchiping 2004; Augustijn-Beckers et al. 2011; Abramo 2012; Heppenstall et al. 2012).

Table 2: Agent atributes.

	accessibility		urban		environmental		
agents	target	interest	nucleus 1947	roads	Jaguarão river	watersheds	crops
low income	0,2	3	3	9	1	3	3
average income	0,6	1	3	1	3	1	1
high income	0,9	3	1	3	3	1	1

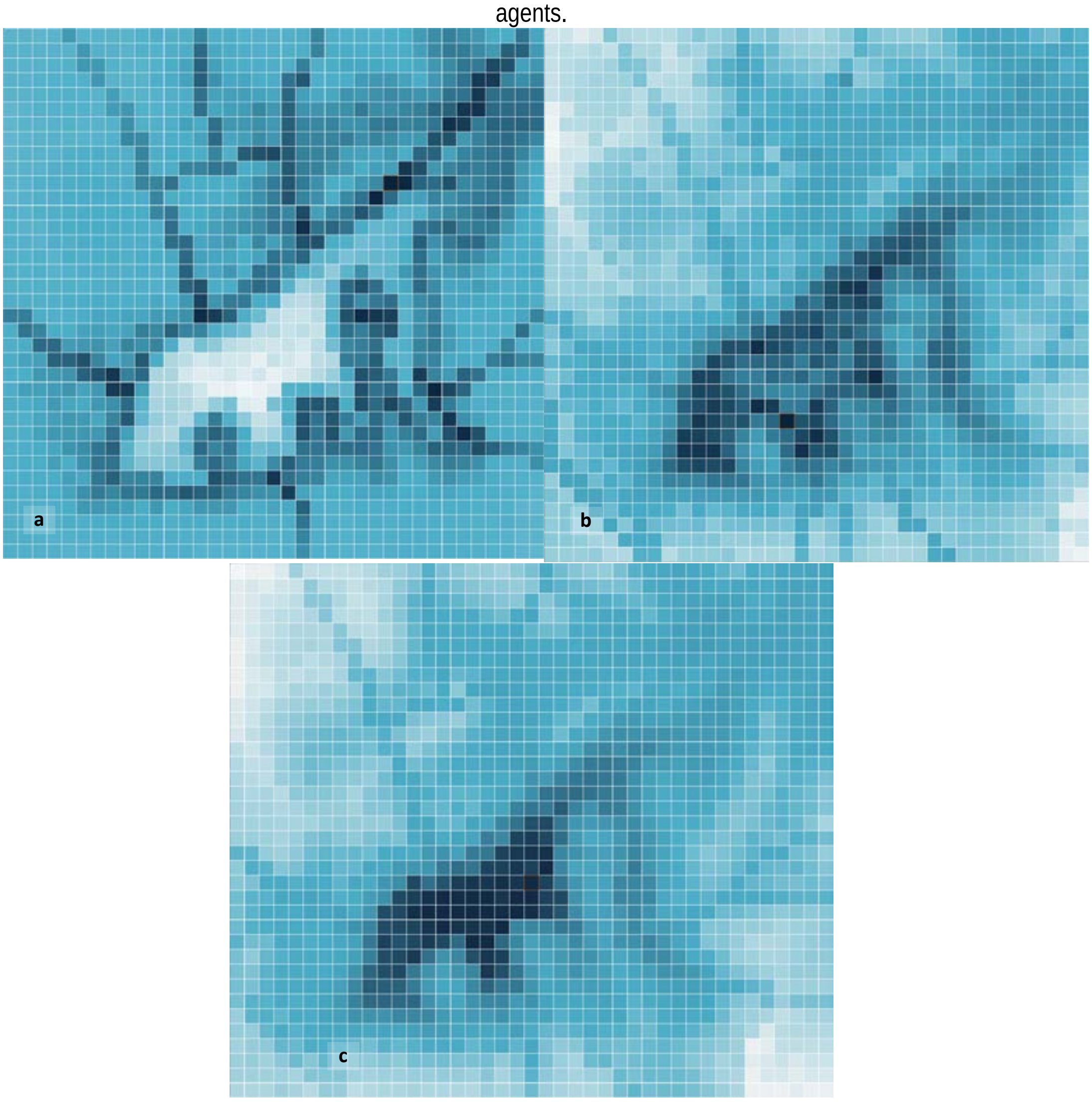
From the target accessibility definition, one can verify its impact on the relative accessibility grid. To this end, the 11th iteration was selected, in which the difference between the *relative accessibility* and agents *target accessibility* was examined, as shown in Image 9.

Image 9: Target accessibility weighing. a) relative accessibility for iteration 11; b) low income agents; c) average income agents; and d) high incomes agents.



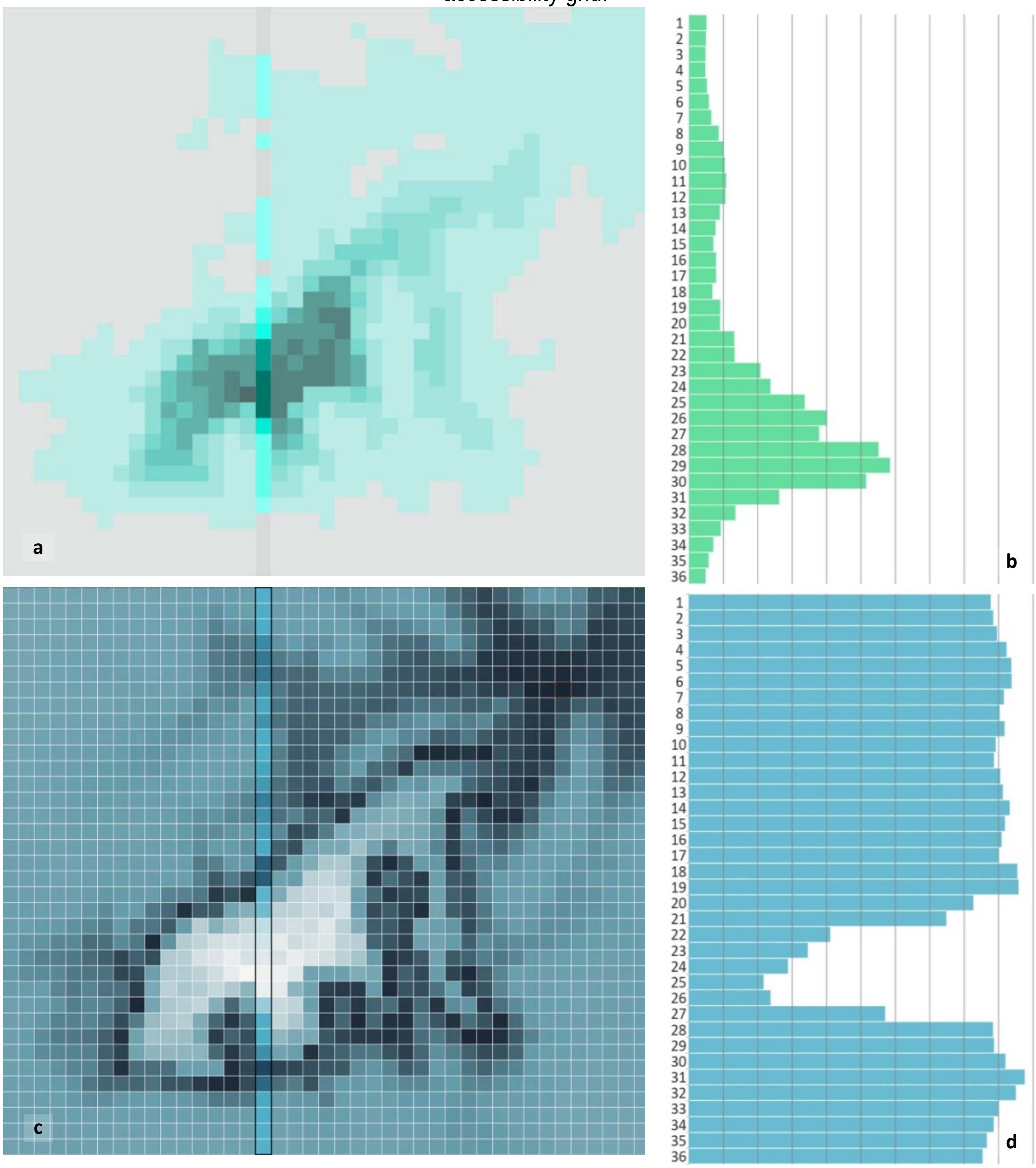
The results reveal the influence of the target accessibility parameter for the three agent types modeled. This measure is added to the weighing of the remaining model attributes, making the final interests matrix for each of the agents, as recorded in the Image 10.

Image 10: weighting for all attributes; a) low-income agents; b) average-income agents; and c) high-income agents.



The creation of different bands among agents' preferences can be observed in the results. It shows the expected responsiveness and sensitivity of the agents' evaluation of the different environmental settings. In the same vein, in comparing the weights with the results of the growth model, it can be noted how the development pattern of the city may have different readings under these "disturbances" from the agents' points of view. The accessibility (a general system measure, even if locally generated) is then defined by a simple method through the particular accessibility feature, as can be seen in Image 11.

Image 11: comparisons between model results; a) relative accessibility grid (it.11, highlighting column 17); b) distribution of the column 17 results from the relative accessibility grid; c) low-income agent particular accessibility grid (it.11, highlighting column 17); d) distribution of the column 17 results from the particular accessibility grid.

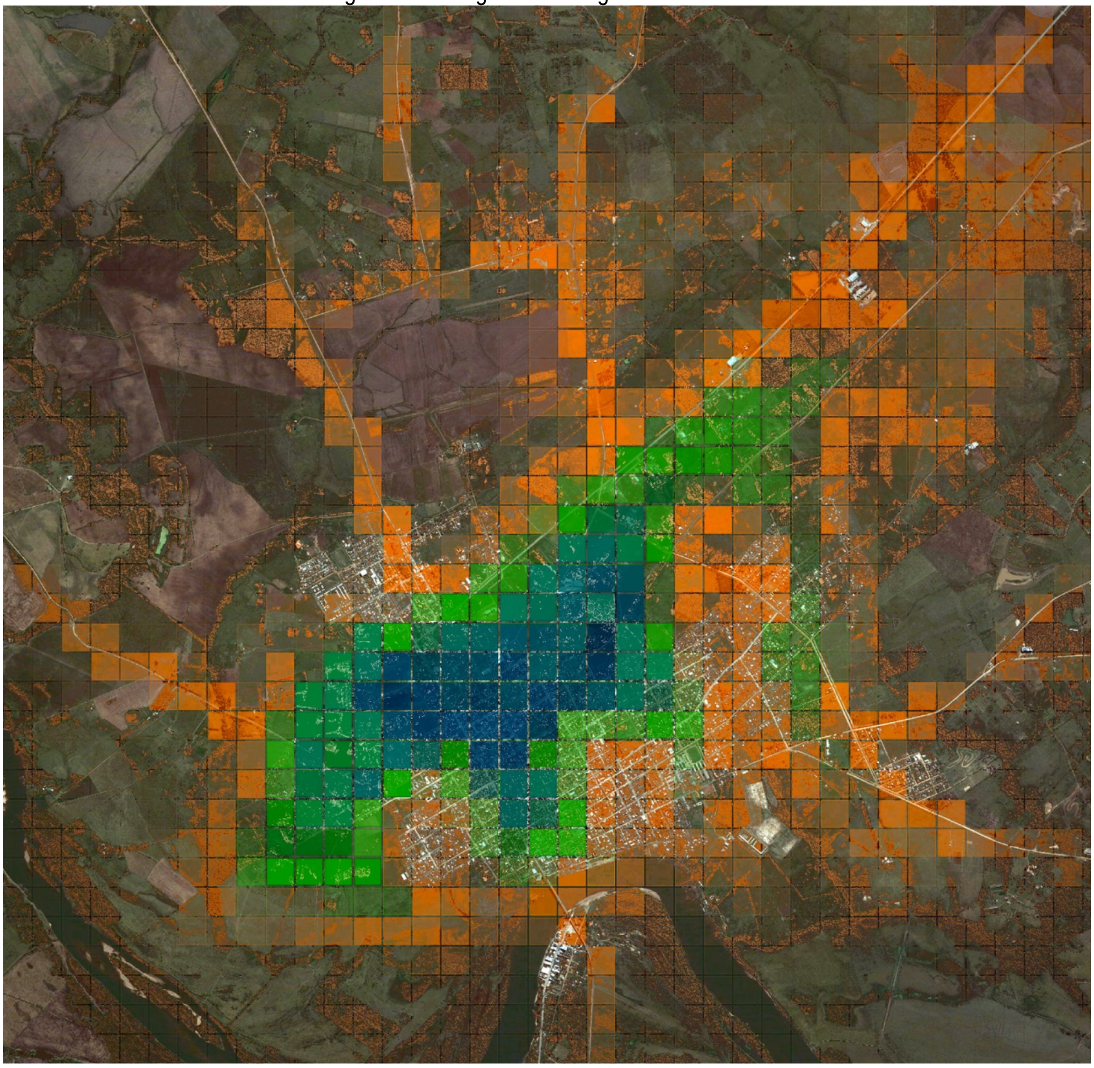


The relative accessibility and particular accessibility grids comparison expressed in the image 11 helps to appraise the impact of this measure. The figures for both variables are shown in image 11b (relative accessibility) and image 11d (particular accessibility). In these, it can be perceived that the approximation of the highest values to those areas closest to the agents preferences, such as those cells in which the relative accessibility is around 0.2.

Moreover, the differentiated spatial perception for the low-income agents has largely decreased their interest on the more central cells through the selection of a reference value for relative accessibility, as noted in the image 11c. It has also created plateaus of interest that span over the urban areas surroundings. The grid column 17 (shown in image 11d) presents interest peaks (around to 0,95) on lines 19 and 20, on those cells which are contiguous to areas which are already urbanized at that time (iteration 11). This pattern is prolonged in a collar shape all around the urban area and lies over cells which are not yet urban (in a prevalent manner at least, so as not to be given the urban cell type in Image 12), but have enough accessibility and will turn urban in the following iterations. This high interest dedicate to these cells coincides with the pioneering role that low-income present in peripheries (Barros 2004; Abramo 2012).

It should be pointed out that for the low-income agents there are large high-interest plateaus on the peripheries beyond the collar region (with values ranging from 0,80 to 0,94). If the modeler would not consider factors such as tenure, urban norms and so forth, these areas can be seen as high potential sites for low-income settlement. This could help explain the great adaptation capacity of low-income populations and their greater flexibility of location choices. If compared to high-income agents, the low-income ones have 28 times more location options (1.238 cells with$t_{\mathrm{low-inc}} \geq 0{,}85$, versus 43 with$t_{\mathrm{high-inc}} \geq 0{,}85$). Obviously, these low accessibility areas are lacking in urban infrastructure and are not urban for their greater part. If this were true, low-income agents would have more choices from the worst places (considering urbanization) while the high income would have fewer options on better locations. It seems clear how these relationships can generate conflicts over urban form and its benefits.

Image 12: Composite from Quickbird image and agent concentration areas. Low-income agents in orange, average-income in green and high-income in blue.

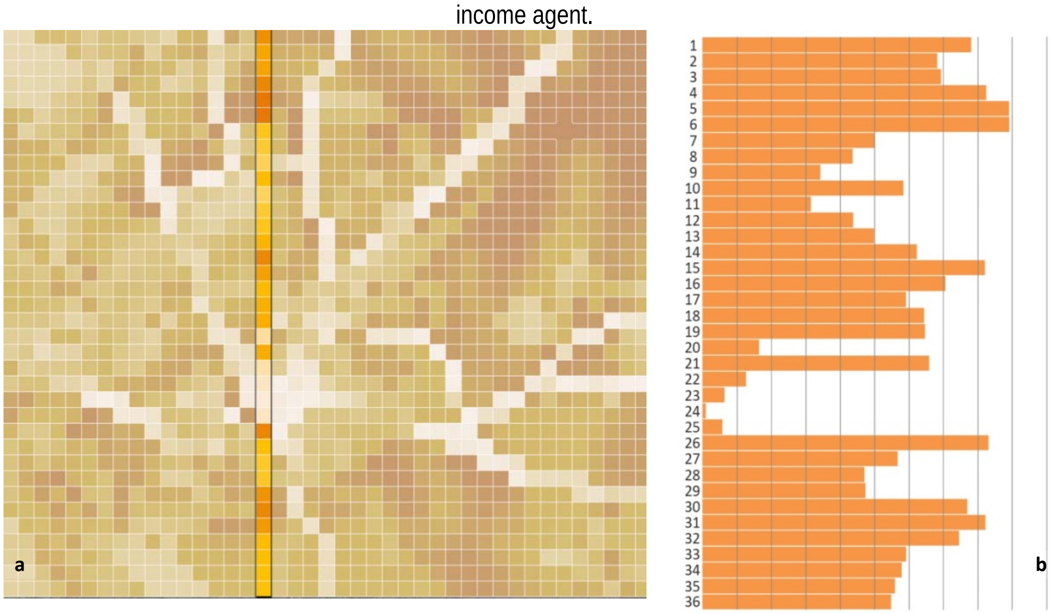


The consideration of remaining attributes brings into view its links to the agents' profiles. Image 12 shows the preferred areas for the three types of agents through the classification of each agent's preference matrix (which stand alone in Image 10a, to low-income agents; 10b, to average-income, 10c for high income).

An inverse Chicago Model is then apparent: the high-income populations settle inside the urban areas and leave the peripheries to the lower-income populations. The outwards expansion tendency for low-income populations is also visible. This happens according to secondary (to the accessibility status) influences as the road network, watersheds and so forth (Bógus & Taschner

1999). Instead of presenting the prevailing economic motivations, these settlement patterns are disturbed by other motivations that actually restrict the final interest spatial pattern. For the low-income agents, the final pattern corresponds to 70% of the particular accessibility pattern (1,238 cells with$t_{\mathrm{low-inc},Ap} \geq 0{,}85$, against 845 with$T_{\mathrm{low-inc}} \geq 0{,}85$). image 13 shows the difference between the particular accessibility grid distribution and the interest matrix.

Image 13: particular accessibility grid compared to interests matrix. a) Particular accessibility and interests matrix subtraction modulus for low-income agent (it.11, highlighting column 17); b) difference between the distributions of the results of column 17 from the particular accessibility grid and interest matrix for low-income agent.



Final remarks

With regard to the question posed for this implementation, the influence of individual decisions on land use patterns can be ascertained, including those associated with poverty. Even on simple weighting of preferences over the environment, it is observed that the inclusion of varying agents' characteristics results in adjusted preferences patterns that drive each agent to a specific cell group on the environment. This steering is sensitive to the attributes selection; the attributes' weights as well as to the attributes' base values, as is apparent in the model results.

Several important challenges remain to be overcome, such as the deeper investigation of the associations of urban attributes and agents; the strengthening of methodological basis for the model; the definition of the movement and allocation processes and the insertion of these features in the software framework.

Even with these limitations, the model displays initial viability for modeling morphological dynamics in interaction with explicit social processes. Regarding empirical questions on the topic of poverty areas on contemporary Brazilian cities, the current implementation has produced embryonic approach to criteria definition for each of the modeled agents. The registered effects indicate further possibilities on the study of linkages between morphological characteristics, environmental and social agents' motivations. In this sense, the perceived adjustment in the agents' parameters sensitivity reinforces the need for calibration from a theoretical, empirical or even hypothetical basis.

The model also displays some initial progress regarding its theoretical assumptions. It may enable the advancement of decision-making systems grounded social and geographical bases. It seeks to bring urban growth models closer to social modeling tradition of Timmermans and Golledge (1990) and Epstein and Axtell (1996).

Similarly, the Uneven Development Theory (Harvey 1978; Walker 1978) may also be represented by urban growth based on weighted accessibility and the unequal settlement patterns produced for agents. The current experiment suggests that agent environment awareness, preferences and movement, once deployed, will allow the representation of formal and informal market dynamics through divergent preferences and conflicting behavior. The heterogeneity in their preferences, tolerance, power and information culminate in parametric (on their environment assessment) and strategic (as compared with other agents) rationalities (Abramo 2012).

Methodologically, it appears there is a suggested increase in capacity in the CityCell framework, with the addition of micro-specification (Epstein & Axtell 1996) of the attributes weights for each agent. One can then generate modeling hypotheses with greater clarity as to its theoretical and empirical assumptions and include the autonomous rationality principle.

On the issue of formation of poverty areas integrated with city growth, the hybrid approach of cellular automata and agent-based models can qualify investigations in urban models of morphological basis by increasing the specification of its dynamics and by allowing the contradiction between its social actors.

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