AN AGENT-BASED MODEL FOR URBAN STRUCTURE: THE CASE OF BELO HORIZONTE - BRAZIL

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ABSTRACT: This paper investigates the spatial organization of urban areas driven by a diversity of agents and a number of pieces of urban infra-structure. The key theoretical and instrumental reference for the paper is a cellular automata model – similar to the one proposed by White & Engelen (1993) – in which agents have different preferences towards land use, income and neighborhood. The contribution proposed is to add urban land prices as a key factor to relate to land uses of the model. The emerging pattern is similar to that of a post-metropolitan region: fragmented, differentiated and multi-polar such as the one described by Soja (2000). As a successful model which is able to mimic developing countries urban structure it hopes to foster urban planning and public policies analyses, as Batty, Xie and Sun (1999; 2003) did for Ann Arbor / Michigan and Bell et. al. for Adelaide, Australia (2000).

Keywords: cellular automata, land rent, land use, metropolitan areas.

Classification JEL: R12, R15

1. INTRODUCTION

Cities – as monopolized spaces – mirror the complex essence of social relations which make them the center of power, center of entertainment and center of economic surplus (SINGER, 1982; MONTE-MÓR, 2006). The city is the result of the dispute for the same space, numerous times valued by its relations of proximity and location, rather than its intrinsic features such as the land itself and its natural characteristics. This predominance of socio-economic relations is typical of urban spaces and that is what makes traditional techniques of modeling – the parametric ones – rather difficult (SHEPPARD, 1999) –, especially considering that socio-economic dimensions are multi-faceted and unbalanced. This diversity is specially evident in peripheral countries where "modern" views live along "old" ones, where income extremes are spatially contiguous, where old-fashioned relations are useful to modern practices (OLIVEIRA, 2003)…

In order to handle this degree of disparities and diversity, the literature points to alternatives such as the bottom-up approach[1]. In urban matters specifically, Batty (1998), Capello (2002), Torrens (2001), Glaeser (2005) and Pines & Thisse (2001) consider cellular automata to be a promising instrument to deal with local interaction, social neighborhoods, spatial irreversibilities, cumulative processes and a variety of behavior and use of urban land. A bottom-up approach means that agents interact locally, have differentiated preferences and budget restrictions. They also follow decision-making rules that abide to a certain socio-spatial neighborhood. As a result, the typical emergent system characteristics are observed (BATTEN, 2000).

This paper objective is to mimic the spatial configuration of the price of urban land along with the land use associated. The emergent characteristic pursued then is to describe what behaviors and restrictions lead individual actions of a diverse number of agents to construe urban space independently and collectively, in particular those complex ones such as metropolitan areas. Posed differently, one might say that the objective of this paper is to follow suit upon the proposed view of Thomas Schelling in his book Micromotives and Macrobehavior (1978) in which an observed characteristic – urban segregation – is the result of the action of a number of agents acting individually in their own accord.

Besides this introduction, this paper contains a brief description of the original model of White & Engelen, the proposed modifications, its features and parameters. After that the criteria used to compare the results of the model with empirical data are described. They are based on income clusters analysis, urban land price gradient and spatial econometric analysis. The similarity of the real data with the results of the simulation is evaluated. The final section speculates about possible future expansions of the model which might contribute to the understanding of public policy in metropolitan areas.

[1] Check Batten (2000), Rauch (2002), Arthur (1994, 1999 e 2005), Holland (1992a e 1992b), Holland & Miller (1991) for examples, procedures, models and arguments.

2. MODELING DIVERSITY IN URBAN SPACES

2.1. WHITE & ENGELEN'S MODEL (1993)[2]

White & Engelen's model aims to portrait the evolution of the use of urban land and, in order to do so, assumes a high socio-spatial resolution in which interaction among agents occurs within the neighborhoods. The model can be viewed as analogous to traditional approaches of spatial interaction in which a number of new-comers at every turn choose to locate according to the status quo at the moment of their joining in. Rules and proceedings are based on the behavior of adjacent cells and although very simple, may have complex spatial patterns as a result. However, it differs from traditional models of location as there are irreversibilities – sunk costs, some might say –, diversity of preferences and limited information concerning future scenarios, especially local ones.

There are different land uses (vacant, residential, industrial and commercial) and the cells are converted from one use to another following the transformation rules (*op. cit.*). The rate of growth (conversion) of cells is determined exogenously and the neighborhood taken into account is that of a radius of six cells. The representation of the behavior of the agents which determines the urban land use is made by the potential transition variable and it is calculated as follows:

$$P_{ij} = S\left(1 + \sum_{h,k,d} m_{kd} I_{hd}\right),$$

Where P_{ij} is the potential transition from state "i" into state "j"; m_{kd} is the weighting parameter applied to cells in state "k" at a distance "d"; h is the index of cells within a given distance; I_{hd} is 1 if state of cell h = k; otherwise, it is zero; S is a stochastic disturbance which is given by $S = 1 + (-\ln R)^{\alpha}$, where R (0 < R < 1) is stochastic and uniform variable, α is a parameter which enables the control of the size of the disturbance.

This very simple model enabled White & Engelen (1993) to simulate patterns of urban land use. Other authors, such as Bell et. al. (2000), Beherens (2005) e Page (1999) applied similar methodology and developed models where there was a wider range of behavior possibilities and irreversibilities were conditioned to cost of relocation, for instance.

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[2] The authors acknowledge Arlan Mendes Mesquita's contribution on this item.

2.2. ADAPTING THE MODEL…

The contribution intended by this paper is to include in the discussed model the inter-connection among (a) socio-spatial preferences (b) urban land rent – land price – and (c) the capacity or ability to pay of each of the land uses. These links are not explicit in White & Engelen's model (1993), in which only locational preferences determined land use. As a result of these changes, land rent gradients are expected to resemble data empirically collected.

The model suggested assumed as a valid presumption that urban land is subject to centripetal and centrifugal forces which conform urban space. Forces of attraction – as described in the works of Christäller (1966) and Lösch (1963) –, lead to urban land occupation that is polarized by hierarchically superior centers which offer products with greater market area (economically speaking: substitution elasticities are low, independently of growing transport costs). Given this relative production monopoly of urban land, a tension is established between advantages and preferences due to proximity which increases prices and how much agents are willing to pay, or, better yet, are able to afford. For some agents, for instance, infra-structure has elasticity of substitution nearly null which in turn impose serious location restrictions[3]. This fact may not impose a conditional choice upon other agents. However, as urban space is unique and occupied by an only agent (or a finite number of agents – even if there is vertical use), the action of one agent will affect decisions made by other agents. In the model, interaction occurs sequentially and it is temporally defined which leads to typical urban construction irreversibilities at average term periods.

Besides this tension generated by proximity and dispute for the same space, a central key feature of the model is to predict the emergence of peripheral areas (not in the developed world sense of edge cities, but faraway locations with near zero offer of infra-structure of any kind, be it public or private, typically encountered at developing countries[4]). These places have the extraordinary ability of having a low-value price which many times makes them the only choice available for some inhabitants, given their income (or lack of it, actually) (FURTADO-a, 2006).

2.3. TYPOLOGY OF AGENTS AND DETAILS OF PARAMETERS

The model was implemented in Netlogo 3.0.2 (WILENSKY, 1999) and consists of a grid raster system (of dimensions 101 x 79[5]) in which every cell has a potential land use (U) and a land price (P).

[3] When city enterprises transplant themselves into a city's own hinterland, they balance their needs to be close to their suppliers and customers against their conflicting aims of escaping the costs of city space and the congestion or other disadvantages of the city (JACOBS, 1970, p. 97).

[4] This is also true in developed countries concerning not infra-structure or urban amenities, but access to some services obtained exclusively on some spots specifically.

[5] Hence with a total of 7.979 individual cells.

There are eight different types of land use, each one with different preferences, following the parameters of the matrix in table 1. They are vacant, residential, residential average income, residential superior income, services, industry, great urban equipment, infra-structure and superior infra-structure. The parameters value the presence of other land uses nearby differently. Superior residential agents tend to value others of the same kind at their neighborhoods. Similarly, they would dislike presence of industries and value services and great equipments positively.

The choice of this typology of agents was made in search of the greatest possible resemblance with real actors of urban arena[6]. Residential land use, for instance, had to be stratified in at least three layers of income level because its distribution in space follows this segregation pattern. Furthermore, their economic leverage to dispute urban space is rather different. An industrial agent is a must because it is a heavy demander of infra-structure, while simultaneously needing workers nearby and negatively impacting its neighborhood. Great urban equipment and services act similarly but the public they attend and their scale of action are different, the further regionally and the latter locally. Superior infra-structure is assumed to be fixed in space. This is so because it is implemented (within a Brazilian perspective) at large intervals of time, at once and it establishes patterns or organization of the territory in long-term periods. Infra-structure (use 5) reflects the average needs of the people and is implemented whenever there is demand and financial resources. It is intended to reflect school needs or healthcare centers for example, which are usually scattered around following population density occupation.

Table 1: Matrix of spatial preferences used in the model

Use	Type/Valueing at Σ	sup. res.	average res.	res.	great equip.	services	industry	sup. infra-struct.	infra-struct.	inc. weight	disturbance
1	residential	1*	1*	3*	2**	2*	-1*	1*	1*	-0,8	0 to 8
2	services	2*	2*	2*	0	2*	1*	2**	2**	-0,2	0 to 8
3	industry	0	0	0	0	1*	1*	3*	2*	0.1	0 to 8
4	superior infra-estructure	0	0	0	0	0	0	0	0	0	0
5	infra-estructure	0	2*	3*	0	1*	1*	1*	1*	0.2	0 to 8
6	superior residential	3*	1*	1*	2***	2*	-2*	1*	1*	0.5	0 to 8
7	great urban equipaments	4***	2***	2***	2***	1***	1***	2***	2***	1,1	0 to 8
8	average residential	1*	2*	1*	2**	2*	-1*	1*	1*	-0,4	0 to 8

* neighborhood radius = 2 cells
** neighborhood radius = 3 cells
*** neighborhood radius = 4 cells

At first, a random initial price (P0) (between 0 e 7) is attributed to every cell. There is also a initial configuration of uses (seeds) with five cells allocated to residential use, four to superior residential, two to services, three to industries, two to great urban equipments and 191 to infra-structure, 53 of which are of the superior kind and are fixed throughout the process[7]. As it will be mentioned afterwards in the paper, this initial configuration has as a reference the urban design of Belo Horizonte – a planned city that is used as reference for the similarity comparison (see Figure 5).

[6] At this moment, the figure of the developer is not present and all land is considered to be urban. In Brazil, even though there is legislation that states otherwise, development of the land may come after it has been occupied.
[7] This means that 0,026% of the territory is allocated a priori in the model.

The model is dynamic as it is marked temporally, starting at period 0 and at every turn (t + 1) some transformation of land use occur. This happens on a constant exogenous rate. So that, every turn vacant areas become other land uses at the following proportion: one great urban equipment; two industries; two cells of services; four superior residential; 8 average residential and 14 residential cells. These numbers are the result of preliminary studies that indicate this to be the average proportion of urban space used by these 8 categories of agents (FURTADO, 2006-a and 2006-b).

The transformation of each land use is given by the maximization of the utility predicted considering spatial preferences (table 1) and the price of the vacant cell. That is, there is a differentiated valuation of neighbor proximity (positive or negative) and the size of the impact of the price of the land that results in decision of location. Formally, we have:

$$\max s_i = \left(\sum \psi\right)_v + \alpha p + \phi ,$$

$p = p_v + p_2$, where:

p_v = average price of the neighborhood,

p_2 = exogenous price,

where, s_i = calculus of the transition potential value following the matrix of preferences for each land use; $\left(\sum \psi\right)_v$ = summation of vector of preference with different degrees of neighbors consideration; p = price of each cell weighted by potential income of each land use (α); ϕ = random disturbance for each summation. As it is, the price of each cell is calculated as an average of neighbors price plus a random exogenous intrinsic price which is responsible for bringing into the models both market fluctuations and intrinsic characteristics of the land (such as topography or zoning). It can be altered to influence more or less accordingly.

3. An illustrative case

3.1. The reference case: the Greater area of Belo Horizonte

The calibration of the model was considered adequate when it responded to the following prerequisites: (a) the dynamics of the evolution observed followed rough guidelines provided by the “traffic system” (represented by the fixed infra-structure – land use 5)[8]; (b) it showed a tendency to agglomerate nearby areas, while forming peripheral patterns away from the major centrality (FURTADO, 2006-a) and (c) resulted in spatial compositions that were similar to the ones observed empirically (Figure 1).

[8] It is implicit in this view that urban infra-structure organizes the development of urban territory.

These assumptions follow empirical observations of the case of the Greater Area of Belo Horizonte. Special emphasis is given to urban discontinuity observed in the evolution of most cities. Centralities that are distant from the city center are later engulfed by sprawling urban areas in succession. The view assumed here is that the explanation for this discontinuity is that a certain part of population, that with lower income, are not able to afford urban land and therefore settle specifically where there is a lack of these services, and therefore price is suitable for them. This line of thought, expressed by Furtado (2003a), therefore, assumes that provide the services demanded would not be enough because price would rise and people would seek land further away.

This is in order with the results of the clusters analysis[9] applied to the Greater Area of Belo Horizonte using official data of residences from census tract produced by the statistical department of Brazil – IBGE (2000). It clearly shows how the segregation pattern is strong. (Figure 1, p.8). By looking at the figure it is easy to see that indeed it confirms the agglomeration of higher income residences, *vis-à-vis* the rest in the south-central areas of Belo Horizonte and Nova Lima; another area in the north-east part of Belo Horizonte and in the nuclear downtown areas of Betim and a few scattered points. It is also clear that the central areas of the nearby cities of Santa Luzia, Sabará, Vespasiano, Ribeirão das Neves and Ibirité are all at average level of income considered the whole of the Greater Area and this is better than their vicinities. The analysis of the percentage of each cluster income class by municipalities (table 2) confirms that part of the elite has migrated to Nova Lima (18%) and that 85% of lower-income families are outside the major city of Belo Horizonte in the peripheral municipalities.

Table 2 – Percentage of income clusters by municipalities, Greater Area of Belo Horizonte (2000).

Municipalities	HIGH-INCOME	AVERAGE	LOW
Belo Horizonte	**0.80**	**0.57**	**0.15**
Betim	**0.02**	0.09	0.07
Contagem	0.00	0.19	**0.11**
Ibirité	0.00	0.01	0.08
Nova Lima	**0.18**	0.01	0.05
Ribeirão das Neves	0.00	0.01	**0.21**
Sabará	0.00	0.03	0.05
Santa Luzia	0.00	0.05	**0.24**
Vespasiano	0.00	0.03	0.04
Total	1.00	1.00	1.00

Source: elaboration of the authors based on the map of figure 1.

[9] The cluster analysis methodology is used to aggregate individuals who possess similar characteristis. In this case, the aim of the exercise was to unite census tract units with similar income level using ten different levels of income prospected at census questionnaire answers (no income, up to half minimum wage (MW); from half to one MW; from one to two, two to three, three to five, five to ten, ten to fifteen, fifteen to twenty and more than twenty MW). All census tract for the agglomerated areas around Belo Horizonte were used. The methodology was implemented using CEDEPLAR/UFMG laboratory licence of ArcGis 8.3. For further details concerning the methodology check Ball, G. H., and D. J. Hall. 1965. A Novel Method of Data Analysis and Pattern Classification. Menlo Park, California: Stanford Research Institute and Richards, J. A. 1986. Remote Sensing Digital Image Analysis: An Introduction. Berlin: Springer–Verlag.

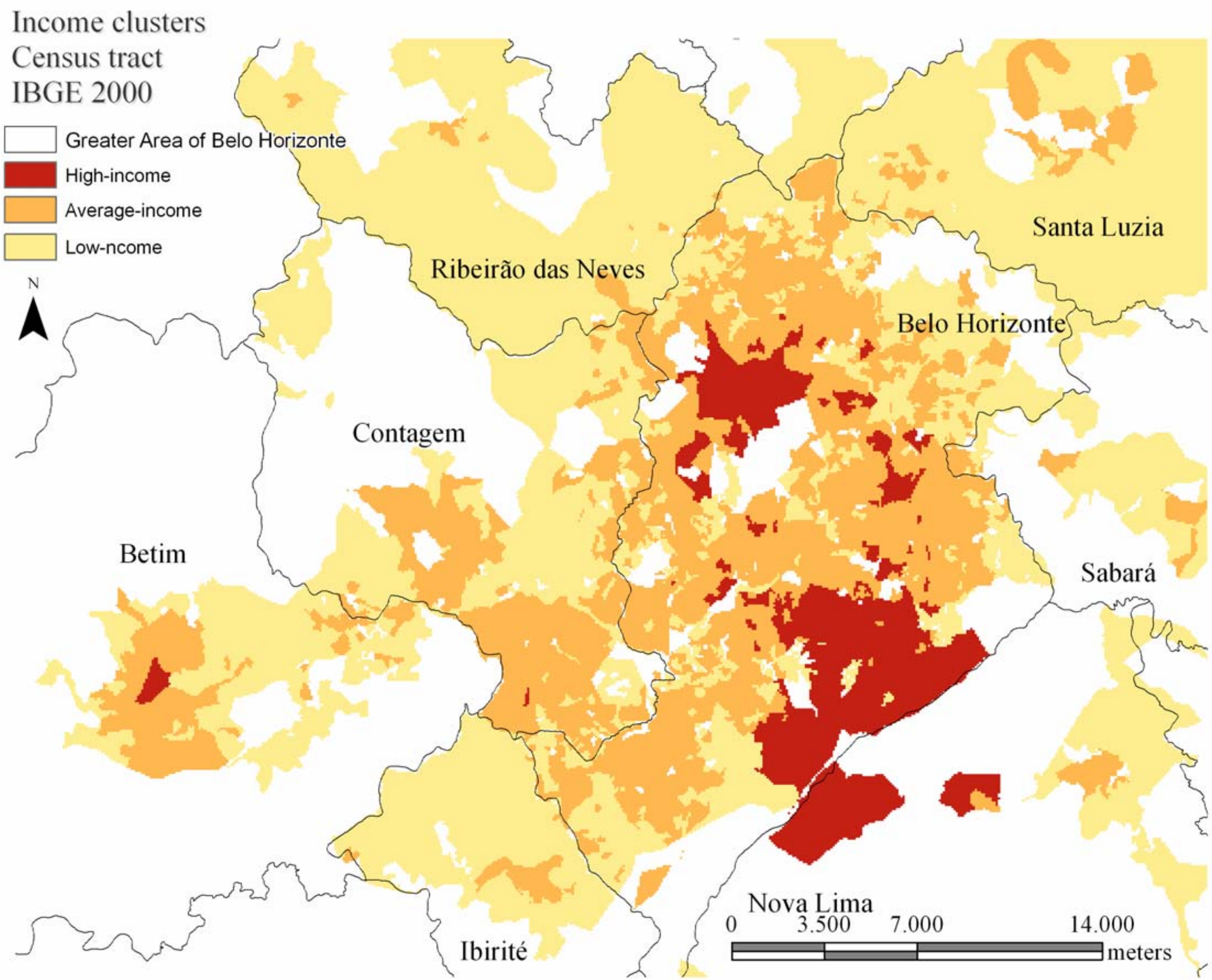
One other important factor to highlight is that empirical collection of land price by square meter for the city of Belo Horizonte follows closely the presence of higher income residences. If one compares figures 1 and 2 he or she will notice that the south-east region of the city is high valued in both maps. Figure 2 was generated based on information for 496 estates advertised for sale[10]. The average for each neighborhood was plotted at its center and they were used to make the gradient map[11].

It is also important to notice the difference of scale in the prices currently being practiced at the high-income neighborhoods and elsewhere in the city.

[10] Data from October, 2005. The authors would like to aknowledge the contribution in data collection of Cristiane Nobre Prudente, Leila Luiza Efigênio and Vladimir Augusto. The database was also used in a paper of spatial econometric analysis (FURTADO, 2006b).

[11] The method applied was kriging interpolation. The neighborhood map was made available by the City of Belo Horizonte.

Figure 1 – Cartogram of income clusters for the Greater Area of Belo Horizonte (2000)



A formal correlation income and price of land is discussed in Furtado (2006-b). In a model in which the logarithm of the prices is regressed against a matrix of characteristics of the estate and an index of residential income, all were statistically significant at 1% (see table 3 and 4). This example suggests, as demonstrated by hedonic prices literature, that real estate prices depend on both: the estate features as well as its location within the city.

Table 3 – Statistics of the main model in Furtado (2006-b)

	average	standard-deviation	maximum	minimum
Income index	3.14	0.96	4	1
Price (reals)	184025	161139	1200000	30000
Area (square meters)	120.88	57.69	450	40
Age (years)	14.31	10.08	50	1
City tax (monthly)	88.10	73.76	400	12.76
Building fee (monthly)	299.08	242.66	1500	25
Places in the garage	1.75	0.95	6	0

Source: FURTADO, 2006-b.

Table 4: Lnprice

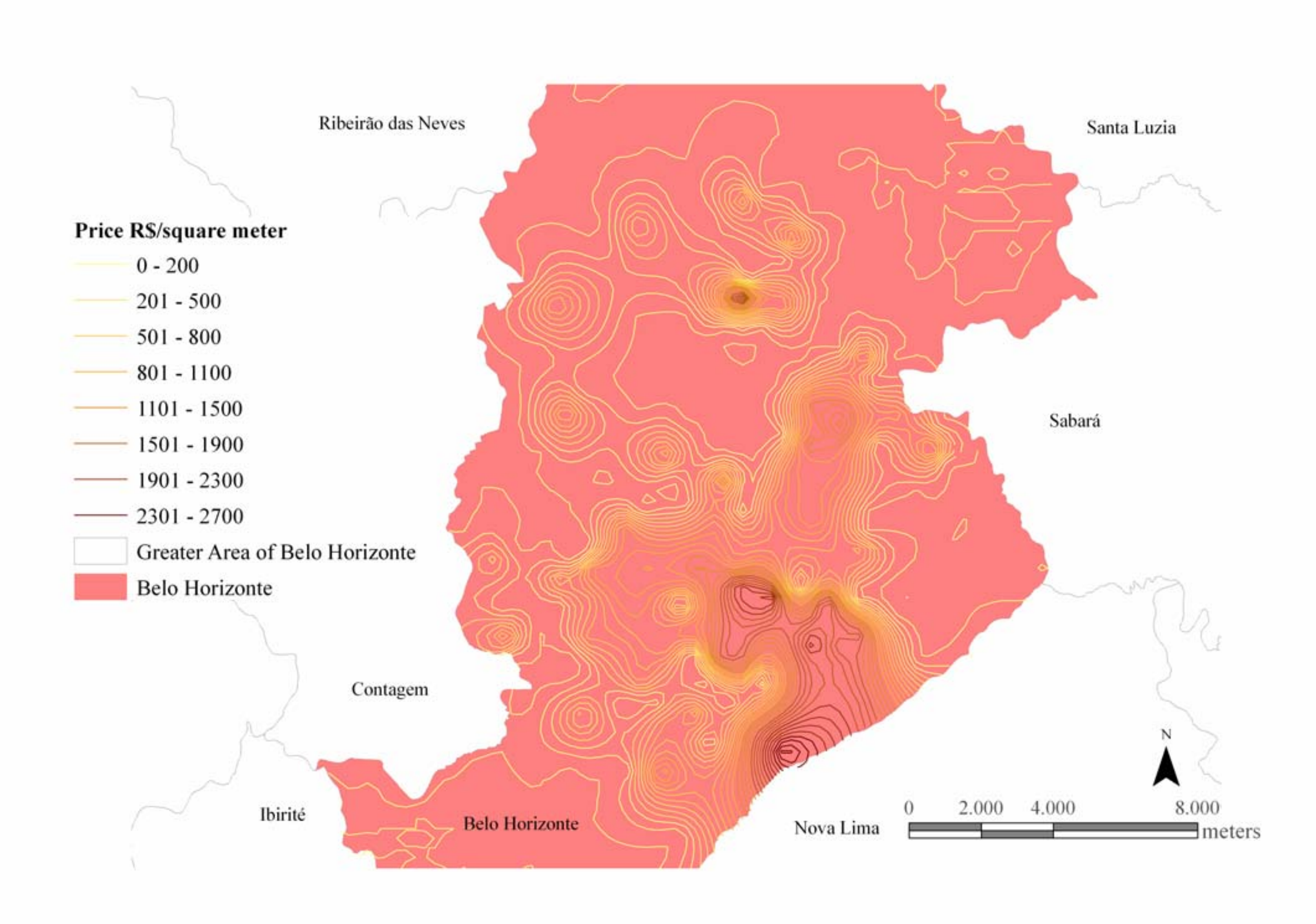
ln_age	-0.103	(7.52)**
ln_building	0.262	(10.53)**
ln_tax	0.123	(5.02)**
ln_area	0.655	(15.68)**
ln_garage	0.129	(7.81)**
Income_index	0.900	(10.78)**
constant	6.302	(46.70)**
observations	487	
R-squared	0.91	

Absolute values of **t** in parenthesis; ** significant at 1%

At first, the spatial dependence was extremely high. And that led to spatial econometric models proposed by Anselin (1999, 2005). However, when a neighborhood income index calculated through principal component analysis was introduced in the model, the spatial model became unnecessary (spatial lag variable and error become statistically non-significant). What is to say that within this model, all neighbors influence (or most of it) is captured by the neighborhood income index. Another model described by Furtado (2006-b) in which the neighborhood income information was less precise[12] again indicated a spatial model as adequate. The conclusion reached from the experience was that whenever the neighborhood is well discriminated, a spatial model will not be a necessity.

[12] Instead of an index, a simple classification that run from 1 (popular) to 4 (luxury) proposed by IPEAD, a consultancy firm hosted by the university.

Figure 2 – Price of residential square meter for Belo Horizonte (2005)



The alternative chosen to mensurate spatial relations both with the collected data and the result of the simulation, so that they can be compared is detailed in the sequence.

A major definition to comprehend spatial analysis is that of spatial dependence. This concept is derived by what is generally referred to as the First Law of Geography of Tobler: "Everything is related to everything else, but near things are more related to each other" (CÂMARA, 2004, p. 11). Spatial autocorrelation, in turn, is the expression the measures this spatial dependence. The first suggestion of the presence of spatial dependence can be given by Moran's I index, which is, formally:

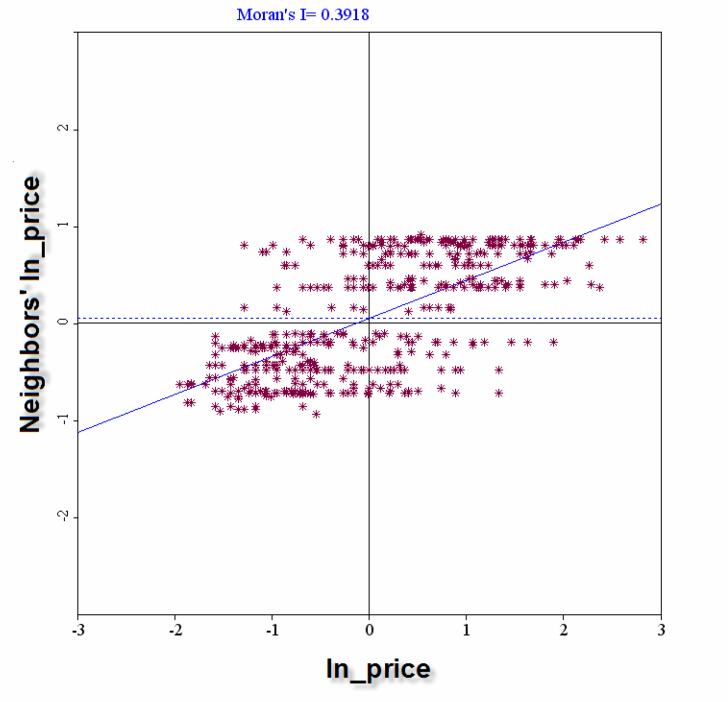
$$I = \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

where, W_{ij} is the neighborhood weights matrix which brings in to the formula neighbors importance and connectivity, n is the number of variables, x_i is the variable to be checked against for spatial dependence.

Anselin (2005) emphasizes the importance of the weights matrix as it is responsible to represent neighbor's relations. However, results are not supposed to be completely different if there is a different choice for this matrix. According to Furtado, the matrix chosen was the k-nearest neighbors with the closest twenty neighbors included. Morans' I statistics is ideal to identify the presence of spatial autocorrelation, it does not indicate, however, how (or why) it occurs (ANSELIN, 2005, p.197)[13].

Morans' I statistic for the data collected, with 490 observations is 0,3918 (figure 3) what strongly suggests high spatial autocorrelation with the observations concentrated on the second quadrant (high-high) and fourth (low-low)[14]. Furthermore, the pseudo significance level – calculated by permutation (9999) is highly statistically significant (p = 0.0001), with average of 0,0151 and standard-deviation of 0,0076. The envelope method (ANSELIN, 2005) also guaranteed the expected results.

Figure 3 –Morans' I statistics



Source: Furtado (2006-b)

3.2. RESULTS OF THE SIMULATION

In order to verify if the model can mimic real urban land configuration and its associated land prices, it is presented below the phases of the results of the simulation for selected periods along with comments and analysis. For some periods (t = 0, 10, 40, 241) the following results will be presented: (a) the Morans' I statistic, (b) the cartogram with urban land uses and (c) the cartogram that portraits the values of urban land prices in the modeled area. The cartogram of urban land prices was generated using

[13] Calculation was made in GeoDa 0.9.5i, by Anselin, Luc. University of Illinois, 2004. See also Anselin (2005).
[14] Morans' I statistic has an expected value of –[1/(n-1)]. In this case, as n = 490, the expected value, if there were no spatial autocorrelation at all, it would have been – 0,0020.

inverse distance weighted (IDW)[15] technique. The urban land uses cartogram is of each cell and its associated land use.

It is important to highlight that at t = 0 the Morans' I statistic is practically 0 (figure 4, p.14), and that suggests that there is no spatial autocorrelation and the urban land prices at each cell is random. (Figure 5, p. 15). The initial configuration of land uses is as described above. Notice that there is a central area located at the south of the figure with infra-structure and two axes leading west and north-west. This choice of urban design was made in order to try to resemble Belo Horizonte's urban history as a planned city at the beginning of the twentieth century (the circle) and the axes of expansion built around the 1950s and 1960s.

The evaluation of the model at only ten times (t = 10) (Figure 7, p.16) already shows some of the objectives planned for the model. One can see the appearance of three nucleus of residential occupation, some industries located alongside the superior infra-structure axes and an average residential spot in the south. One relevant feature of the results of the model is that even though most of the modeled area is vacant (7,143 cells, about 90%), urban land price has already been conformed to some ordering. This was true for the history of Belo Horizonte where most of the central planned area was left unoccupied whereas the unplanned neighborhoods were populated. Formally, this means that Morans' I statistic expresses spatial autocorrelation at I = 0.0843[16] (figure 6). Visually, it is possible to see that regions close to infra-structure have higher uniform land prices, though not occupied. The peripheral areas of the formed nucleus already show land price patterns that are compatible with their land uses. That is, neighborhoods of average residential occupation are proportionally more expensive than those of residential land use.

Some isolated locations, probably due to intrinsic characteristics of the terrain (random price P2), have higher prices and regions with popular occupation have lower land prices as well as a lack of infra-structure, services or industries[17].

At t = 40 (figure 9), spatial configuration of land prices is very well delineated with a high spatial autocorrelation expressed by Morans' I statistic I = 0.3704 (figure 8, p. 14). This result is close to the one observed with empirical data for Belo Horizonte (Figure 3). The best regions, those with infra-structure, great urban equipments, nice neighborhood and offer of services, already presents prices that are unaffordable for residential use – that with lowest income weight parameter.

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[15] To further details on the methodology see: Philip, G.M., and D.F. Watson. A Precise Method for Determining Contoured Surfaces. Australian Petroleum Exploration Association Journal 22: 205-212. 1982 and Watson, D.F., and G.M. Philip. A Refinement of Inverse Distance Weighted Interpolation. Geoprocessing, 2:315-327. 1985.

[16] Again Morans' I statistic has an expected value of $-[1/(n-1)]$. In this case, as n = 7979, the expected value if there were no spatial autocorrelation would have been 0,0001253.

[17] The authors would like to remind readers that the theoretical drive comes from a developing country meaning that land is not always developed prior to occupation. Rather the contrary happens more often.

Another feature to notice is that because some regions become expensive rather quickly, they are occupied more slowly than others. This is a stylized fact in contemporary metropolis and has been object of discussion of sociologists, urbanists, architects and geographers for quite some time.[18].

The final results of the simulation occur at t = 241 when all vacant spaces have been transformed into other uses (figure 11, p. 18). At this moment, as all information is available for all cells, all prices are up to date and there are absolutely no vacant areas, spatial autocorrelation is nearly perfect with Morans' I statistic at I = 0.9963 (figure 10, p. 14). This would never have happened in real cases because there are always vacant areas in a metropolis; there are no boundering limits as it is the case of the simulation and definitely not all estates are available for sale. The final urban land prices configuration, however, is compatible with metropolises cases in general, and with Greater Belo Horizonte in particular.

One final point to highlight is that even though the resulting configuration is a sum of actions of individual agents acting locally, the emergent pattern follows the ones described both empirically and theoretically. It is conformed so that access to better quality urban places is restricted and simultaneously it segregates the neighborhoods. In fact, a visual analysis of figure 11 reveals that average residential areas act as buffers between popular residences and superior ones. Only as a result of random chance or old occupation (old established slums), there is the possibility of lower income families to benefit from well-serviced urban places[19]. From this, it can be said that urban irreversibilities act favorably on offer access for the less-favored. Hence the importance of understanding the filigrans of the process.

4. Final considerations

The success of this model allows one to think further onto two follow-up possibilities: tax analysis of urban space and the dynamics of re-allocation of urban space to new uses.

In the first case, as it has been established that neighborhood characteristics determine urban land rent gradient, it might be possible to investigate further if a distinction between processes of tax collecting and offer of urban services funded by them are compatible. In other words, the question to pose is that if a citizen who works in a certain city and therefore contributes to its tax generation, but does not have enough income so afford that quality of urban space has to move to another one where he or she can buy the land[20].

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[18] For further details check the references of Furtado (2006a).

[19] Note that average price of urba land, according to the legens at figures 5, 7, 9 and 11 go up steadily. This is because the exougenous price P2 that reflects characteristics of the terrain and of the market in general. When P2 is fixed at 0, city prices are stagnated from an economic point of view and there are no changes in prices of urban land.

[20] This theoretical issue was first discussed by Tiebout (C. M. Tiebout, A pure theory of local expenditures, **Journal of Political Economy, 64**,416-424, 1956), and it was also theme of discussions in Urban Economics in general, see for example HOYT, William H. Household Location and Tiebout: Do Families Sort According to Preferences for Locational Amenities? **Journal of Urban Economics, 42,** 159-178, 1997.

The second promising alternative is the redesign of the model in order to include the analysis of land use change (not only from vacant to other uses, but also use succession) as well as the continuous presence of vacant uses.

Figure 4 –Moran's I statistic = 0.0005, t = 0

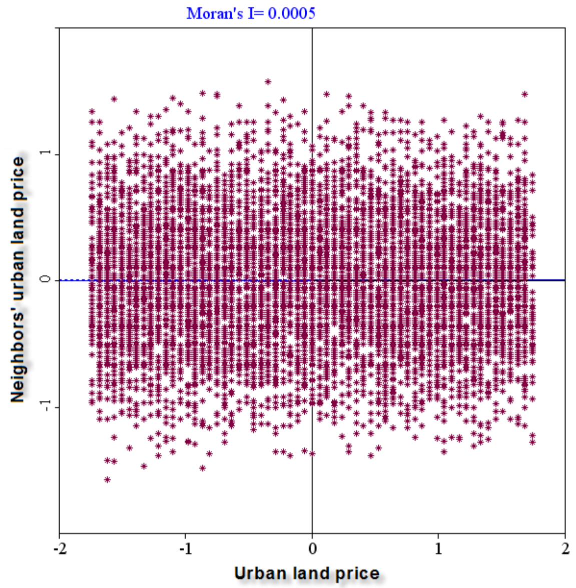


Figure 6 –Moran's I statistic = 0.0843, t = 10

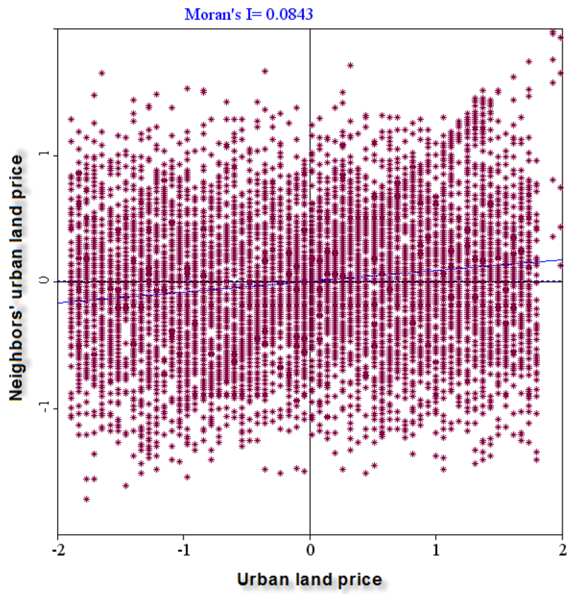


Figure 8 - Moran's I statistic = 0.3704, t = 40

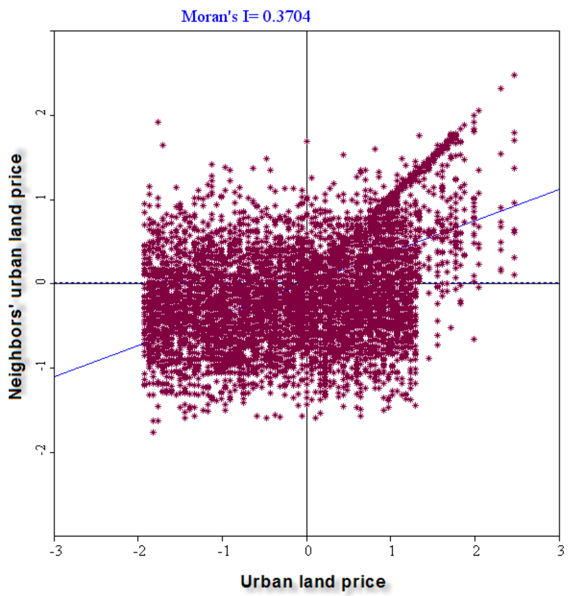


Figure 10 –Moran's I statistic = 0.9963, t = 241

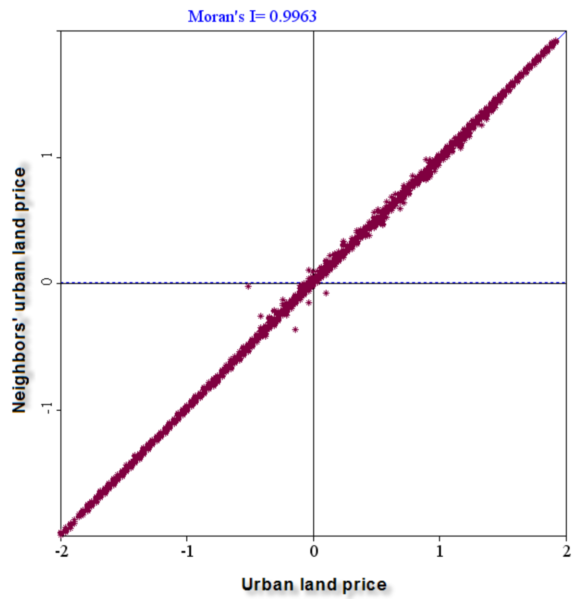


Figure 5 – Land use at t = 0 e Urban land prices.

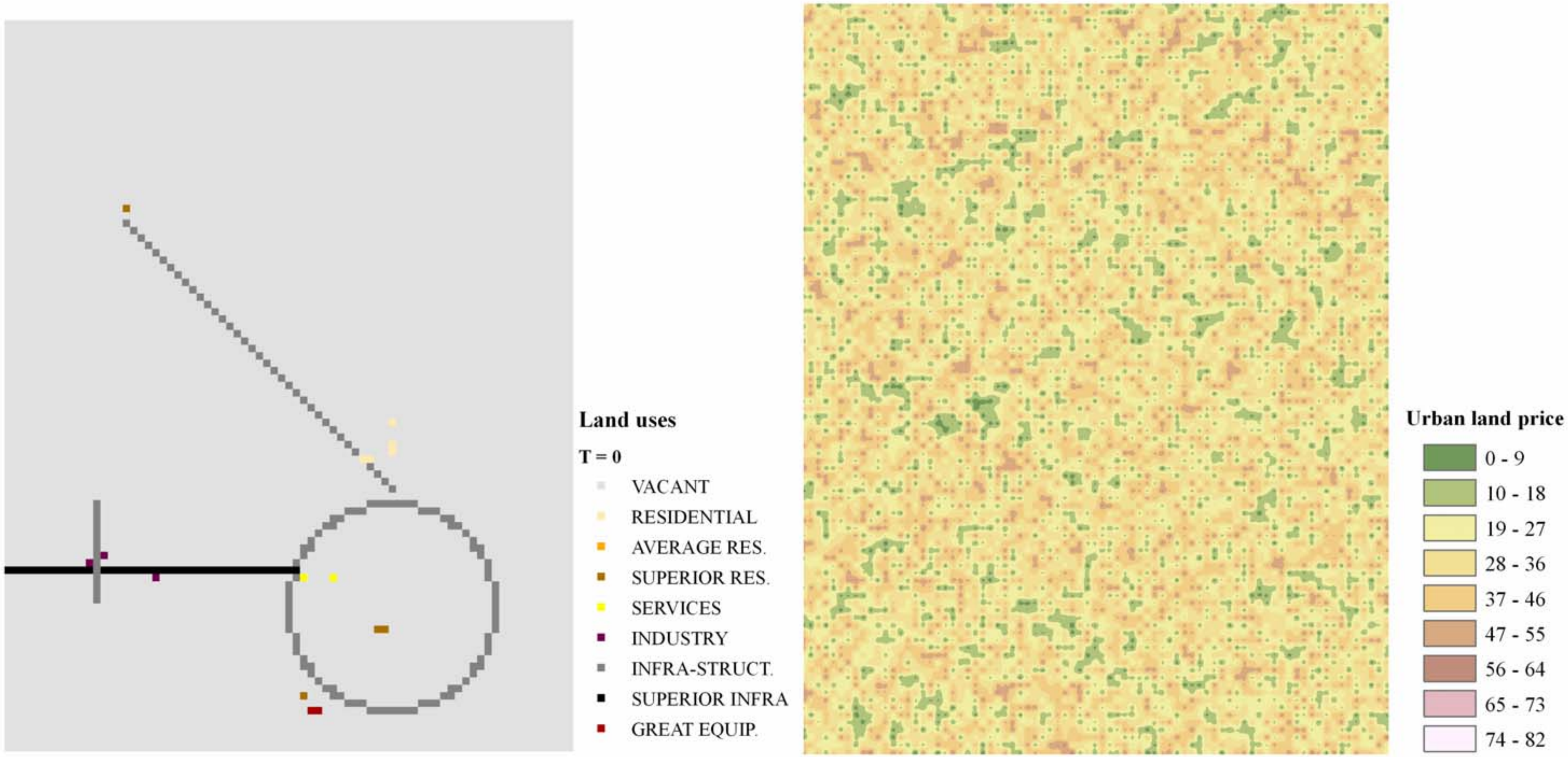
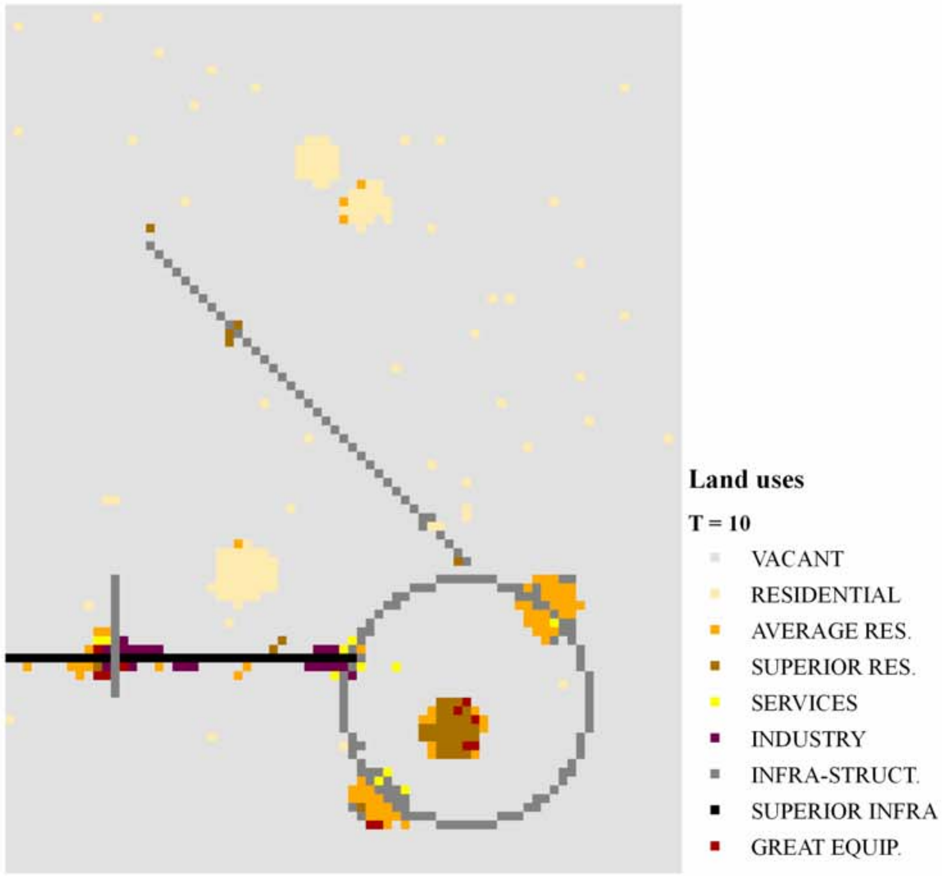


Figure 7 – Land use at t = 10 and Urban land prices.



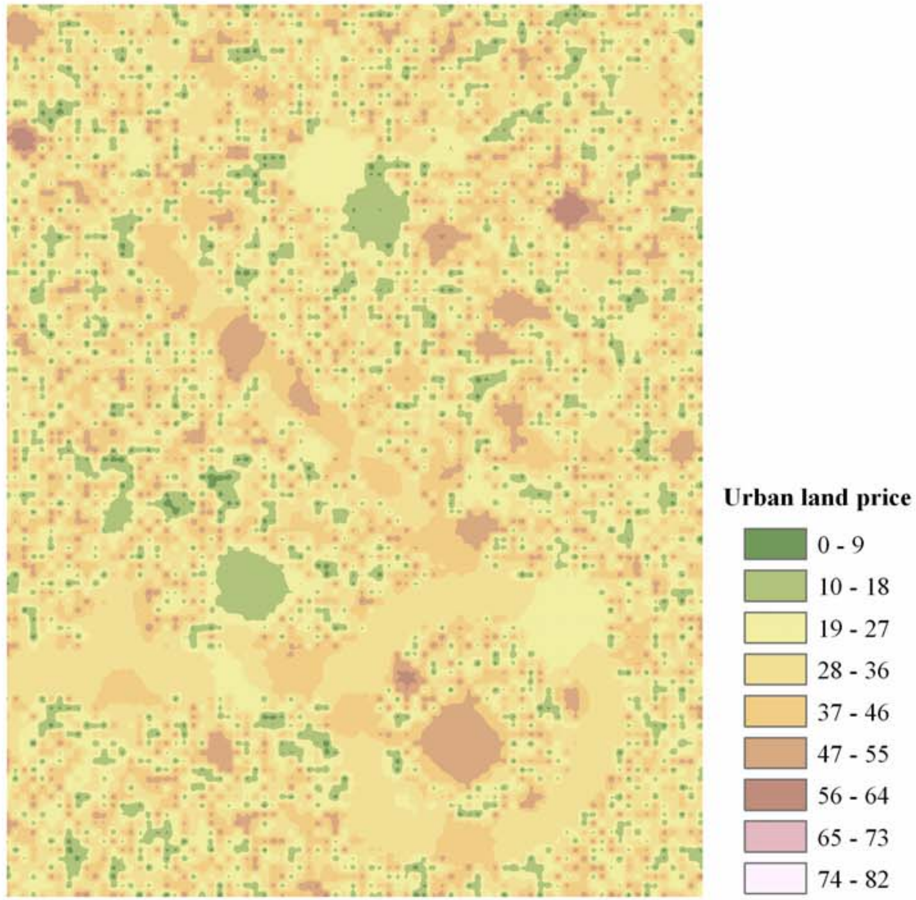


Figure 9 – Land use at t = 40 and Urban land prices.

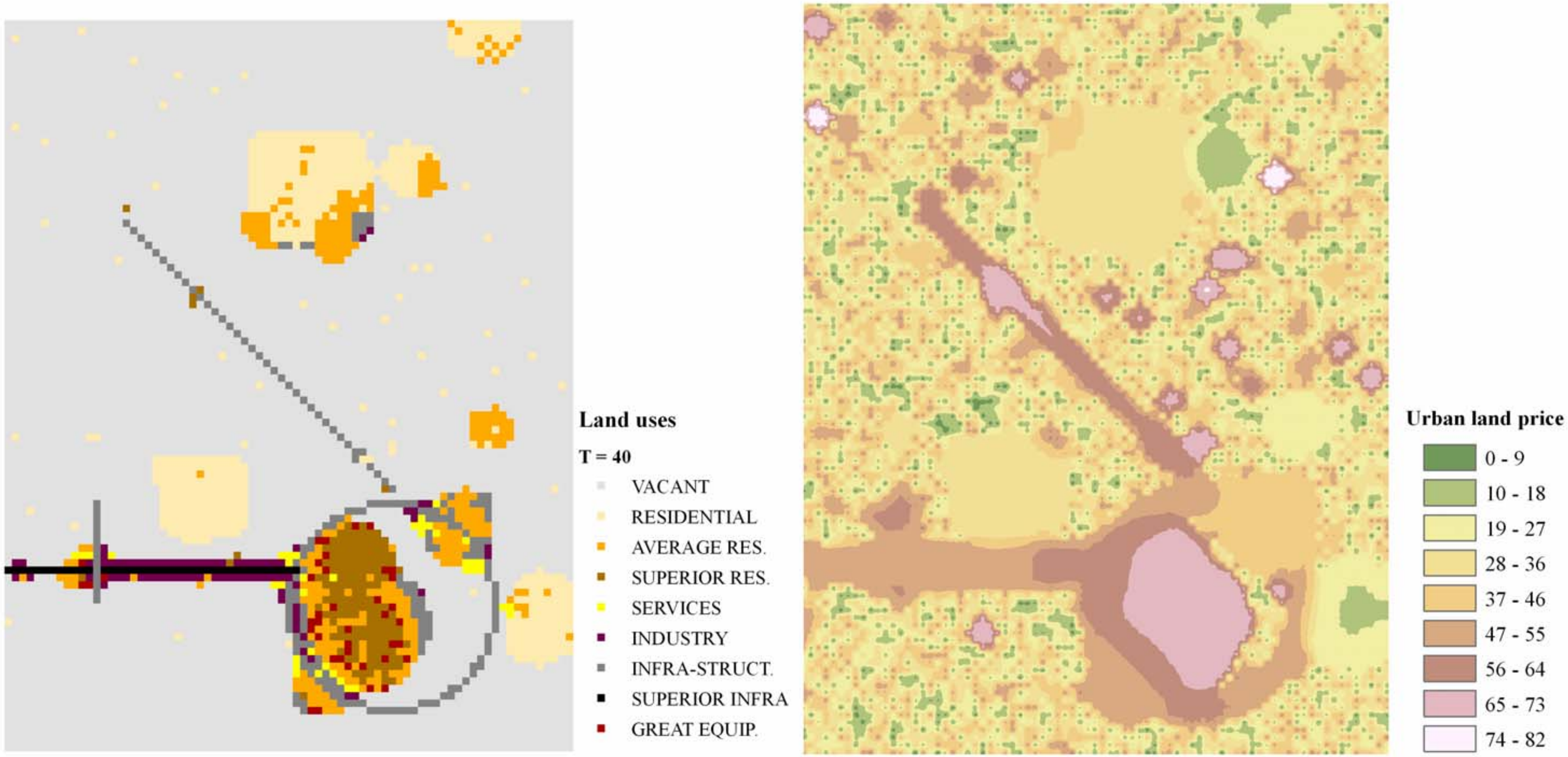
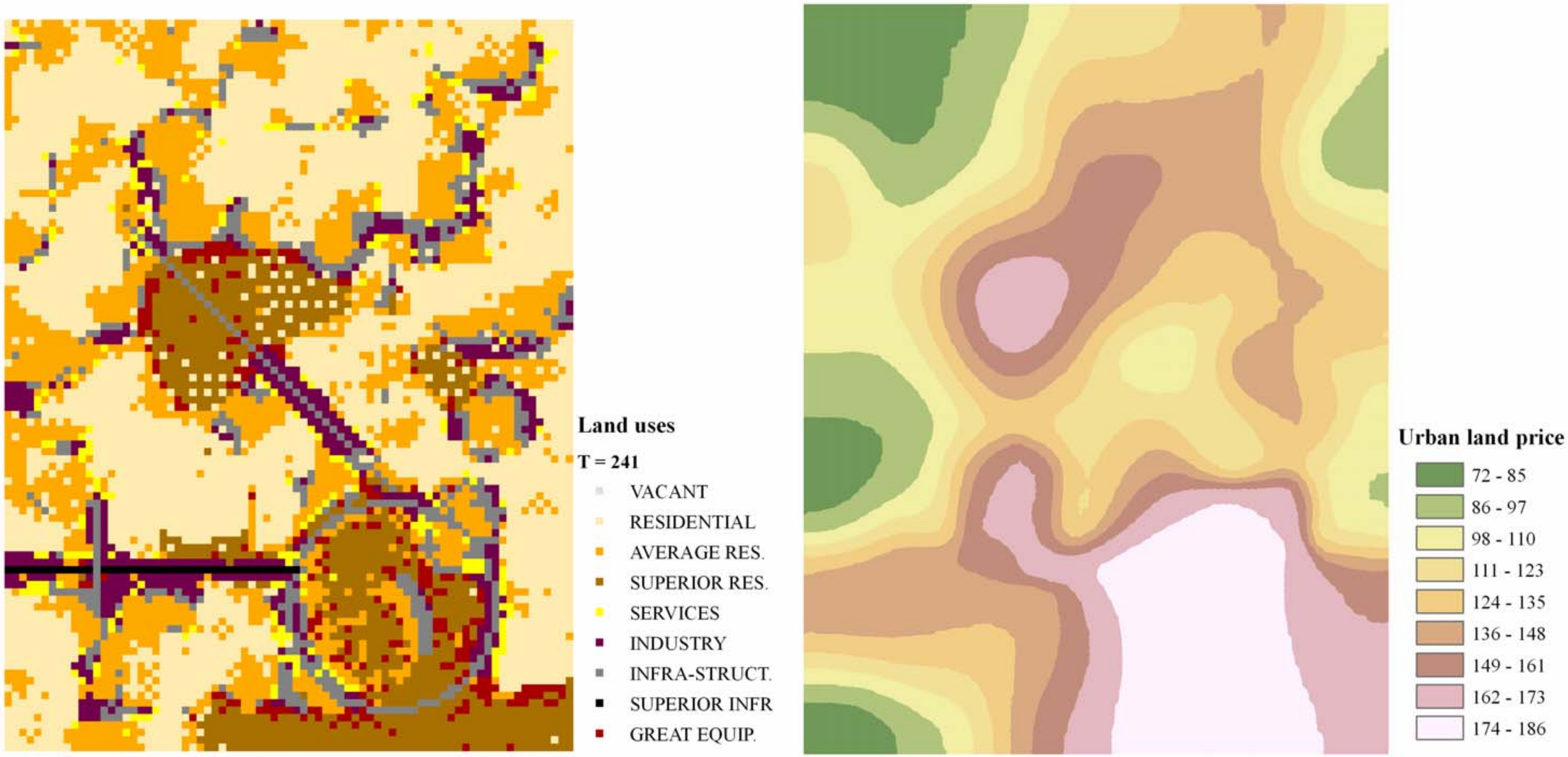


Figure 11 – Land use at t = 241 and Land urban prices



References

1. ALMEIDA, Eduardo Simões. **Curso de Econometria Espacial Aplicada**, ESALQP-USP, Piracicaba, 2004.
2. ANSELIN, Luc. **Exploring Spatial Data with GeoDaTM** : A Workbook. Spatial Analysis Laboratory, Department of Geography, University of Illinois, Urbana-Champaign, Center for Spatially Integrated Social Science, March 6, 2005.
3. ANSELIN, Luc. **Spatial Econometrics: Methods and Models.** Kluwer Academic. Dordrecht, 1988.
4. ARTHUR, W.B. Complexity and the Economy, in: **Science** 2 April 1999, 284, 107-109**.**
5. ARTHUR, W.B. Out-of-Equilibrium and Agent-Based Modeling. **Handbook of Computational Economics**, vol.2: Agent-Based Computational Economics, K. Judd and L. Tesfatsion, eds, ELSEVIER/North-Holland, 2005.
6. ARTHUR, W.B. The End of Certainty in Economics, in Aerts, D.; Broekaert, J. & Mathijs, E. (1999) **Einstein meets Magritte**. Klumer Academic Publishers, Holland. (1994-A).
7. BATTEN, David Complex landscapes of spatial interaction**. The Annals of Regional Science**, Springer-verlarg, 35:81-111, 2001
8. BATTY Michael, BARROS, J e JUNIOR, S. **Cities: Continuity,Transformation,and Emergence.** Centre for Advanced Spatial Analysis, University College London, London, UK, February 2004
9. BATTY, M., XIE, Y. Integrated Urban Evolutionary Modeling, **Geocomputation 2003**, the University of Southampton, 8-10, September 2003.
10. BATTY, M., XIE, Y., e SUN, Z. Modeling Urban Dynamics through GIS-Based Cellular Automata, **Computers, Environments and Urban Systems**, 233: 205-233, 1999.
11. BEHERENS, Kristian. Market size and industry location: traded vs. non-traded goods. **Journal of Urban Economics,** 58, 24–44, 2005.
12. BELL, M; DEAN, C. E BLAKE, M. Forecasting the pattern of urban growth with PUP: a web-based model interfaced with GIS and 3D animation. **Computers, Environment and Urban Systems** 24 pp. 559 – 58, 2000.
13. CÂMARA, Gilberto. Análise Espacial e Geoprocessamento, capítulo 1, in: Druck, S.; Carvalho, M.S.; Câmara, G.; Monteiro, A.V.M. (eds) **Análise Espacial de Dados Geográficos**. Brasília, EMBRAPA, 2004.
14. CAPELLO Roberta. Urban rent and urban dynamics: The determinants of urban development in Italy **Annals of Regional Science** 36:593–611, 2002.
15. CHRISTÄLLER, W. **Central Places in Southern Germany**. New Jersey: Prentice-Hall, 1966.
16. FOLEY, D.K. **The Strange Story of Economic Agent.** Department of Economics, Graduate Faculty – New School University, New York. 2002.
17. FURTADO-a, Bernardo. Crítica à lógica da urbanização. **Geosul,** v. 41 jan/jun, Universidade Federal de Santa Catarina, Florianópolis, SC, 2006.
18. FURTADO-b, Bernardo. **Mercado Imobiliário Bairro a Bairro: uma análise exploratória de econometria espacial em Belo Horizonte.** CEDEPLAR/FACE/UFMG, 2006. p. 20. (mimeo).
19. GLAESER, Edward, GYOURKO, Joseph e SAKS, Raven. Urban growth and housing. **Journal of Economic Geography** 6, 2006 pp. 71–89

20. HOLLAND, J.H. and MILLER, J.H. Artificial Adaptive Agents in Economic Theory. **AEA Papers and Proceedings**, May 1991.

21. HOLLAND, John. Complex Adaptive Systems. **Daedalus** 121:17-30, 1992-A.

22. HOLLAND, John. Genetic Algorithms. **Scientific American**. July. pp. 66-72. 1992-B.

23. JACOBS, Jane. **The Economy of Cities.** Ney York: Vintage Books, 1970. 268p.

24. LÖSCH, August. The Nature of Economic Regions. **Southern Economic Journal**, vol. 29, Aug., 1963.

25. MONTE-MÓR, R. L. **O que é o urbano no mundo contemporâneo.** Texto para discussão 281, CEDEPLAR/UFMG, 2006.

26. OLIVEIRA, Francisco de. **Crítica à razão dualista – O Ornitorrinco**. São Paulo: Boitempo Editorial 150 p., 2003.

27. PAGE, Scott. On the emergence of cities. **Journal of Urban Economics** 45, 184–208, 1999.

28. PARUNAK, et al. Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide. **Proceedings on Multi-agent systems and Agent-based Simulation**, Springer: 1998.

29. PINES & THISSE, Urban Systems: Market And Efficiency. **Journal of Public Economic Theory** 3(1), 2001. PP. 7-14.

30. RAUCH, J. Seeing Around Corners. **The Atlantic Monthly**, Volume 289, No. 4; 35-48, 2002.

31. SCHELLING, Thomas C. **Micromotives and macrobehavior.** New York, 1982.

32. SINGER, P. O Uso do Solo na Economia Capitalista. In: MARICATO, E. **A produção capitalista da casa e da cidade no Brasil industrial.** São Paulo: Alfa-Ômega, pp 21-36, 1982.

33. SOJA, Edward W. (2000). **Postmetropolis' critical studies of cities and regions** Oxford Malden, Mass.: Blackwell Publishers.

34. TORRENS, Paul, **New Advances in Urban Simulation: Cellular Automata and Multi-Agent Systems as Planning Support Tools.** CASA, London, 2001.

35. WHITE, R. & ENGELEN, G. Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land-use patterns. **Environment and Planning A,** 1993, volume 25, pp. 1175-1199.

36. WILENSKY, U. **NetLogo**. *http://ccl.northwestern.edu/netlogo/.* Center for Connected Learning and Computer−Based Modeling, Northwestern University, Evanston, IL., 1999.