Modelling intra-urban dynamics in the Savassi neighbourhood, Belo Horizonte city, Brazil

In: Paegelow M. & Camacho Olmedo M.T., Ed. Modelling Environmental Dynamics, Springer-Verlag, in press.

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Abstract
We have developed a space-time model to analyze and simulate the land use changes from 1985 to 2004 in the Savassi neighbourhood, Belo Horizonte, Brazil. The study area represents an important commercial reference to the city of Belo Horizonte, although it currently needs a new model for revitalization of its economic sector. We analyzed two periods: 1985 to 1996, the rising of a burgeoning street commerce in the region, and 1996-2004, the decline of this commerce and intense transformation of Savassi into a service zone. The conceptual basis for the development of the spatial simulation model was the technique of cellular automata, implemented on the software DINAMICA. Results from simulations for the 1996-2004 period approached the historical spatial patterns of change and projections to 2020 demonstrated the trend of this neighbourhood, continuing its transformation into a major service zone, thus concentrating commercial establishments into a few shopping malls. Therefore, the utilization of this land-use simulation model showed its potential as a tool for urban planning, aiming to foresee urbanistic implications due to land-use dynamics.

Keywords: land use analyses, dynamic model, urban simulation, cellular automata, intra-urban dynamics

Resumen
Hemos desarrollado un modelo del espacio-tiempo para analizar y simular los cambios de la utilización del suelo entre 1985 y 2004 en la vecindad de

Savassi, Belo Horizonte, Brasil. El área del estudio representa una referencia comercial importante a la ciudad de Belo Horizonte, aunque necesita actualmente un nuevo modelo para la revitalización de su sector económico. Analizábamos dos períodos: 1985 a 1996, del levantamiento de crecimiento de un comercio de la calle en la región, y 1996-2004, de la declinación de este comercio y de la transformación intensa de Savassi en una zona del servicio. La base conceptual para el desarrollo del modelo espacial de la simulación fue la técnica de autómatas celulares, puesta en ejecución en el software DINAMICA. Los resultados de las simulaciones para el período 1996-2004 acercaron a los patrones espaciales históricos del cambio y las proyecciones a 2020 demostraron la tendencia de esta vecindad en transformarse en una zona importante del servicio, así concentrando los establecimientos comerciales a algunas alamedas de compras. Por lo tanto, el modelo de la simulación de la utilización del suelo demostró su potencial como herramienta de ser utilizado en el planeamiento urbano, apuntando prever las implicaciones urbanísticas debido a la dinámica de la utilización del suelo.

Palabras clave: análisis de la utilización del suelo, modelo dinámico, simulación urbana autómatas celulares, dinâmica intra-urbana

Résumé

Nous avons développé un modèle d'espace-temps pour analyser et simuler le changement de l'utilisation du territoire urbaine de 1985 à 2004 dans le voisinage de la Savassi, Belo Horizonte, Brésil. Le secteur d'étude représente une référence commerciale importante à la ville de Belo Horizonte, bien qu'il ait besoin actuellement d'un nouveau modèle pour la revitalisation de son secteur économique. Nous avons analysé deux périodes: 1985 à 1996 (ascension d'un commerce de rue dans la région) et 1996-2004 (déclin de ce commerce et transformation intense de la Savassi dans une zone de service). La base conceptuelle pour le développement du modèle spatial de simulation était la technique des automates cellulaires, mise en application dans le logiciel DINAMICA. Les résultats des simulations entre 1996-2004 ont approché les modèles spatiaux historiques du changement du territoire. Les projections à 2020 ont démontré la tendance de transformation de ce voisinage dans une zone importante de service, avec la concentration des établissements commerciaux à quelques centres commerciaux. En conclusion, l'utilisation de ce modèle de simulation de changement du territoire urbaine peut être employé comme instrument d'aide à la planification urbaine, visant à prévoir des implications urbanistiques dues à la dynamique d'utilisation du territoire

Mots clefs: analyses d'utilisation du territoire urbaine, modèle dynamique, simulation urbaine, automates cellulaires, dynamique intra-urbaine.

1 Introduction

The city is a live phenomenon, in which interactions between the economics, societal pressures and politics drive its permanent transformation and growth. Hence, the urban changes consist of a process driven by demographic and economic growths, as well as public policies, which is stimulated by the commercial, industrial and services activities. These are the sectors that determine the city's dynamism, growth and the adaptation of the urban space as well as the urban daily routine. A better understanding of the urban evolution process requires the development of methods capable of representing this constant urban mutation (Batty et al., 2004), which, in fact, poses a major challenge to Geographical Information Systems (GIS), still strongly based upon a static vision of the geographic realm.

The advent of space-time models, in which the state or attribute of a certain spatial location changes over a period of time as a response of particular drivers (Burrough, 1998) creates a new field of possibilities for urban dynamics representation. Amongst these models lie the systems based on the cellular automata technique. This model envisages the space as an array of cells on which each cell assumes a different state based on the other cells' states within a certain cell neighbourhood and according to a specific set of transition rules (White and Engelen, 2000). All the transitions occur simultaneously as time advances in small discrete steps. Although this concept is very simple, it emerges as a very powerful tool for modelling urban phenomena, because of its tractability and flexibility to adapt to different geographical abstractions. This is the reason why this concept is often used by several researchers for urban dynamics representation, e.g. Engelen et al., 1997; Wu (1998), White et al. (2000), Li and Yeh (2000), Almeida et al. (2003), and Almeida et al (2008). These models aim to subsidize urban and regional planning, considering that information on land use change trend is necessary for the decision-making process. For example, the trend of land use dynamics consists of an important criterion to select areas needing urban renovation, improvement on transportation services and environmental quality, as well as installation of urban equipment, and revitalization of the commercial and residential sectors.

In this work, we applied the software DINAMICA, a generic type of cellular automata (Soares et al., 2002; Soares et al, 2005; Hermann et al., 2007), to develop a space-time model for the analysis and simulation of land use changes that occurred in the Savassi neighbourhood, Belo Horizonte, within the periods of 1985-1996 and 1996-2004. DINAMICA considers the 2D urban landscape represented as a fine grain matrix, in which each cell has a state that can be changed to another state depending on pre-quantified dynamics and the configuration of the cell neighbourhood. The influence of the cell neighbourhood is given by a set of territorial variables that control the land use transitions and the spatial pattern of changes. In a general way, the setup and operation of the simulation model consisted of: 1) the organization of a multi-temporal cartographic database for the land uses; 2) transition rates quantification; 3) selection of variables that, as urban and architectural references, influence land use changes; 4) calibration of the simulation system to achieve the best performance and validation aiming at assessing its ability to reproduce the intra-urban dynamics observed within the modelling time-period, and 5) prognostic for near future (2020) using the land use change trend of the most recent analysed period (1996-2004).

As a result, the present model aims to show not only the recent urban dynamic spatial patterns for Savassi, but also how this trend can provide insights to foresee possible near future spatial configuration as well as its urban implications. As a contribution, this tool will allow the assessment of outcomes of prospective scenarios for urban revitalization, something the residents of Belo Horizonte have been looking forward to for so long.

2 The Savassi Neighbourhood

The foundation of the Belo Horizonte city, in 1897, was a response to the need for a new state capital that could exert a regional political balance and minimize the economic differences that existed in the state of Minas Gerais at that time. This event also reflected a new era, which began with the proclamation of the republic, since Ouro Preto, the old capital, was seen as a symbol of colonial domination and monarchist power. Belo Horizonte creation was based upon the positivism concept, an outcome of the Illuminist manifestation at the end of the XIX century. The original project organized the city space in three different categories or zones: Firstly, at the centre, a zone was planned with meticulous orthogonal streets and large, treed avenues. The second category comprises the suburb (separate from the urban zones by a large circular avenue called Contorno, which means boundary in Portuguese) and the third were the agricultural zones (intended to serve as a greenbelt around the city). Both the second and third categories presented more flexible urbanization standards and were reserved for future urban expansion (Monte-Mór et al. 1994).

One of neighbourhoods within the Contorno avenue belt, known as Funcionários, was originally populated by public employees who had to move to the new capital. During the eighties and nineties this neighbourhood passed through an amazing valorisation process, resulting in the creation of the Savassi neighbourhood in 1991, a section of the original neighbourhood (municipal Law 5872), which by that time already consisted of an emerging zone of intense street commerce (Fig. 1).

The name Savassi came from a bakery located at 13 de Maio Square (current Diogo de Vasconcelos or Savassi square). In 1940, a trader Arthur Savassi, owner of a dairy, decided to open a bakery at 13 de Maio square, which soon became one of most popular places in Belo Horizonte city due to its delicious products.

In the eighties, several blocks were closed, resulting in the creation of paseos for strollers. The region around the paseos flourished with a prosperous commerce, especially for fine garments. However, in the beginning of the nineties, the street commerce, common in Savassi, declined due to the development in the city of several shopping malls that offered better parking facilities and more security for shoppers.

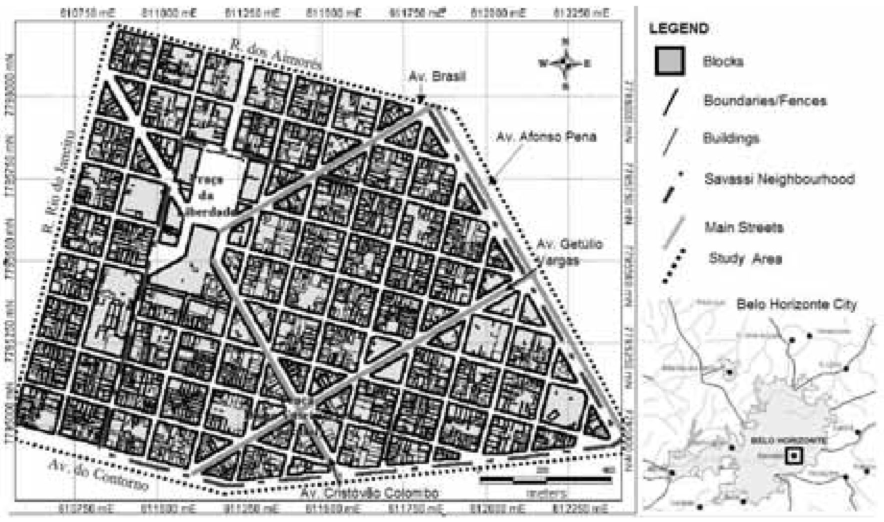
Amongst the transformations that occurred in the Funcionários neighbourhood to date, we distinguish the three most significant phases: The first is the creation and separation of the Savassi from the Funcionários neighbourhood. The second relates to the transformation from a traditional residential zone into an area of intense commerce of fashion and stylist garments. Around the commercial zone, the neighbourhood was also transformed into a place with bars and night clubs, gourmet restaurants, cafes and snack bars, therefore with intense social life day and night. Currently, the Savassi neighbourhood continues to present the same cultural and nocturnal emphases. There are abundant restaurants, bars, dance clubs, snack bars and everything that rhymes with fun. Recently, the commerce gave way to the services activities, with the establishment of several offices and headquarters for small business and even larger companies in the region. This span of vivid history occurred during the last two decades in Savassi will be the object for the simulation model presented below.

3 Methodology

3.1 Space-Time Model

Up-to-date GIS applications have focused mostly on static spatial models, for example, the land use zone proposition for urban or rural uses (Pedrosa and Chamber 2002). However, spatial phenomena, such as urban growth and land use change, are inherently dynamic and thus demand dynamic representations, uncommon to most traditional GIS (Batty et al. 2004).

Figure 1. The Savassi neighbourhood and its location with respect to the city of Belo Horizonte.



Space-time models aim to analyse and numerically simulate real world processes that show territorial expression. Hence, one of the greatest challenges for Spatial Information Science is the development of abstraction methods capable of adequately representing such processes, and as a result, modelling the system changes with respect to quantity and location (Chamber and Hunter 2003).

For this study, we employed a simulation model based on a cellular automata system. The cellular automata concept encompasses a set of interacting cells that allows the establishment of bridges between macroscopic and microscopic representations. Because of their tractability, cellular automata models have been applied to several applications, e.g. fire spreading (Karafyllidis and Thanailakis 1997), epidemic propagation (Sirakoulis et al. 2000) and deforestation (Soares-Filho et al. 2004 and Soares-Filho et al. 2006).

In this study, DINAMICA software is used as a simulation platform for our urban dynamics model. DINAMICA employs, as input, a set of maps, including the initial and final map of land use, also known as landscape maps, considering that a landscape could be viewed as a bi-dimensional array of land use types; the sojourn time map that keeps track of the time since the last change, and two sets of ancillary maps: the static and dynamic variables, the latter named so because they are updated by the model iteration. These two sets of variables control the location of changes (Fig. 2). These variables are combined by summing their Weights of Evidences (Goodacre et al. 1993; Bonham-Carter, 1994 and Soares-Filho et al. 2005), to produce a transition probability map, which depicts the most favourable areas for change (Soares-Filho et al. 2002, 2004 and 2005). Weights of Evidence consists of a Bayesian method, in which the effect of each spatial variable on a transition is calculated independently of a combined solution. The Weights of Evidence represent each variable influence on the spatial probability of a transition $i \Rightarrow j$ and are calculated as follows.

$$O\{D|B\} = \frac{P\{D|B\}}{P\{\overline{D}|B\}} \tag{1}$$

$$\log\{D|B\} = \log\{D\} + W^{+} \tag{2}$$

Where W^{+} is the weight of evidence of occurring event *D*, given a spatial pattern *B*. The spatial post-probability of a transition $i \Rightarrow j$, given a set of spatial data (*B, C, D,... N*), is expressed as follows:

$$\mathrm{P}\{i \Rightarrow j|B \cap C \cap D... \cap N\} = \frac{e^{\sum W_N{}^{+}}}{1 + e^{\sum W_N{}^{+}}} \tag{3}$$

Where *B*, *C*, *D*, and *N* are the values of *k* spatial variables that are measured at location *x,y* and represented by its weights W^{+}_{N}

The only assumption for the Weights of Evidence method is that the input maps have to be spatially independent. A set of measures can be used to assess this assumption, such as the Cramer test and the Joint-Uncertainty Information (Bonham-Carter 2004). Correlated variables must be disregarded or combined into a third that will be used in the model. As a result, the spatial relationships calculated by Weights of Evidence method are used to parameterize and calibrate the simulation model with respect to the spatial configuration of changes.

Another component of the model, the transition function, operates on the probability maps, and is constrained by the quantity of changes specified as input for each transition. This function draws the higher probability cells, after having ranked them in a vector file. The quantities of changes are determined *a priori* through the calculation of a historical transition matrix.

The transition matrix describes a system that changes over discrete time increments, in which the value of any variable in a given time period is the sum of fixed percentages of the value of the variables in the previous time period. The sum of fractions along the column of the transition matrix is equal to one (eq. 4). The diagonal line of the transition matrix does not need to be filled in since it models the percentage of unchangeable cells. The transition rates are passed on to the model as a fixed parameter. For DINAMICA, time step can comprise any span of time, since the time unit is only an externally set reference parameter.

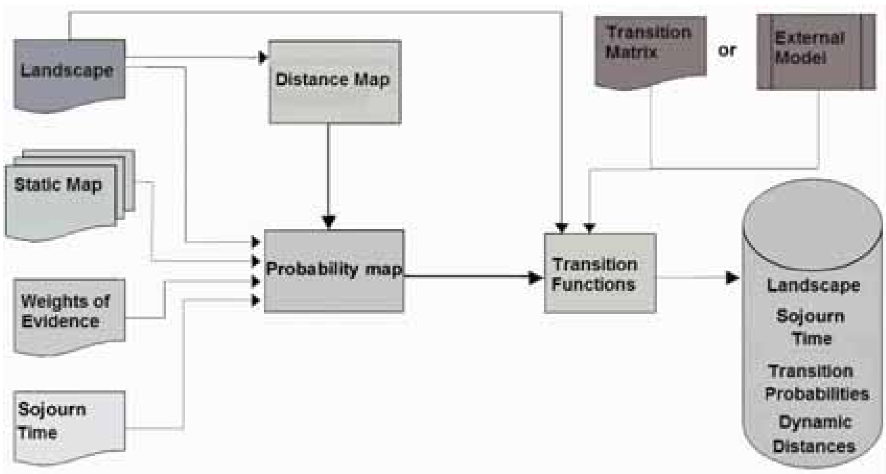
$$\begin{bmatrix} 1 \\ 2 \\ . \\ j \end{bmatrix}_{t=v} = \begin{bmatrix} P_{11} & P_{21} & P_{.1} & P_{j1} \\ P_{12} & P_{22} & P_{.2} & P_{j2} \\ P_{1.} & P_{2.} & P_{..} & P_{j.} \\ P_{1j} & P_{2j} & P_{.j} & P_{jj} \end{bmatrix}^{v} * \begin{bmatrix} 1 \\ 2 \\ . \\ j \end{bmatrix}_{t=0} \tag{4}$$

DINAMICA uses as a local CA rule, a transition engine composed of two complementary transition functions, the Expander and the *Patcher* (Soares-Filho et al. 2002). DINAMICA splits the cell selection mechanism into these two processes. The first process is dedicated only to the expansion or contraction of previous patches of a certain class, and it is called *Expander*. The second process is designed to generate or form new patches through a seeding mechanism, and it is called *Patcher*. For each transition, the percentage of transitions executed by the *Expander* function in relation to *Patcher* must be defined. The Patch Isometry is a number varying from 0 to 2. The patches assume a more isometric form as this number increases. The size of new patches and expansion fringes are set according to a lognormal probability distribution. Therefore, it is necessary to specify the parameters of this distribution represented by the mean and variance of the patch sizes to be formed.

As the quantity of changes is passed as fixed parameter to the model, its validation considers only the spatial locations of the changes. This is the last procedure before the model can be used for prognosis. It consists of a comparison between the model results and a reference map, in this case, the land use map at the simulation final time. To date, there are several map comparison techniques that have gained prominence as they apply multiple resolution windows to asses the spatial match between two maps, e.g. Costanza (1989), Pontius (2002), Power et al. (2001) and Hagen (2003). Nonetheless, there is neither consensus about which technique yields the most appropriate validation, nor what fitness value should be taken as a threshold to accept or reject the model. Of these techniques, the fuzzy comparison method by Hagen (2003) was adapted to be used in Dinamica, named therein as the "Reciprocal Similarity". This method employs a decay exponential function with the distance to weight the cell state distribution around a central cell. Generally, one can say that a simulated map presents good result when it has a fitness value higher than the one obtained through a comparison between the final and initial historical maps (Hagen 2003).

Although this study involves two time periods (1985-1996 and 1996-2004), the simulation model was only implemented for the last period. Finally after the model calibration, the model was applied to project the Savassi spatial configuration by the year of 2020, using the 1996-2004 parameters.

Figure 2. A simplified view of DINAMICA simulation model.



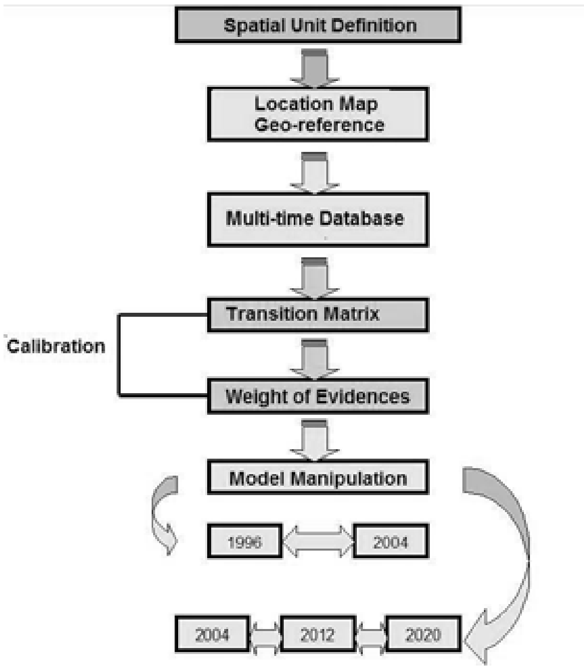
3.2 Multi-temporal Database Setup

A municipal law defines the Savassi neighbourhood boundaries. However, for this particular modelling exercise, two blocks were added to the east side and another additional two blocks to the north side of its formal neighbourhood boundary (Fig. 1), considering that the Bahia street and the

Brasil Avenue (original boundaries) do not represent urban barriers for the development and occupation of this region. The methodology applied in this study follows the flowchart presented in Fig. 3.

In this work, the modelling spatial unit is the urban land lot, with its boundaries defined from the original land parcelling map established by the municipality of Belo Horizonte. Land use can be defined as the utilization purpose given to a specific tract of land (Jensen and di Gregorio 2002). In this work, we used land use types defined by the municipality of Belo Horizonte city in its land-use zoning law (PBH, 1996) and mapped them for three specific years: 1985, 1996 and 2004.

Figure 3. Model development flowchart.

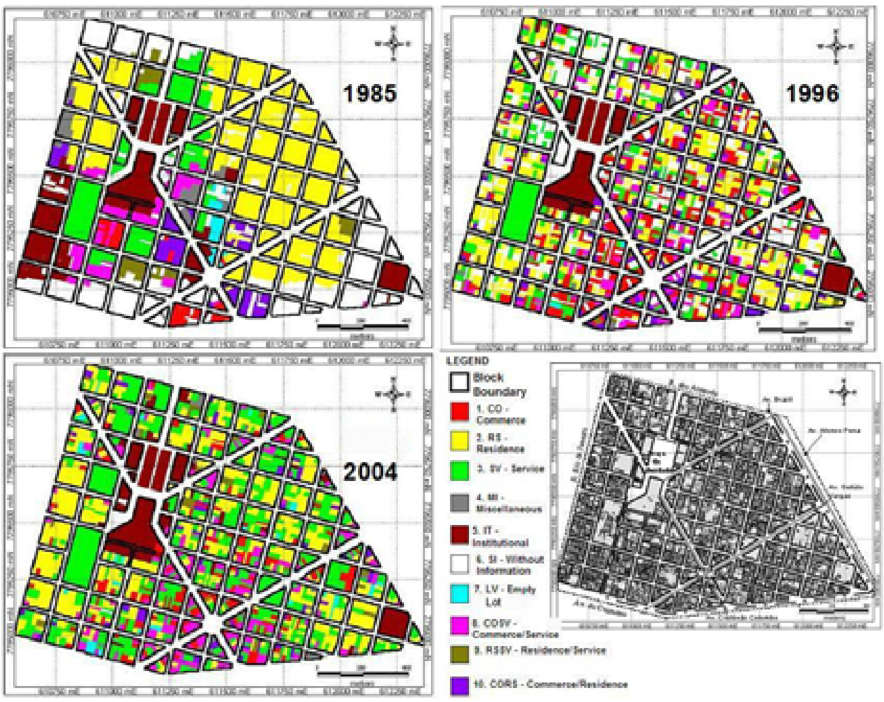


For 1985 and 1996, information on land use was extracted from a research project called “Percurso” (Passage) developed and organised by Prodabel (Data processing company of Belo Horizonte). For those data, the collection methodology is not known or published, nor are the criteria for land use classification known. Since these data are only available in microfilms at Prodabel, we had to digitize them by means of a scanner and then geo-reference the data using the municipal map of land lots.

Information on land use for 2004 was gathered through a field work. We took photography of the façades throughout the study area and made some visits to clarify some doubts. In this research, 1681 properties were surveyed. The data collected were then assigned to the map of land lots already in vector format.

Considering that the data have come from several sources, a standardization process became necessary in order to establish a common land use classification system. As a result, the final land use classes encompassed the following types: 1 - Commercial (CO); 2 - Residential (RS); 3 – Services (SV); 4 - Institutional (IT); 5 – Empty Lot (LV). Also, as we can find more than one activity per land lot since some of the original land parcels contain more than one property, we included combinations of these individual uses and when they were superior to 03 (three) uses per spatial unit, they were reclassified as 6 - Miscellaneous (MI). The lots whose use could not be identified were classified as: 7 - Without Information (SI). Other mixed uses were: 8. Commercial and Services (COSV); 9. Residential and Services (RSSV); 10. Commercial and Residential (CORS) - Fig. 4.

Figure 4. Land use in the Savassi region in the three observed times.



4 Results

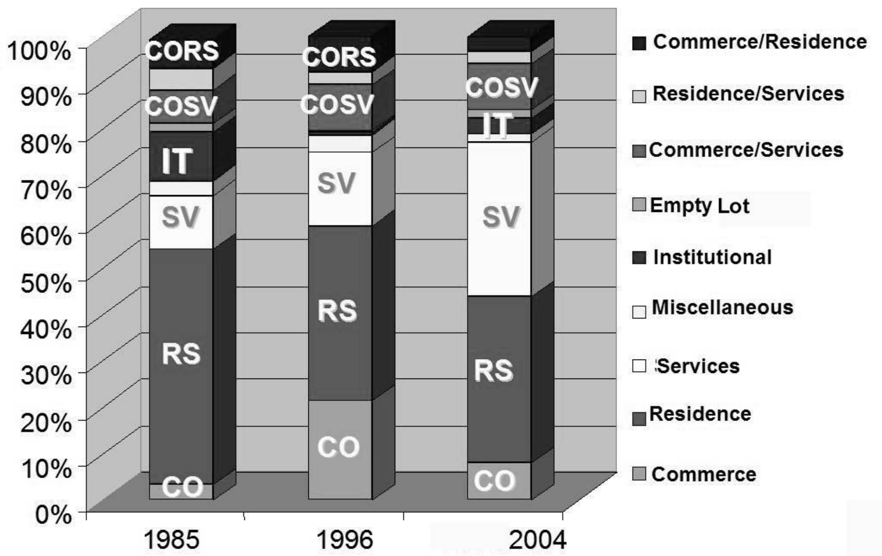
4.1 Change Analysis

Fig. 4 shows the distribution of land uses in the three observed times. One can observe an increasing diversification of the major land uses as a consequence of the new law on land use, approved and implemented in 1985, which reflects the concepts of pluralism and flexibility (PBH, 1985; 1996). This tendency was also maintained for the period of 1996-2004.

In the first period, there was an expansion of the commerce and mixed use of commerce and services, which was concentrated around the Diogo Vasconcelos Square. The eastern Savassi, traditionally occupied by residences in 1985, passed through a profound transformation, initially with the establishment of shops and afterwards with the spreading of offices and other small services, such as restaurants and bars.

This acute transformation is summarized in Fig. 5, which shows firstly the rise of the commerce between 1985 and 1996, and the resulting decline of the residential use. Over the 1996-2004 period, the recent trajectory of expansion of the service replaced some originally commercial areas, while the residential use remained practically unchanged.

Figure 5. Land use distribution in Savassi in the three observed times. Commercial (CO), Residential (RS), Services (SV), Institutional (IT), Empty Lot (LV), Miscellaneous (MI), Without Information (SI), Commercial and Services (COSV), Residential and Services (RSSV), Commercial and Residential (CORS)



The dynamics of empty lots must be regarded as a special phenomenon. A major decrease in their number can be observed until the middle of the nineties and an increase towards 2004. This can be explained by the real estate speculation. In this area, the properties have become extremely appreciated. As a consequence and common practice in the region, the real state market brought about the demolition of old houses to create space for apartment buildings, which led to an artificial increase of empty lots while these building were being designed. In turn, the oscillations in the institutional use can be attributed to the different methodologies employed in the data gathering processes.

The transition matrices were obtained by cross-tabulating the land use information per lot. They were useful to quantify the intra-urban dynamic tendencies over the two analyzed periods (Fig. 6). Both matrices 1985/1996 and 1996/2004 represent the intense dynamism, which occurred in the Savassi region through these two decades, indicating that most of the lots changed their uses. Notice that the diagonal line of the transition matrix indicates the permanence of the uses, of which, during the first period, 32% of commerce, 44% of residences and 22% of services remained unchanged. In turn, for the second period, 17%, 60% and 44%, respectively, of the uses above have not changed.

Another important observation for the first period is that 27% of commercial use has changed to residence (maybe, a return to the original use), while 24% have changed into mixed use of commerce and service. More than 40% of the residences have changed into commerce or services and 32% of the services have changed to residential use, while 15% have changed into commerce.

The continuous changes for the commerce use were intense during the last decade, in which only 17% of it remains unchanged, 25% has changed into residences and 34% into services. During this period, the residential use was more constant, when only 10% changed into services and another 20% for other uses. The services showed the most constant use (45%), while 38% changed into the residential use and the remaining, approximately 17%, has changed into other uses.

The permanence of the miscellaneous use is meaningless, because of the several different uses (more then two) present at the same spatial unit. Between 1985 and 1996, the permanence of the institutional use was small; approximately 58% of it changed into residence and 15% into services use. The institutional use did not present any type of changes between 1996 and 2004. The empty lots presented 0% of permanence through the two analyzed periods. In synthesis, the dominant land uses in the region over the study period have been the commercial, residential, services and mixed use of commerce and service. During the first period, the residential use increased, despite the advance of the commerce in the region. In the latter period, the services spread at the expense of commerce; even so the extent of the residential use has been practically constant.

Fig. 6. Transition matrices for 1985/1996 and 1996/2004, from cross-tabulating information per lot and 1996/2004 from cross-tabulating information per cell on the raster maps.

1996

1985	CO	RS	SV	MI	IT	LV	COSV	RSSV	CORS
CO	0.324324	0.27027	0.081081	0.054054	0	0	0.162162	0.027027	0.08108
RS	0.188596	0.445175	0.144737	0.037281	0	0	0.078947	0.019737	0.08552
SV	0.150538	0.322581	0.225806	0.053763	0	0	0.16129	0.043011	0.04301
MI	0.184211	0.315789	0.210526	0.026316	0	0	0.105263	0.026316	0.13157
IT	0.098039	0.578431	0.147059	0.019608	0.068627	0	0	0.029412	0.05882
LV	0.533333	0.133333	0.2	0	0	0	0.066667	0	0.06666
COSV	0.1	0.457143	0.157143	0.071429	0	0	0.114286	0.014286	0.08571
RSSV	0.228571	0.2	0.285714	0.028571	0	0	0.2	0	0.05714
CORS	0.389831	0.135593	0.101695	0.033898	0	0.016949	0.152542	0.016949	0.15254

2004

1996	CO	RS	SV	MI	IT	LV	COSV	RSSV	CORS
CO	0.177143	0.245714	0.342857	0.022857	0.028571	0.022857	0.12	0.011429	0.02857
RS	0.060606	0.600551	0.203857	0.008264	0.013774	0.022039	0.035813	0.027548	0.02754
SV	0.048951	0.377622	0.447552	0	0.020979	0.013986	0.041958	0.041958	0.00699
MI	0.057143	0.228571	0.257143	0.028571	0	0	0.257143	0.085714	0.08571
IT	0	0	0	0	1	0	0	0	0
LV	1	0	0	0	0	0	0	0	0
COSV	0.05814	0.186047	0.290698	0.081395	0	0.011628	0.22093	0.046512	0.10465
RSSV	0	0.25	0.65	0	0	0	0.05	0.05	0
CORS	0.173333	0.226667	0.24	0.013333	0	0.013333	0.32	0	0.01333

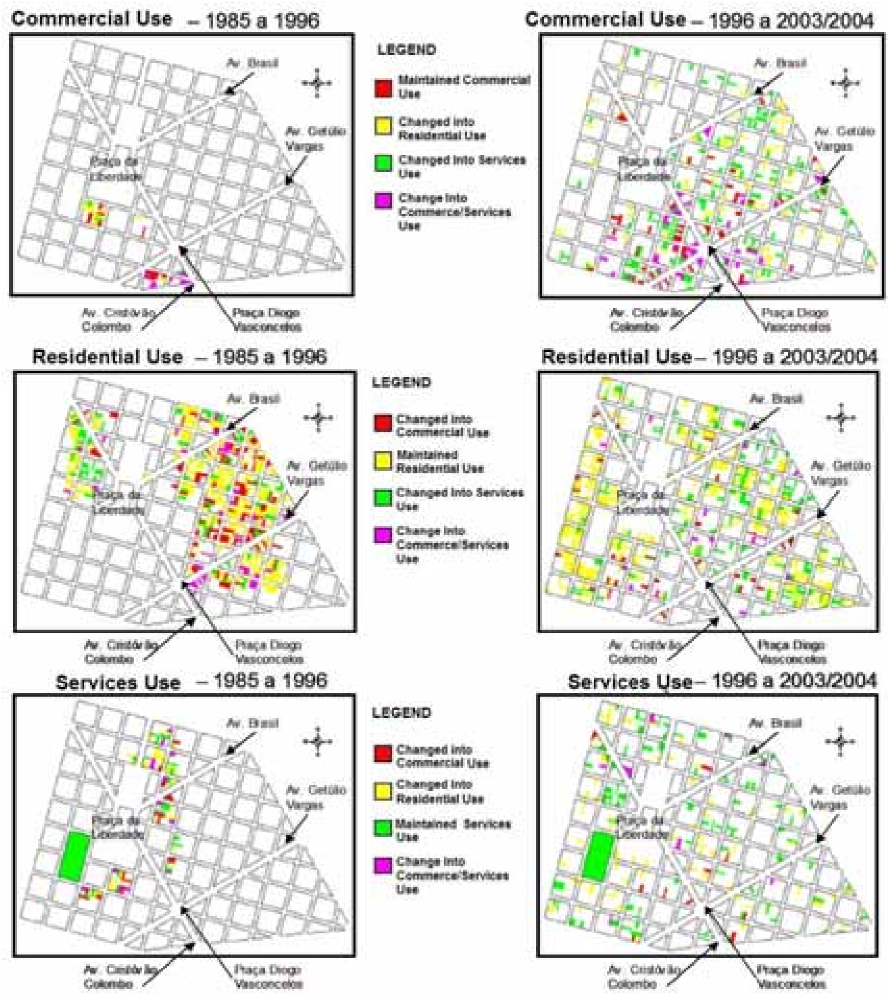
2004 Per cell

1996	CO	RS	SV	MI	IT	LV	COSV	RSSV	CORS
CO	0,1612	0,2176	0,3695	0,0242	0,0298	0,0267	0,1438	0,0099	0,0174
RS	0,0415	0,4593	0,2569	0,0065	0,1464	0,0172	0,0266	0,0226	0,0229
SV	0,0632	0,3420	0,4407	0,0121	0,0147	0,0251	0,0632	0,0346	0,0043
MI	0,0789	0,2434	0,2566	0,0197	0,0000	0,0000	0,2500	0,0724	0,0789
IT	0,0000	0,0000	1,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
LV	0,3125	0,0000	0,6875	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
COSV	0,0573	0,1762	0,2421	0,0917	0,0086	0,015759	0,2407	0,0444	0,1232
RSSV	0,0000	0,2488	0,5493	0,0751	0,0000	0,0000	0,070423	0,0563	0,0000
CORS	0,1373	0,2246	0,2310	0,0468	0,0000	0,0097	0,3425	0	0,0081

The analysis of the maps of changes allows us to identify the hot spots of changes for each land use as well as its major urban attractors (Fig. 7). In this figure, one can notice that the commerce activity, initially located at the sector east of the region, tended to concentrate around Diogo de Vasconcelos Square (Savassi) and through Cristóvão Colombo and Getúlio Vargas avenues and adjacent streets. The residential use remained at the most peripheral portions of the region, both east and west of Savassi (next to the Liberdade Square), far away from the major access axes, i.e. avenues. The service use indistinctly occupies the whole region. This analysis allows us to identify the territorial variables that influence most the location of the changes: 1) distance to the Savassi Square; 2) distance to the

Liberdade Square; 3) distance to the main avenues (Cristóvão Colombo and Getúlio Vargas avenues); 4) distance to the residential use and 5) distance to the commercial use. The inclusion of these two latter variables aims to add to the model the contagious effect present in the commerce development and in the permanence of the residential use.

Figure 7. Maps of changes for commercial, residential, and service uses.



4.2 Land use change simulation model

The spatial simulation model was developed only for the period 1996-2004, because the data for the previous period presented larger uncertainties. As an input parameter, DINAMICA receives a transition matrix. Because this model operates at the raster cell level, it was necessary to transform the transition matrix obtained at the land lot level (generally about 400 m² in size) to the dimensions of the raster cells, in this study with the resolution of 10x10 meters – 100 m².

In this way, a new transition matrix was obtained by cross-tabulating the raster maps (Fig. 8). Despite the different spatial units, the matrices conformed in terms of the corresponding transition rates. Nevertheless, this new matrix does not represent the changes in terms of lot boundaries, but as the areal extent occupied by each land use.

Another important step in the development of the simulation model consisted of reducing its original complexity due to the large number of cell states and transitions. Notice that it is necessary to calibrate the model for each transition using the Weights of Evidence method. As a result, the model was reduced to 8 states, with the exclusion of the empty lot and the prevention of transitions between the large institutional areas, such as "Minas Tenis Clube" – a major sport centre and "Palácio da Liberdade" – the state of Minas Gerais government seat. Fig. 8 illustrates the transition matrix implemented in the simulation model, with 8 states and 45 transitions.

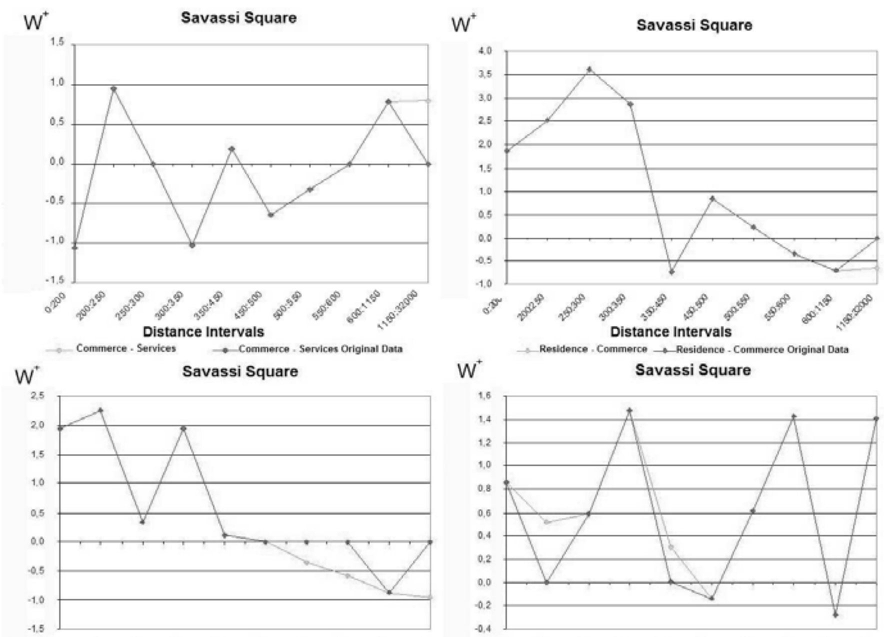
Fig. 8. Transition Matrix for the simulation model.

		2004							
		commerce	residence	service	miscellaneous	institutional	com_serv	res_serv	com_res
1996	commerce	0.166	0.224	0.380	0.025	0.031	0.148	0.010	0.018
	residence	0.053	0.587	0.215	0.008	0.044	0.034	0.029	0.029
	service	0.065	0.351	0.452	0.012	0.015	0.065	0.036	0.004
	miscellaneous	0.079	0.243	0.257	0.020	0.000	0.250	0.072	0.079
	institutional	0.000	0.000	0.017	0.000	0.983	0.000	0.000	0.000
	com_serv	0.058	0.179	0.246	0.093	0.009	0.245	0.045	0.125
	res_serv	0.000	0.249	0.549	0.075	0.000	0.070	0.056	0.000
	com_res	0.139	0.227	0.233	0.047	0.000	0.346	0.000	0.008

The next step consisted of obtaining the Weights of Evidence coefficients that define the influence of each one of the five territorial variables on the modelled 45 transitions (distance to Savassi square; distance to Liberdade square; distance to the main avenues, distance to residences and distance to commerce). The graphs in Fig. 9 illustrate the spatial relationship given by the Weights of Evidence with the variable "distance to Savassi square" and the main four land use transitions observed in the region. Positive Weight of Evidence values favour a transition whereas negative values repel it. These functions have been corrected to prevent the "block effect", that is the lack of information on land use over the street network. Observe the favourability of the commerce transition close to the Savassi Square (Fig. 9).

As a consequence of the large number of transitions, a total of 225 Weight of Evidences functions to be employed in the simulation model were obtained. This became possible thanks to DINAMICA modules that allow the categorization of continuous grey-tone variables and the calculation of their weights of evidence coefficients in an automatic fashion. Finally, a transition probability map was produced for each transition by summing the Weights of Evidence related to each of the five territorial variables (Soares-Filho et al., 2005). Notice that in the case of distances to residential and commercial areas, these variables can be recalculated as the model iterates, thus representing dynamic feedback from the model.

Figure 9. Weights of Evidences coefficients for distances intervals to Savassi square with respect to the transitions: commerce-service, residence-commerce, service-commerce and service-residence.



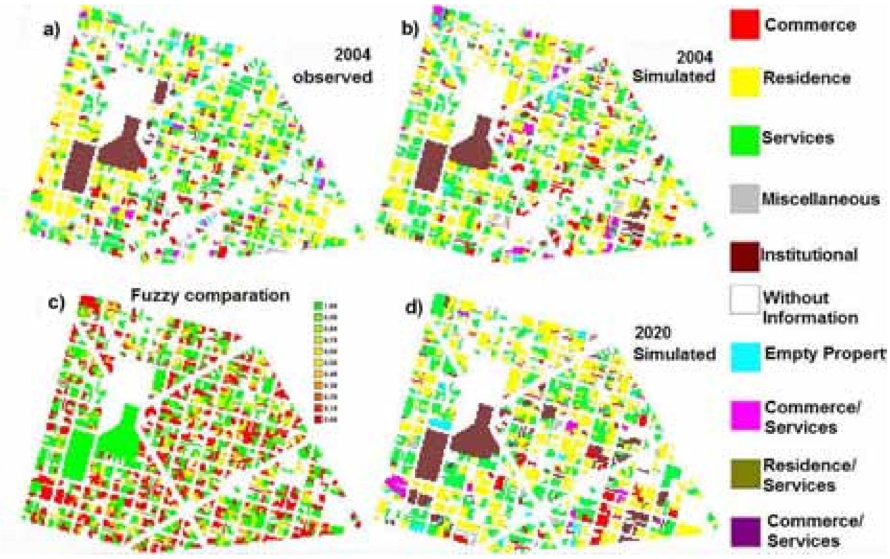
The transition probability maps determine the most probable locations for the quantity of cells to be changed as specified by the transition matrix

(Fig. 8), both of which are input for Dinamica's CA transition functions. These special functions were designed to allocate the transitions throughout the land use map, with the aim of reproducing the patterns of changes. In order to do this, these functions permit the formation of a variety of sizes and shapes of patches of change, using the input parameters specified by the user. In this study, the *Patcher* function was set to produce patches with the size of four cells (each cell = 100 m²), aiming to approximate the size of urban lots - the original spatial unit of analysis – with in average of 400 m². Finally, the model was run for a single time step equivalent of 8 years, since its transition matrix could not be decomposed in a matrix of annual steps.

Fig. 10 presents the map output from the simulation for the period 1996-2004 in comparison with the real situation observed in 2004 and the spatial fitness map using the fuzzy method with an exponential decay function. The average adjustment of the simulation model achieved 54% in comparison with the score of 52% obtained when comparing the input map of 1996 and the reference map of 2004. According to Hagen (2003), one can consider a reasonable match when a simulation shows an increase in the fuzzy metrics from a reference situation that employs the initial and final observed maps. Therefore, the result of the model can be regarded as appropriate, especially taking into consideration its large number of states and transitions.

Using the same configuration of the 1996-2004 simulation model and input map of 2004, we performed a simulation with two time steps, each one with eight years, aiming to project the spatial configuration of Savassi neighbourhood by the year 2020. As a result, Fig. 10 (d) shows if the current trends persist into the near future, there will be a dominance of the service uses around the major commercial point of the Savassi neighbourhood - the Savassi square - and the formation of clusters for the remaining land uses.

Figure 10. a) Land use observed map compared with the simulation for 2004 (b) and the fuzzy validation map (c), and 2020 simulated land use map (d). Notice the tendency to form clusters of commerce in 2020 map.



5 Conclusion and outlook

Through this study, we showed that the Savassi neighbourhood passed through a profound transformation during the last two decades, resulting today in a region where street commerce mingles with a large number of offices amid islands of residential buildings. The co-occurrence of services and residences is a result of land speculation, which stimulated the concentration of high buildings with mixed use of commerce at the street level and residences in the upper stores.

The direct outcome of this land use intensification is the increase of traffic and people circulating through the region, which leads to the need of a new urban planning able to mitigate this situation. Also observed was the permanence of the institutional use and the reduction and agglutination of the commercial use in clusters, the latter phenomenon demonstrates the consolidation of “shopping malls” and commercial galleries to the detriment of street commerce. This trend has prevailed as a consequence of the lack of security on the streets, as well as the scarcity of infrastructure for public parking. The simulation model was useful to demonstrate that these changes do not occur randomly. In fact, they are influenced by the spatial arrangement of main urban land marks, such as squares and avenues.

An important limitation to the spatial simulation model is its capacity to reproduce the observed patterns of change – a complicated process, especially in this study, considering the large number of parameters to be calibrated. However, the analyses, calibration and validation tools available in DINAMICA have facilitated the setup and operation of this complex model, showing that it is feasible to handle multiple states and transitions at a fine spatial resolution unit represented by the urban land lot. Moreover, the *Patcher* CA function can mimic this fine spatial unit using a raster representation.

Therefore, the complexity of the observed dynamics, with 8 land uses and 45 transitions, of which several were concurrent, could be represented using the DINAMICA platform. Applications using this software involve studies from the local scale, such as the case of Savassi, with cell of 10x10 meters, up to continental level simulations, such as the example of the SimAmazonia model - an array of 140 million cells at 1 km² resolution developed to depict the Amazon basin dynamics (Soares-Filho et al., 2006). This shows the potential and flexibility of this software architecture for modelling various dynamic phenomena.

The projection for 2020 (Fig. 10 d) provided the opportunity to explore the potential spatial configurations that may emerge from this recent intra-urban dynamics as well as its urban implications. In this context, it is important to mention that the model represents possible urban trajectories and not exactly what the future will present.

The availability of such tools for the representation of urban dynamics offers new possibilities for urban planning as they allow us to explore the impacts of a proposed intervention beforehand. Although this has not been a common approach to date, it is expected that the developed methodology will become an effective tool for supporting urban planning decisions, considering that the city is under a perpetual mutation. In this way, the model has also been designed to be used as a communication tool to warn decision-makers for future urban outcomes as well as to make the community aware about the need for investments for the development, preservation or recuperation of this important urban space. Conscious

Acknowledgments

The authors thanks FAPEMIG for the financial support for this project (CRA-2463/98), the CSR team (Remote Sensing Centre - UFMG) for the technical support and the Gordon and Betty Moore Foundation and LBA Project (Large Scale Experiment of Biosphere and Atmosphere in the Amazon) which have indirectly, through the Project "Scenarios for Amazonia", supported the DINAMICA software development.

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