"Geocomputation Applied to the Forecast[1] of Sustainable Strategies[2] for Land Occupation: The Case of the Tietê Downstream Watershed"

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Abstract. This scientific paper, a brief summary of a PhD Thesis currently under execution at the Division of Image Processing of the Brazilian National Institute for Space Research (DPI – INPE), is committed with building up a methodological guideline to the prediction of sustainable strategies for land occupation. By means of quantitative as well as qualitative models and the usage of GIS (Geographic Information Systems), land occupation and land development scenarios[3] shall be generated for the particular case of the Tietê River Downstream Watershed, west of São Paulo State. This forecast shall thus be made possible through advanced spatial analysis and modelling techniques, involving linear and non-linear micro- and macro-scale models, and through the employment of last generation satellite images, aerial and digital photos as well as socio-economic data interpreted in an integrated manner in space and time.

Keywords: Cellular Automata, Geocomputation, Land Use Dynamics, Town Planning

1. Introduction

The present application of advanced spatial analysis techniques in environmental, regional, and town planning points to an enhancement of the geotechnologies that wisely embody mathematical and statistical packages, compatible with the multi-dimensional complexity of factors influencing the land occupation processes. This complexity refers to the temporal (over time), spatial (scale) and hierarchical (occurrence and importance) features of these factors and their mutual implications.

In a near future, the analogical conventional planning methods will rapidly become inappropriate to meet the increasingly fast demand for solutions, inducing therefore the regional, town, and environmental planning and management governmental organisations to rely upon the geotechnologies output on their daily decision making processes.

2. Study Area

The Tietê River Watershed extends over a 71,800 km^2 surface and shelters a population of about 23.8 million inhabitants. It experienced one of the most important industrialisation processes held in South America and hence presents the common impacts resulting from uncontrolled urban agglomerations, agricultural and industrial development as well as from the implementation of several medium- and big-sized dams. Upon the correct usage of the natural resources available on this strategic area, the success of its future development will depend, which also plays a decisive role for the Mercosur´s (South American Economic Community) performance.

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[1] Forecast means, in this particular case, the hypothesis about the development of a certain situation upon basis of its diagnosis, i.e. of a detailed study on its evolutionary process as well as on its present conditions.
[2] Strategies are to be understood as a set of defining variables, which impel the land occupation and development processes.
[3] Scenarios represent here the materialisation of strategies in the physical space under different land occupation profiles.

3. Methodology

The thesis accomplishment follows the procedures described below, which consist of five major topic sections.

3.1 Multi-Temporal Analysis of Occupation Trends in the Latest Four Decades

Through the overlay of land use maps for three representative municipalities (case studies) of the watershed, obtained from or crosschecked with high resolution satellite images, and referring to the time intervals 1962-1974, 1974-1985, 1985-1999, transition maps are hence elaborated for the same periods. The transition probability for each cell (300 m x 300 m) of the study area is then calculated not only as a function of the observed variables, but also in view of the neighbouring cells land use. Spatial statistics techniques such as logistical regressions are used for relating the spatially observed land use transitions with the biophysical and socio-economic variables (Filho 1998; Geoghegan et al. 1998; White et al. 1999). A series of models involving different combinations of explaining variables are employed for estimating the types of land use transitions for the first time interval (1962-1974). The estimated coefficients of each model are utilised for predicting the land use changes in the following time intervals.

3.2 Accuracy Check of the Land Use Transition Probabilities

The transition probabilities foreseen for the time intervals 1974-1985 and 1985-1999 are then compared with the transition that actually took place in these periods. This aims at verifying the effectiveness of the endogenous as well as exogenous biophysical and socio-economic variables employed in the analysis, and at evaluating their incidence and importance degree throughout time and different scales, so as to enable, by means of successive experiments, the building up of a transition forecast model adjusted by the historical sequence. Such variables refer to the land use management system; physical characteristics of the environment (like declivity and soil type); zoning regulations; the institutional framework; infrastructure network; land price; the investments scenario; population distribution and employment offer; domestic and external economy; landscape valuation; local, national, and international public policies, and so forth. The way such a transition forecast model, operating on two spatial scales (macro and micro), integrates several sub-models to cope with the diversity of variables is described in Figure 1 (White et al. 1999).

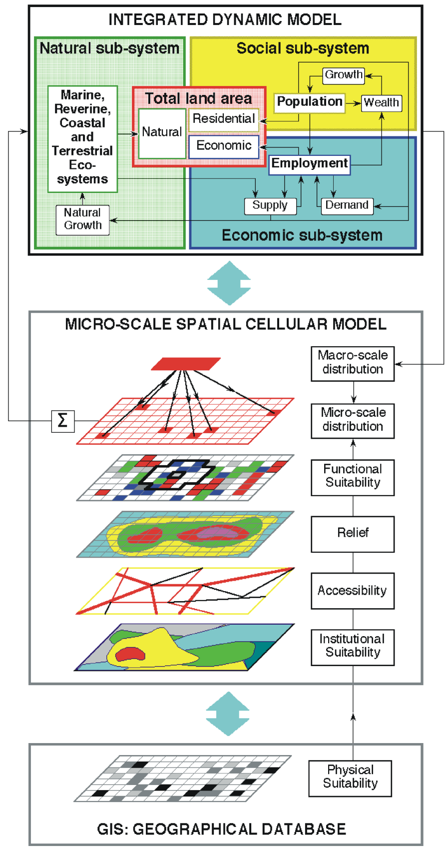

Fig. 1: Land Use Dynamics Simulation Model (White et al.), 1999

3.3 Generation of Qualitative and Quantitative Scenarios for the Project Horizons 2005 and 2010

Considering the transition forecast models (land use dynamics simulation models), qualitative and quantitative land occupation and development scenarios are hypothesised for the study area, with the simultaneous estimation of their degree of occurrence probability. By means of spatial-econometric models, each variable must be carefully weighted according to its role and contribution in the time horizons being considered. New variables are then added, such as the envisaged possibilities of the productive sectors, the positive impacts deriving from the enhancement of the Tietê Waterway activities, the new trends of local economy and those imposed by the Mercosur-oriented development policies.

In the scenarios formulation, interactions between slow and fast variables are explored. The former ones refer to those variables which present a high degree of occurrence inertial probability and highly predictable effects. On the other hand, the fast variables concern those ones which lead to sudden qualitative and/or quantitative changes in the land use dynamics, usually breaking the major spatial structure trends. These interactions will allow the determination of the scenarios predictability limits (reliability degree).
Likewise the preceding sections, this one will work on the basis of cells, which can be defined as the minimum homogeneous spatial units of the study area. These cells, also known as ***cellular automata*** (CA), are attractive for a number of reasons (Engelen and White 1999):

- they are inherently spatial (typically defined on a raster cell space) and are thus compatible with most spatial data sets;
- they are dynamic, and can therefore represent spatial processes in a direct way;
- they are highly adaptable – they can be set up to represent a very wide range of situations and processes;
- they are rule-based, and can thus capture a wide variety of spatial behaviours;

- they are simple, and therefore computationally efficient; and
- in spite of their simplicity, they can exhibit extraordinarily rich behaviour, once complex global patterns emerge directly from the application of simple rules embodied in CA models (Couclelis 1997). Some simple CA have been shown to be formally equivalent to a Turing Machine (Universal Machine) – i.e. these CA can represent and execute any possible algorithm (Engelen and White 1999; White et al. 1998; White et al. 1999).

Together with CA, ***multi-agent systems*** (MA) are the favoured techniques for implementing high-resolution models of spatial dynamics, once such systems account for the diversity of variables influencing spatial dynamic processes. Unlike conventional system dynamics techniques, CA and MA have proven able to handle high resolution applications easily, and thus to combine the precision of high quality data sets typically resident in GIS with the realism of dynamics to yield convincing predictions of the future states of spatial systems (Engelen and White 1999).

3.4 Inter-scale Implications: Demonstrative Zoom for the Multi-Temporal Analysis and the Future Scenarios in Selected Subareas

The methodological procedures undertaken in the previous topic sections are then repeated for selected subareas, particularly prone to urbanisation booms. It is aimed herewith the examination of mutual inter-scale implications, such as:

- the changes of the variables occurrence and importance on different analysis scales and throughout time;
- the extent to which the endogenous land use transition processes account for the urban landscape configuration;
- retard and acceleration of the land use dynamics;
- transition processes that are spatially diffuse, buffered, amplified, inverted, or otherwise transformed and their impacts on the spatial structure patterns;
- how exogenous variables can be handled so as to fit progressive smaller scales;
- the filtering of variables from smaller to bigger scales (smoothed out or aggregated);
- the required nesting models for scaling up and down, and the weak linkages among them;
- the horizontal correlation among parallel hierarchies within the same analysis scale, but with different temporal dynamics;
- how diverse circumstances can change previously unimportant variables into critical and radical factors for land use transition; etc. (Geoghegan et al. 1998).

3.5 Macro Environmental Impact Assessment for the Hypothesised Scenarios and Proposal of Corrective Guidelines

For each hypothesised scenario on different scales, macro environmental impact assessments should be carried out, focusing not only on the scenarios impacts over the physical environment, but also over the:

- socio-economic environment (effects on the local development: employment offer, income increase, quality of life, etc.);
- political scene (the adjustment degree of the different scenarios to the development strategies of local and regional authorities);
- the institutional framework (the scenarios matching to the local administrators´ expectations and the scenarios adjustment to the institutions building capacity in the considered project horizons);
- the regional and continental setting (the possibilities offered by each scenario towards a rationalisation and optimisation in the Mercosur envisaged integrated production).

This impact assessment does not aim at a deeper detailing and shall as well provide general corrective and/or amendatory measures for the undesirable effects of each scenario, offering thus alternatives of sustainable strategies for land occupation.

4. Results

As this paper relates to a work in progress, the preliminary results of the land use dynamics simulation are being worked out. Although cities display variety and complexity (Batty and Xie 1997), the modelling techniques adopted shall observe fidelity and realism in delineating urban landscape. The products to be obtained will undergo a continuous refinement by means of improvements in the models calibration and statistical validation tests.

An innovating contribution of this research project to the field of geocomputation applied to land use dynamics simulation lies on the fact that it is committed with exploring the modelling of exogenous variables like public policies, the impact of great undertakings (industrial poles, the Tietê Waterway and its intermodal terminals), the rules of the unified South American market (Mercosur), amongst others.

With this end, a new program that optimally merges the functions offered by the presently available softwares with those ones specifically required by this research project is currently under development. It is conceived to operate on micro- and macro-scale, offer high spatial resolution, incorporate the notion of multi-agent systems and add neural networks packages for the simulation operators, which can rely on transition probabilities calculated by fuzzy logic.

5. Discussion

CA urban models have been extensively used (Batty and Xie 1997; Couclelis 1997; White et al. 1999). Whereas models with simple rules seem to better fit those cases with few categories of land use (Clarke et al. 1997), more refined modelling techniques have been commonly employed in cases presenting a complexity of variables and diversity of land use categories (White et al. 1998). The modelling of exogenous variables of larger scales implications still represents a challenge, and the answers offered in this regard until then are far from exhausting the wide range of modelling possibilities.

6. Conclusion

The addition of a more complete variables network and refined modelling techniques concur for a keen improvement in the quality of the simulation results. According to White et al. (1999), while we can never know precisely what the future will bring, such models of land use dynamics simulation give a usefully reliable indication that if current conditions are like *this*, then the situation in ten years will probably be substantially like *that*. Such general indications of future conditions are potentially quite useful to planners and policy makers.

As it is intended that the envisaged simulation model be operated by end users such as urban planners who have access to a wealth of data, it will be possible to extend the richness of the modelling framework to provide better estimates of future conditions under various scenarios.

Acknowledgements

The author wishes to thank Prof. Dr. Antonio Miguel V. Monteiro and Prof. Dr. Gilberto Câmara for their insightful comments and ideas which have improved the quality of this paper.

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