URBAN GROWTH MANAGEMENT IN AFRICA WITH GEOGRAPHICAL INFORMATION TECHNOLOGIES. MAPUTO CITY CASE STUDY

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1. Introduction

The main goal of this study is to understand the dynamic of human intervention on the landscape organization of Maputo City in Mozambique.

The land use change is an unquestionable indicator of urban change. If we center the evolution of a city in its geometrical and semantic of its smallest parts which will reproduce themselves along time we can understand, although partially, the dominant model of this evolution.

The monitoring and the quantitative and qualitative evaluation of the spatial and temporal land use changes is a fundamental stage in the understanding of the dynamics of the processes which leads to the transformation of the urban landscapes and therefore to the geographical framing of the planning actions.

The land use model of Maputo concerning the prediction of its change patterns seems to be relevant once its dynamics and growth fits in the set of the African rapid growth cities and therefore with serious problems in respect to its management and planning.

The development of a model that previews the future land use considering the occurred changes and considering some physical constraints (in the absence of director plans) allows a contribution to the make up of planning scenarios and of alternative policies in terms of its effects in the future development of the land use in Maputo city.

Remote sensing, geographical information systems and cellular automata are nowadays indispensible tools in systematization, analysis and simulation of the land use change processes. In this study the geographical technologies are used as a mean to represent the city, in other words a way to describe a set of features of the urban world considering its management and planning. Google Earth also was a resource to present results.

2. Information for Land Use Analysis within a GIS

The perception of the dynamic of the human actions in the organization of Maputo city was carried out, in a first stage, from the analysis and overlay of the five land use digital maps (1964-2001). The first step concerning the elaboration process of land use maps based on visual interpretation of aerial photos was the definition of the minimum mapping unit which is the smallest area of the study territory for which we pretend to represent its land use. The selection of this minimum mapping unit is determined by the resolution/scale of the source data (aerial photos and satellite images) and determines the detail of the final land use map. For the land use maps of Maputo we established $25m^2$ for the minimum representation unit.

The second step during the land use maps creation process was the outline of a classification system and of the criteria used to distinguish the different categories of the features. The classification was understood here as an intellectual process of generalization to group phenomena with the intention of obtaining relative simplicity typifying them.

The classification method used in this project took into account the following objectives: i) susceptibility of being used in all the data sources; ii) possibility of the land use be inferred in the majority of the cases from the different land occupation; iii) possibility of integration and conciliation with future lands uses; iv) possibility of production of different scale land use maps using the adequate specification level.

The nomenclature obtain was therefore organized in three levels resultant from a hierarchical classification system that includes descriptive classes and parametric classes:

- Level I contains the main types of land occupation: build-up areas (residential, economic activity, equipments and infrastructures) and vacant and natural areas. This level is suited for analysis that may serve the definition of policies for resource management at regional or national scale;
- Level II contains 26 land use classes which can be identified through visual interpretation of remotely sensed images resourcing to deductive analysis using the primitives shape, tone, size, texture, shade, site, pattern, association (Lillesand; Kiefer, 1997) and in some cases complemented with ancillary documents. This level allows the diachronic analysis of the land use and is suitable for municipal planning and management;
- Level III contains classes with a high degree of specification concerning the land use where besides visual interpretation with a strong deductive component requires also an intensive field work. It is conceived for the production of actual land use maps to support urbanization plans and implies the manipulation of an operational Geographical Information System (GIS).

Among a set of varied geographical documentation existing for Maputo City, the remotely sensed images, namely aerial photos and high resolution satellite images, were the main sources of data for the production of the land use maps concerning the period 1964-2001.

In spite of the automatic classification of remotely sensed images being nowadays quite developed and spread over commercial software, its application in the recognition of urban land uses are still limited. Within the urban systems there are complex economic and social activities with visible space repercussions and the existing software, even the ones supported by object oriented algorithms, are still far from the levels of interpretation required in this project.

Therefore we had recourse to the visual interpretation method of the images with onscreen polygon digitizing using a GIS. This process occurred in four steps: the identification of the objects by its basic characteristics; the interpretation by the analysis of relationships and by the observation of regularities and by deduction expressed in associations and correlations; the synthesis expressed by the delimitation of the polygons classified with a certain land used; the registry in an alphanumeric database of the land use class for each delimited polygon.

Some other sources like topographic and thematic maps were used as a complement to the visual interpretation of the images and for the land use polygon delimitation.

The processes, the tools and the geographical data promote the whole process of conception and production of the land use maps. The guaranty of the quality of the land use maps, mainly concerning the thematic completeness and semantic accuracy is strongly dependent on the regular application of these procedures on the visual interpretation of the images.

Deduction is the correct basis of the correct semantic identification and the identification of the objects from the primitives is the necessary condition to determine area of equal appearance. These areas of equal appearance should express the morphological and functional homogeneity that characterizes each land use polygon.

The multi-temporal cartographic results were materialized in land use maps produced both in digital format and in paper. To each land use class there is an associated registry in the database which allows queries concerning operational urban issues. The operational issues can cover different topics: the quantification of land use by class and location, the overlay with social and demographic variables, the simulation of social equipment best sites, and the determination of urban expansion priority areas.

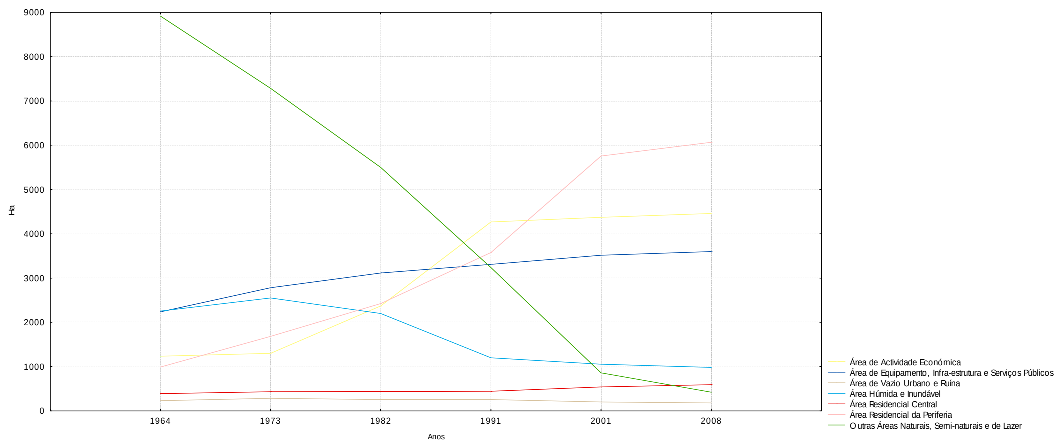
3. Land Use and Land Use Change

3.1 Land Use

Land use change is an unquestionable indicator of urban transformation. Effectively if we center the evolution of a city on the geometric and semantic alterations of the smallest parts that makes it up and that reproduces themselves in time, we can understand, thou partially, the dominant model of that evolution. The measurable part of that transition explains a good deal of the city produced in Maputo. If its certain that we shouldn’t reduce the evolution of a city to only one of its tangible aspects (the land use) it is also true that the ignorance of that fastness of the change is serious in a frame where only the less tangible aspects (like culture, policies, development, etc) are considered.

In 1964 the different land uses of Maputo City were distributed asymmetrically through the different land use classes. More than 50% of the actual territory of Maputo City had as main land use “Bush Areas”. The principal diversity of land uses occurred in the “Cement City” (the colonial build-up area). In 1973 the land use repartition through the land use classes was still very heterogeneous. The ”Bush Areas” keep the predominance over the other land uses, but below de 50% (42%). The residential areas of the suburbs start to gain importance since the beginning of the seventies representing an increase of 54% relatively to 1964. Maputo City is characterized in the year of 1981, concerning its land uses, by the predominance of “Bush Areas” (31%). However, the agricultural areas start to assume in this period a significant percentage of the total area (12%). But, in 1991 the agricultural land uses occupy the greatest percentage of Maputo City territory: almost one fourth of the total area. The “Bush Area” only represents 19% of the land uses and the residential areas of the periphery start to become more representative. The year 2001 is characterized by a less heterogeneity in the repartition of the territory through the different land use classes considered. None of the land use classes have more than 18% of the total area. The residential areas increase their weight in terms of territory occupation and the “Bush Areas” only represent 7% of the total area. In 2008 these tendencies are accentuated: 1,5% are “Bush Areas” and 35% are residential areas of the periphery.

Figure 1. Evolution of Land Uses (Level I) between 1964 and 2008.



3.2 Land Use Change

The process of urban landscape change is directly related with complex political, economical and social systems. The actors of the urban development vary and assume different roles in the course of time. The comprehension of the land use change in Maputo needs a political, economical and social contextualization, needs the understanding of the relations between State, market and foreign investment and its framing in the policies in each time concerning the management of the territory.

The analysis of the land use change between 1964 and 1973 allows the identification of the main change: almost 30% of the total land use change correspond to the alteration from “Other Natural, semi-natural and Leisure Areas” to “Periphery Residential Area”, originating an occupation mainly residential made through the appropriation of “Bush Areas”. The period coincides with the implementation of strategic policies that pretended to maintain the Portuguese presence in the colonies as a response to the nationalistic movements, resulting in a migration wave from the metropolis to the colonized territories and some investment in industry and in infrastructures.

The years between 1973 and 1982 were years of political change in Mozambique. The Independence brought changes in the systems of the administration of the territory, namely with the nationalization of land and of built property. The rural exodus had reflects in the urban landscape especially in the growth of the periphery. The incentive to agriculture production and the stimulus to create cooperatives had as main impact in the landscape the utilization of the best soil areas for agricultural production.

Between 1982 and 1991 the civil war was still devastating Mozambique. As a consequence the rural exodus to Maputo City was intensified stressing the accelerated growth of the periphery. Many areas that were rejected for residential purposes were occupied with houses during this period. During the decade of 1991-2001 the peace agreement and the democratization of the political system marked definitively the process of urban development. In terms of land use change these years were clearly marked with the expansion of the periphery to remote areas.

Table 1. Changed Area 1964-2001

Intervalo temporal	Área alterada (ha)
1964-1973	2671.33
1973-1982	2890.81
1982-1991	3796.23
1991-2001	3747.23
TOTAL (1964-2001)	13105.59

4. Land Use Change Model 2001-2011

The use of land use models remounts the seventies and has been developed with the objective of reproducing mathematically the non linear dynamic relations that characterize the spatial evolution of the urban areas. Its utilization allowed the measurement, the reconnaissance, the interpretation and the anticipation of some sustainability problems of the cities.

The pertinence of using these models is still up-to-date especially in fast growing urban areas like the African ones. These models can be a tool to support planning actions by providing ways to understand the urban dynamics and its consequences on the human dimension. Modeling the land use of Maputo City having in view the prevision of the changes in its patterns seems to be relevant because the dynamics of this city fits the set of the African cities with an accelerated urban growth and therefore with serious problems concerning urban management and planning.

The production of a model that predicts the future land use based on the transformations occurred and on some physical constraints (in the absence of director plans) can contribute to create planning scenarios as also the definition of alternative policies in terms of its effects in the future of the land use development of Maputo City.

The representation of the geographical space in a GIS environment is mainly static. Therefore some research has been carried out to conceive models that combine the structural objects of the space (geographical features) with processes that modify it (Human actions and the way they are processed along time). These models pretend to overcome this static analysis of the territory and to confirm the dynamic component as an essential part of the geographical space.

This motivation led to the use of cellular automata as a method for simulating the urban growth as they allow the visualization of a whole set of pixels in a dynamic interaction. The approach adopted by this type of models stresses the formation of complex global patterns from local interactions (neighborhood). The cellular automata can be understood as a dynamic spatial system in which the state of each pixel depends on the previous state of the neighbor pixels and considers a set of transition rules. In these models the result of the former iteration is determinant in the result of the following one, allowing the formation of global patterns of land use by the end of several iterations.

The cellular automata models have a superior modeling capacity then the GIS either at the level of urban growth or at the level of land use change. The spatial variables included in the cellular automata are updated dynamically during the iterative cycle which portrays non deterministic results. Most of GIS models find difficulties in simulating the land use without resorting to local rules and using static spatial variables and hardly can capture non linear features that are present in many geographical phenomena.

A conventional cellular automaton is constituted by the following components: i) an Euclidean space divided in a regular matrix; ii) a moving window with a neighborhood function associated; iii) a set of discrete layers which establish the state of the cells; iv) a set of transition rules; v) a predefined iteration set. Due to the spatial nature of many of the initial variables the integration of the cellular automata in a GIS is essential. GIS allow the user to manipulate and analyze spatial data explicitly associated with the models. They also allow the production of the input variables, the identification of heterogeneities or patterns, the quantification of changed areas or the predicted ones, the access to facts that operate at different scales, the visualization of the outputs of these models.

The various transformations occurred on the land use of Maputo City in the last 5 decades have changed significantly the landscape of this city and the *modus vivendi* of its population. The prevision of the changes for the next decade based in cellular automata models could give some indications of the type and form of the changes and providing a useful tool to urban managers, planners and politicians.

The model proposed for this study is based on four sequential steps: processing/codification of the information creating spatial levels from the prevision variables; application of the spatial rules which relates the prevision variables with the transformation of the land use in each site; integration of all the levels of information using a multi-criteria analysis; temporal indexing.

The input data are generated from a set of information levels integrated and managed in a GIS. A database was created with the goal of providing the spatial data necessary for the simulation. The levels of information represent different themes: residential areas, economic activity areas, infrastructures and social equipment areas, vacant area, natural areas, best agricultural areas.

This model is supported by a matrix structure based on pixels (cells). Therefore the used data from the themes referred above were converted to a raster format with a 5mX5m cell dimension. The pixels were then codified to represent constrains or probabilities of occurring. In the first case they represent binary layers where “0” represents impossibility and “1” and in the second case they constitute continuous variables.

The input data were manipulated by using a set of transition rules which quantify the spatial effects that the prevision cells have in the land use changes. In this model two classes of transition rules were used; the neighborhoods and the distance to the prevision cells. The effects of neighborhood are based on the premise that the composition of the neighbor cells has an effect on the trend of a central cell to change its land use. The spatial transition rules based on the distance relate de Euclidian distance between each cell and the closest prevision variable. The integration of the prevision variables can be made through logistic regression, multi-criteria analysis or neural networks (Pijanowski et al, 2002). In this case we used the multi-criteria analysis which has been used by several authors with confirmed results and also because it allows a better control upon the sequence of operations. The multi-criteria analysis uses a set of criteria in a way that we can have a base to support decisions.

For example, to decide which areas are more suited for residential land use expansion. The criteria correspond to layers like the proximity to roads, social equipments, etc. These layers which represent the optimal conditions for residential land use expansion, concerning a certain criteria, can be combined to produce a capacity map from which the choice for a determinate location can be made.

To proceed with the multi-criteria analysis it is necessary to define the procedure to follow (intersection, Boolean, linear weighted combination…) to select the information to be used (factors and constraints) and to impute weights to the factors. The number of cells that can possibly change from a land use to another can be calculated through different processes namely using Markov chains. In this case the matrix of the probable transition is the result of the crossing of the land use map of 1991 with the land use map of 2001.

The results obtained through this model, which only considered the airport, the magazine, the railway/port areas, and the roads as constraints (in the absence of physical planning tools that demarked the land use transformations),reveal a continuity in the process of the transformation of the landscape. In a scenery of weak legal restrictions to urban expansion the results show that the growth of the residential areas of the periphery will cover the remain “bush areas”. This means that almost 100 ha of the 130 existing in 2001 of natural areas will change to Residential Area of the Periphery (Table 2).

This model reveals also some expansion of the central residential areas “gained” from the residential areas of the periphery where the population with less purchasing power are “pushed” to more remote areas of the municipality where the land cost for residential use is lower. The densification of the residential areas of the periphery is another phenomenon that continues to occur, by filling the urban vacant areas. However it is also in these vacant areas where the new social equipments are probable to find.

Table 2. Land use change matrix in hectares between 2001 and 2011

2001 \ 2011	Área Residencial Central	Área Residencial da Periferia	Área de Actividade Económica	Área de Equipamentos, Infra-estruturas e Serviços Públicos	Área de Vazio Urbano e Ruína	Área Húmida e Inundável	Outras Áreas Naturais, Semi-naturais e de Lazer
Área Residencial Central	-	0.00	0.01	0.05	0.01	0.00	0.00
Área Residencial da Periferia	0.52	-	0.44	0.46	0.21	0.24	0.00
Área de Actividade Económica	0.72	13.11	-	1.87	0.18	39.78	0.93
Área de Equipamentos, Infra-estruturas e Serviços Públicos	0.05	3.04	0.24	-	0.38	0.80	0.02
Área de Vazio Urbano e Ruína	0.65	3.95	1.29	2.10	-	0.01	0.01
Área Húmida e Inundável	0.24	0.42	5.46	0.33	0.01	-	0.02
Outras Áreas Naturais, Semi-naturais e de Lazer	1.89	99.81	10.60	5.16	0.94	0.97	-

5. Conclusions

Land use and land use change detection is one of the most used skills for observing changes in urban areas with very high urban growth rates. For monitoring purposes we demonstrated the use of remotely sensed data and of the still fragile capacity of the automatic processes for extracting in number and type the land use classes with an acceptable precision.

This fact constrained us to visual analysis of aerial photos and of satellite images during an adequate lack of time necessary to register the areas that suffered from a stronger pressure for changing land use. The GIS database provided topological coherency and precise quantification, at a 1/25000 scale, of the areas that change their land use. Until now there were not any similar studies available for the urban areas of Mozambique.

The five land use maps produced for Maputo City (concerning the last five decades) are fundamental documents to understand the spatial temporal pattern of the land use of this city. These maps were created using geographical information technologies and therefore can be used as base information for the monitoring and management of this urban territory. This information can be accessed at http://cdh.fa.utl.pt/sig_maputo.html and displayed in Google Earth.

Cellular automata models introduced in urban change analysis a way to simulate the future evolution of the city. These models allow simulations of vast areas from simple transition rules as they show how local interactions determine the complex behaviors at the global level of the urban systems. They are dynamic models where space, time and state are discrete.

The simulation carried out using CA reveals a great compliance with the actual trends: continuous and dense urban growth (mainly with residential areas), extensive urban occupation (suburban sprawl) with weak administrative control.

The ongoing projects are looking forward to test the strength of the CA model applied to African cities where legal regulation to land occupation is absent and where the mapping of the physical restrictions to land use change is inexistent.

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