UNDERSTANDING INFORMAL URBAN PATTERNS BY INTEGRATING GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND CELLULAR AUTOMATA (CA) MODELLING

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ABSTRACT

Cities in developing countries are expanding at a tremendous rate and informal settlements (where 40 to 80% of city dwellers live) occur in unplanned urban areas. In planned cities in developed countries, Geographic Information Systems (GIS) and cellular automata (CA) are favourable tools for modelling urban dynamics. This paper discusses the growth of informal settlements, describes the tools adopted to model urban dynamics in western society, and suggests how a similar approach can be used to understand the dynamic of informal settlements in Yaounde, Cameroon.

Keywords: GIS, Cellular Automata, urban dynamics, informal settlements, modelling

INTRODUCTION

Whereas the urbanization process in developed countries is driven by planning strategies, modern cities in less developed countries (LDCs) are rapidly expanded under various crises, which are expressed in the urban physical environment. This context of unplanned establishment and unprecedented growth of cities should be part of the perception one has in considering modelling urban dynamics in LDCs. Geographic Information Systems (GIS) and cellular automata (CA) are currently used in planned cities in developed countries to model urban dynamics and land use. While the unplanned cities do not have the logic behind these tools, few attempts have been made so far to model informal settlements in LDCs. Yaounde, the capital city of Cameroon, illustrates this growing phenomenon of fast-changing cities.

In Yaounde as in most cities in LDCs, informal settlements characterise the city building process. More than 75% of built-up areas and land-use is thought to be informal. The first section of this paper discusses the question of informal settlements and their importance. Section Two presents an overview of modelling approach within GIS. Section Three considers the CA approach. Finally, section Four explores the new ways of using the two tools (GIS and CA) in modelling urban expansion in LDC, particularly, the informal settlements on urban fringes.

INFORMAL SETTLEMENTS

The world population has more than doubled in the last 50 years (from 2.52 billion in 1950 to 6 billion in 2000). Moreover, the United Nations (1999) estimate that 97% of growth is taking place in LDCs, with Africa as a fast-growing area. Cities such as Bombay, Calcutta, Karachi, Jakarta, Nairobi, Manila, Lagos and Cairo are examples of rapid human concentration. This makes the current planning strategies inefficient and ineffective (if they even exist). Consequently, slums and squatter and informal settlements in those cities are the expression of a marginalisation of a big and growing range of city dwellers. In the 1970s, informal settlements represent almost two thirds of urban settlement stocks in Africa (World Bank 1975). Two decades later, this figure is still high and ranges between 40 and 70 % (Fernandes 1999) and informal settlements accommodate between 50 and 90% of city dwellers.

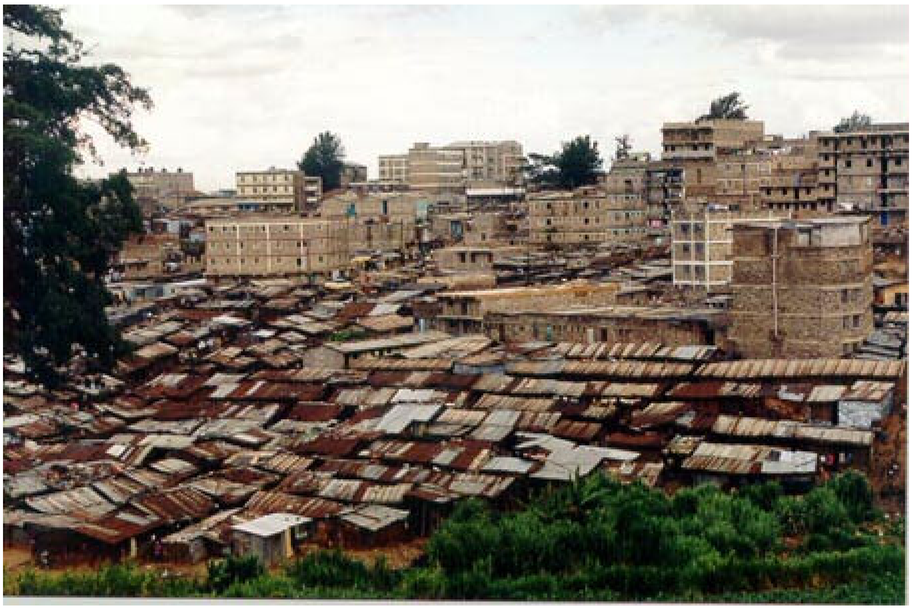

Figure 1 Informal settlements in a valley in Nairobi.

Informal settlements: definition and characteristics

In this paper, we refer to 'Informal Settlement' as any human establishment or land use in the urban area which is not suitable and/or is in opposition to the expected standard and regulations. Here, the suitability of an area is its viability and functionality. For instance, slums comprise older areas of existing cities undergoing deterioration and decay, but IS also include the poor and precarious housing and environment near the CBD, within the city or on the city fringes or other areas where lands are vacant, accessible and affordable. They constitute an expression of poor urbanization and poverty of city dwellers as well as "...failed policies, bad governance, corruption, inappropriate regulation, dysfunctional land markets..." (World Bank 1999). Dwellings are built by the spontaneous, undirected, and untrained efforts of the squatters who cannot afford to secure legal land or a safe site on which a house can be built. Usually, IS are located on vulnerable and unbuilt areas such as deep valleys (Nairobi), river banks (Bombay), abandoned waste dumps (Manila) or dangerous slopes (Yaounde). They are known as catastrophe-prone areas (floods, landslides and health hazard).

IS have originated from difficult problems of housing, immigration rates, politics, physical planning, landlessness, and employment in urban areas. In particular, they originate from the existing gap between the number of regular dwellings supplied and the need (Yapi-Diahou 1994). There is a strong correlation between IS and informal economic sectors as well (Badshah et al 1991, Kengne 1992).

Informal settlements are characterized by overcrowding, deterioration, insanitary conditions, absence or insufficiency of basic facilities or amenities which, because of these conditions or any of them, endanger the health, safety or morals of their inhabitants or the community. The fact that IS escape or are established with the knowledge of urban planners, suggests that current planning strategies failed to capture and anticipate the move. So far, master planning in many LDCs is dealing with those slums which have been settled for long time, not trying to anticipate the future distribution. This is the case in Ghana (Banes et al. 2000), India (Ali 1995), Brazil (Pino 1997) an so on. In the 1970s, the government of Cameroon tried two strategies: (1) the delocalisation of informal settlements within the city and their "relocalisation" to the fringe, and (2) the upgrading of slums. But these two options fuelled the expansion of informal settlements, which was the opposite of the government's intention (figure 2).

From the mid-1980s to the present there has been an unprecedented boom in informal settlements in the Yaounde area. Many causes can be found for this rapid growth. (1) This has been a period in which the last urban planning document proposed in 1982 has been completely ignored by the administration and the city developers (both private and public). Also (2) the annual population growth rate (7%) has been high enough for Yaounde to reach a million inhabitants by 1990 (from 300.000 in 1976). In the meantime (3) the country has experienced severe crises (economical, social and political). Besides (4) the trend in IS observed for many years has been sustained in many ways. Accordingly, the combination of those factors plays an important role in the actual expansion of uncontrolled human settlement. As shown by an official document of 1990 by the Ministry of Planning, informal settlements provided shelter at that time for more than 75% of Yaounde dwellers. Today this figure is much higher and this type of land development will for the coming years shape the Yaounde landscape. One of the main issue to be addressed is how accurate IS can be mapped, modelled and predicted in order to understand their future distribution? How can a mapping technique and a modelling-oriented approached can be combined to build a model of IS growth? Similarly, on what insight the integration of qualitative and quantitative techniques can provide for understanding the process of IS development. These questions constitute a growing challenge for urban systems modelling in developing countries.

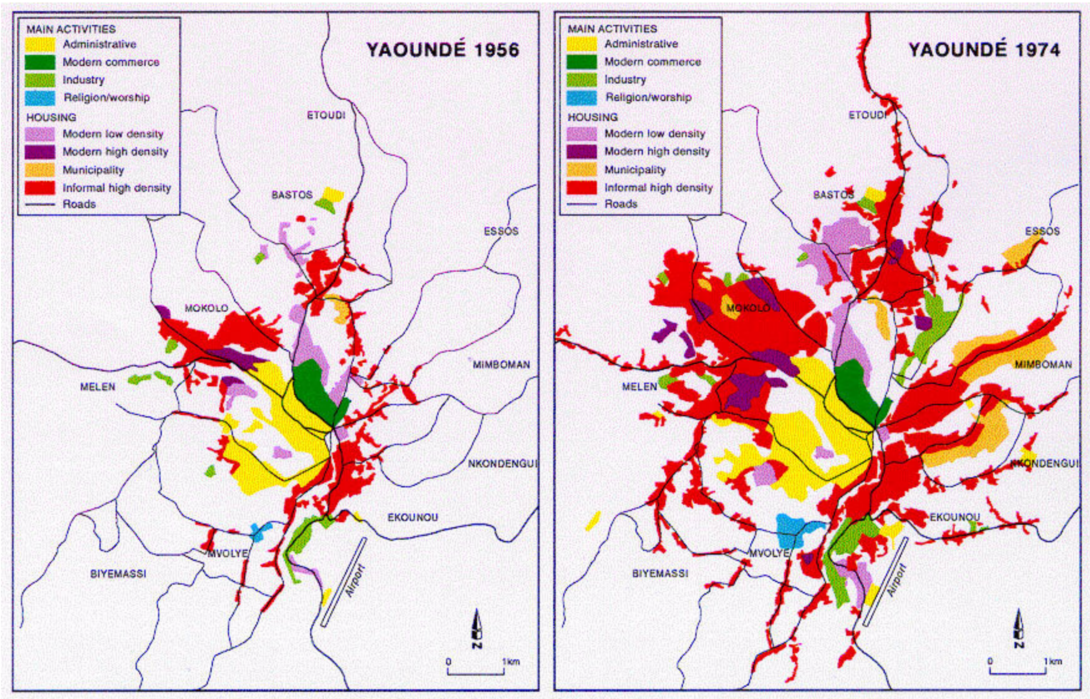

Figure 2: Informal Settlements expansion 1956-1974.

GEOGRAPHIC INFORMATION SYSTEMS (GIS) MODELS

Yaounde is not an isolated case and there is a need to investigate new approaches for a better understanding and modelling of self-help urbanization of a third of city dwellers in DC. GIS and CA have been used in developed countries to study the planned urban growth and land use. How have these technologies been used in unplanned contexts?

Geographic Information Systems (GIS) is a two-dimensional storage and display data package. GIS environment as location tools "do not have modelling capabilities" (Fedra 1993) *per se* and integration is usually suggested as a possibility to address this weakness (Yates and Bishop 1998, Batty and Jiang 1999)). The importance of GIS lies in its capacity to prepare input data (from various sources) and afterwards, for displaying and visualisation. Modelling within GIS is static (while all geographic phenomena are dynamic), selective and restrictive (separating growth from location) and covers "any operation involving the representation and manipulation of spatial data, particularly in composition of new features and patterns through the process of overlay" (Batty and Xie 1994a). There are applications of modelling urban dynamic using GIS packages: Meaile and Wald (1990) have used a GIS package to simulate the growth of the city of Marseilles in France. This model failed to produce realistic patterns of urban changes. Batty and Xie (1994a and b) have discussed a framework to incorporate urban model within GIS environment using ARC-INFO™. They applied the model to the city of Buffalo (USA). Temporal and predictive dimensions are lacking. There is a growing concern to incorporate the predictive modelling dimension within GIS softwares (Raines Bonham-Carter and Kemp 2000), but we have not reach the stage of full application.

Meanwhile in system science in general, the model is known to be predictive and involves simulation based on processes which give rise to system structure (the use we adopt in this paper). Thus, in a strict and generic sense, as Parker (1988) noted, "GIS offer little modelling capability, with most offering primary modelling tools, such as map overlays and buffering". A GIS, as mapping package can be used to represent the past growth of IS. Progress in computer sciences now enables us to consider including new approaches such as Cellular automata, in the GIS environment, to capture land use in unplanned cities.

CELLULAR AUTOMATA (CA) MODELS

Cellular automata (CA) are mathematical models where space is dynamic with discrete time systems. A cellular automaton consists of regular *grids of cells*; each of them can be in one of a finite number of k *possible states*, updated synchronously in discrete time steps according to a local and identical interaction *rule*. The state of a cell is determined by the previous states of a surrounding *neighbourhood* of cells (Fogelman et al.1987, Toffoli and Margolus 1987).

The use of mathematical modelling in the study of transport, land use and urban dynamics in the 1960s treat cities as in equilibrium (Wegener 1994). The earlier model was influenced by economic theories. Even if some progress has been noticed in the study of static urban forms and structures, it is only recently that researchers (Couclelis 1987, White and Engelen 1993) have established the importance of using complex systems such as CA to simulate, model and understand how western cities emerge and change. The initial models in geography were based on social and ethnic patterns to explain urban structures. One of these approaches referred to a Central Place Theory (White 1977, Wilson 1978) to model the land use changes. Tobler (1970) was one of the pioneers in developing a forecasting model based on urban growth. He called it *computer movie* but that description was confined to classic cellular automata.

Later, he published an interesting paper, which opened up the possibility for geographers of using CA for simulation (1979). Tobler's work was improved by Couclelis (1985, 1988, 1997) and Batty (and Longley1994, and Xie 1999, 1998) who have provided the theoretical and methodological framework for the integration of CA to the analysis and in modelling complex dynamic geographical problems. But the main limit is that Couclelis's work was not originally intended to produce a realistic representation of the urban dynamic as compared to White and Engelen's (1993a, 1993b and 1994) model which is capable of generating realistic urban land-use patterns.

As far as application in urban systems is concerned, it is important to mention the attempt by Batty and Longley (1986) to build a discrete fractal grid to simulate the London land-use map. Couclelis (1988) has demonstrated how CA might be used as an analog or metaphor to study how different varieties of urban dynamics might arise. With the enhancement of computer technologies, urban modeling with CA has become widespread amongst urban researchers. Cecchini (1996) has used CA to simulate and predict the urban structures in *fictitious cities*. This imaginary model shows how various classes can be formed from CA. The results are interesting and useful for the insight they provide into the nature of the dynamics of urban land use. However, the model is too artificial and simplistic to give a very realistic representation and deal with specific urban dynamics.

Recently, there have been noticed some attempts to apply CA to real geographical problems. Phipps and Langlois (1997) have used a CA version of the Von Thünen model in order to establish its suitability for the interpretation of real patterns. Their work was interesting in that it showed another possibility for understanding a well-established geographical model. But the study was not sufficient to bring out all the potentialities of CA for the sharpness of real urban dynamic. The real cases started to appear in the mid-1990s. White, Engelen and Uljee (1997), for instance, managed to implement CA to model and predict the land use of the city of Cincinnati in USA. However, this model covered just a small area and dealt with few data. Also, with only two simulations, the prediction period was too short to be realistic: one simulation represents more than a century in real life. Moreover, some areas (like the CBD) appeared underestimated compared to others. The researchers realised that to build a more realistic urban dynamics model mimicking and forecasting real situations, there is a great need to combine GIS data with CA-based model.

INTEGRATING GIS WITH CA

Comparing GIS and CA, Wagner (1997) recognised that they are both space-time models of their universe and are both based on a two-dimensional plane. Also, raster GIS are similar to the CA environment. The integration of CA potentialities (dynamic and prediction power, neighbourhood coherence, flexibility) into a GIS environment has been shown to be promising.

GIS provided a good environment for a retrospective analysis of retrieval varieties types of data. White and Engelen (1994a) demonstrate the purpose to build a raster-based GIS incorporating CA that can be used to simulate regional development. Furthermore, dynamical modelling and prediction goes far beyond GIS capacities (White and Engelen 1993 and 1994b, White, Engelen and Uljee 1997), which could be completed and improved with CA environment. In fact, urban dynamics is a relevant field for practical examples for point-in-cell methods of spatial subdivision and analysis of problems (Sugihara, Okabe and Boots 1992). For a similar purpose, Wagner (1997) has gone further to discuss the similarities between the GIS and the CA models. He suggested that the integration of the two systems through a CA machine as an analytical engine for raster GIS will probably help to overcome some inadequacies of GIS. Amongst the weaknesses of GIS, Wagner drew out the poor capacity to simulate and model real patterns, the incomplete ability to handle dynamic spatio-temporal phenomena and the lack of speed when dealing with large and complex problems. The products of GIS are static and non-temporal. These GIS deficiencies could find a solution in CA environment, which has a temporal logic, is oriented to location probabilities and is suitable for small and large scale modelling. Basically, CA is adapted for complex dynamic models. Additionally, Couclelis (1997) provides a generic framework for the exploration of the common features in the GIS and CA environments in order to develop better computer models of real urban dynamics and structures. Furthermore, the theoretical works of Webster, Wu and Zhou (1998) have clearly demonstrated the necessity of combining the two approaches.

The successful application of GIS and CA in simulation and modelling a real urban dynamics has been achieved by a research group of Silicon Valley (USA). This multi-disciplinary team has put together a simulation of urban

growth in the San Francisco Bay Area to study the impact of human activities on the spatial organisation of land use and change (Clarke and Gaydos 1998). First, to illustrate this change, they elaborated a model of urban growth in this area. The data of the period of 1820 to 1990 were compiled using GIS tools. The second step was to simulate the potential of development of the future land transformations caused by human activities. They finally developed a model based on GIS and CA of urban growth in a well-planned city. This model simulates the growth of the area till the year 2100, so that it can be visualised.
The same approach has been used for the study of the urban sprawl of Buffalo and Baltimore and it opens up the way for future applications. We believe that Clarke's model can be adjusted to the context of exploring unplanned dynamics modelling and prediction.

CONCLUSION

It seems to us that the GIS and CA tools used in modelling urban dynamics in planned cities in the developed countries can be explored in order to understand and model informal settlements in cities in developing countries. We believe that GIS might be used in tracking the historical expansion of the IS. In the application projected for Yaounde, various data sources (population, maps, satellite images, aerial photos) will be used to build a GIS database of IS. The potentialities and flexibility of CA will be applied and some social and cultural factors incorporated in the rules. Western models are rigid and based on structured data, while urbanization in LDC and their IS have cultural and social factors. IS are likely to develop where the land is available (31%), close to the centre of activities (22%), and where there is a strong social and cultural link (20%) (HABITAT 1996 P.208). The vacant and affordable lands are mostly found on the fringes and the actual layout of new IS is in the periurban areas. It is also clear that the slums near the CBD were previously on the fringes which become "part" of the city. Again, in the case of Yaounde, there is a strong correlation between urban and periurban agriculture, the informal economic sector, the cultural origins of population in the suburbs and IS dwellers (Kengne 1992).
The approach we have advocated is at a preliminary stage. However, we believe that there is an urgent need for an informative model of the dynamics of IS in developing countries. We have demonstrated the scale of the problem in IS. Geographic Information Systems and cellular automata have been presented as one of the favourable tools for a comprehensive modelling of urban dynamics in western cities. We have mentioned the lack of urban models for unplanned cities in LDCs and envisaged the possibility of providing a new way of looking at the IS and project their future expansion.
At the next stage, this research will seek how to model the IS dynamics using GIS and CA tools. Our research not only aims to provide new insight into the expansion of IS but also explores the future representation of unplanned urban landscape. Another innovation of this research will be to incorporate social and cultural factors in the simulation of IS.

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