MODELLING FAVELAS
Heuristic Agent Based Models for Squatter Settlements Growth and Consolidation

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ABSTRACT

In the present paper, we argue that the relative location of peripheral spontaneous settlements is dynamic and changes with the growth of the city. The periphery is a place under constant mutation, always reproducing new extensions of land while the old peripheries are gradually incorporated to the city and occupied by new inhabitants. It focuses on the process of consolidation within the urban growth dynamics of third world cities. Our aim is to study, in a heuristic basis, how the global process of urban growth contributes to both the formation of spontaneous settlements and its morphological transformation in time. We argue that the process of consolidation is a feature of the process of spatial growth and, therefore, there is a two way growth process: the urban growth determines the consolidation of spontaneous settlements and this consolidation changes the course of urban growth process, contributing to a fragmented and discontinuous urban form. This issue is explored through 'Favelas', an agent-based model (built in StarLogo for PC) that focuses on the process of consolidation of inner-city squatter settlements within a decentralised process. Preliminary results suggest that favelas are the result of a growth and consolidation process in which resistance is the cause, consolidation is the process and fragmentation is the result.

1 INTRODUCTION

Recent studies have pointed out that the level of consolidation, "the spatial configuration of settlements, and particularly the way in which the site is embedded in the larger spatial structure of the city determines whether the spontaneous settlement is successfully incorporated to the city body or remains 'slum-like'" (Hillier et al, 2000, p.62). Other studies (Mujhika, 2001) argue that the location of settlements, the land use in them, the settlements layouts and the size of the lots within them, all can impact the success of upgrading process.

Actually, when analysing the development of squatter settlement areas in third world cities, one can observe a feedback process: the urban growth determines the consolidation of spontaneous settlements and this consolidation changes the course of urban growth process, contributing to a fragmented urban form.

In this paper spetial attention is dedicated to inner-city squatter settlements, that are located close to the most integrated urban areas and generally present high densities, since most of these settlements are consolidated and have reached the limits of growth (UNCHS, 1982). These settlements are usually bounded by roads, which are highly integrated in relation to the overall structure of the city. Because they develop in spatially restricted non-occupied land, these settlements face spatial restriction, and therefore tend to present a highly dense spatial structure. Besides, the proximity of central sites to job opportunities makes them a more competitive and overcrowded site (figure 1).

In this paper, the inner city squatter settlements development is analysed in two complementary scales, through two agent based models: AxialAgents and Favela. Both models are based in random walk dynamics and are built in StarLogo, a parallel programming tool developed by the Epistemology and Learning Group of the Massachusetts Institute of Technology for agent based heuristic experiments (Resnick, 2000).

Through AxialAgents we discuss the arising and development of spontaneous settlements in a virtual city centre where some aspects of the typical structure and dynamics of Third World cities are reproduced. This process is analysed according to the location of these void spaces (non-occupied land), in relation to the grid structure and to the existence of movement generators. AxialAgents is an heuristic agent based model in which decentralised agents run over an axial lines like environment, searching for available space to settle.

Figure 1 - squatter settlement in Caracas, Venezuela - source: author's collection

Favelas is also an agent based model which simulates (or illustrates), in a heuristic basis, some aspects of the process of settling dwellings inside an non-occupied land surrounded by attractive and non-attractive boundaries. This approach is developed in a closer scale, and is related to the development of the squatter settlement itself. We analyse the growth and consolidation of squatter settlements according to decentralised agent based decisions.

Before going to the models analysis, some considerations must be presented, about complexity as a theoretical basis to agent based models construction.

2 COMPLEX, BUT NOT COMPLICATED

The morphological structure of the city is built from the interplay of different dynamics, offering an extra level of complexity to these systems. As Holland (1995, p.1) suggests, "a city's coherence is somehow imposed on a perpetual flux of people and structures". From Holland's words one can identify two different kinds of fluxes: the flux of people and the flux (or change) of structures. The ever-changing nature of cities, however, seems to require both interpretations for a better understanding. Not only it is necessary to understand the complexity of its structure, but it also seems to be necessary to understand the movement of people in it.

Spontaneous settlements are clear examples of complex subsystems within a complex urban system. Their morphological characteristics combined with their development process are misunderstood as chaotic and unorganised, when complex should be the appropriate designation. And so are Third World cities, traditionally known for their apparently chaotic feature, because their discontinuous spatial patterns and rapid and fragmented development process.

The idea of a structure emerging from a bottom-up process where local actions and interactions produce the global pattern has been widely developed through Emergence based tools and technologies. Although a number of models have been developed using agent-based techniques to simulate urban scenarios, including land use, pedestrian modelling, and so on, the use of agent-based simulation to urban spatial change is not a consensus in the research community. Indeed, agent-based models can arise too much complexity making difficult to track elements and relationships within the model and thus, make difficult any kind of conclusion. But the choice of increasing the degree of complexity of the model or keeping it simple depends entirely on the researcher and the purposes of the model in hand. So, from this perspective, Agent based models are more suitable to simulations focusing on the human behaviour in a given spatial environment. Viewed as such, they open up an avenue for analysis of dynamic processes that link spatial development with social issues. This kind of analysis is of fundamental importance when dealing with cases characterised by a highly decentralised development process as the case of urban growth in the Third World (Barros & Sobreira, 2002).

3 AXIAL AGENTS

3.1 The economy movement of third world cities

The Economy Movement, proposed by Hillier (1996), relates spatial structure to social development. This is the basis of 'natural movement', which is the relationship between the structure of the urban grid and movement densities along lines in an urban structure: "natural movement is the proportion of movement on each line that is determined by the structure of the urban grid itself rather than by the presence of specific attractors or magnets" (Hillier, 1996, p. 161). So, according to Hillier, the structure of the grid itself accounts for much of the variation in movement densities. In this sense, considering a city from the axial map perspective, the most integrated streets would be lined by the most developed areas, while the less integrating streets, as the most segregated areas, would line the poorests areas of the city.

But third world cities are characterized by a typical fragmented structure (Balbao, 1993). The urbanization process in cities of developing countries is often insufficiently planned and poorly coordinated. The morphological result is a fragmented set of patches, with different morphological patterns often disconnected from each other. This fragmented pattern has its origins in the successive superposition of different urban typologies, including planned areas, spontaneous settlements, housing tracts, slums, vacant sites, institutional areas, shopping malls, informal town centres and so on. The Third World city is the result of the combined dynamics of fragments that are in constant mutation and evolution. It is fairly common to find, in highly integrated areas, lots of non-occupied land, some of them being occupied by squatter settlements, as well as less integrating areas occupied by high class private residential areas.

Spontaneous settlements fill some of the gaps in this erratic development, at the same time creating obstacles for any attempts to rationalize the development process and introduce effective land-use control measures (UNCHS, 1982). Spontaneous settlement is not only one of the elements that compose this fragmented pattern but also it is itself a fragmented object, composed by smaller fragments. It lead us to suppose that along with structure itself other complementary elements could be considered when analysing squatter settlements in Third World cities.

According to Pacione (2001, p. 497), "the form of squatter dwelling and their location in the city vary. Most cities have squatter communities in their central areas adjacent to the major employment sources". An example of that spreading dynamics is the city of Kuala Lumpur, in Malaysia. In the figure *2.A* one can see that squatter settlements spread along the main roads of the city, from the city centre to the peryphery. Squatters usually follow jobs opportunities areas, and then look for available and affordable places close to these areas. The following diagrams present some clues about these movement processes. In figure *2.B* - Pacione (2001) - one can observe migration patterns among low-income neighbourhoods in a Third World city. There is a rural migrant flow (A) that leads people to low-income inner-city slums, searching for job opportunities and places close to them. From this point, when no affordable space is found, people move to intermediate and peripheral zones (L2). A similar approach is suggested by the diagram in figure *2.C*, from which one can speculate that "land availability and proximity of high-intensity mixed land use, usually jobs opportunities, are the major controlling elements in spontaneous settlement location" (Dwyer, 1975).

So, despite there is no generally accepted or consensual theory about spontaneous settlement location, there is an agreement that because the discontinuos, fragmented and decentralised growth process in Third World cities, the street pattern itself is not enough to analyse development, as the poor and rich areas are located bothly in segregated and integrated areas. It seems that central business districts, commercial corridors, employment centres, transport connection points (train and bus stations) are complementary elements to be considered along with the spatial configuration of the grid, when analysing squatter settlements development in highly integrated areas. It seems important, therefore, to better understand the consolidation of inner-city squatter settlements (already located in highly integrated areas) to consider, as complementary parameterrs, two key elements: movement generators and people flux. Both of them can be analysed from the agent based perspective.

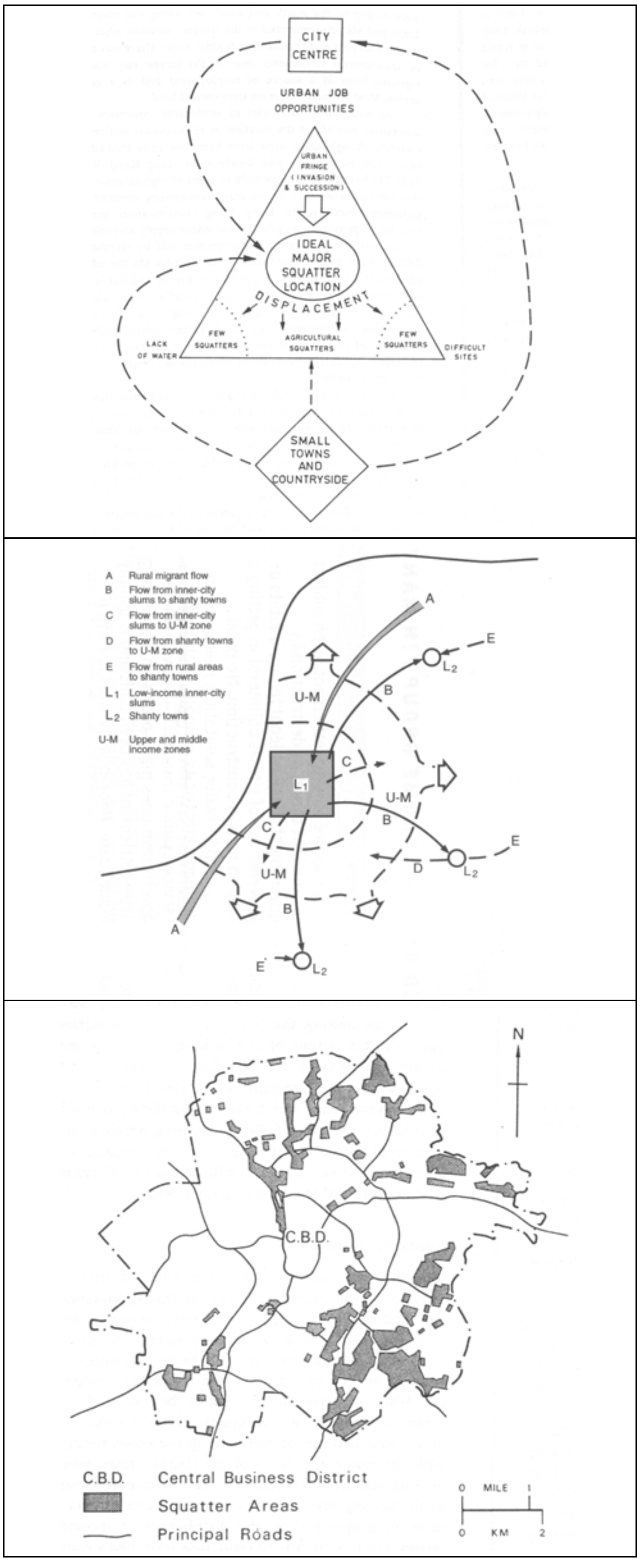


Figure 2 – (A) Top: movement dynamics in Third World cities - source: Dwyer, 1975 ; (B) Middle: migration movement patterns - source: Pacione, 2001; (C) Bottom: Kuala Lumpur squatter settlements map - source: Dwyer, 1975

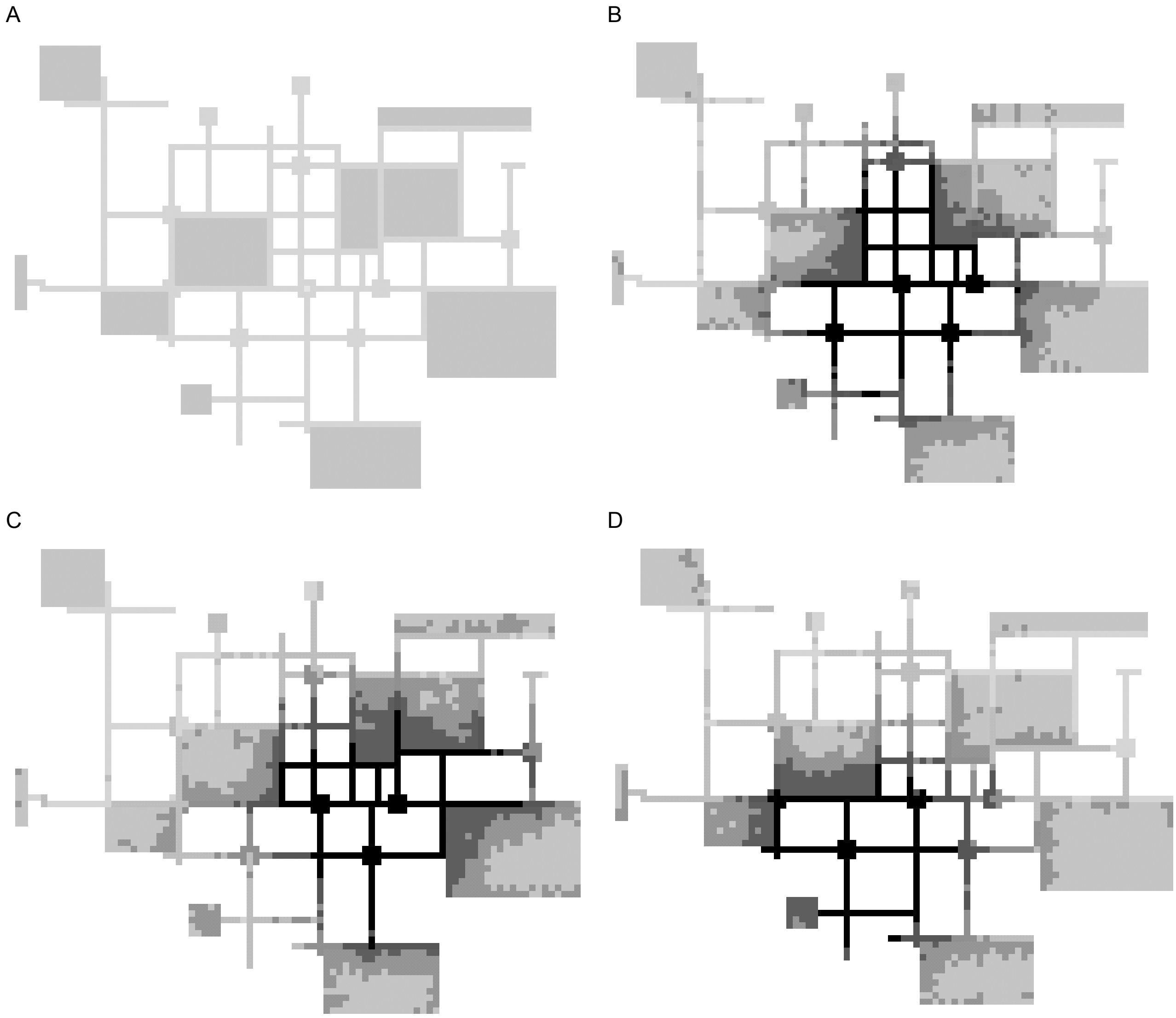
3.2 An agent based model in an axial like environment

Through AxialAgents we analyse the interrelationship between the growth of spontaneous settlements and the movement flows in the urban grid. It is based on random walking agents which are set to search available spaces (in central non-occupied land) to build their dwellings, in an axial like environment which represents a Third World city highly integrated area (city centre, for example).

The agent's movement depends essentially on randomised walking parameters and on the cordinates of movement generators. The model interface allows the user to control parameters, as well as the start up cordinates, the number of agents running over the virtual environment, and the consolidation limit.

The consolidation limit controls an important development rule: it refers to a process in which spontaneous settlements are gradually upgraded, and, as time passes, turn into consolidated favelas or, in other words, spontaneous settlements that are harder to evict. As a result of the introduction of the consolidation logic, it is possible to speculate about differences of development among settlements.

Technically speaking, the consolidation process is built into the model through a "cons" variable (Barros & Sobreira, 2002). This "cons" variable has its value increased at each iteration of the model and, at a certain threshold (defined by the user), the patch turns into the consolidation state (represented in the open spaces by the dark grey cells. In resume, once the "go" bottom is pressed, the model start running and the agents go walking through the axial like structure, surrounded by open spaces ready to be occupied. The user has the option to hide or show the agents while running the program. Another element present in AxialAgent is the "flux gradient", that is a spatial representation of the most visited streets in the system. Each time an agent passes through a cell, it adds value to the flux gradient variable of that cell. The resulting map is a network of streets varying from black (high flux) to light grey (low flux). This mapping process can be used as a complementary tool along with the integration maps of space syntax. Both of them illustrate street hierarchy according to movement patterns. The first one through a dynamic mapping, while the latter by a static graphic representation.



Figures 3.A-3.D - AxialAgents outputs

Figure 3 shows a sequence of outputs originated from AxialAgents. In the figure *3.A*, it is presented the irregular grid that is the virtual environment for the agents search. It is composed by lines and open spaces (both represented by light grey color) and represent a highly integrated section of an urban centre in a Third World city. The following parameters are common to the three experiments shown in figures *3.B* to *3.D*: 1000 agents running in a random walk, defined by an random angle between +93º and -93º;

consolidation threshold: 8 ; and final snapshots at 407 iterations (programming time). The only difference between the three experiments is the start up cordinate. In experiment 1 (figure *3.B*) the agents search starts up from cordinate (0,-3), leading to a development pattern in which 628 cells were left as open spaces and 506 were occupied, resulting in a average density for the overall system of 44%. In experiment 2 (figure *3.C*) the origin cordinate is (12, -3), that is quite close to the previous one, but resulting in a distinct pattern of development. The average density in this case is 53%. Finally, in experiment 3 (figure *3.D*), the movement generator is situated in cordinate (-11,-11), and the snapshot shows a development where 725 cells refers to open spaces, 409 to occupied plots, resulting in a low average density of 36% (probably because the relative low integration of the cordinate).

From the experiments some observations can be made. Firstly, a quite obvious result that is confirmed by the model: by varying cordinates of the movement generators and keeping the same axial lines structure, we find distinct patterns of development and consolidation. This seems to reinforce the pressuposition that movement based on people flux and movement generators can be an additional parameter to be considered, when analysing settlements that present a similar degree of integration in the structure. So, we conjecture that for each new cordinate of generators, there is a new consolidation map and development pattern. In other words, in a real urban centre of Third World cities, even keeping the same axial structure, if some generators (as employment sources, transport central stations, business and services areas) are displaced or inserted into the structure, there will be different in development pattern of informal growth.

So, if through integration maps it is possible to take conclusions about squatter settlements consolidation, through AxialAgents or other similar agent based models it is possible to speculate about development patterns, which will affect their configurational properties, growth tendencies and even details on consolidation degrees.

4 FAVELA

4.1 Growing from the edge

Inner-city squatter settlements grow and consolidate from the edge (Sobreira, 2002). They are dynamic systems and result from the decentralised behaviour of local agents that can be illustrated by generative models based on boundaries as attractors and on emergence as a process. It reinforces a conjecture (Sobreira & Gomes, 2001) according to which in spatially constrained squatter settlement development, boundary is the cause, packing is the process and diversity is the route. The *Favela* project simulates the spatial development of spontaneous settlements at local scale. The experiments are based on randomly walking agents over a cellular environment, constrained by attractive and non-attractive boundaries. This is based on the features of most of the inner-city settlements, which grow in empty sites within urban areas resulted from the fragmented and discontinuous development of Third World cities as described previously. These settlements grow from “attractive boundaries” towards the inner part of the urban site, and the built structure is developed prior to any network and rough foot tracks arise in between built structures and often consolidate, connecting houses to local services situated on the site’s borders (Sobreira, 2002).

In such settlements, the streets of the existent city, which bound the site, tend to attract the development of building structures to the borders. Following this logic, the model’s rules are based on the idea that the spatial development of spontaneous settlements is both constrained and stimulated by the boundaries. In the Favela project the agent’s rules resemble some of the constraints and opportunities faced by actual people when looking for attractive urban sites to settle. The behaviour rules tell the agents to wonder around the site and, when reaching an attractive boundary, find an available place to settle.

Among a number of interface options that allow the user to draw the site and change the parameters of development, the model presents a “feedback” procedure in which the agents are “fed” with information about the environment and, based on that information (as global density, for example), change their behaviour, which in turn drives the spatial development to a different path. The most important parameters are the settling patterns (dwelling tipology), the agents searching features, and the density threshold. *Figure 4* illustrate a sequential output of Favela, in which the site in bounded by attractive boundaries at the bottom and right hand side only.

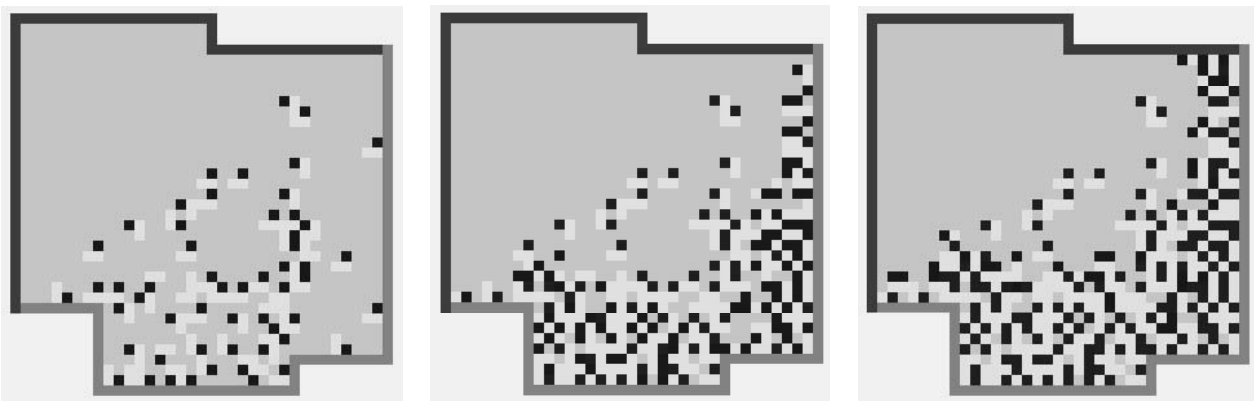


Figure 4 - sequential output of Favela experiments

As one can see from the snapshots, the spatial configuration resemble the development process of a settlement in Acera, Ghana (*figure 5*), starting with isolated building units combined with open areas (left) and as the density increases, the clustering and densification are inevitable (right). As the settlement gets dense and more agents come to the site searching for available space, agents take longer in the searching process, finally settling in more restricted spaces, occupying vacant spaces between existing dwellers and, thus, causing in this case the diversity of size of building clusters. Different initial conditions were also tested, in an attempt to explore to what extent path dependence influences the model’s behaviour.

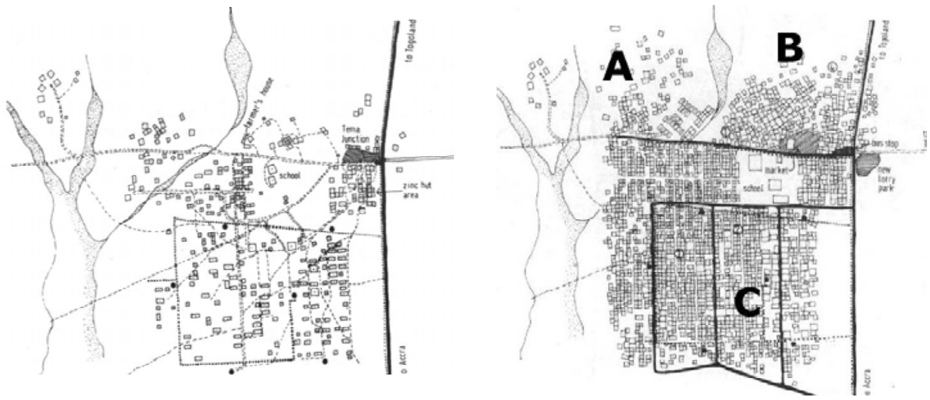


Figure 5 - squatter settlement in the city of Acera, Ghana. Early situation (left) confronted to the consolidated one (right)

4.2 Fragmentation: statistical properties of spatial complexity

In recent years a great deal of effort in pure and applied science has been devoted to the study of nontrivial spatial and temporal scaling laws which are robust, i.e. independent of the details of particular systems (Bak, P. 1997; Batty, M. and Longley, P. 1994; Gomes, M. et al, 1999). In recent work, Sobreira e Gomes (2001) show that spontaneous settlements tend to follow these scaling laws in both scales, local and global. This multiscaling order is analysed here by a fragmentation measure which is related to the diversity of sizes of fragments (built units) in these systems. Diversity is understood here as a measure of complexity (Gomes et al, 1999) and an expression of universal dynamics. In the settlement scale the fragmentation pattern refers to the diversity of size of islands (cluster of connected dwellings).

Figure 6 presents the maps three squatter settlements showing in black the islands formed by groups of houses. The *figure 7* presents three samples run through the Favela project. The snapshots are related to the time when the development reached approximately the same number of houses of the real settlements of *figure 6* (around 250 dwellings), what allows a more precise statistical comparison.

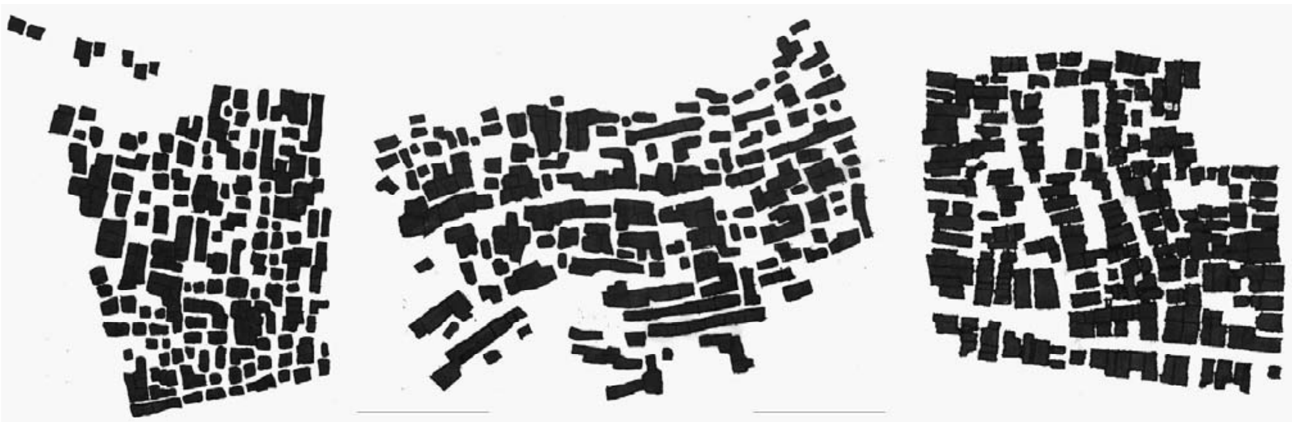


Figure 6 - graphic representations of three squatter settlements situated, respectively, in Bangkok - Thailand, Nairobi - Kenya and Recife - Brazil.

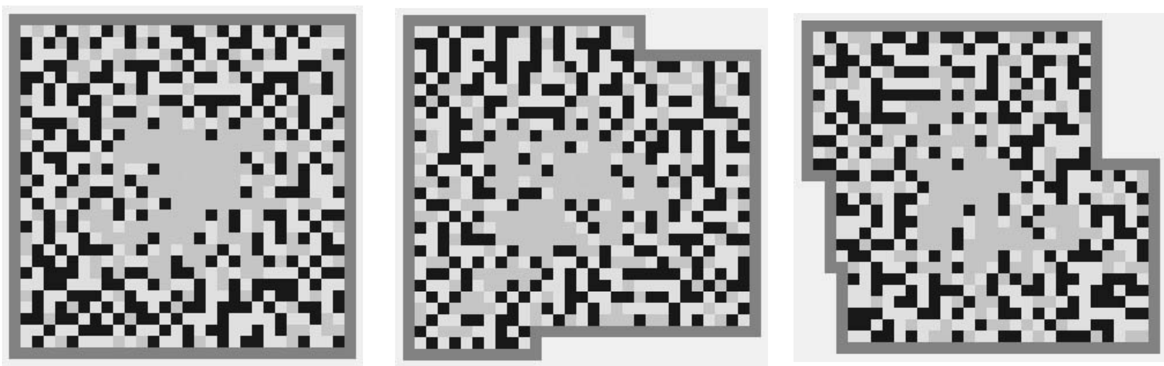


Figure 7 - Favela snapshots

The graphs in *figure 8* describe the correlation between the frequency of islands "f(s)", according to its size "s". The discrete variable "s" gives a measure of the size or area of an island (group of interconnected houses). The scaling distribution found for the settlements in Figure 6, represented by the graph of figure 8.A, is statistically the same that is related to the settlements generated by Favela (figure 8.B), which reinforce our conjecture, which connects boundaries, packing and diversity as the interrelated key aspects to the internal development of squatter settlements. The distribution f(s) in both graph of figure 8 obeys a scaling relation given by $f(s) \sim s^{-\tau}$, with $\tau = 1.6 \pm 0.2$. The exponent τ is robust and refers to the degree of fragmentation of the settlement. The negative exponent τ indicates a non-linear scaling order, in which there is a great number of small units (islands, group of houses), a small number of big units, and a consistent distribution between them.

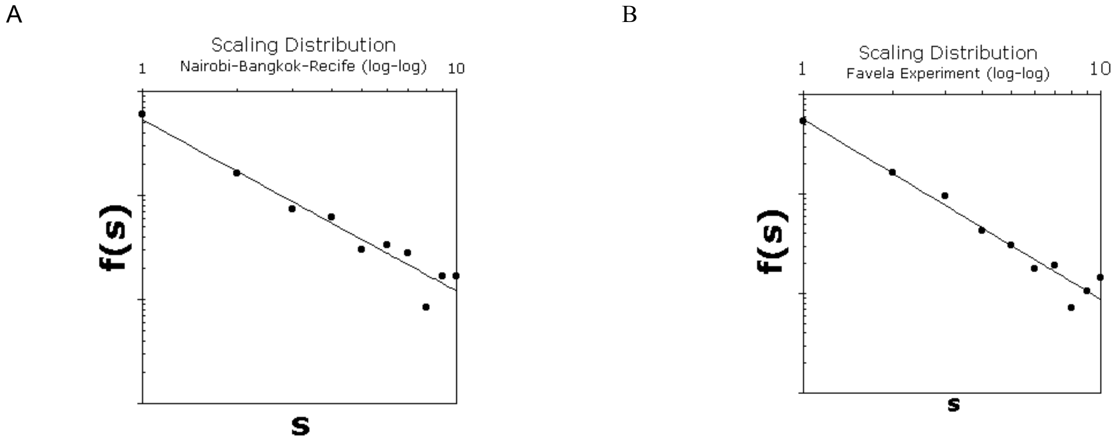


Figure 8 - Fragmentation analysis: (A) Scaling distribution - settlements in Bangkok, Nairobi and Recife; (B) Scaling distribution - virtual settlements generated by the Favela agent based model

Fragmentation measures come as a way to compare the result of experiments on the dynamic processes, that is, on how these systems behave in time and space with the patterns found in empirical examples. In this aspect, we argue that such similarity of patterns is clearly an empirical evidence of a decentrilised process of development of inner-city squatter settlements, which leads to a fragmented pattern, growing from the edge.

5 CONCLUSIONS

From the AxialAgents experiments, preliminary results suggest that it seems to be important a complementary analysis considering flux and relative location of movement generators to better understand the squatter settlements development dynamics. This approach can be complementary to axial lines based analysis, adding a dynamic view to that static perspective, despite some mathematical validation to the model would be usefull.

Regarding Favela, experiments led us to come up to a suggestive indication that squatter settlements decentralised dynamics can be simulated by agent-based models, which can describe the fragmented features of these self-organised systems. In this dynamics, boundaries play an important role in the settlement development, which occurs through a decentralised packing process and results in a robust and universal fragmented pattern. Statistical analysis based on Fractal Geometry, presented in 4.2 is suggested as an way of mathematical validation of this model

It is important to stress that both projects were built with strictly speculative purposes. They focus on how simple local rules generate emergent and complex structures. In other words, how do people without collective leading, searching for a place to settle their own houses, are capable of building such intriguing and surprisingly complex spatial structures.

Naturally, as it is suggested by Pacione (2001), the subsequent development of the squatter settlement into a settled community is a complex process that is related to the socio-economic status and motivation of the inhabitants and dependent upon the attitude of the government towards illegal settlement. Speculations presented in this paper are centred on rather specific spatial aspects of such complex and multifaced urban dynamics. Therefore, both AxialAgent and Favela models are set to be complementary (and not exclusive) tools for spatial analysis of decentralised and dynamic urban process as those related to Third World cities.

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