CENTRE FOR ADVANCED SPATIAL ANALYSIS
Working Paper Series

Paper 55

CITY OF SLUMS: SELF-ORGANISATION ACROSS SCALES

Joana Barros
Fabiano Sobreira

UCL

Centre for Advanced Spatial Analysis
University College London
1-19 Torrington Place
Gower Street
London WC1E 6BT

[t] +44 (0) 20 7679 1782
[f] +44 (0) 20 7813 2843
[e] casa@ucl.ac.uk
[w] www.casa.ucl.ac.uk

http//www.casa.ucl.ac.uk/working_papers/paper55.pdf

Date: June 2002

ISSN: 1467-1298

City of Slums: self-organisation across scales

Joana Barros
Centre for Advanced Spatial Analysis - CASA
University College London
j.barros@ucl.ac.uk

Fabiano Sobreira
Programa de Pós-graduação em Desenvolvimento Urbano
Universidade Federal de Pernambuco
fjasobreira@yahoo.co.uk

Paper presented at the International Conference on Complex Systems (ICCS2002), Nashua, NH, USA, June 9-14, 2002.

City of Slums: self-organisation across scales

Joana Barros
Centre for Advanced Spatial Analysis - CASA
University College London
j.barros@ucl.ac.uk

Fabiano Sobreira
Programa de Pós-graduação em Desenvolvimento Urbano
Universidade Federal de Pernambuco
fjasobreira@yahoo.co.uk

Paper presented at the International Conference on Complex Systems (ICCS2002), Nashua, NH, USA, June 9-14, 2002.

1.1. Introduction

The city is certainly a fine example of a complex system, where the parts can only be understood through the whole, and the whole is more than the simple sum of the parts. In the present paper we explore the idea that some of these parts are themselves complex systems and the interrelation between complex subsystems with the overall system is a necessary issue to the understanding of the urban complex system.

Spontaneous settlements are clear examples of complex subsystems within a complex urban system. Their morphological characteristics combined with their development process are traditionally understood as chaotic and unorganised. And so are Third World cities, traditionally known for their inherent chaotic and discontinuous spatial patterns and rapid and unorganised development process.

The paper consists in a brief theoretical analysis developed on the interrelationship between two urban processes across scales: the local process of formation of inner-city squatter settlements and the global process of urban growth. What is the role that spontaneous settlements play in the global dynamics of the city? We explore this issue by analysing experiments of 'City-of-slums', an agent-based model that focuses on the process of consolidation of inner-city squatter settlements within a peripherisation process.

The paper also includes two previous studies on these topics where the dynamics of these two urban processes are examined as two isolated complex systems and an analysis of the morphological fragmentation of the distribution of spontaneous settlements within the overall city and within the spontaneous settlements themselves. Based on these analyses, we conclude with a brief discussion on the role of self-organisation in the socio-spatial dynamics of Third World cities.

1.2. Latin American cities: growth and fragmentation

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 dynamic of fragments that are in constant mutation and evolution.

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). Hence, land occupation by spontaneous settlements not only adds to this haphazard growth, but it is also partly a result of it. Spontaneous settlements can be classified according to locational and morphological characteristics in *inner city* and *peripheral settlements.*

Yet there is no generally accepted theory of spontaneous settlement location. However, there is an agreement that land availability and proximity of high-intensity mixed land use, usually jobs opportunities, have strong influence on it (Dwyer, 1975; Ulack, 1978). The most interesting characteristic of those settlements, however, is their evolution in time. At the same time that the housing stock and services are improving, or being ‘upgraded’, the city grows as a whole, changing the relative location of such settlements. Peripheral settlements are incorporated to the inner city by urban growth. Thus, spontaneous settlements that developed on what once was the city’s periphery are often on land that has become very valuable, as the city expands. (UNCHS, 1996).

1.3. Complex systems of complex objects

The study of urban systems in the light of complexity theory is now well established. Cities are clearly complex systems and with advances and popularisation of computer tools, the possibilities to explore this viewpoint are constantly increasing.

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 (1995:1) 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 complex nature of each one of these fluxes, but it also seems to be necessary to understand the connections (or interactions) between these complex layers that together produce the emergent structure of urban space.

Complexity theory came to shift the approach in the use of computational models and quantitative measures, which have been traditionally used in quantitative urban morphology research. Cellular automata models replaced traditional causal models, shifting the paradigm of urban models towards a complexity approach. The idea of a structure emerging from a bottom-up process where local actions and interactions produce the global pattern has been widely developed ever since. CA models, however, explore only the spatial layer of the city and, although transition rules often were representations of human decision making, this representation is not explicit.

In order to explore the second layer of urban complexity, the flux of people, agent-based models were introduced in urban simulation. This came to meet the understanding that human decision making plays a major role. 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 application of agent-based simulation to urban spatial change is not a consensus in the research community.

Agent-based modelling can be seen as an approach in which benefits "exceed the considerable cost of the added dimensions of complexity introduced into the modelling effort" (Couclelis, 2001). Agent-based models can also be seen as models of 'mobile cells' (Batty & Torrens, 2001). This point of view suggests that these models would be suitable to simulations focusing on the human behaviour in a given spatial environment, as it is the case of pedestrian modelling, for example, rather than to urban spatial change.

In the present paper an agent-based model is seen as a cellular based model (raster) like cellular automaton, in which the transition rules of the CA are replaced by actual decision-making rules. Like in CA models, 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. We argue that agent-based models, viewed as such, 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 of strong social differentiation as the case of urban development in the Third World.

1.4. City of Slums

City-of-slums comes to combine the ideas behind two previous simulation exercises, Favela Project (Sobreira, 2002) and Peripherisation Project (Barros, 2002), to be detailed in the next sections. The aim of these three projects is to develop heuristic-descriptive models on the decentralised process underlying the spatial development of squatter settlements and growth of Latin American cities. Models are seen here as testable theories, in this case, built upon the assumption that the systems in hand are complex systems, and therefore, are systems in which local simple rules generate a complex global pattern. Thus, the models were elaborated in such a way that the behaviour rules were as simple as possible. They are totally based on the relationship agent-environment and do not explore either environment-environment or agent-agent relationships. All projects were developed in a STARLOGO platform that is a friendly user parallel programming tool developed by the Epistemology and Learning Group of the Massachusetts Institute of Technology (Resnick, 2000).

1.4.1. Favela project

The Favela project simulates the spatial development of spontaneous settlements in a local scale. The experiment is based on randomly walking agents over a cellular space, 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 develop in a self-organized way, starting from "attractive boundaries" (streets of the existent city, which bound the site). 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. 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 the favela project the agent's rules resemble the behaviour of actual people looking for attractive urban sites to settle. The behaviour rules tell the agents to wonder around the site and, when reach an attractive boundary, to find an available place to settle. The model presents a "feedback" procedure in which the agents are "fed" with information about the environment and, based on that information, change their behaviour, which in turn drives the spatial development to a different path. In this case, according to a density threshold, the agents change their settling patterns (dwelling typology) and searching features. As it can be observed on the snapshots in the figure 1, the sequence of outputs from the Favela model (figure 1a) resembles the development process of a settlement in Acera, Ghana (figure 1b). This resemblance is not just related to the static features (spatial configuration) but to the dynamics (development process) of the settlement, as well: starting with isolated building units combined with open areas and as the density increases, the clustering and densification are inevitable. 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.

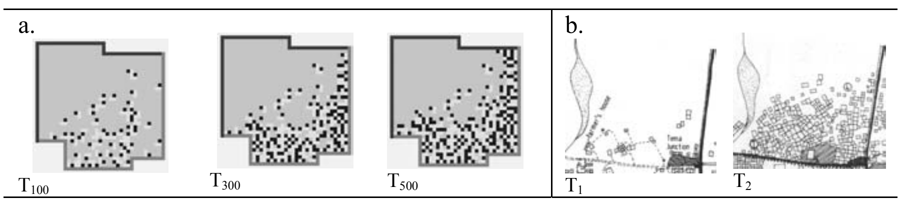

Figure 1. (a) Sequence of Favela outputs, with attractive boundaries at the bottom and right hand side only; and, (b) development process of Ashaiman settlement in Acera.

1.4.2. Peripherisation project

The peripherisation model simulates a specific mode of growth, which is characteristic of Third World cities, more specifically of Latin American cities. Peripherisation can be defined as a kind of growth process characterised by the expansion of borders of the city through the formation of peripheral settlements, which are, in most cases, low-income residential areas. These areas are incorporated to the city by a long-term process of expansion in which some of the low-income areas are recontextualised within the urban system and occupied by a higher economic group while new low-income settlements keep emerging on the periphery (Barros, 2002).

The model reproduces the process of expulsion and expansion by simulating the locational process of different economic groups in an attempt to reproduce the residential patterns of these cities. In the model, the population is divided in three distinct economic groups according to the pyramidal model of distribution of income in these countries. The model assumes that, despite the economic differences, all agents have the same locational preferences, that is, they all want to locate close to the areas that are served by infrastructure, with nearby commerce, job opportunities and so on. As in Third World cities these facilities are found mostly close to the high-income residential areas, the preference of location is to be close to a high-income group residential area. What differentiates the behaviour of the three income groups is the restrictions imposed by their economic power. Thus, the high-income group (represented in the model in red) is able to locate in any place of its preference. The medium-income group (in yellow) can locate everywhere except where the high-income group is already located and, in turn, the low-income group (in blue) can locate only in the vacant space.

In the model there are agents divided into three breeds (and colours) in a proportion based on the division of Latin American society by income. These societies have a triangle-like structure where the high-income group are minority on the top of the triangle, the middle-income group are the middle part of the triangle and the low-income group is on the bottom of the triangle. All the agents have the same objective that is to be as closer as possible to the red patches but they present different restrictions to the place they can locate. Since some agents can occupy another agent's patch, it means that the latter is "evicted" and must find another place to settle.

1.4.3. City of Slums: consolidation in a peripherisation context

City of Slums was built upon the peripherisation model by combining the original peripherisation logic to a *consolidation rule*. This rule 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, the city of slums model generates a more fragmented landscape than the homogeneous concentric-like spatial distribution of classes in which consolidated spontaneous settlements are spread all over the city.

The consolidation process is built into the model through a *cons* variable. This *cons* variable has its value increased at each iteration of the model and, at a certain threshold, the blue patch turns into the consolidation state, represented by the brown color in the model. If a red or a yellow agent tries to settle on the blue patch in a stage previous to the consolidation threshold, the blue patch is replaced by the respective new occupant's patch color. Otherwise, brown patches are 'immune' to eviction.

Three basic parameters were tested in the development of the model: proportion of agents per breed, consolidation threshold, and steps; the latter concerning the number of steps each agent walks in its searching for a place to settle. The result of such variations can be observed on the figure 2 where step = 2 presents a clearly more fragmented pattern than step = 1. The parameter step = 2 also leads to a faster spatial development in the simulation. This is due to the fact that the larger the step, the more empty spaces are left between patches, making the search virtually easier, that is, the agents find an appropriate place to settle faster. As a consequence, the simulation grows rapidly, and a combination of empty spaces and more mixed pattern produce a fragmented spatial result. This process resembles what actually can be observed in the Third World cities, where, despite the general tendency for economic segregation, there are 'fragments' of low and middle income residential areas within high-income zones, and vice-versa, what is caused by the accelerated and discontinuous process of development.

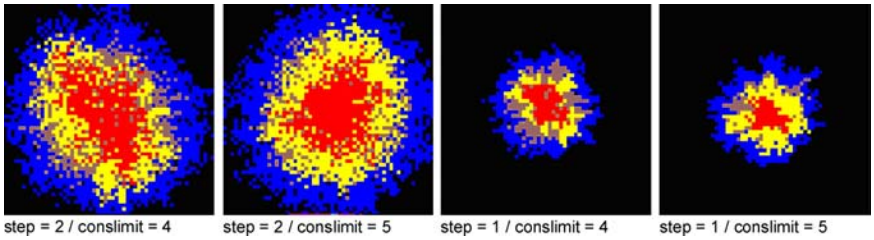

Figure 2. Variations of step and consolidation threshold parameters, time = 2000.

It is important to mention that in this kind of model the 'time' can only be measured through the number of iterations of the agents within the model. This condition opens up new possibilities of analysis of the model considering that, at the same number of iterations (t), the spatial development of the system will present variations depending on the parameters. This can be observed in the figure 2, where the variation of parameters at t = 2000 were tested.

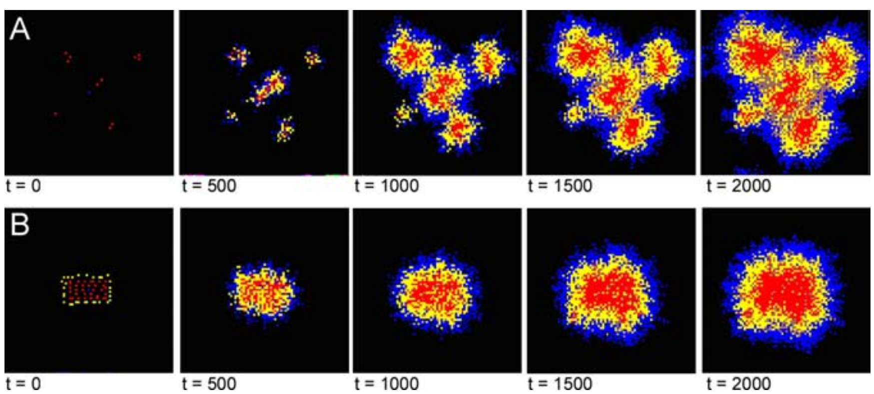

Figure 3. Experience with different initial conditions, polycentric (A) and colonial grid (B)

Different initial conditions were also tested, in an attempt to explore to what extend path dependence influences the model's behaviour. The figure 3 presents two sequences of the *city of slums* model with different initial conditions. As it can be observed, at the beginning of both simulations there are no brown patches (consolidated spontaneous settlements) in the virtual urban landscape. After some iterations, brown cells appear in all the three social-economic zones, resembling what occurs in actual cities. In the two last snapshot (t=1500 and t=2000) one can identify a very peculiar pattern, which seems quite similar to the typical distribution of spontaneous settlements in Third World, in special Latin American cities.

1.5. 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 all, 1999). Spontaneous settlements tend to follow these scaling laws in both scales, local and global (Sobreira & Gomes, 2001; Sobreira, 2002). 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 all, 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) while in the global scale it concerns the size distribution of patches of spontaneous settlements within the city.

Figure 4. Graphic representations of three squatter settlements situated, respectively, in Bangkok (Thailand), Nairobi (Kenya) and Recife (Brazil) and fragmentation graph .

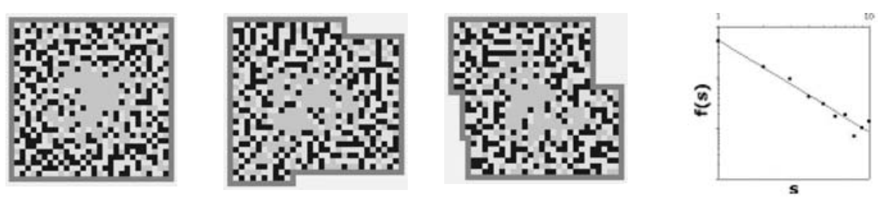

Figure 5. Favela project samples and fragmentation graph.

The figure 4 presents graphic representations of three squatter settlements and a graph which describe the average scaling pattern of their islands. The discrete variable s gives a measure of the size or area of an island. The figure 5 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 4 (around 250 dwellings), what allows us a more precise statistical comparison. The graphs in figure 5 describe the same variables and coefficients of the figure 4. So, when analysing the samples generated under such local-rule parameters, we find the same statistical pattern of fragmentation and diversity, which reinforce our conjecture, which connects boundaries, packing and diversity as the interrelated key aspects to the internal development of squatter settlements. This distribution f(s) in the graphs of figures 4 and 5 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.

In figure 6 the fragmentation pattern is analysed through the size distribution of settlements in three Third World cities and compared to the size distribution of settlements in the *City of Slums* simulations in figure 7. In particular, the settlements in each city were grouped according to their area, and the relation between number of settlements ($N_{(a)}$) and respective size interval (a) were plotted in a log-log graph. As one can observe from the graph of figure 6, the scaling law which describe the settlements size distribution in the real cities falls in the same statistical fluctuation of the scaling law which describe the size distribution of the *city of slums* simulations. The graphs in figure 6 and figure 7 describe the same scaling relation $N(a) \sim a^{-\alpha}$., where $\alpha = 1,4 \pm 0,2$.

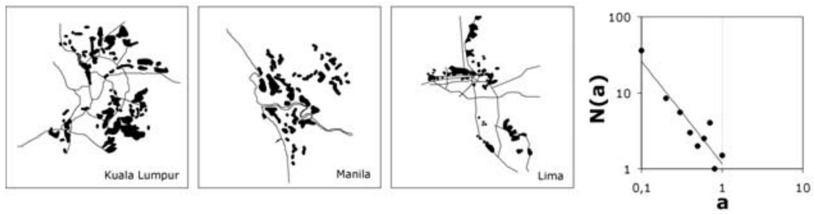

Figure 6. Fragmentation pattern of settlements in three Third World cities: Kuala Lumpur, in Malaysia; Manila, in Philippines; and Lima, in Peru.

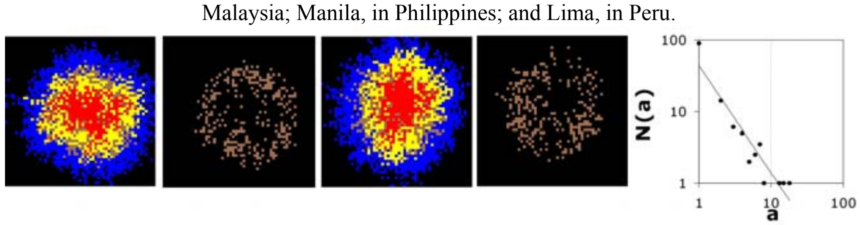

Figure 7. Distribution of settlements in the City of Slums model with fragmentation graph

Both global scale fragmentation patterns (real and simulated) are statistically the same, found for the local scale internal morphologies of the settlements. The negative exponents (α and τ) indicate a non-linear scaling order, in which there is a great number of small units (islands, at the local scale, and settlements at the global scale), a small number of big units, and a consistent distribution between them. In this aspect, we argue that such similarity of patterns is clearly an empirical evidence of a multiscaling relation between local and global urban systems and it is a suggestive indication that the agent-based models generate simulations which truly describe the fragmented features of these self-organised systems.

1.6. Conclusions

Third World cities have been traditionally studied as chaotic and uncontrolled spatial structures. Furthermore, they have always called attention for their high rates of growth and intriguing spatial structures with odd elements. Spontaneous settlements, in this context, have been seen as isolated structures within this messy system, usually approached as anomaly rather than as an inherent global feature.

The present paper presents a change to this perspective, focusing on the role that spontaneous settlements – as complex subsystems – play in the global dynamics of development. We understand that spontaneous settlements are constantly shaping and being shaped by a self-organised process which drives the system to a fragmented pattern that can be verified across scales. Therefore, they are key elements to understand the spatial pattern of Third World cities.

From a socio-spatial point of view, the existence of spontaneous settlements can be understood as instability pockets which are necessary for the structural stability of the global system (Portugali, 2000). If we consider that spontaneous settlements actually absorb part of the existent social instability - translated here as housing deficit - in unstable pockets within the city, one could say that they are necessary for the structural stability of the global system. Viewed as such, spontaneous settlements are fragments that keep the system away from what otherwise would be a breakdown of the already fragile and unstable equilibrium of Third World cities socio-spatial structure. This idea comes to reinforce Turner's (1988) argument that spontaneous settlements can be seen as an alternative solution, rather than a problem for the housing deficit. In the Third World urban context, spontaneous settlements play a paramount role within a system in which the parts do explain the whole, but only when seen in the light of a self-organised process.

References

Bak, P. (1997), "How Nature Works: The science of self-organized criticality", Oxford, University Press.

Barros, J. (2002), "Research Report" (unpublished), University College London.

Batty, M., Longley, P. (1994), "Fractal Cities: A Geometry of Form and Function", London, Academic Press.

Batty, M., Torrens, P. (2001), "Modeling Complexity: The Limits to Prediction", CASA Working Paper Series, **36**, available on-line at www.casa.ucl.ac.uk.

Couclelis, H. (2001), "Why I no longer work with Agents", in Special Workshop on Agent-Based Models of Land-Use, Land-Cover Change, CSISS, Irvine, available on-line at www.csiss.org/events/other/agent-based/papers/couclelis.pdf.

Dwyer, D. J. (1975), "People and housing in Third World cities: perspectives on the problem of spontaneous settlements", London, Longman.

Gomes, M., Garcia, J., Jyh, T., Rent, T., Sales, T. (1999), "Diversity and Complexity: Two sides of the same coin?", in The Evolution of Complexity, 8, 117-123, Dordrecht, Kluwer Academic.

Holland, J. (1995), "Hidden Order: how adaptation builds complexity", Massachusetts, Helix Books.

Portugali, J. (2000), "Self-organization and the City", London, Springer-Verlag.

Resnick, M. (2000), "Turtles, termites, and traffic jams: explorations in massively parallel microworlds", Cambridge, The MIT Press.

Sobreira, F., Gomes, M. (2001), "The Geometry of Slums: boundaries, packing and diversity", CASA Working Paper Series, **30**, available on-line at www.casa.ucl.ac.uk.

Sobreira, F. (2002), "The Logic of Diversity: complexity and dynamic in spontaneous settlements". Doctorate thesis. Federal University of Pernambuco.

Turner, J. (1988), "An introductory perspective", in Turner, B. (edit), A Third World case book, London, BCB/HFB.

Ulack, R. (1978), "The role of urban squatter settlements", Annals of the Association of American Geographers, **4**, 68, 535-550.

UNCHS – Habitat (1982), "Survey of slum and squatter settlements", Dublin, Tycooly International Publishing Limited.

UNCHS – Habitat (1996), "An urbanizing world: global report on human settlements", Oxford, Oxford University Press.