ACE Architecture, City, and Environment ©
Arquitectura, Ciudad y Entorno

MODELING AND URBAN STUDIES: AN INTRODUCTION

Nuno Norte Pinto
Polytechnic Institute of Leiria
Leiria, Portugal
npinto@estg.ipleiria.pt

António Pais Antunes
University of Coimbra
Coimbra, Portugal
antunes@dec.uc.pt

Remisión Artículo: 25 -5-2007

Keywords: Urban studies, urban modeling, microsimulation.

Abstract: This paper presents an introductory reading on modeling and urban studies. The main goal is to gather key information and literature references on the subject to allow the readers to establish a starting point for the study of the field. Issues regarding the evolution of urban modeling will be addressed. The relationship between theory (mainly related to modeling) and practice (regarding planning activities) will also be discussed. A set of modeling techniques will be presented. Finally, some conclusions will be drawn on the use of models and on its weakness and strengths.

Resumo: Este artigo apresenta uma leitura introdutória sobre modelação e estudos urbanos. O objectivo principal é reunir informação e referências importantes para permitir aos leitores uma base inicial de estudo do tema. A evolução da modelação urbana é apresentada. A relação entre a teoria (relacionada com o desenvolvimento de modelos) e a prática (relativa à prática em planeamento) será também discutida. Serão apresentadas diversas técnicas de modelação. Finalmente, algumas conclusões sobre as fragilidades e possibilidades do uso de modelação urbana serão apresentadas.

1 Introduction

The use of mathematical tools to model a wide range of spatial problems has been classified for the last decades as an important approach to scientific planning (Batty, 1994). The growth of urban areas is one of the issues which have concentrated a large research effort (Tobler, 1970, 1979, Couclelis, 1985, White and Engelen, 1993, Batty, Couclelis and Eichen, 1997, Clarke, Hoppen and Gaydos, 1997, Couclelis, 1997, Fragkias and Seto, 2005). Before the democratization of the use of computers, back in the 1970s, modeling approaches were usually applied on problems which demanded few information and, consequently, small computational effort. The information was taken in aggregate form, reducing the sensitiveness of those models, which were mainly static and deterministic. The models assumed an initial state of equilibrium, both in time and space, evolving to a new equilibrium after an exogenous stimulus (Waddell and Ulfarsson, 2004). In the mid 1970s, a period of reflection started after the publication of Douglass Lee paper "*Requiem for large-scale models*" (Lee, 1973), where the role of models as tools for scientific planning was severely criticized.

After this first period of large scale modeling that somehow ended by the time Lee published his criticisms, a series of new attempts were made and a new era of modeling began with the new computational resources provided by micro computation. Researchers seek new mathematical approaches founded in much more complex theories, such as discrete choice, agent-based simulation, or cellular automata, as the capacity of processing data at lower costs increased exponentially. At the same time, the development of new computers capable of producing better

graphical representations of the problems brought new enthusiasm to the use of models (Klosterman, 1994). The new mathematical theories and modeling tools made feasible the use of disaggregate information and the application of stochastic approaches, reducing the scale of the problems down to agents themselves (individuals, households, trips), thus improving the feasibility of the models (Waddell and Ulfarsson, 2004). It was the beginning of the microsimulation era.
The paper will firstly address the evolution of modeling and the planning process in Section 2. In Section 3 a brief discussion between the development of models and its integration in the planning process will be addressed. Finally, in Section 4, issues regarding the use of modeling approaches in urban studies are discussed. Several modeling tools used in simulation will be addressed, such as agent-based and multi-agent simulation, cellular automata, discrete-choice, rule-based simulation, and geographical information system (GIS) based simulation.

2 Modeling and the planning process

From the very early days of planning, like in several other areas of knowledge, a discussion over how it should be approached took place, creating the usual and most certainly necessary tension between theorists and practitioners.
In the specific case of planning, this issue becomes even more complex as it encompasses all sectors of society, from citizens to politicians, from bureaucrats to general stakeholders. Therefore, a necessity for creating a strong and organized planning system emerged from both planning theory and planning practice. As one of the most complex human activities, planning can use all the help it can get from a wide spread areas of knowledge (Couclelis, 2005).
After the blueprint planning era, where the final plan, the final image of the landscape or of the city represented the ultimate goal to achieve, planning become more comprehensive, incorporating social sciences, operations research, economic theories and regional science, trend introduced by the work of Rexford Tugwell and Harvey Perloff at the Chicago School (Klosterman, 1994).
The increasing interest in rational planning (a basic assumption of the Chicago School), was founded on the assumption that scientific approaches and systematic decision-making were the best way to deal with problems in such fields as management, politics and economics. Modeling was considered a major achievement of this scientific approach, therefore a new and important way to assist planning activities (Batty, 1994, Lee, 1994). These “new tools of planning” as Britton Harris called them in 1965, were thought to be a major technological breakthrough that would revolutionize the practice of urban policy making (Wegener, 1994).The idea of planning as a straight and rigid process that lead from a problem to a solution (materialized by the plan), without perturbations of any kind (judgment errors, public participation, monitorization, re-orientation of goals) changed to the cyclic approach proposed for example by McLoughlin (1969).
The introduction of computer sciences in the early 1950s brought new capabilities to mathematical calculus and data processing, limited only by the speed constraints of computer processors and available memory space. By that period the first models of cities were introduced. These models usually focused on transportation and land use allocation problems (Klosterman, 1994). During the 1960s, an important number of cities in the United States already had ambitious land use and transportation models running, and some of these models were already assisting planning activities (Lee, 1973, Batty, 1994, Klosterman, 1994).
In 1973 Douglass Lee published in the Journal of American Planners one of the most important papers ever published in the field, the famous “*Requiem for large-scale models*” (Lee, 1973). He identifies in this paper seven major “sins” of large-scale models: (1) *hypercomprehensiveness*: the early models tried to replicate too large and too complex a system in only one model, in a time when urban knowledge still was taking its first steps; (2) *grossness*: aiming for a large number of results obtained from the models, the information outputted by them was too rough to be use in practice; (3) *hungriness*: these models demand an enormous amount of data; (4) *wrongheadedness*: the models often deduced behaviors for some relationships that could not

bet generalized for a different subset of data obtained from the same problem; (5) *complicatedness*: the results of those models were somewhat so complex that they usually need some kind of exogenous intervention that would rebalance the output, with the consequent lost of scientific validity; (6) *mechanicalness*: the systematic errors due to mathematical processes usually produced large amounts of untraceable errors; and finally 7) *expensiveness*: the first theoretical and operational models from the 1960s were to much expensive, in the order of a few millions of dollars. Lee also emphasized the fact that, at the time, no model had produced any kind of relevant theory, as well as no model was founded on strong theoretical grounds.

To make some progress in this field at this critical turning point, Lee draws four major conclusions: (1) models should be more intuitive for potential users; (2) models should combine strong theoretical foundations, objective information and judgment, in order to eliminate the empiricism and the abstract, mainly futile, theorizing; (3) planners should start from simple, well defined problems, towards methods aimed to well identified purposes; and finally (4) models should be simple by nature, since complex models had failed to simulate real life.

Some of the criticism made by Lee where limited by its own boundaries: computational technology was still in a very initial phase, which was, by itself, a strong limitation to the development of models (no matter what the chosen scale was), both in available mathematical tools that were able to be implemented and in data processing capability.

But another author, Gary Brewer, published at the same year of "*Requiem*…", results from his work on the organizational limits to the development of large-scale models. He argued that, rather than theory, technology, data availability, or technical expertise, the inherent difficulties in adapting organizations to technology was the cause for the misuse of models (Batty, 1994).

Batty presents three major achievements that took place in the 1970s, despite this disturbance (Batty, 1994): first, a series of modest but steady refinements on the side of practical applications of land use and transportation models; second, and perhaps the most significant one as Batty argues, the introduction to the urban systems theory of the general concept of optimization, linked to several studies on econometrics and market behaviors; and third, the most challenging one, the incorporation of time – the dynamic behavior – that could only take place after the development of several new mathematical concepts during the 1960s.

The year of 1973 was the first moment of retrospective for the urban modeling science. Many authors argued opposite opinions on these subjects, but the sense that large scale urban modeling had had its days was evident. Lee's criticisms made a huge impact on the planning community, by the time when the modeling practice had acquired a rudimentary organization, and some tradition and the scientific approach applied to planning was making its first "incursions" in Europe (Batty, 1994). It is symptomatic that the number of papers published on large-scale modeling decreased dramatically, and for a long period of time the subject was, despite a hand full of works, practically put aside (Klosterman, 1994). And Lee's "*Requiem*…" still is, in our days, one of the most cited papers in the field of urban modeling.

One of the consequences of the social change of paradigms that occurred in the 1970s with the end of the post-World War II economical boom and with the early signs of weakness shown by the welfare state was a shift on the planning horizon adopted by the majority of practitioners. The object of planning was re-centered on short term goals, on immediate solutions to problems, rather than to accomplish ambitious long-term strategic objectives, a characteristic of large-scale planning as it was proposed by the Chicago School, for example. It was the shift from planning to management (Batty, 1994).

Another crucial concept of planning had passed virtually untouchable during these turbulent times for the science of modeling: the vital need for large amounts of information. In the 1960s, alongside with modeling techniques, the management of large information systems were the cutting edge of scientific planning (Batty, 1994). The advent of sophisticated data base management systems provided powerful tools for planners as they could now process a larger amount of more disaggregate data in increasingly shorter amounts of time.

The next step that took place in the 1980s was the diffusion of the concept of geographical information systems (GIS). Although, for many years until the mid 1990s, these software tools

were mainly used for cartography processing and mapping (Batty, 1994), the integration of new, sophisticated, built in modeling with GIS has provided new grounds for the planning activity (Takeyama and Couclelis, 1997, Wagner, 1997, Batty, Xie and Sun, 1999).
At present, new paths are being explored. Computer capabilities are now at a level which planners and modelers in the 1960s would consider almost science fiction. Whereas location and transportation were the key to the first generation of urban models, the dynamics of growth and diffusion phenomena at a fine scale are the subjects of the new generation of micro-scale modeling (Batty, 2004). Object-oriented programming brought new and powerful tools for modeling at a disaggregate micro-scale (Benenson, Omer and Hatna, 2002, Barros, 2005, Benenson, Aronovich and Noam, 2005, Semboloni, 2005). Micro-simulation is now a reality, supported by a series of techniques such as cellular automata and agent-based simulation. GIS and data base management are two of the most developed areas in software, with a series of commercial products that easily and by lower costs provide the necessary data processing capacity. The developments in the last two decades both in data availability and computational capacity have created a big impulse on the use of models, clarifying their role as a scientific approach to the highly comprehensive planning process (Couclelis, 2005).
Models are shifting from a comprehensive perspective, the main assumption of the first generation of models, to a sketch-planning-type modeling, oriented for solving closely adapted local situations, standing out policy-oriented, practical goals rather than broad strategic goals, a characteristic of the former ones (Batty, 2004, Couclelis, 2005).
But some of the critics formulated in the 1970s remain present. There are some concerns that modelers still focus their main attention on model development rather than on the planning problem underlying the model. Urban simulation is as much a planning exercise in simulation as it is in planning sciences (Torrens and O'Sullivan, 2001). Couclelis stated that in all but trivial cases, the hope on good predictive models in the field of social phenomena is lost (Couclelis, 1997). There still is an apparent paradox on the fact that, as well intentioned modelers were creating land use models aimed to forecast future states of complex systems, these models helped little (or not helped at all) planners in their tasks (Couclelis, 2005).

3 The theory/practice dichotomy

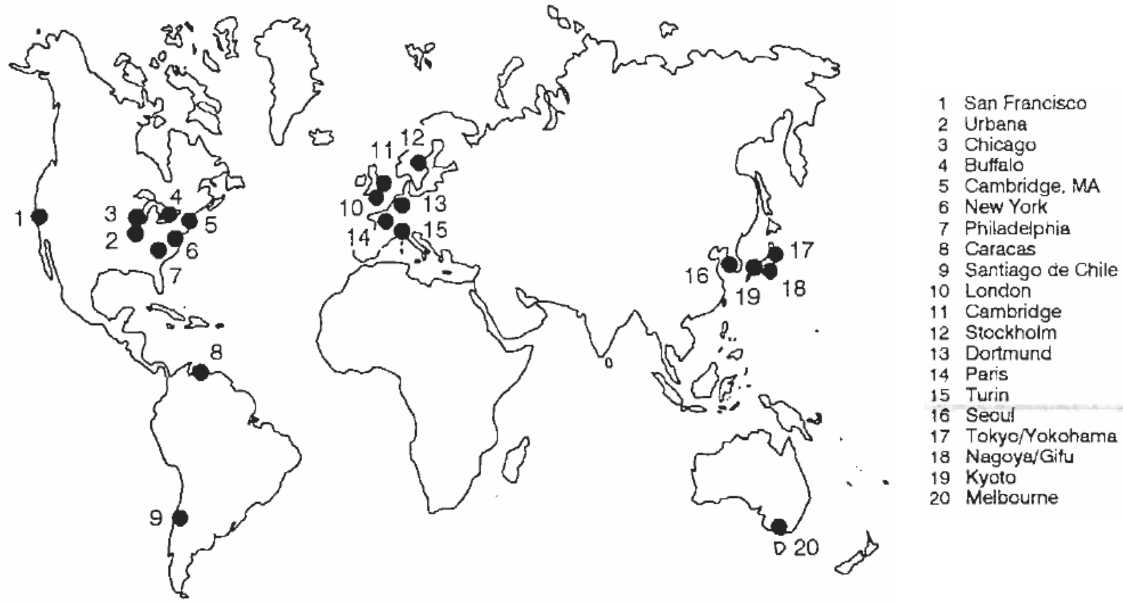
The important notion of the conflict that exists in urban modeling between theoretical and practical perspectives, between the use of models and the practice of planning, is very well described by Couclelis (2005) (page 1359):

"Models are based on science; planning is about policy. Models are much better (…) at dealing with natural science problems; planning is mired in difficulties most often due to issues in the purview of social sciences. Models are usually developed from within particular disciplinary perspectives; planning must integrate across all domains. Models are about information and facts; planning is about interpretation and values. (…) Models codify uncertain knowledge; planning must lead to certain action. (…)"

This natural tension between theorists and practitioners, between modelers and planners was already mentioned in the previous section. This continuous tension between modeling and planning results from those general dichotomies mentioned before between science and policy, natural and social sciences, between analysis and synthesis, studying the past and preparing the future (Couclelis, 2005). Modeling was firstly considered the new grounds for a new scientific approach to planning (Batty, 1994, Wegener, 1994). Despite of the disturbance experienced by urban modeling throughout the past decades (or, in a more realistic perspective, since almost the beginning of its practice), the practice of planning was always considered intimately dependent of its theory, only varying the scale and the extent of dependence the later imposed to the former.
There still is a structural gap between planning theory and practice. It only emphasizes the mistrust in the scientific approach made by the use of models. Modelers and planning support

systems (PSS) developers must try hard on developing solutions that meet the planners needs (Couclelis, 2005). Therefore, applicability must be one of the major aims (if not the goal to achieve) of current and future studies in urban modeling, as it constitutes the means that will provide the needed validation to this scientific area. Modelers must accept that the role of scientific planning goes far beyond the implementation of forecasting models; at the same time, planners must find a balance between participation and systematic expertise (Couclelis, 2005).
The shift of paradigm from the pioneers of the 1960s to the current practice is mainly associated with the general perception that rational planning, aiming to understand and control the entire system, failed to accomplish the needs of more modest, incrementalist interpretation of planning (Wegener, 1994). In this context of integration of stakeholders, a major aim of current planning practice, the recent development of new methodologies for the integration of stakeholders' values, such as multi-criteria evaluation and the new Value Sensitive Design methodology (Friedman, Kahn and Borning, 2002) can improve the use of simulation in the planning process (Waddell and Ulfarsson, 2004). It is also very important to capacitate models to evaluate objectives that are stated in planning policies, even when they are somehow undefined (Waddell and Ulfarsson, 2004).
The integration of stakeholders and their value systems, along side with the fact that planning generates a variable set of goals and actions, imposes the consideration of uncertainty as a key factor for the success of the relationship modeling/planning (Couclelis, 2005). Three major roles for land use models are proposed by Couclelis in order to increase their mission to support planning: scenario writing (what may be), visioning (what should be) and storytelling (what could be) (Couclelis, 2005). Scenario writing is a notion that has its roots on modeling science, being one of its historical goals. Visioning is useful to integrate community interests and values in order to try to reach broad consensus on strategic matters. Storytelling can help to compare future desired and feared evolutions, in realistic terms that could effectively assist the planning process.
Since those uncertain times, a small but steady increase has been registered in the field of urban modeling. Time had tempered the experience and what had been accomplished between 1973 and the early 1990s could not be considered as failure (Batty, 2004). This increase promoted by the spectacular development of computational capacities, was studied by Wegener for the special issue of the Journal of American Planners published in 1994 (Wegener, 1994). Wegener assembled a list of groups and locals that were developing and implementing urban models of any kind with an operational perspective (see Figure 1).
The criteria for choosing a particular group was: (1) that a mathematical model implemented on a computer and aimed to analyze past evolution and to forecast future urban scenarios should be the basis of the urban model itself; (2) that the modeling approach should have a comprehensive framework, integrating all the essential processes of urban phenomena; and (3) were excluded all those works that only presented theoretical work without any operational implementation, as valid as those works could be. It is interesting to notice that by that time, 20 years after Lee's "*Requiem*…" an important group of scientists was developing urban modeling and had constituted an informal scientific network, crucial for the strengthening and increasing gain in coherence of this scientific field (Wegener, 1994).
In the present, the number of active groups working on integrated urban models has reached the highest point, with a series of operational models implemented all over the world. Waddell, Bhat, Ruiter, Bekhor, Outwater and Schroer (2001) reports a series of ongoing work on the field: the UrbanSim framework is in operational use in the Puget Sound Region, in the state of Washington (Waddell and Ulfarsson, 2004); the Reusable Modeling Components for Land Use, Transportation, and Land Cover project is dedicated to the development of robust and modular set of modeling tools capable of being replicated in different urban and regional contexts. Miller, Hunt, Abraham and Salvini (2004) refers some integrated land use and transportation software packages that are already available, as MEPLAM (Hunt and Simmonds, 1993) and TRANUS (de la Barra, 2001), although these models are founded on aggregate approaches with strong equilibrium assumptions on several variables of the systems (Miller *et al.*, 2004).

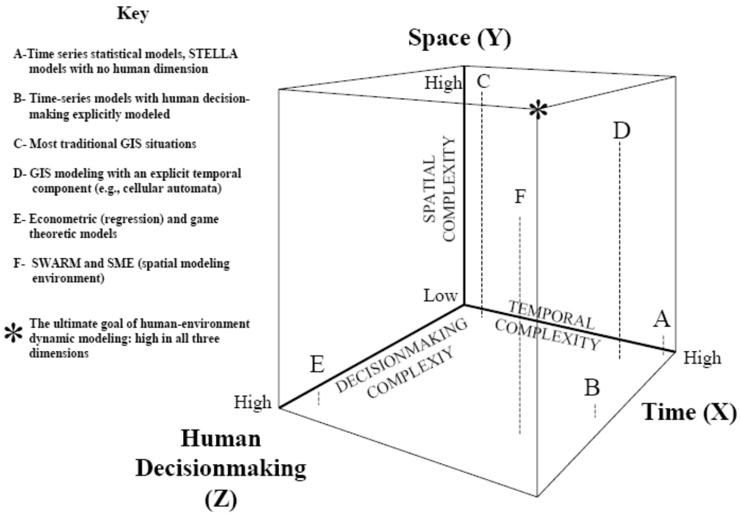
Figure 1 **Map of active urban modeling centers**



Source: Wegener, 1994

Agarwal, Green, Grove, Evans and Schweik (2002) proposed a classification methodology for land use/land cover change models. They established a series of key factors that influence model performance by analyzing several agricultural, forestry, and land use models. Their work was of particular interest because they established three major vectors for the classification of land use models: space complexity, temporal complexity and decision making complexity. Although it seems obvious that these three components are determinant for model classification, it was necessary to establish parameters that could classify a model considering different degrees of complexity. The relationship between these three vectors of complexity can be easily interpreted from the scheme depicted in Figure 2.

Figure 2 **Three-dimensional framework for reviewing and assessing land-use change models**



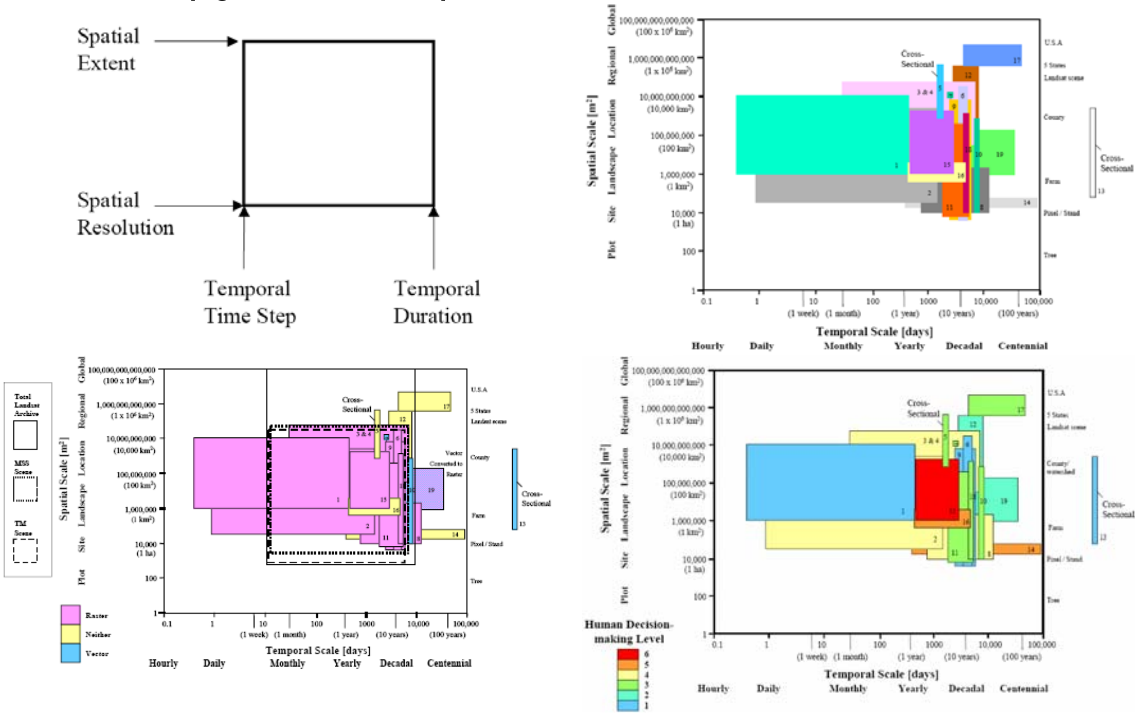
Source: Agarwal *et al.*, 2002

Six degrees of classification for human decision making complexity were proposed: from grade 1 (No human decision making – only biophysical variables in the model) up to grade 6 (Multiple types of agents whose decisions are modeled overtly in regard to choices made about variables that affect other processes and outcomes).

The study analyzed nineteen models that cover different modeling approaches. It classified these models and compared them considering a series of human drivers or social patterns and preference variables. An intuitive analysis was presented in the form of comparison graphics where the entire set of models was compared considering not only their spatial and temporal levels of complexity but also a series of other characteristics (some examples are depicted in Figure 3).

The study pointed out some orientations for the future in land use modeling. The use of open-source platforms was referred as a proficient path to pursue in order to enhance the collaborative basis of land use modeling (some modeling techniques are currently embracing this paradigm, for example agent-based simulation (Swarm, 2002)). This new vision of modeling could also deal with the concurrent work developed by independent research groups on common modeling techniques. Another important conclusion is related with the incorporation of land use policy in model development. Models should meet the needs of policy makers and planners in order to enhance their applicability for assisting the planning process.

Figure 3 **Comparative graphic for human decisionmaking complexity (for the complete list of models see (Agarwal *et al.*, 2002)**



Source: Agarwal *et al.*, 2002

Klosterman and Petit updated the list of significant urban models that are currently being implemented (Klosterman and Petit, 2005). They assembled this list considering simultaneously the modeling approach of each work and the main task purpose by each model, which is summed up in Table 1 and Table 2.

Complexity is also one of the major investigation areas currently under attention. Many authors identifies complexity as the key factor to understand urban phenomena (White and Engelen, 1997, Benguigui, Czamanski, Marinov and Portugali, 2000, Batty and Torrens, 2001, Li and Yeh, 2001, De Keersmaecker, Frankhauser and Thomas, 2003, Batty, 2005b).

Table 1 **Categorization of selected planning support systems**

Technique	Task			
	Land use/Land cover change	Comprehensive projection	3D visualization	Impact assessment
Large-scale urban	METROPILUS SPARTACUS TRANUS UrbanSim	METROPILUS SPARTACUS TRANUS UrbanSim		
Rule-based	CUF WhatIf?™1.1	WhatIf?™ 2.0	CommunityViz	CommunittyViz INDEX© Place^{3}S
State-change	CUF II CURBA			
Cellular automata	SLEUTH DUEM			

Source: Klosterman and Petit, 2005

Cities, like several spatial phenomena, are complex systems. "The mixture of different urban activities creates a logic of its own, but a logic nonetheless. As almost all cities presents this complexity, it is reasonable to suppose that complexity is somehow one of its essential qualities" (White and Engelen, 1993). Complexity expresses itself through spatial scale: from local scale behaviors of individuals (vehicles or people) emerge structured and ordered patterns in aggregate large scale. In fact, the hole concept of complexity hinges on the notion of emergence (Torrens, 2000). One of the goals of complexity studies is to derive universal laws of complex systems from common principles based on simple features (Torrens, 2000). However, many processes in the natural world may not be deduced in universal laws capable of granting a decent theoretical basis of complex systems (Casti, 1997) cited by (Torrens, 2000).

Table 2 **Information sources for selected planning support systems**

Model	References	Web-site
CommunityViz	(Kwartler and Bernar, 2001)	http://www.communityviz.com
CUF, CUF II and CURBA	(Landis, 2001)	
DUEM	(Xie, 1996)	http://lgre.emich.edu
INDEX©	(Allen, 2001)	http://www.crit.com
METROPILUS	(Putman and Shih-Liang, 2001)	
Place^{3}S	(Snyder, 2001)	http://www.energy.ca.gov/places
SLEUTH	(Clarke *et al.*, 1997, Silva and Clarke, 2002)	http://ngcia.ucsb.edu/projects/gig
SPARTACUS	(Latuso, 2003)	http://www.fhwa.dot.gov/planning
TRANUS	(de la Barra, 2001)	http://www.modelistica.com
UrbanSim	(Waddell, 2001)	http://www.urbansim.org
WhatIf? ™	(Klosterman, 2001, Klosterman, Siebert, Hoque, Kim and Parveen, 2003)	http://www.what-if-pss.com

Source: Klosterman and Petit, 2005

The best way to characterize a complex system is identifying the states it can take and the conditions to take them. This can be easily understood with a simple example based on cellular automata. Considering a system with *n* elements (for instance cells) describing a particular state, each state described by a binary existence (say developed) or otherwise for each element, then there are 2^n distinct states. If a lattice of some hundreds cells is considered, with a wider set of rules for transit between those states, then conventional theorizing can not describe the problem (Batty and Torrens, 2001).

Complex systems include two key elements (Batty and Torrens, 2001): first, "system extensiveness" along any spatial, temporal or topical dimension[1], as complex systems can not be reduced or aggregated without lost of their structure; second, process, meaning that space and time dynamics suffers unexpected changes, often followed by emergence.

[1] The fact that complex systems are allowed to evolve without the constraints of reductionism runs directly against the traditional scientific paradigm of analysing the essence of phenomena to deduce theory.

4 The microsimulation approach

In Section 2.1 the evolution of urban modeling throughout the past decades was shortly described, since the early efforts from the 1950s to the new paths based on powerful and inexpensive computation. This evolution kept up with the evolution of computer science, benefiting with the new calculus resources provided by computer.
The transition from the early large scale modeling phase, based on equilibrium assumptions and deterministic approaches gave place to the fine scale based modeling supported by new scientific approaches. Microsimulation, which was developed in the 1960's, was only applied to urban modeling later in the 1980's. Since then, the development of discrete choice modeling and the emergence of cellular automata and multi-agent simulation techniques have created a proliferation of modeling approaches (Waddell and Ulfarsson, 2004).
Waddell and Ulfarsson (2004) presents a series of preliminary model design choices that must be considered in urban modeling. These assumptions establish the difference between macrosimulation and microsimulation, as they set up a series of orientations that are thought to adjust the simulation to the reality they aim to simulate.
The first choice regards behavioral resolution. Systems can be considered working at an aggregate scale of average behavior or they can be assumed working at a disaggregate level, based on individual agents. Secondly, the simulation must be based on deterministic or on stochastic behavior: deterministic models are commonly used along with aggregate scale of behavior since the average behaviors can be easily approximated with fixed rates of change. Finally, issues related with the resolution of agents, space and time must be pondered. Simulation systems range, in general, from macroscopic resolution to microscopic resolution.
Macroscopic systems have larger units of analysis, dealing with aggregate information both spatially and statistically and they are essentially static and deterministic. The low consumption of data and computational resources make macroscopic simulation one of the most widely used approaches (Waddell and Ulfarsson, 2004).
Microscopic models have, in opposition to the previous scale, small units of analysis. These scale level of modeling is the strongest beneficiary of the evolution of computation throughout the last twenty years. As computational resources evolved and become less expensive and faster, microscopic models started to increase the amount of data processed and to deepen the resolution of the models, with a consequent increase in their feasibility. These models have a stochastic behavior as they support clearer behavioral specifications (Waddell and Ulfarsson, 2004).
In between these two modeling scales there is an intermediate mesoscopic scale. This term is essentially used to classify models that integrate characteristics of both macroscopic and microscopic models. They can present large analysis units with small time steps or they can use aggregate data for some aspects of the model at the same time they use detailed information for other aspects (Waddell and Ulfarsson, 2004).
Most geographic theories are static where rational actors were assumed to interact in a market that remains in a state of equilibrium. This is not a reasonable way to describe a city, which common sense and experience tell us is rarely if ever in an equilibrium state. Almost all cities are undergoing continual growth, change, decline and restructuring, usually simultaneous (White and Engelen, 1993).
The assumption that urban systems are better represented by dynamic, stochastic, high resolution models along with impressive developments on computation made microsimulation the most fitted approach for dealing with these issues. Applications based on microsimulation are being developed both in theoretical and operational perspectives in different areas of urban sciences. Transport systems analysis produced a series of real-time applications, based on individual agents (see Miller *et al.*(2004) for a brief list of models). Integrated land use models are also being developed in the last few years using microsimulation, such as UrbanSim, SLEUTH and WhatIf? operational models (see Table 1 on page 478).
Although microsimulation was introduced in the 1960s, it was only in the 1980s that it started to be used in urban modeling (Waddell and Ulfarsson, 2004).

The early modeling approaches were based on techniques as spatial interaction, spatial input/output and linear programming. Spatial interaction is founded on the gravity model applied to model trip destination choices or residential and employment location. These models are limited in the degree of spatial detail used and do not represent the behavioral factors influencing the phenomena they try to simulate, especially market and prices behaviors (Waddell and Ulfarsson, 2004). Spatial input/output models are an extended application of the input/output model of the US economy presented by Leontief to represent spatial patterns of location for economic activities and people and goods movements between zones (Leontief, 1966). This approach has the merit of including explicit real estate and labor markets, as well as travel demand, but it still considers different states of equilibrium for changes in the model inputs (Waddell and Ulfarsson, 2004). Another technique used in early models, although less often, is linear programming. This technique is focused on the optimization of an objective function and it is more suited to the exploration of land use alternatives that optimize some urban function (such as travel cost), than to simulate complex and realistic behavioral responses to input changes (Waddell and Ulfarsson, 2004).
Microsimulation as a modeling approach essentially implies the use of individual-level scales. Waddell and Ulfarsson (2004) describes the most important microsimulation techniques currently under use.
Discrete choice modeling is a standard method whenever the behavior of individuals (households, people, and trips) is modeled, particularly after the publication of the Random Utility Theory by Daniel McFadden (Waddell and Ulfarsson, 2004). Models such as logit and nested logit are frequently used to predict individual choices among finite sets of alternatives, a very common goal on travel demand and mode choice modeling.
There are several land use models developed in recent years using GIS and a rule-based set of procedures to allocate population, employment, and/or land use. Examples include the CUF model (Landis, 2001) and WhatIf? (Klosterman, 2001). These applications may have a useful role in making models more accessible, but there is a risk that model users would interpret the models as having a more behavioral basis than their rules actually contain (Waddell and Ulfarsson, 2004).
Multi-agent simulation (a generalization of agent-based simulation) is another simulation method available that works on a disaggregate level. It draws upon complex systems theory, focusing the modeling on the emergent systems behavior arising from the interactions between agents (Waddell and Ulfarsson, 2004). This techniques has been the object of intensive research since the creation of the Swarm software environment for implementation of models of this type (Swarm, 2002). There is extensive ongoing research on this methods with promising results (Barros, 2005, Benenson *et al.*, 2005, Semboloni, 2005).
Cellular automata modeling has emerged from the field of complex systems theory as a means of representing emergent properties derived from sets of simple behavioral rules operating over a cell-based pattern. This approach was introduced to spatial problems by Waldo Tobler in his ground breaking work “*Cellular Geography*” (Tobler, 1979) and has been widely applied since then in many land use and land cover change problems (Couclelis, 1985, White and Engelen, 1993, Xie, 1996, Clarke *et al.*, 1997, O'Sullivan, 2001, Barredo, Kasanko, McCormick and Lavalle, 2003, Batty, 2005a, Pinto, 2006).
Cellular automata present many advantages for modeling urban phenomena. Their conceptual simplicity and the high level of spatial resolution can be pointed out as two of their main features. It is a decentralized approach, it provides a link to complexity theory, and it makes the connection of form with function and of pattern with process. It has good visualization characteristics, it is a flexible and dynamic approach and, more important, it is based on a set of very simple elements (Torrens and O'Sullivan, 2001). Cellular automata also have advantage when facing the traditional simulation approaches based on differential or difference equations: it is inherently spatial, with rule-base dynamics, with a much higher computational efficiency which means that dynamics can be modeled with very high spatial resolution (White and Engelen, 1993, Batty *et al.*, 1997). But these advantages yields simultaneously its handicap: cellular automata models are constrained by their own simplicity and their ability to illustrate real

world phenomena is often diluted by their abstract characteristics (Torrens and O'Sullivan, 2001). For an extensive presentation of cellular automata concepts and their application to urban studies see Pinto and Antunes (2007).

5 Conclusions

This paper aimed to briefly introduce the theme of modeling and urban studies. The goal was to gather key information and literature references on the subject and to allow the readers to establish a starting point for the study of the field.
Key issues were addressed. A brief evolution of the use of models in urban studies was presented and the dichotomy between theory (regarding modeling) and practice (in planning) was discussed. This discussion is considered of great importance as it defines the real extent of the applicability of models in urban studies. The tension observed by many authors between modelers and planning practitioners was (and still is) at the same time the weakness and the strength of urban modeling. The skepticism with which many planners still face the use of models creates a difficult framework to the introduction of modeling approaches. On the other hand, the necessity for proving models' validity and applicability is a major motivation for modelers to carry on in the search for more sophisticated, collaborative, and effective modeling tools.
Finally, the large set of modeling tools that are currently under use gives hope to the future of urban modeling. Different approaches are been carried out in an increasingly integrated fashion. Collaborative approaches are in current development and the effective integration of human decision making and policy issues with spatial and temporal complexity provides models a whole new set of possibilities. Issues regarding spatial and temporal resolution still are in the centre of theoretical discussion. And the goal of developing modular modeling tools capable of being applied to a wide set of different urban contexts is one of then most challenging line of research in the field.

Literature References

Agarwal, **C., G.M. Green, J.M. Grove, T.P. Evans and C.M. Schweik**. 2002. A review and assessment of land-use change models: dynamics of space, time, and human choice. U.S.

Department of Agriculture, Forest Service, Northeastern Research Station, Newton Square, PA. 61 61 Allen, E. 2001. INDEX: software for community indicators, Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 229-262.

Barredo, J., M. Kasanko, N. McCormick and C. Lavalle. 2003. Modelling dynamic spatial processes: simulation of urban future scenarios through cellular automata, Landscape and Urban Planning, 64 145-160.

Barros, J. 2005. Urban dynamics in Latin American cities: an agent-based simulation approach. Proceedings of Ninth Computers in Urban Planning and Urban Management. Ed. London, United Kingdom, 29 June - 1 July 2005.

Batty, M. 1994. A chronicle of scientific planning - The Anglo-American modelling experience, Journal of the American Planning Association, 60 (1) 7-16.

_____. 2004. Dissecting the streams of planning history: technology versus policy trough models, Environment and Planning B: Planning and Design, 31 326-330.

_____. 2005a. Agents, cells and cities: new representational models for simulating multiscale urban dynamics, Environment and Planning A, 37 1373-1394.

_____. 2005b. Cities and complexity : understanding cities with cellular automata, agent-based models, and fractals, MIT, Cambridge, Mass. ; London. xxiii, 565 pages.

Batty, M., H. Couclelis and M. Eichen. 1997. Editorial: Urban systems as cellular automata, Environment and Planning B: Planning and Design, 24 159-164.

Batty, M. and P. Torrens. 2001. Modelling complexity: the limits to prediction, CASA Working Papers Series,

Batty, M., Y. Xie and Z. Sun. 1999. Modelling urban dynamics through GIS-based cellular automata, Computers, Environment and Urban Systems, 23 205-233.

Benenson, I., S. Aronovich and S. Noam. 2005. Let's talk objects: generic methodology for urban high-resolution simulation, Computers, Environment and Urban Systems, 29 425-453.

Benenson, I., I. Omer and E. Hatna. 2002. Entity-based modelling of urban residential dynamics: the case of Yaffo, Tel Aviv, Environment and Planning B: Planning and Design, 29 491-512.

Benguigui, L., D. Czamanski, M. Marinov and Y. Portugali. 2000. When and where is a city fractal?, Environment and Planning B: Planning and Design, 27 507-519.
Casti, J. 1997. Would-be worlds: how simulation is changing the frontiers of science, John Wiley and Sons, New York. 256 pages.

Clarke, K., S. Hoppen and L. Gaydos. 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area, Environment and Planning B: Planning and Design, 24 247-261.

Couclelis, H. 1985. Cellular worlds: a framework for modelling micro-macro dynamics, Environment and Planning A, 17 585-596.

_____. 1997. From cellular automata to urban models: new principles for model development and implementation, Environment and Planning B: Planning and Design, 24 165-174.

_____. 2005. "Where has the future gone?" Rethinking the role of integrated lad-use models in spatial planning, Environment and Planning A, 37 1353-1371.

De Keersmaecker, M.-L., P. Frankhauser and I. Thomas. 2003. Using fractal dimensions for characterizing intra-urban diversity: the example of Brussels, Geographical Analysis, 35 (4) 310-328.de la Barra, T. 2001. Integrated land use and transport modelling: the TRANUS experience,

Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 129-156.
Fragkias, M. and K. Seto. 2005. Modelling urban growth in data-sparse environments: a new approach. Proceedings of XII CUPUM. Ed. London, UK,

Friedman, B., P. Kahn and A. Borning. 2002. Value Sensitive Design: Theory and Methods. University of Washington, Seattle. 8 8

Hunt, J.D. and D.C. Simmonds. 1993. Theory and application of an integrated land-use and transport modelling framework., Environment and Planning, 20B 221–244.

Klosterman, R. 1994. Large-Scale urban models - Retrospect and prospect, Journal of the American Planning Association, 60 (1) 3-6.

Klosterman, R. and C. Petit. 2005. Editorial: An update on planning support systems, Environment and Planning B: Planning and Design, 32 477-484.

Klosterman, R.E. 2001. The What If? planning support system, Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 263-284.

Klosterman, R.E., L. Siebert, M.A. Hoque, J.W. Kim and A. Parveen. 2003. Using an operational planning support system to evaluate farmland preservation policies, Planning Support Systems in Practice. Ed. Geertman, S and J Stillwell. 391-407.

Kwartler, M. and R.N. Bernar. 2001. CommunityViz: an integrated planning support system, Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 285-308

Landis, J. 2001. CUF, CUF II and CURBA: a family of spatially explicit urban growth and land-use policy simulation models, Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 157-200.

Latuso, K. 2003. The SPARTACUS system for defining and analysing sustainable land use and transport policies, Planning Support Systems in Practice. Ed. Geertman, S and J Stillwell. Springer, Heidelberg. 453-463.

Lee, D. 1973. Requiem for large-scale models, Journal of the American Planning Association, 39 (3) 163-178.

_____. 1994. Retrospective on large-scale urban models, Journal of the American Planning Association, 60 (1) 35-40.

Leontief, W.W. 1966. Input-output economics, Oxford University Press, New York,. viii, 257 pages.

Li, X. and A. Yeh. 2001. Calibration of cellular automata by using neural networks for the simulation of complex urban systems, Environment and Planning A, 33 1445-1462.

McLoughlin, J.B. 1969. Urban and Regional Planning, Faber and Faber, London. pages.
Miller, E., J. Hunt, J. Abraham and P. Salvini. 2004. Microsimulating urban systems, Computers, Environment and Urban Systems, 28 9-44.

O'Sullivan, D. 2001. Graph-based cellular automaton models of urban spatial processes. PhD Thesis, Bartlett School of Architecture and Planning, University College, London. 317 pages

Pinto, N.N. 2006. A microsimulation approach for modelling the growth of small urban areas. MSc Thesis, Department of Civil Engineering, School of Engineering of the University of Porto, Porto. 156 pages

Pinto, N.N. and A.P. Antunes. 2007. Cellular Automata and Urban Studies: a Literature Survey, Architecture, City and Environment, 1 (3) 368-399.

Putman, S.H. and C. Shih-Liang. 2001. The METROPILUS planning support system: urban models and GIS, Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 99-128.

Semboloni, F. 2005. Multi-agents simulation of urban dynamic. Proceedings of XII CUPUM. Ed. London,

Silva, E. and K.C. Clarke. 2002. Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal, Computers, Environment and Urban Systems, 26 525-552.

Snyder, K. 2001. Tools for community design and decision-making, Planning Support Systems in Practice. Ed. Geertman, S and J Stillwell. Springer, Hedelberg. 99-120.

Swarm. 2002. Swarm - Multi-Agent Simulation Environment. Available at http://www.swarm.org/wiki/Main_Page, Accessed in 2006/09/07

Takeyama, M. and H. Couclelis. 1997. Map dynamics: integrating cellular automata and GIS through Geo-Algebra, International Journal of Geographical Information Science, 11 (1) 73-91.
Tobler, W. 1970. A Computer Movie Simulating Urban Growth in the Detroit Region, Economic Geography, 46 (2) 234-240.

_____. 1979. Cellular geography, Philosophy in Geography. Ed. Gale, S and G Olsson. D. Reidel, Boston. 379-386.

Torrens, P. 2000. How cellular models of urban systems work (1. Theory). CASA Working Papers Series. Available at http://www.casa.ucl.ac.uk/working_papers.htm, Accessed in November 2005

Torrens, P. and D. O'Sullivan. 2001. Editorial: Cellular automata and urban simulation: where do we go from here?, Environment and Planning B: Planning and Design, 28 163-168.

Waddell, P. 2001. Between politics and planning: UrbanSim as a decision-support system for metropolitan planning, Planning Support Systems: Integrating Geographical Information Systems, Models and Visualization Tools. Ed. Brail, RK and RE Klosterman. ESRI Press, Redlands, CA. 201-228.

Waddell, P., C. Bhat, E. Ruiter, S. Bekhor, M. Outwater and E.L. Schroer. 2001. Review of the Literature and Operational Models. University of Washington, Puget Sound Region.

Waddell, P. and G. Ulfarsson. 2004. Introduction to urban simulation: design and development of operational models, Handbook of Transport Geography and Spatial Systems, Volume 5 (Handbooks in Transport). Ed. Hensher, D, K Button, K Haynes and P Stopher. Elsevier Science, 203-236.

Wagner, D.F. 1997. Cellular automata and geographic information systems, Environment and Planning B: Planning and Design, 24 219-234.

Wegener, M. 1994. Operational urban models - State of the Art, Journal of the American Planning Association, 60 (1) 17-29.

White, R. and G. Engelen. 1993. Cellular Automata and fractal urban form: a cellular modelling approach to the evolution of urban land-use patterns, Environment and Planning A, 25 1175-1199.

_____. 1997. Cellular automata as the basis of integrated dynamic regional modelling, Environment and Planning B: Planning and Design, 24 235-246.
Xie, Y. 1996. A generalized model for cellular urban dynamics, Geographical Analysis, 284 350-373.