UrbanLab

Agent-Based Simulation of Urban and Regional Dynamics

Luca CANEPARO and Matteo ROBIGLIO
Department of Architectural Design, Politecnico di Torino, Italy

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Abstract: An overview of the two stages of the UrbanLab model is presented, focusing on the layering between the two stages: the first using GIS based socio-economic data, communicating the second stage, which is an agent-based dynamic model of citizens' activities.

1 INTRODUCTION

The paper presents an ongoing project to interactively simulate urban and regional dynamics at the building scale.

We consider the urban and regional systems an "auto-organising" system (Lanzani 1991). The dynamics of the system is driven by the relationships between "local" actors (e.g. the owners of the land, dwellings etc.), "global" actors (investors, public decision-makers etc.), their interactions (market, social, etc.), and macro-dynamics, which tend to orient the overall system (economy, planning, policy etc.). Recent studies and numerical models (U.S. EPA 2000) confirm these hypotheses of our model.

In collaboration with mathematicians, physicists and artificial intelligence researchers we have been working to address the above issues. The main objective of this collaboration is to design and develop a virtual laboratory for interactively designing and planning at urban and regional scales: *UrbanLab*.

UrbanLab aims to assist designers, planner, and public decision-makers in interactive design and planning processes: choice → simulation → evaluation → adaptation/change → choice →simulation… The capability of interactively simulating different possible directions of urban and regional evolution would allow planners and designers an early evaluation of the consequences of design and planning strategies, in their overall complexity.

This can be done in two different ways: either by pursuing the most faithful representation of reality-to-be, i.e. by constructing photorealistic renderings allowing virtual experience of a proposed environment, or by pushing schematisation to extremes, by proposing schematic, manifestly false representations of possible environment. The first possibility is a broadly recognised task implying some technical difficulties but no epistemological ones.

On the contrary, simulation of "extreme" scenarios that, despite their improbability, allow both planners and citizens to reason *ab absurdo*, to discover unrealistic ideal typical hypotheses, is fairly easily from the technical point of view, but uncommon in urban simulation. These hypotheses are not utopian; rather they are the schematisation of alternative work-hypotheses, supporting the decision-making process by visualising not the future but the rationality implied in a proposed scheme. Although quite unusual in urban simulation, where realism is the rule, this ideal-tipic schematisation of reality not only belongs to artistic knowledge (Honoré Daumier's caricatures might provide a good example) but is also commonly accepted in human sciences as anthropology, as a way of providing typified representation of reality without compelling individualities to be absorbed by the "type" that should interpret them (Geertz 1995).

2 CITIZENS AND ADMINISTRATORS STRATEGIES

The first and essential stage in the implementation of UrbanLab is the creation of a methodology for describing local and global actors' actions, their interactions, both mutual and with macro-dynamics. The paper presents the applied methodology, which is required to be both *efficient*, for up-to the regional scale simulation, and *reliable*, in order to be effectively applied during design and planning processes.

Simulation does not mean that actual behaviours or preferences of actors can be substituted by a model. The model can simulate large-scale process in which individual preferences and strategies can be statistically outcast through socio-economic surveys, ordinary available and reliable at regional scale. But models can also be used as tools for real interaction, in participatory processes implying the actual presence of citizens, administrators, interest groups etc. In the first case, the model is used as "reactive" machine that simulates the behaviour of a complex territorial system. In the second case, the model provides a communicative and easily-read representation of a future-to be, facilitating non-professional audiences in taking part into aware decision-making (Forester 1999).

3 4D URBAN AND REGIONAL DESIGN

UrbanLab deals with phenomena in three-dimensions plus time, i.e. it simulates urban and regional dynamics in four-dimensions. 4D simulation overcomes the drawbacks of bi-dimensional planning and urban design, which often produce mere outlay of zoning areas. Furthermore, 4D simulations allow a more direct interplay between planners, designers, decision-makers, citizens and users. The 4D spatial and temporal evidence would remove evaluation and decision from the elite hands of technicians, widening and opening public discussion and participation by means of an intuitive, despite rigorous, language.

4 MULTI-AGENT MODEL

Currently several research groups (Dijkstra et al. 2002; Gero 1999; Lees 2001; Liew 2002; O'Sullivan and Haklay 2000) are working to various fine-grained spatial models, simulating the interaction of individual actors, whose behaviours produce either architectural, urban or regional dynamic. These models produce surprising interaction pattern; in fact, they produce patterns and properties that just cannot be predicted from knowledge of their individual actors taken in isolation. These so-called "emergent properties" are probably the single most distinguishing feature of these works and allow us to suppose that urban and regional systems give rise to patterns which imply some measure of self-organisation.

This approach comes up against some theoretical and computational problems. First of all, which scale should be used: micro, at the level of the individuals, or macro, taking in account exogenous factors and endogenous processes, e.g. economic trends, national and local politics etc. The crux of the matter in areas of urban and territorial, research shared with economic, social and psychological disciplines, and with the human sciences generally, is the peculiar nature of phenomena, in fact they bring with them a collection of meanings which resist a straightforward transformation into objects. It seems difficult to be able to reduce a feeling, a collective reaction, or a human interaction into such abstract structures. On the other hand, the issue is not to *reduce them*, but to *represent them*, even if only partially.

These difficulties and concerns have led our approach to simulating urban form as the interaction of different processes at various scales. In the present implementation, each scale is represented by a model, respectively the model of the socio-economic and zoning dynamics and the citizens model.

4.1 Socio-Economic and Zoning Model

The Socio-Economic and Zoning Model has already been presented in Caneparo and Robiglio (2001), and simulates exogenous factors and endogenous processes of large-scale urban and regional dynamics. The main issues of the model are:

- The scale of model is 1:25˙000, and the minimum mapping unit is 1 hectare, called a cell. When defining this unit, it must always be borne in mind that, in reality (in the field) land cover always occurs as a combination of surfaces, which are to a greater or lesser degree homogeneous/ heterogeneous, whatever the scale used.
- The space of the model is anisotropy: a vector representing respectively actual

use, location, accessibility and zoning status of the area, making it more or less suitable for development is associated with each cell.

- The dynamics is simulated by means of Cellular Automata: the state of any cell is related to the states of the neighbouring ones.
- Cellular automata is a discrete dynamical system. Space, time, and the states of the system are discrete. Each site - the so-called cell - in a regular spatial lattice or array - the grid - can have any one of a finite number of states. The states of the cells in the lattice are updated according to the given rules.
- The state of a cell, at a given time, depends only on its own state one time step previously, and the states of its nearby neighbours at the previous time step. All cells on the lattice are updated synchronously. (Batty and Xie 1994; Cecchini 1999; Couclelis 1997; Engelen et al. 1997; Wagner 1997).

4.2 The Citizens Model

People matter in urban and territorial design: the decision to settle, the choice of a location, the seek for visibility or, on the contrary, privacy, the choice of a building typology and construction system, the necessity for adaptation and further change when facing new needs… Citizens' and users' decisions are relevant to shape our cities and the landscapes. Thus while the Socio-Economic and Zoning Model formalises large-scale, global processes, e.g. general planning, socio-economic trends, market dynamics, infrastructure, mobility and accessibility, the Citizens Model attempts to deal with people's expectations, priorities, and concerns in home, office, firm, shop etc.

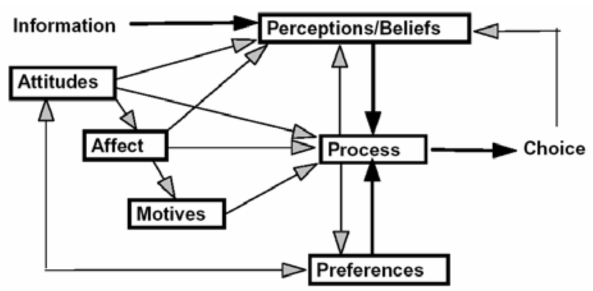

Figure 1 The Elements in the Decision Process and Their Linkages (after McFadden 1999)

This is a paradigm shift from the economists' Chicago-man model, where the people's preference is simply a maximization process, given market constraints (process-rationality). Architects are aware that their clients' expectations are much more complex than this. After McFadden (1999), the economists recognise *process effects* informing human choices, because users establish aspiration levels or reference points and set goals relative to these expectations; derive benefits and losses from the decision-making process itself; and respond to perceived interactions between the process and other activities and rules of conduct, e.g. esthetical and affective beliefs (Figure 1).

4.2.1 Citizens' Information Inputs

The player in the model is the individual, who can own/ trade/ rent a property that, according to the area (country/ suburb/ city), could be a plot, dwelling or flat. An estimation of construction-restoration expense or renting cost for every property is based on:

- Building and zoning regulations (i.e. maximum heights, minimum distances etc.) (Figure 2);
- Accessibility (e.g. main axis, secondary or private roads, entrance(s)) and services (e.g. commerce, recreation) (Figure 3);
- Typological and constructive recurrences (e.g. residential and industrial types, prefab building spans etc.).

4.2.2 Process Effects

We do not even expect a model to simulate a feeling, a collective reaction, or a human interaction, thus our approach to model citizens' decision is bringing the real citizens into the model, giving them some capability for interacting with each other through the model. We are aware that interposing an interface substantially modifies the very nature of human relationships. While human interaction is a crucial aspect in any design and planning process (Sanoff 2000), the system allows to extend both the scale of the interaction, behind neighbourhood, and to release the nature of social and psychological constraints, allowing people acting according to they true desires and expectations.

To model process effects, we are committed to stressing the morphologic aspects of citizens' decisions over the cognitive and psychological ones, for instance:

- Commercial activities look for visibility, thus a localisation process is informed by the maximisation of this perceived value (Figure 4);
- Residential settlement patterns are oriented to privacy and quietness (Figure 4),
- Certain constructive technologies and typologies are preferred because they communicate desirable values.

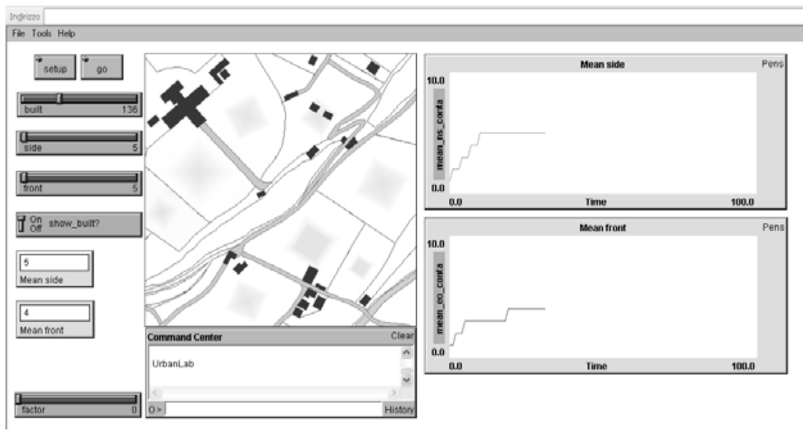

Figure 2 The map illustrates the legal constraints, building and zoning regulations mainly, to housing in the area of interest. The portions of the plots suitable to construction are in shades of green (white = housing not allowed, grey = allowed to).

5 THE AGENT MODEL

The unitary element in the simulation is the individual citizen and her/ his property(ies), which according to the area could be plot(s), dwelling(s) or flat(s). In the model each citizen is represented by an agent.

An agent-based model is one in which the basic unit of activity is the agent. In our model each agent represents explicitly the individual citizen and her/ his property(ies), which could be plot(s), dwelling(s) or flat(s). We not intend to define what an agent is explicitly, also because this is controversial in literature, but instead focus on the capabilities and roles our agents have.

5.1 Agents’ Learning

In the simulation, each agent represents a citizen (hereinafter also called a user), who learns by observing her/ him acting in the simulation.

When a user enters the simulation, s/he has several 2D (Figure 2, 3, 4 and 5) or 3D representations of the city or region.

The themes of the representations can change according to the aims of the simulation. In the case considered, they represent respectively regulations, accessibility and psychological values.

The user is given economical resources and, sometimes, goals, for example if the simulation is oriented to any decision process. The goals are stated, unsorted, in a computer window. In the case considered, the goal is finding a satisfactory home or office location.

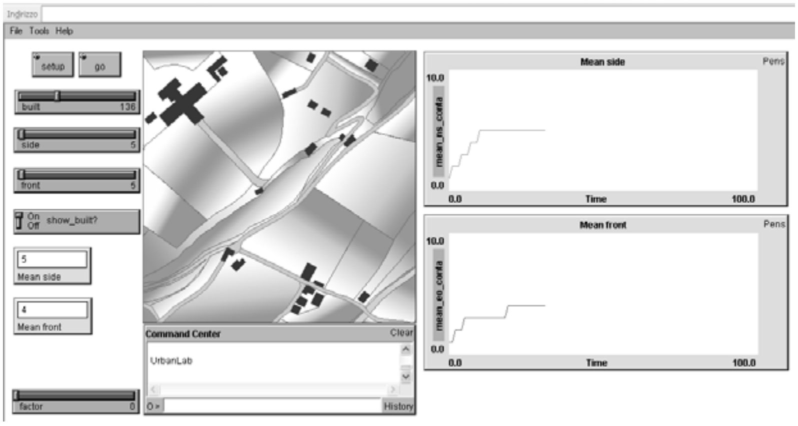

Figure 3 Plot accessibility to roads and services (white = max, grey = min).

Each agent implements a Q-Learning (QL) algorithm (Watkins and Dayan 1992), which uses a lookup table with an entry for each state-action pair, in which the utility of an action *Q(s,a)* is saved. *Q(s,a)* represents the utility of doing action *a* when the simulation is at the state *s*. The choice of certain action *a*, given that the simulation is in state *s*, is based on probability *p(a|s)*, given by a Boltzman distribution. Every time the user makes a new action the agent verify if its own goals and expectations matched the ones of its user, if yes the utility values are reinforced, otherwise they are weakened.

The main goal of the agents' learning is that simulation at the urban and regional scale is lengthy and the action is not exactly the same as a computer game! Thus many users get bored or have not enough time to take part to the complete simulation. The agent can question its user on a decision to take by means of several media (cf. 5.4) even if she/ he is not sitting in front of a computer. If there is no feedback from the user, the agent can take a decision in the place of its user, according to the experience the agent collected on previous user's decisions.

5.2 Agents' Actions

At each timestep, a user-agent has the capability to deal with a certain number of other users-agents (this number is a parameter of the model currently). Thus all the agents pursue goals with incomplete information. That is no user-agent has a full picture neither of the market, nor of the market of the properties, nor of the capitals in play at a given moment.

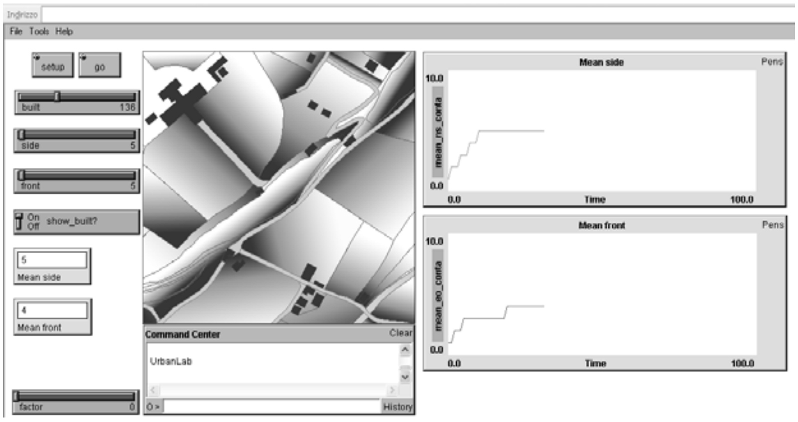

Figure 4 Plot privacy and quietness (white = max, black = min).

In the case considered, at any timestep of the simulation the actions that a user-agent can deal with are:

- Start a new trading dialogue, i.e. make/ receive an offer.
- Continuing an already commenced dialogue, an offer is evaluated.
- Quitting a trading dialogue, the agent does that in order to free some places in its list of priority vendors/ sellers, to start over with new dialogue(s).

5.3 Agents' Roles

In the case considered, two groups of agents are implemented, the mentioned users group and the investors group. The investors are implemented to represent macro-dynamics, from the layered Socio-Economic and Zoning model. The investor agents have an overall capital, which is an exogenous variable from the layered model. Each investor agent is autonomous and pursues the perceived benefit of its group that is the expectation of revenue (i.e. the agent's goal) from its properties/assets/capitals at a given time vs. future expectations. Thus, knowing the agent's information input, the agent's process effects can be computed according to Axelrod (1997).

5.4 Agents' Implementation

The fact that all the agents pursue goals with incomplete information is really important from both methodological and computational points of view, because this lack of information precludes the capability to find the optimal solution for the problem. We consider a complete definition of the equations and their solving for this model a "non-sense", for this specific domain. Furthermore this problem is distributed in nature, that is every agent can run on a different computer and the agents' communication can rely on present broadband.

The present implementation is based on Java applets, which can run on any Java enabled device, thus not only workstations, PCs, handhelds etc. but also on some mobile phones of the present GSM technology, not to say the next one based on the UMTS.

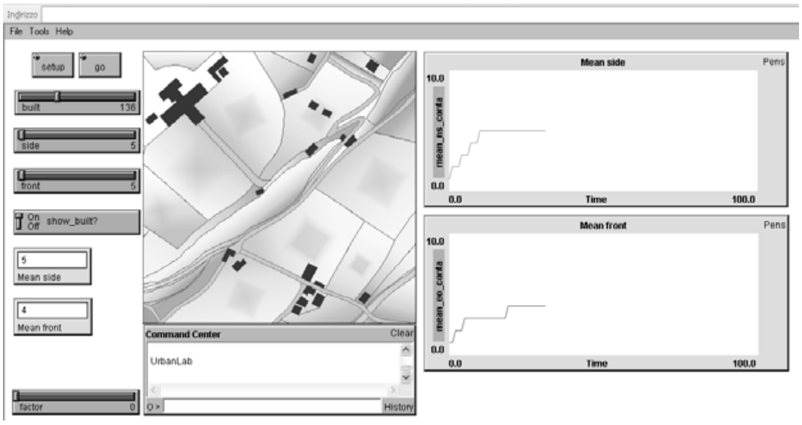

Figure 5 Map of the Computation of the Values in Figures 2, 3 and 4

The intrinsic lower performance of many of these devices is counterbalanced by their pervasivity: the capability to bring the UrbanLab to the citizens and users wherever they are and whatever they are doing, widening a further interaction capability for urban and regional simulation.

6 EXPERIMENTS AND RESULTS

As two light bulbs never break in the same exact way, similarly the dynamics of urban and regional systems is never the same. Anyway in the case of the bulb, it is possible to statistically relate lines of breaks in the glass and the expected ways of breaking. These “statistical” relationships are currently studied in multidisciplinary groups, with contributions from mathematics, physics, social sciences, economics, information technology…

In this early phase of implementation and experimentation of the model, a suburban area in Italy, close to Torino, has been used, because of this area we have detailed historical datasets over the past 50 years, which allows us direct comparisons between observed and simulated patterns.

Currently we are carrying out two kinds of comparisons between observed and simulated scenarios of the area. The first is a statistical quantitative comparison between the lands uses, in most recent simulation for residential, industrial and commercial areas the mean difference is 18%, with the worst cases in the residence around 22%. The second is a fractal analysis of land use patterns for residence, industry and commerce. We describe these patterns for both the observed and simulated area by a fractal dimension, which can fall between one and two. The boundaries can have a fractal dimension somewhere between a straight line, with a fractal dimension of one, and a boundary, that is so complex, it is space filling with a fractal dimension of two. Thus the fractal dimensions can be used as an index for measuring the complexity of the land use boundary (curve) or land use area (polygon) (Batty 1989; DeCola 1993). In the case of residence and industry, the results are quite fitting with a mean difference of 21%, while in the case of the commerce, especially for malls the difference raises up to 38%.

7 CONCLUDING REMARKS

Both the comparison methods contribute to partially picture the model results. Anyway what we consider relevant is that the observed and simulated patterns are similar and "resemble" each other. To us the aim of simulating is not predicting future developments, which can be falsified by any endogenous and exogenous factor, possibly neglected in the modelisation. In contrast the aim is the capability to generate multiple scenarios of an area and relating them with the factors, parameters and data, which contribute to shape the area. Representing urban and regional processes and formalising some their aspects in a model is a valuable and rigorous contribution to a design-plan. Moreover, the visual evidence of 4D representations contributes to communicating these relationships by means of both intuitive and rigorous language, for the understanding of urban and regional designs and plans to architects, planners, decision-makers and citizens.

The latter will allow us to include actual actors into real-life decision-making and participatory processes, thus providing a further possible comparison between simulation outputs and real design and planning decision. This implies not only the possibility of "tuning" the model/ simulator, but also the chance of observing with ethnographic methodologies the interactions between actors and model in reality: an observation that might lead to surprising conclusions, questioning the border between expert and non-expert users of urban models.

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