UrbanLab

Generative platform for urban and regional design

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Keywords: Generative modelling, Participatory design, DSS, GIS, Software agent, Urban design, Regional design

Abstract: UrbanLab is a computer system supporting urban and regional design. The papers outlines two leading aspects of this large research project, aimed respectively to make explicit the dynamic of the design in its time and geographic dimensions, and to interactively represent the interplay of some, explicitly, recognised factors, for instance the role of a multitude of different (local) actors in the design process. UrbanLab has been applied to several projects at different scales. We consider the applications to dynamically and interactively generating models of an Alpine valley. The modelling in the spatial and temporal dimensions provided us with the elements to study the evolution over the next twenty years.

1. PLATFORM FOR SUPPORTING URBAN AND REGIONAL DESIGN

UrbanLab is a computer system supporting urban and regional design. We have been developing a generative modelling platform with the central goal of turning ideas into simulation of design proposals at the urban or regional scale simply and promptly.

The main aims of the system are:
1. to go over a static conception of the urban design, towards a dynamic one, along the temporal axis;
2. interactively represent in the design process the interplay of some, explicitly, recognised factors.

1.1 Dynamics in the Design Process

In the last three decades a number of researches has been investigating the dynamic nature of urban and regional systems. Several studies have considered the theoretical shift from morphology to processes. This shift has been encouraged by new scientific theories of change, emerged at the cross-over of different disciplines (e.g. cognitive, biology, physics artificial intelligence), namely under the umbrella of the science of complexity. Self-organization theory has been considered promising, because it provides both an effective theoretical framework for connecting natural and social sciences, and modelling the dynamic of system, whose previously were considered incompatible with fundamental properties of social systems. The social dimension of urban systems is considered one of the irreducible properties to study and understand the phenomena (Larco, 2003).

Modelling urban and regional process as self-organising systems turns out making explicit the dynamic, rather than the states of the system, the operational among the actors, rather than of their intentionality. Consequently the dynamics of urban systems do not fall into the class of heteronomy systems, defined by hierarchical, top-down oriented process, where exogenous factors and endogenous variables direct the evolution from macro–decision and macro–scale towards the micro, nor of self-standing systems, with no actual interplay occurring between inside and outside, for which definitive solutions can ideally be deduced. Instead they fall into the class of systems defined by internal self-organisation, autonomy systems.

«Autonomy, implied in the notion of territory as an auto-organising system, is a serious challenge to urban planning and design: perhaps the most radical since planning and design have become specific disciplinary, technical and professional fields. It may be of some use to remember that our activity field is an historical construct, whose cultural roots can be traced to the XV century Italian Renaissance (Choay, 1980), but which became generalised, structured and socially recognised in the XVIII and XIX century’s processes of modern State organisation (Picon, 1988), reaching its peak in ‘50es post-war-reconstruction and ‘60es welfare societies (Picon and Desportes, 1997). A constant and profound relationship (dependence) on power and state has somehow inscribed hierarchy and authority in the genetic code of architecture and urban planning, making the final user (the citizen, the inhabitant, the visitor) into a voiceless quantity, incapable of individual choice (Tosi, 1994) (Hall, 1988). When asked by Doctor Jaoul’s little daughter about her room in the father’s new house, Le Corbusier answered: “Go and play, little darling, I know what you need.”» (Caneparo 2001).
So, we think that the time has come to enter an “age of maturity” for the considerable amount of useful experimental results of the theories and methods on the dynamic for the practice of urban and regional designers and planners.

1.2 Dynamic Modelling

The UrbanLab platform implements concepts for dynamic modelling of cities and regions. By dynamic modelling we mean a system that evolves in time according to the reciprocal actions between micro-scale and macro-scale.

The micro-dynamics works from the bottom-up: it is driven from individual local actors (e.g. the landowners, households etc.), and actors from organisations (e.g. real estate developers, decision-makers etc.), their actions, aims and aspiration (e.g. 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, etc.), and their interactions (market, social etc.).

The macro-dynamics works from the top-down, at the levels of spatial and socioeconomic resolutions (e.g. general planning, socio-economic trends, demographic and market dynamics, infrastructure, mobility and accessibility etc.), that tends to orient the overall system in the medium/long-term.

Modelling urban and regional dynamics means taking a step towards dealing with the wide range of possible results a self-organising system can produce, and can also be a step towards reaffirming a role for architects, planners and designers.

1.3 Interaction of Explicited Factors in the Design Process

Among the major investigation issues in architecture, planning and geography in the second half of the twentieth century are the levels of formalisation at the micro- and macro-scale (Batty and Torrens, 2001; Broadbent, 1990; Calthorpe, 1993; Krieger, 1999; Hillier and Hanson, 1984; Holland, 1998; Portugali, 2000; Torrens, 2006). While concepts related to the identification of each scale, respectively micro- and macro-, of the phenomena and structures have been defined and documented, the dynamic interaction of between different scales is less explored and known.

Self-organising systems can produce a wide range of possible results, the challenge in modelling them is evaluating the effects of parameters ingrained
in a complex dynamics, in measuring their real effects and relating them to the hypotheses. The theoretical capability to interrelate the behaviours of the individuals at the micro-scale with the cumulative behaviour and evolution of systems at the macro-scale is hardly to be measured and validated, because it demonstrates difficult to actually identify and evaluate the contributions of individual agents/events in the whole dynamic.

In the short novel, “On Exactitude in Science”, Jorge Luis Borges (1975) imagines an empire where the science of cartography achieves such perfection that the map of a single Province occupies the whole city, while the map of the Empire the whole Province and so on. At the end, this science of representation becomes so exact and increasingly complex, to evolve in a map at the full-scale of the Empire itself. Borges comments that the Empire no longer exists, and we guess that the map itself becomes the reality, overcoming the problematical and arbitrary aspects of the model-making.

Every model should assume hypothesis and from them apply simplifications, otherwise the model will evolve in Borges’ full-scale representation of the world. At the moment, we don’t have access to a theory for defining most significant variables, describing the dynamics of the urban and regional system. In this lack of theoretical and methodological frameworks, we have required UrbanLab to support software rapid prototyping: to turn hypothesis into software, for verifying them rapidly and accurately into a working model. Changing a hypothesis in a model could require, in some way, structural modifications to the system, for modifying or adding functions and variables.

The rapid prototyping capabilities of UrbanLab should be considered within the application domain of design and planning. The capability of modelling a project rapidly and accurately along its temporal and geographical axes allows designers and planners an early evaluation of the effects, in the complex dimension of their interrelations. These are often exceedingly complex, driven by a plurality of actors and interests (often conflicting, but subjectively regarded as licit and justified), that can not be solved, as a problem setting and solving. Instead it opens a process that hopefully will lead to a convergence toward a balance, defined on the base of a set of agreed goals, of policies, and strategies for achieving them.

The very nature of this process is dynamic and interactive: the recursive interaction with policy, planning and design making by means either of successive corrections and adaptations or of radical changes of strategy, when needed, i.e. choice $\rightarrow$ design-model $\rightarrow$ outcome $\rightarrow$ evaluation $\rightarrow$ adaptation/change $\rightarrow$ choice…

For urban and regional designs, software rapid prototyping turns out as an interactive tool for modelling, simulating, evaluating, open to architects, planners, decision-makers, as well as researchers.
2. URBANLAB SOFTWARE STRUCTURE

With CAD systems models are created at design time. On the other hand, we are committed to dynamically and interactively generating models according to users’ interactions. Our approach relies on a generative platform: a software system generating design simulation at run-time. To this aim, we have been developing a generative modelling platform with the central goal of rapidly prototyping design into dynamic simulation simply and promptly.

Providentially, in the past decades ICT has progressed a number of advanced tools that our research can profit of.

Firstly Wirth’s (1975) groundbreaking separation between data structures and algorithms. Since, especially in Europe, the geographical structures change relatively slowly (e.g. infrastructures and land use, workplaces and residences), comparing to the activities (e.g. travel patterns, works and residents), we have mapped this in the configuration of the system, separating the description of the urban or regional structures, from the ones of the actors, and from the models of interactions-activities.

UrbanLab implements a generative description – a.k.a. workflow – where datasets are associated to tasks to perform on that data.

2.1 Datasets

The datasets describes the urban and regional structures, intended as structured data describing aspects of a city or region.

Usually in developed countries, there is a large availability of databases maintained by a number of public administrations, agencies, corporations etc. For instance, the available data could be digital terrain models, regulatory plans, CAD models of buildings and infrastructures, Census, Registry, Local Tax information, commuting times, but also consumers’ locations and choices from telecommunications companies or from other commerce-oriented services. The data exists, but it is heterogeneous and sparse, spread over different formats, sources and ownerships.

UrbanLab implements the methods and tools to read these data from various authorities (Figure 1) and to organize and correlate it into datasets, representing the structure of a city or region.
2.2 Tasks

To compute a task, it is necessary to group and relate different datasets, both in input and output. It is possible to have more than one input dataset, which can also be derived from previous output. Tasks are especially powerful when they integrate generative procedures in a dynamic, self-organizing system. Several dynamic procedures can coexist, for instance spatial, temporal and scale ones. Procedures differ from algorithms in that the dynamics of the systems emerges from the interaction of numerous, concurrent tasks, rather than from the application of some mechanism (Lodding, 2004).

The spatial dynamics influences the morphology of a model. For example several tasks can be structured in order to define these relationships: the plan of a building from GIS or CAD data, the number of its stories from a property database, the terrain elevation from a digital terrain model, the texture of the roof from an aerial photograph. But it can also define how to stack the stories, how they are connected with the roof, or how to map the textures. These tasks can propagate downward to micro-levels and spread over the full urban or regional extent (Figure 2). Datasets, resulting from a task, can also be reiterated in other tasks. In this way, a small number of tasks can usually generate a wide variety of models which, according to our experience, can be fine-tuned to cities and regions in different countries.

In the temporal dynamics, tasks can be defined to model the temporal evolution. For instance, in one case project after we mapped an area on a
rectangular grid, we proceeded to associate each cell to a vector by which we defined its status, while the transition rules defined its evolution in time. The results have been useful in representing the outcomes of planning strategies and policies.

Concerning the scale dynamics, our present approach is to simulate urban and regional dynamics through the modelling of different interacting processes at various scales: at the macro-scale long term, large scale dynamics of the area are modelled, whereas at the micro-scale individual decision-making is the starting point for urban or regional dynamic generation.

Figure 2. Screenshot of the real-time navigation in the generative model of an urban scenario: the central area of Torino.

2.3 Workflow

UrbanLab platform defines the relationships between the different datasets and the tasks in the workflow. It is executed at run time to create detailed, generative and dynamic models of large areas. Because the workflow just defines the relationships and tasks, the very nature of the system is both interactive and dynamic. It rapidly propagates not only the resulting changes in the datasets or tasks, but also the apposite tasks which represent time dynamics or user interactions at the macro- and micro-scales of the model.
3. DYNAMIC AND INTERACTIVE TASKS

UrbanLab approach to model urban or regional dynamics is through the interaction of tasks at different scales.

3.1 Cellular Automaton Tasks

At macro scale, the urban and regional dynamics are treated in the formal Cellular Automata definition, as originally introduced by von Neumann (1963 and 1966) and Ulam (1974).

For the purposes of the macro-scale model, a cellular automaton is a discrete dynamical system. Space, time, and the states of the system are discrete. Each site, defined a 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 rules. That is, 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. Thus the state of the entire lattice advances in discrete time steps (Batty and Xie, 1994; Couclelis, 1997; Engelen et al., 1999).

The mathematician’s definition (Wolfram, 1994) of a cellular automaton is: a regular lattice of sites, where each site takes on \( k \) possible values, and is updated in discrete time steps according to a rule that depends on the value of sites \( r \) in some neighbourhood around it.

Usually, \( d=\text{dimension}, \ k=\text{states per site}, \ r=\text{radius} \). In the macro-scale model are assumed \( d=2, \ k=24 \) and \( r=8 \).

A \( d \)-dimensional cellular automaton takes as its underlying space the lattice \( \mathbb{Z}^d \) (\( \mathbb{Z} \)=integers, infinite in both positive and negative directions) where \( \mathbb{S} \) is a finite set of \( k \) elements. The dynamics are determined by a global function

\[
F: \mathbb{S}^d \rightarrow \mathbb{S}^d
\]

whose dynamics are determined “locally”. A “local (or neighbourhood) function” \( f \) is defined on a finite region

\[
f: \mathbb{S}^{2r+1} \rightarrow \mathbb{S}^d
\]

The global function \( F \) arises from \( f \) by defining

\[
F(c)_i = f(c_{i-r}, \ldots, c_{i+r})
\]

Cities and regions do not behave like cells. To be more precise, they mutate in time due to anthropic factors and thropic processes. Furthermore, the hypothesis of autonomy, as is implicit in the paradigm of cities and regions as self-organising systems, is a leading factor to commitment to innovative planning and design practices. From this point of view, a simple cellular automaton modelling approach is hardly justified, especially where
transition rules exemplify anthropic factors. We have thus opted for the interaction of tasks at different scales: at the socio-economic scale by Cellular Automaton and at the morphological scale by individuals and their system representation by software-agents.

3.2 Multi-Agent Tasks

At the micro-scale cities and regions are generatively modelled from individuals’ decisions. The approach is bottom-up, starting from the decision-making processes.

Every individual is simulated by a software agent. To simulate at the extent of a city or region, such a large number of individuals-agents, rapidly and faithfully, role modelling has supported us in defining the personal position and the set of responsibilities within the defined context. In the case of an urban scenario, the personal positions can be real estate redevelopers, households and/or businesses. While the responsibilities can be respectively: edification / adaptation / increase of development, mobility or location decisions.

The implementation of role modelling in a task is actually an agent-oriented extension (Kendall, 1999) of usual object-oriented modelling (Kristensen, 1999).

For the Definition in a task, every agent is viewed as an autonomous, rational being, with reasoning capabilities, resources, skills, goals and preferences. At the implementation level, it is done by classes from the platform agent library. Usually the implementation requires entering the parameters for configuring the relevant classes.

For the Organisation in a task, the agent is positioned within its social context, with relationships with other agents. This relies on the concept of agency: a group of allied and/or competing agents. Agencies can be collaborative, e.g. behaviours that concur to determine the settlement-building of collectives services (schools, hospitals, bus stops, parks, parking lots) or competitive, e.g. behaviour oriented towards the market, real estate and personal profit on the example of the "Monopoly" game or of stock market simulators. At the implementation level, the platform requires us assigning the agents to the agency they belongs to, the roles they play within the agency, the agents’ awareness of and the abilities they know other agents have.
4. ALPINE VALLEY PROJECT

Until now, UrbanLab has been applied to various projects at different scales. For instance, it has been used at the urban scale for evaluating the transformation of a central area in the city of Torino, Italy. This project involved the re-functionalising of an old industrial district into a new cultural centrality by changing the infrastructures and building new centres and complexes (Figure 2).

Here we present a project on a regional scale: the possible evolution scenarios of an Alpine valley (Val di Susa, Italy, a site of the '06 Winter Olympic games), which needs to re-program its future, in search of a competitive and sustainable growth in a landscape quality prospective. Crossed by main road axes, highway, railways and a river, the region is structured in the form of a long corridor compressed along its infrastructures.

The project concerns a 1,000 km² area, where a main unresolved problem is the relationship between the regional infrastructures and the settlements. The generative modelling platform was thus directed at creating four ideal/typical scenarios: 1. Ordinary Dynamic, 2. Linear Growth, 3. Reticular Growth, and 4. Green Corridors (Figure 3). These were not merely future scenarios, but effective anticipations of development capabilities over a twenty year period.

Figure 3. The four scenarios modelled.
4.1 Cellular Automaton Tasks

Specific instances of the Tasks have been defined to implement the general definition of Cellular Automaton (1) in the platform: a software agent \( a \) relates to an object \( c \) that represents the attributes of a cell at time \( t \). In the current project, the attributes of the cell-object \( c \) are: Land use \( L \), Zoning \( Z \), Accessibility \( A \) and an aggregate value defined as Suitability \( U \). Every agent \( a \) implements a set of Transition Rules \( T \), specifying the changes of non-spatial states, i.e. \( L, Z, A \) and \( U \).

The agency system for this project has been defined in:

\[ A \sim (S, T_S; L, C_L; R, N_R) \] (2)

The first pair denotes a set of states \( S \), associated with the agent, and a set of state transition rules \( T_S \), used to determine how agent states should change over time. The second pair represents the location \( L \) of information of object \( c \) \( C_L \). \( R \) specifies the neighbours of the agent and \( N_R \) represents the neighbourhood transition rules that govern how agents relate to the other agents in their vicinity. According to this definition (2), state transitions and changes in location for an agent depend on the agent itself and on the input, given by the states of the neighbouring agents and objects.

At the macro-scale the region has been mapped on a grid of one hectare cells (100 by 100 m side), to which has been assigned the prevalent land use \( L \). Zoning \( Z \) is based on 1990-2000 Regulatory Plan of every Municipality. Local Accessibility \( A \) to cell \( c \) is computed considering the structure of the network or the type of link within the infrastructures. Finally Suitability \( U \) is the geocomputation of the amenity at \( c \) as the weighted mean of the local visibility, the desirability of the neighbourhood (e.g. parks, recreation etc.) and the solar radiation.

4.2 Multi-Agent Tasks

The aim of the Micro-Scale Tasks is to develop a dynamic, four-dimensional model (3D + time) of the region.

This Task is based on interacting agents to which are assigned specific design tasks and that they have to pursue. Each agent views its local part of the system at a given time step.

According to Franklin and Graesser (1996), the agents in this case project can be defined as:

a) \textit{autonomous}, because they are able to meet autonomously their own design tasks;

b) \textit{situated}, because they relate to a specific portion of the region;

c) \textit{reactive}, because they perceive the environment through communication with other agents and from its representation, i.e. datasets.
The implementation relies on agent roles and role models for describing agent systems. The role models and agency defined for this case project are:

- **Floor Area Ratio**: for a given cell $c$ is the ratio of useable floor area to the land area from the Property Parcels. The inputs are from both agents $a$, the Property Parcels and a possible Regulatory Plan dataset. The task is defining a ratio, e.g. 1 suggests that one story building covers the entire site, 2 story building covers half the site and so on.

- **Property Parcels**: trade alternative aggregations of the parcels to define a site. The inputs are from Floor Area Ratio and Building layout. The task is to meet a building layout possibly across several parcels. These parcels have to be cleared because the area of the building footprint must be considered in its number of stories to fit a Floor Area Ratio.

- **Accessibility**: for a given parcel is the local measure according to the typology of transportation means and its proximity. The inputs are from Property Parcels and Infrastructure dataset. The task is the computation of the local accessibility to a parcel.

- **Building typology**: generatively modelled from a given library of typologies. The inputs are from the Floor Area Ratio, the Property Parcels, the Accessibility and the Regulatory Plan dataset, if any. The task is to fit a typology to generate a building footprint on one or more adjacent parcels to meet the Floor Area Ratio.

- **Building Budget**: estimates the total-building construction budget. The inputs are from the building typology and the shape.

- **Building Sustainability**: evaluate the budget for the energy both of construction and maintenance of the building over the simulated period. The inputs are from the building typology, the shape and the site (solar radiation).

Each of the defined roles is played by an individual agent that can collaborate or compete with other agents to accomplish a common task.

Once role models and agency have been designed, the platform automatically translates the role-specific solutions into agent descriptions. From the agent descriptions the Agent Generator can create an individual agent, assigning to it a situated and specific task, e.g. a specific cell from the macro-model or a property parcel from a taxation dataset.

### 4.3 Building Design Multi-Agent Tasks

A Building design agent sets the relationships:

- competitive with the Floor Area Ratio agents for defining the highest ratio possible, the Building Budget and Sustainability to find a balance with the developer investment, which is an input from the macro-scale model,
– collaborative ones with both Property Parcel and Accessibility agents to optimise respectively the building plan in a site layout and the access to the infrastructures. An example of working relationships is fitting the ratio of a building Floor Area to Accessibility.

Figure 4. Graphical editor of the inputs in the Micro-Scale Tasks: the Regulatory constraints (min green), accessibility to roads and services (min yellow), privacy and quietness (min pink).

4.4 **Ordinary Dynamic Scenario**

Of the four ideal-typical scenarios generated, for concision, is presented just the one defined as “Ordinary Dynamic”.

In this scenario the constraints posed by the Regulatory Plans are relaxed and the dynamics of the region are generated over the next twenty years. UrbanLab allows the users to interactively navigate inside the scenario at different time steps. To understand the dynamics quickly and faithfully, it is possible to set two or more windows, side-by-side, each of a different time step. Figure 5 shows the same scenario presented for respectively the year 2000 and 2020.

The scenario dynamic highlights a large number of new settlements and a sprawling trend along the main longitudinal infrastructural axes.
5. CONCLUDING REMARKS

5.1 Complex System Modelling

As two light bulbs never break in the exact same way, similarly the dynamics of urban or 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 our Laboratory by an interdisciplinary group, with contributions from physics, mathematics, geography, economics, and information technology (cf. Acknowledgments). We are experimenting two different methodologies of comparisons between observed and simulated scenarios: from the known past to the observed present. The first methodology is based on statistical spatial metrics to compare the observed and simulated (Lucà et al. 2005). The second is based on the fractal analysis of urban or regional patterns. We study these patterns by a fractal dimension, which range falls 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 pattern, between a polygon and a curve (Batty et al., 1993; De Cola and Lam, 1993).

In addition, we are experimenting both spatial metrics and the fractal dimension for evaluating if and how dynamic and interactive generative modelling represents an effective approach to urban simulation in linking local processes, i.e. the ones modelled at the macro-scale with the cellular automaton, to the morphological processes, i.e. the ones modelled at the micro-scale with agents.

We are studying how unstable spatial changes at the neighbourhood scale becomes smooth at a larger scale, and how continuous changes at the urban scale and smooth change at short time steps can lead main discontinuities in longer time periods. How and when emerges order from micro-dynamics? The emerging synthesis methodology is demonstrating counter to usual strategies in urban or regional modelling that instead tends to reduce or aggregate the essence of these systems.

5.2 Knowledge Sharing through Dynamic and Interactive Generative Modelling

Dynamic and interactive generative modelling represents an innovative methodology for sharing knowledge through scenarios. In the case project considered, dynamic generative modelling has proven to be an effective metaphor of argument and narrative: our methodological commitment is simulating as a medium for dialoguing with real people (Guhathakurta, 2002) about their expectations, projects, interests as well as frustrations in the city/region. To this aim, our experimentation in case projects has been oriented to generating ideal-typical scenarios. This has been pursued to the conscious detriment of realistic representation in the models, because spatial and temporal evidence would extend and encourage public discussion and participation by means of an intuitive, yet rigorous, visual language.

Because urban or regional systems are exceedingly complex, and cannot be accurately predicted, we promote interactive modelling to understand the dynamic, as open and transparent decision making processes: not as predictions, but as one possible future.

Dynamic generative modelling has proven to be a working tool for designers, planners, communities and decision-makers. The case projects have taught us that complex social systems can be profoundly influenced by a pervasive access to information. Thus we are considering the sharing of urban and regional “knowledge” through interactive modelling, not just as a
communication tool, but also as an integral part of the design and planning processes.

6. ACKNOWLEDGMENTS

This research is supported in part by the Politecnico research grant PTOL014234, Science and University Ministry research grant 2005088848 and Lagrange Foundation grant.

The conception and development of the platform is and was undertaken by an interdisciplinary group at High-Quality Laboratory – Territorial Integrated Project, Politecnico di Torino, especially by Prof. Franco Corsico, Prof. Matteo Robiglio, Prof. Lamberto Rondoni.

7. REFERENCES


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