Dynamic Generative Modelling System for Urban and Regional Design

Background and Case Project

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Abstract: This paper introduces a dynamic generative modelling system for urban and regional design. Through dynamic modelling the system evolves in time according to the interactions of the planners, decision-makers and citizens. On the basis of several synchronous and/or asynchronous user interactions, models are dynamically generated at run time. The models are built by defining the data (datasets) and the actions to perform on that data (tasks). The system reads and correlates data at urban and regional scale from various authorities to generate dynamic datasets. Tasks are especially powerful when they integrate generative procedures in a hierarchical structure. This allows us to model urban and regional dynamics through the interaction of tasks at micro- and macro-scale. Tasks can also implement either Cellular Automata or software agents. We examine the system application to a case project: the simulation of micro- and macro-dynamics in an Alpine valley, with specific challenges to fit competitive and sustainable growth in a landscape quality perspective. The simulation in spatial and temporal dimensions of regional data provided us with the elements to study the territorial evolution over the next twenty years. Four strategies gave as many scenarios highlighting the results of specific policies.

1 INTRODUCTION

The research project brings together two fields: the study of complex dynamic systems through emerging synthesis and the use of participatory design as a pioneering approach to modelling systems.

In the framework of the emerging synthesis, the dialogue and the interaction in urban and regional design are modelled as processes that evolve and change in time. Not only do we have to consider space-place or time events, but urban and regional dynamics are also factors with which to formulate the temporal and spatial emerging of cities and regions. The process notion requires an increased awareness of numerous and simultaneous interrelations among the factors involved in the design: from the individual to the social, from the building to the city and the environment. The emerging synthesis, applied to trans-disciplinary fields, such as physical and natural sciences, has developed new research methods and tools. For the design processes, these experimental methods mark the distance from any positivist mechanism, whose automatic and autonomous assumptions produce specific design results: simulation as the algorithmic automation of a design process. Simulation is used in these practices through an interactive process, across policy, planning and design. The method can be outlined by choice → simulation → evaluation → adaptation / modification → choice → … The design process advances by means of either successive corrections and adaptations or, if needed, by radical changes of strategy. This methodological conception is far from an algorithmic formalisation and is closer to the concept of method as strategy: «a global scheme within which actions must take place» (Gabetti 1983).

To accomplish these goals, we introduce a dynamic generative modelling system for urban and regional design. By dynamic modelling we mean a system that evolves in time according to the interactions of planners and all others involved. In the following sections of the paper, we introduce the project and examine a case study at a regional scale.

2 THE GENERATIVE MODELLING SYSTEM

With CAD systems, models are created at design time. We, on the other hand, are committed to dynamically generating models according to synchronous and/or asynchronous user interactions. Our approach relies on a generative system: a software generating design proposals at run-time. The system implements a generative description – a.k.a. *workflow* – where *datasets* are associated to *tasks* to perform on that data.

2.1 Datasets

Urban and regional datasets, intended as structured data describing a reality, often already exist, but may be spread over different formats, sources and ownerships.

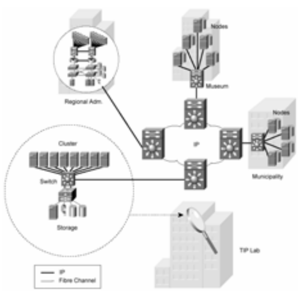


Figure 1 Scheme of the system for generating dynamic datasets from different data owners

We have developed a method and a computer system to read and correlate these data from various authorities (Figure 1). For instance, the available data could be images from aerial or satellite or ground surveys, CAD models of buildings and infrastructures, digital terrain models, regulatory plans, Census, Registry or Local Tax information.

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 hierarchical structure (Figure 2). Several hierarchical structures can coexist, for instance spatial, temporal and scale hierarchies.

Figure 2 The hierarchical structures of the generative procedure

The *spatial hierarchy* 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 census 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 in the hierarchy to lower levels and spread over the full urban or regional extent. 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 hierarchy*, tasks can be defined to model the temporal evolution. This simulation is possible through computing or imaging pre-figuration. 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 consequences of planning decisions.

Concerning the *scale hierarchy*, 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 and regional generation.

2.3 Workflow

Our system defines the relationships between its 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 is limited to defining relationships and tasks, the very nature of the system is interactive. 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 macro- and micro- scales to the model.

3 INTERACTING TASKS

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

3.1 Macro-Scale

At macro scale, the urban and regional dynamics are treated in the formal Cellular Automata definition (von Neumann 1963, Wolfram 1994) as cells in a n-dimensional grid-based lattice with *n* equal to 2 or 3. Hierarchical tasks can easily implement spatial grid structures, i.e. 2- and 3-dimensional lattice. The model space is anisotropic: to each cell is associated a vector representing respectively current use, location, accessibility and zoning status of the area, making it more or less suitable for development. System dynamics are determined by transition rules which map the current state of a cell's neighbourhood at subsequent time steps. Conventionally the task implementation of the dynamic is:

$$s_{i_{t+1}} = f\left(s_i g_{j_t}^{n}\right) \qquad (1)$$

where s_i is the state of a given cell i at time t + 1, *f*( ) determines the "local" (or neighbourhood) function for a finite region *g* (of neighbourhood size n) in the vicinity of the cell j at time t. The core question is the *f*( ) function, that composes the transition rules. 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 mere cellular automata modelling approach was 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 Automata and at the morphological scale by human agents and their system representation by software-agents.

3.2 Micro-Scale

At the micro-scale cities and regions are generatively modelled from individuals' decisions. The approach is bottom-up, starting with the decision-making processes. The tasks are assigned to software agents, which can represent the individuals. The agents move and act in the city/region, and interact among themselves socially. During model run time, the agents are requested to make decisions, to establish social relationships and to define the strategies whereby they can achieve personal and/or collective benefits. In their actions there are two recognisable main orders of relationships: 1) *collaborative,* behaviour that concurs to determine the settlement-building of collectives services, e.g. schools, hospitals, bus stops, parks, parking lots; 2) *competitive*, behaviour oriented towards the market, real estate and personal profit on the model of the "Monopoly" game or of stock market simulators.

4 CASE PROJECT

Until now, the methodology and system presented here have been applied to a number of 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 area into a new cultural centrality by changing the infrastructures and building new centres and complexes. Here we present a project on a regional scale: the possible evolution scenarios of an Alpine valley (Val di Susa, Italy), 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.

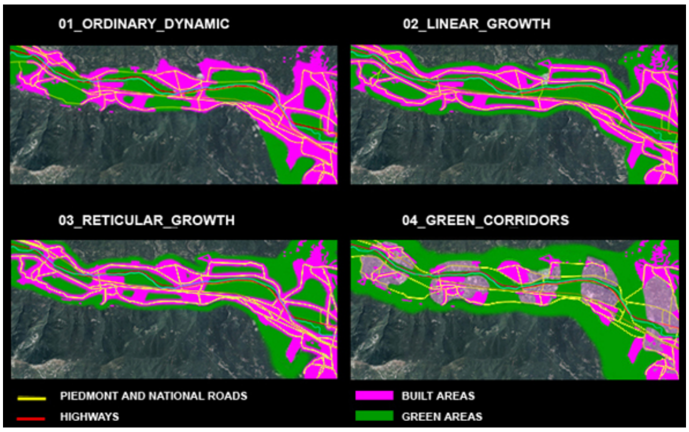


Figure 3 The four ideal/typical scenarios

The study concerns a 1˙000 km^2 area, where the main unresolved problem is the relationship between the regional infrastructures and the settlements. The generative modelling system was thus directed at creating four ideal/typical scenarios (Figure 3) that were not merely future scenarios, but real projections of development options over a twenty year period.

4.1 Macro-Scale Tasks

Specific instances of the *Tasks* (cf .3) have been defined to implement the general definition of Cellular Automaton (1) in the system: 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:

$$A \sim (S, T_S; L, C_L; R, N_R) \quad (2)$$

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 neighbors of the agent and N_R represents the neighborhood 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 neighboring agents and objects.

At the macro-scale the region has been mapped on a grid of one hectare cells (100 by 100m side), to which has been assigned the prevalent land use *L*, according to the revised CORINE land cover (Bossard et al. 2000). Zoning *Z* is based on 1990-2000 Regulatory Plan of every Commune. Local Accessibility *A* to cell *c* is computed considering the kind of the network or the type of link within the network. Finally Suitability *U* is the geocomputation of the amenities at *c* as the weighted mean of the local visibility, the desirability of the neighborhood (e.g. parks, recreation etc.) and solar radiation.

4.2 Micro-Scale Tasks

The aim of the Micro-Scale Tasks is to develop a full three-dimensional model of the region at every evolution time step. The system is based on interacting agents to which specific design tasks are assigned and which they are committed to meet. In this case project the agents can be defined as: a) *autonomous*, because they are able to meet autonomously their own design tasks; b) *situated*, because they relate to a specific portion of the region; c) *reactive*, because they perceive the environment through communication with other agents and from its representation, i.e. datasets.

They also react according to their design tasks. The implementation relies on agent roles and *role models* for describing agent systems. Each role describes a position and a set of responsibilities within a specific context or role model. Role models are inspired by the work of Kendall (1999), which formalises the definition of an agent role so that it can be modelled and implemented. The role models and typologies of tasks defined for this case project are:

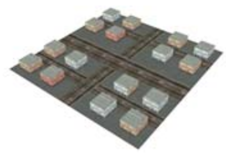
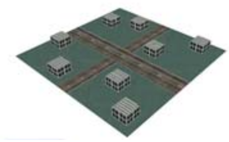
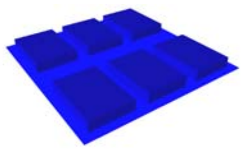
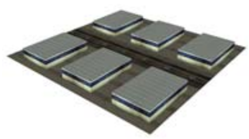
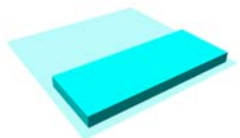
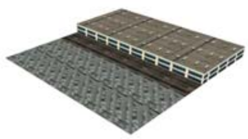
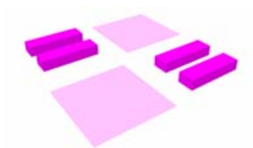
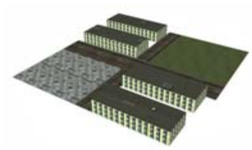
- *Floor Area Ratio*: for a given cell *c* is the ratio of useable floor area to the land area from the Property Parcels. The inputs are from both agents *a*, the Property Parcels and a possible Regulatory Plan dataset. The task is defining a ratio, e.g. 1 suggests that one story building covers the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

Each of the defined roles is played by an individual agent that can collaborate or compete (cf. 3.2) with other agents to accomplish a common task. Once role models and tasks have been designed, the system automatically translates the role-specific solutions into agent descriptions. From the agent descriptions the Agent Generator can generate 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 tax dataset.

4.2.1 Building Design Agents

A Building design agent sets the relationships: a competitive one with the Floor Area Ratio agents for defining the highest ratio possible, and a collaborative one 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. To define a building plan the system implements a library of typologies for each instance of the Land Use *L*. For every building typology the following parameters are defined: a) building width and length, relating to construction technologies; b) the ratio between building footprint and number of stories; c) possible joint at the corners; d) the span from a front and a side of site. Table 1 illustrates some instances with their symbolic and photo-realistic representations.

Table 1 Land use and library of typologies

Land Use *L*	Symbolic representation	Photo-realistic representation	Height
Residential continuous dense urban fabric			12m
Residential continuous medium-dense urban fabric			9m
Residential discontinuous urban fabric			7m
Residential discontinuous sparse urban fabric			6m
Industrial areas			6m
Commercial areas			6m
Public or private services			6m

4.3 Ordinary Dynamic Scenario

This is a detailed look at just one of the four ideal-typical scenarios, 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 for the next twenty years. The system allows the users to navigate inside the scenario at different time steps. To understand the dynamics better, it is possible to set two windows side-by-side, each on a different time step. Figure 4 shows the same scenario presented at respectively the year 2000 and 2020. The scenario dynamic highlights a large number of new settlements and a sprawling trend along the main longitudinal axes.

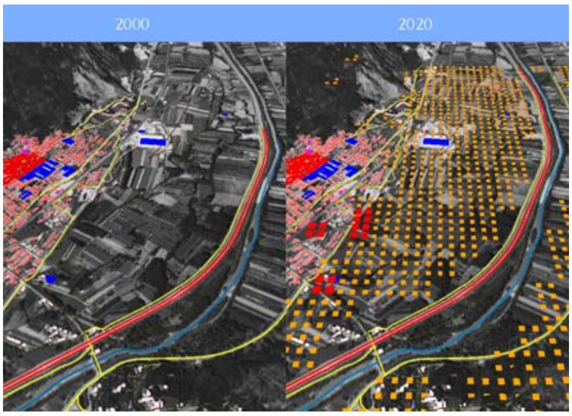


Figure 4 Synchronised views of the Ordinary Dynamic Scenario: 2000 vs. 2020

5 CONCLUSION

Dynamic 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 social systems are so complex and cannot be accurately predicted, we promote interactive modelling to understand the dynamic, as open and transparent decision making processes: not as forecasts, but as one possible future.

Dynamic generative modelling has proven to be a working tool for both 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.

REFERENCES

Batty, M., and Y. Xie. 1994. From cells to cities. In *Environment and planning B*, 21: 31-48.

Bossard, M., J. Feranec, and J. Otahel. 2000. *CORINE land cover technical guide - Addendum 2000*. Bruxelles: European Environment Agency.

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

Engelen, G., S. Geertman, P. Smits, and C. Wessels. 1999. Integration of GIS and Dynamic Modelling for Regional Planning. In *Geographical information and planning,* ed. Geertman, S., S. Openshaw, and J. Stillwell: 87-111. Berlin: Springer-Verlag.

Franklin, S., and A. Graesser. 1996. Is it an agent, or just a program?: A taxonomy for autonomous agents. In *Proceedings of the Third International Workshop on Agent Theories, Architectures, and Languages*: 21-35. Berlin: Springer-Verlag.

Gabetti, R. 1983. Progettazione architettonica e ricerca tecnico-scientifica nella costruzione della città. In *Storia e progetto*, ed. Roberto Gabetti et al.: 47-96. Milano: Franco Angeli.

Guhathakurta, S. 2002. Urban Modeling as Storytelling: Using Simulation Models as a Narrative. In *Environment and Planning B*: 985-911.

Kendall, E.A. 1999. Role model designs and implementations with aspect-oriented programming. In *ACM SIGPLAN Notices*, October: 34-10.

Louis, E.A., and A.K. Graham. 1976. *Introduction to urban dynamics*. Cambridge, Mass.: Wright-Allen Press.

von Neumann, J. 1963. The general and logical theory of automata. In *Collected Works*, *Design of computers, theory of automata and numerical analysis*, ed. von Neumann, J. and A. H. Taub: 288-328. Oxford: Pergamon.

Wolfram, S. 1994. *Cellular Automata and Complexity*. Reading, Mass: Addison-Wesley.