Simulation Tools for Transparent Decision Making in Environmental Planning

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ABSTRACT

The planning and territorial management process is often disparaged and subjected to criticism based on the way environmental decisions are taken. The lack of transparency and the high technical level of the Environmental Impact Assessment process do not ease public agreement. The increasing development in Geographical Information technologies has helped the construction of GIS-based Spatial Decision Support Systems (SDSS) enabling 'multipurpose planning'. The SDSS example presented below shows the potential for integration of several levels of involvement around an open platform aiming at a more scientific and shared decision in environmental planning. However, the development of this environmental SDSS has lead to the identification of a major need for an engagement effort towards the structuring and normalisation of the information to be created and published. It has become necessary to develop methodologies that will enable the systematisation, modelling, quantification and qualification of geographic space. This paper proposes that the definition of minimal geographic elements and the conceptualisation of geographical space into such description components leads to the creation of structures which allow for the thorough application of spatial analysis in environmental planning.

1 INTRODUCTION

Official forecasts indicate that, without drastic changes in policies, environmental quality will deteriorate over the coming years. The pressure on the environment will impair its potential to provide functions to society such as supply of drinking water, forestry and recreation. It is of major importance that planning activities become primarily based on environmental concerns. Moreover, Portugal has, in the last 10 years, dealt with strong economical concerns to achieve the now forthcoming challenges dictated by the european context. The resulting environmental pressure led to a major necessity in the definition of tools that could help decision makers scientifically integrate environmental values into the planning process and, at the same time, keep this integration transparent and understandable to the public.

The project presented focuses on the possibility of simulating the effects of human actions and land use transformations on an interactive basis. It is based on land use characterization through the association of hazard effects with types of land use. This paper describes the inception of the project, its first steps and current state, with new methodologies and technology being fed into it. It also presents new developments related to representation models which, we argue, will definitely improve its performance as a decision-making tool.

2 A DECISION SUPPORT SYSTEM FOR MUNICIPAL ENVIRONMENTAL PLANNING

The basis for this work was the SIGLA project (GIS Simulation of integrated environmental indicators). It was based on a decision model primarily conceived with the objective of providing a standard approach for planning evaluation methodologies and a new basis for normative procedures. Its initial funding (provided by The Portuguese Environmental General Direction) aimed to get results as tools for the development and assessment of new rules in planning activities. Moreover, it was necessary to provide planners with entertaining experimentation tools for the calculation of alternative planning scenarios (Janssen, 1991). In this way, the conception and application of normative could be simulated and evaluated at the desktop. The model is structured according to a simulation/evaluation approach. Evaluation perspectives are provided at three levels: The expert level, the municipal level and the public level. The expert level requires the intervention of a team of planning experts to define a system of dependencies between the model components and a set of rules for normalisation in the definition of weights. At the Municipal level a team of technicians defines the set of weights that implement their municipality policy and perspective, following the normalisation rules defined at the previous level. The public can demonstrate its preoccupations (Shiffer, 1992) by suggesting modifications to the perspective applied by the municipality. This provides the model transparency component often lacking in the decision process by allowing non-technical users to interact with its implementation, modify its criteria and evaluate the result of changes. The project was instanciated in a agent-based SDSS providing decision elements from simulation of changes. This system supports evaluation, simulation of changes according to the evaluation perspective, integration of judgement with methods and data and processing of all relevant information (Janssen, 1991). Therefore, the conceptual definition includes, the definition of evaluation perspectives, simulation tools and decision processes.

2.1 Definition of evaluation components

The basic geographical unit of the model is the land use parcel. Each of the components defined is classified according to the type of land use. This classification was based on the following evaluation components:

- Effects (E)- The actions resulting from human activity which are susceptible of decreasing the environmental quality of the studied area. In this project the following effects were considered relevant: Water release, Habitat destruction, Solid residue release, Noise emission, Air emission and Erosion;
- Attenuation scenarios (A) - An attenuation scenario represents the attenuating potential of each land use when related with one type of effect; One land use parcel may either attenuate or magnify specific effects that happen with its boundaries: Attenuation is represented by a value inferior to one; Magnification should be superior to one but it is not being considered currently. These values are also determined expertly, they are qualitative parameters and not spatial characteristics of propagation;
- Sensitivities (S) - The environmental quality components were classified and weighed against the land use classification producing the concept of Environmental Sensitivity (in this case Biodiversity, Quality of superficial water, Air quality, Soil quality, Acoustic quality and Landscape quality).

The sensitivities, effects and attenuation scenarios are evaluated, at the three user levels defined above, through a system of weights that qualifies them for each land use. This system allows the definition of the importance given to land use types. Each component's evaluation on the land use is translated into a values map (Fig. 1), a spatial classification of the existing land uses according to the evaluation perspective applied.

The definition of evaluation components is structured in evaluation profiles which can be interactively defined and modified. The evaluation perspective of one user can be stored and compared against others, enabling the experimentation and transparency capabilities of the model.

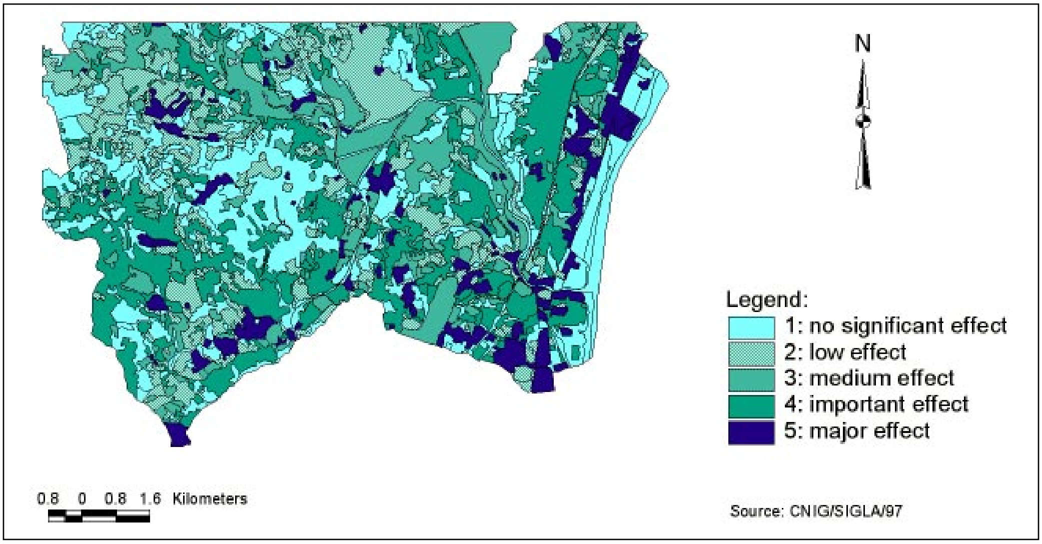

Fig. 1 - Water Release effect values for the current land use map of the Southern area of the Loures Municipality

2.2 Simulation Tools

The simulation tools were development as a toolbox that enables the generation of different simulation lines and their integration according to a specific evaluation perspective.

2.2.1 Propagation Scenarios

A Propagation scenario (CP) is a map of the potential spatial diffusion of an effect resulting from a land use transformation. In this project, propagation can be effected through superficial water, air, underground water or landscape. The propagation scenarios are calculated from physical elements of space. The scenarios have been implemented using cartographic modelling processes.

2.2.2 Simulation lines

The components described above are combined to generate the intermediate and final results which are called Simulation lines (L_{ikjl}). The impact of one effect is calculated by combining the effect's value map with the associated sensitivity map, the chosen propagation scenario and the relevant attenuation values. The result is called a simulation line representing the potential environmental risk for the current set of land use parcels in one defined moment t.

The functional representation of the simulation can be expressed in the following way:

$$L_{ikjl}(LU_t) = S_i(LU_t)\ q\ E_k(LU_t)\ q\ CP_j(LU_t)\ q\ A_l(LU_t)$$

Where LU_t is the set of land use parcels representative of one moment t; q is the function that enables the combination of two simulation components (in this case grid multiplication). $S_i(LU_t)$, $E_k(LU_t)$ and $A_l(LU_t)$ represent the mapping of, respectively, one of the Sensitivities, Effects and Attenuation Scenarios associated with the current set of land use parcels; $CP_j(LU_t)$ is the representation of the chosen propagation scenario for this simulation. Although the number of possible simulation lines is extremely high, only the ones resulting from compatible components will be generated.

2.2.3 Simulation Integration

The definition of integration rules enables the estimation of a general situation or an oriented study, towards one or several of the defined components. It is possible to evaluate the results from simulations based on one specific theme or on a combination of themes. For example, the impact of a transformed land use parcel can be studied for all of the environmental quality components or oriented towards one of them (biodiversity, etc). It is also possible to integrate similar simulations created according to different evaluation perspectives. This will generate solutions representing areas of agreement among different users.

2.3 The Decision Process

One of the main objectives of this project was the possibility of improving decision-making through the use of simulation tools, describing processes and discriminating options resulting in extensive forms of visualization, according to evaluation perspectives defined in a municipal planning process. In this section we will describe the decision tools which were conceived and developed using the simulation and evaluation modules of the system.

2.3.1 Environmental Risk and Performance

The potential environmental risk of the area results from the generation of simulation lines and enables the assessment of the development of area by identifying major risks and priorities of development. A reference simulation line is calculated (for time t) using the registered pollution sources. Additional simulations will be derived from this reference. Inverting the values of environmental risk generates the evaluation of environmental performance.

2.3.2 Visualisation of a Land Use Transformation Impact

Environmental performance and risks are represented as a $2^{1/2}$ D metaphorical model to increase visual perception and to allow the caracterization of the impact properties (figure 2).

2.3.3 Decision Parameters

One modification of the geographical elements (land use parcels) between time t and t+1 generates two simulation lines. The impact of this change can be measured by the difference between the two lines and the characterization of the resulting shape. This shape produces parameters for decision making as variations in Area, Volume and Depth. These parameters describe the importance of the impact and enhance the understanding of its distribution.

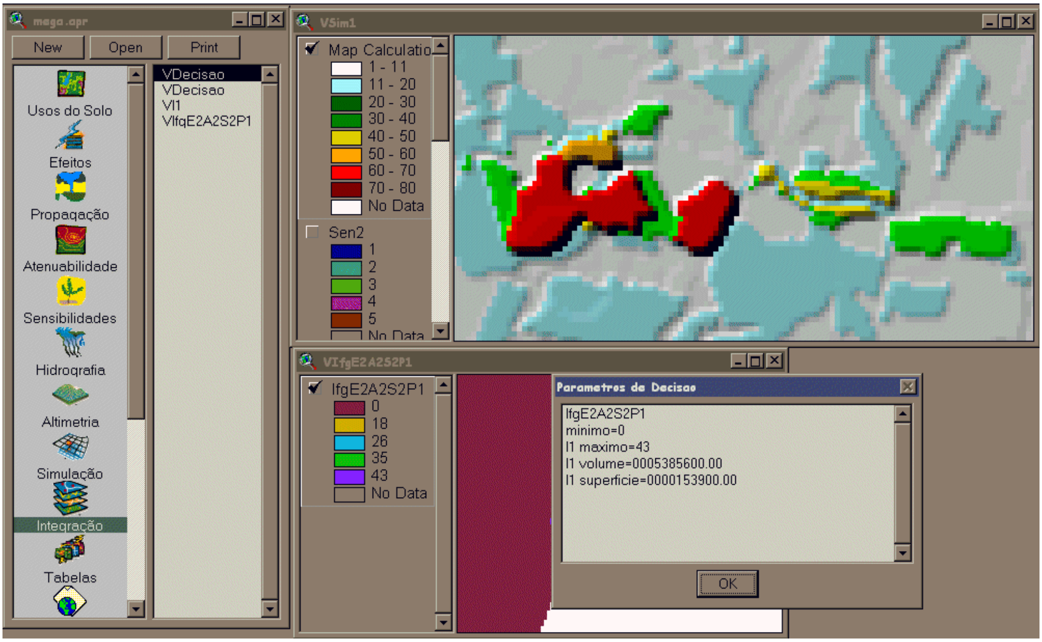

Fig. 2 - $2^{1/2}$ D representation of a simulation line $L_{ikjl}(LU_t) = S_i(LU_t)\ q\ E_k(LU_t)\ q\ CP_j(LU_t)\ q\ A_l(LU_t)$
S_i = Sensitivity to Water Quality, E_k = Water Release effect, CP_j = Superficial water propagation scenario, A_l = Water Release Attenuation Scenario

2.3.4 Location problems

When concerned with a territory under study, the planner is often searching for the best place to locate a new plant, a new structure or trying to select priority parcels for remediation. The solution adopted in this project was to build a planning memory where simulation parameters and results are recorded. This memory is built from classifications of parcels provided by Land Use agents. These are intelligent agents which can evaluate their fitness for a specific land use change and bid for that change to be effected in their location. The fitness of each parcel/agent is ranked by its nature (type of land use), neighbourhood sensitivities, topological properties, and planning normative associated. Land use agents are currently under development.

2.4 System Architecture

The system control relies on a multi-agent system being built using Java and an associated Intelligent Agent library. Being a portable, object-oriented language, Java was an obvious choice for the development of the system, enabling the creation of modules than can easily be extended and dynamically changed. The intelligent agent library includes communication and reasoning as basic mechanisms allowing the developer to easily create and manipulate agents while concentrating on their behavioural characteristics. This architecture includes the modelling system, data storage and analysis tools.

2.4.1 The Dynamic Structure of the system

A multi-agent system structure was created to enable the system with dynamic and transitive connections between the components. When one spatial component or criteria changes during execution, this change will be reflected in all the components that depend on the former. Therefore, all these components must be updated. This operation is activated autonomously by the spatial agent responsible for the changed component. The system of dependencies is provided by a knowledge base of connection rules which is also updateable. Fig. 3 shows the structure of the system.

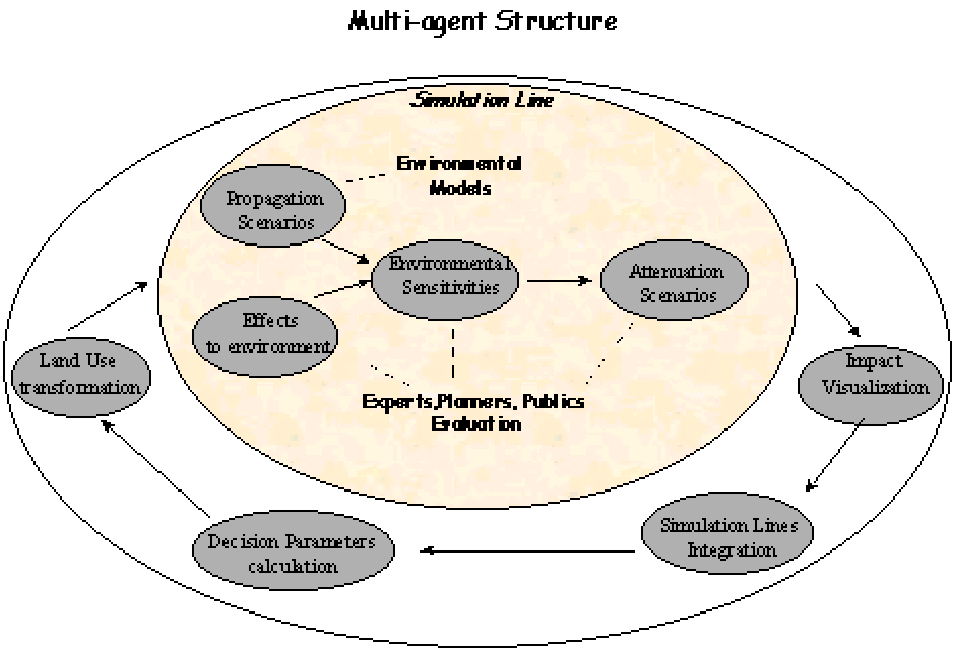

Fig. 3 — Functional structure of the system

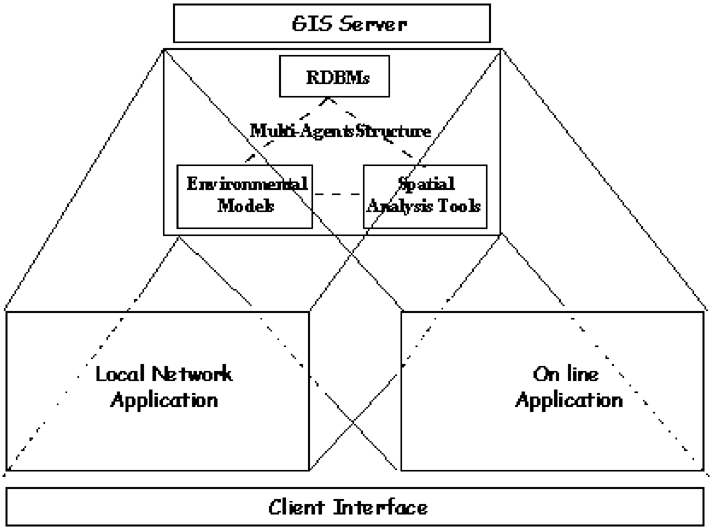

Fig. 4 - Application Design

2.4.2 Client Interfaces

The current prototype implementation has been built using the client-server paradigm . It has been constructed around a GIS server remotely accessed by two kinds of interfaces as shown in Fig. 4.

The local network application has been designed to work at the municipal level and enable the complete toolbox.An online application is also being created to store public proposals. It is an online mapping application which interacts with the land use data using evaluation profiles defined by the current user.The Java-based interface allows for the definition of the user's profile, the execution of simple simulations and the presentation of mapping results. This tool not only realises the transparent property but also constitutes a way to inform the public about the methodology used.

3 THE NEED FOR NEW DATA REPRESENTATION MODELS TO REACH HIGHER SIMULATION DIMENSIONS

Currently, the existing implementation does not solve all of the planning problems involved.The system implemented does not allow the cumulative impact evaluation of simultaneous land use transformations (Schweigert, 1994).Also, there are some problems with associating spatial and non spatial information. Finally, we have identified serious limitations in modelling non-continuous phenomena and transport mechanisms.The use of vectorial structures for modelling municipal information has clarified a need for new forms of representation that, not only handle vectorial information, but that can also enable non-contiguous forms of propagation. This will allow for the modelling of the complex environmental interactions involved as well as their temporal characteristics.

3.1 Heuristic Definitions

The definition of the data model is now underway and it will include the representations to be used and the properties associated with each object or class of land use (spatial and non-spatial elements of the system). A major effort is also being made to define a behavioural model for the land use object when confronted with a negative effect emitted by another object.These two models represent heuristic definitions from which the rules to be computed are explicitly created.

3.2 Data Modelling Issues

The data model required has to integrate topological descriptions that will enable effective qualitative spatial reasoning (like distance and orientation description) related with the currently studied phenomena. The Object Oriented model will then appear as an appropriate structure to represent environmental interactions.

3.2.1 Object Orientation

The Object-Oriented (OO) model can be seen not only as an elegant alternative to the relational model but also as a solution for a more appropriate description of phenomena. The concept of object emerges from the necessity of manipulating, not only the static structures of information (data oriented) but also the dynamic behaviour of the system. Just like in the Entity-Relationship diagram, the static aspect of an object is presented as a collection of attributes. The set of attributes of one object is called its state. The dynamic and behavioural side of the object is presented through a set of operations (called methods) that will be executed under certain conditions. This possibility led the project to an OO approach, as the necessity for the definition of behaviour for different types of object became clear.

3.2.2 Minimisation of impacts

Hazard zones can also be represented as objects and their spatial interaction can be studied through topological and distance properties between different impact shapes and pollution sources. The objective is now to define rules and methods to minimize impacts, by reasoning spatially on the qualitative properties of the impact shape. Those methods will highlight the action to be taken at the pollution source to reduce the impact, measuring the simulation results through the decision parameters.

3.2.3 Temporal Aspects

Temporal representation is often limited in most of the systems used. However, new techniques have been recently proposed. In this project, we are considering the existence of different temporal versions of a same object generated by events (Wachwicz and Healey, 1994). Each impact is represented as a geometric object able to be represented by a different temporal version. Another interesting approach results from Peuquet and Duan's (1995) who consider an event-based spatio-temporal data model to handle forestry change. This approach is currently under a comparative study with the one suggested above.

3.2.4 Computational Implementation

The object characteristics of the model offer a few computational advantages. The most prominent one resides on the natural implementation of software interfaces and their flexibility. Moreover, the coupling process models facilitate the agents manipulation of the model elements. Finally, spatial, attribute and thematic relationships can be easily described and maintained by the feature itself as the input of new data (Crosbie, 1996).

4 CONCLUSIONS

It is our belief that the first implementation of the Decision Support System may lead to the reduction of the gap between the modeler's perspective and the decision-maker's habits. The opportunity to simulate changes in the studied area and experiment with new planning methodologies enables the planner with information and tools for simulating possible scenarios while the modeler can test new tools and receive feedback from the decision-maker. The main advantage is to get both parties to communicate and reach solutions together. The agent-based architecture can also act as a guiding mechanism, helping the user avoid evaluation parameters that cannot be applied in the specific problem (e.g.: avoiding decisions that go against normative). The evaluation perspective is not fixed and can interactively evolve in time. The planning decision process differs between countries but the difficulty of introducing new support tools is still the same in most contexts. This implementation completes the fundamental objective which was to propose a system that would integrate environmental matters in the planning process in a clear and scientific way. The implementation has been based on two components: a GIS server and a distributed access system. The GIS server uses a Multi-agent framework to link the modelling support system with the data storage and the analysis tools. The Internet application allows the storage of public opinion and its familiarisation with such tools in a simple, inductive and educating way. Investment is now turned to the system's improvement through the exploration of new data structures and new process models. Another idea to be implemented is concerned with the calculus of the action to be taken at the source to reduce the studied impact in a qualitative way. We hope that future results will support us in the idea that new data models have to be imagined to increase the cognitive representation of space and our understanding of the Earth's mechanisms.

5 ACKNOWLEDGMENTS

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