Towards a Local Planning Support System, Introducing the MASQUE Framework

D.J.M. Saarloos, T.A. Arentze, A.W.J. Borgers and H.J.P. Timmermans
Eindhoven University of Technology
Urban Planning Group
Eindhoven
The Netherlands

ABSTRACT

Urban planning is an important instrument for improving the quality of life, but it is hampered by the fact that the effects of many decisions, to be made by the planner, are practically unknown or at best unclear. The high level of complexity, uncertainty and subjectivity involved in urban plan development is seriously troubling the planner. One way of facilitating the plan development process, and potentially improving the decision-making, is developing a Planning Support System (PSS) that combines artificial intelligence with a gamut of computational tools that support the process. At the Eindhoven University of Technology a research program is conducted to develop such a system for local urban planning in the Netherlands. The system, named MASQUE (Multi-Agent System for supporting the Quest for Urban Excellence), applies Multi-Agent technology to incorporate multidisciplinary expertise on both tools and domains as well as to enable intelligent guidance and assistance towards the user. Strong emphasis is put on the scenario-based way of working that is common in urban planning. This paper puts forward the difficulties faced in local planning practice and discusses the possibilities for computer-assistance. This finally resolves into the introduction of the MASQUE framework, describing how the system is organized and how the agents will be involved.

1 INTRODUCTION

Potentially, urban planning is an important instrument for improving the quality of life due to the fact that it is concerned with configuring and shaping the environment by locating objects and activities in both space and time. To be able to fulfill his task profoundly an urban planner needs to know the (possible) effects of his decisions on the quality of life. Due to the “high complexity, uncertainty and subjectivity of urban planning” (Yeh and Shi 1999), however, it is often difficult to foresee the consequences of such decisions. This means that future problems can easily be overlooked. In answer to this, the urban planner is more or less forced to postpone decisions by defining different scenarios and evaluate them at a later stage. This way of working can be seen as building up a ‘tree structure’ in which finally every path from root to leave represents a scenario. A practical problem, however, is that this ‘scenario tree’ can become very extensive and complicated when all decisions of which the effects cannot be (exactly) foreseen are postponed. To keep the tree as simple as possible the planner will need tools with which the effects of decisions can be predicted reliably. Because such decision support tools usually require intensive computation, they can best be embedded in a computer environment, which at the same time allows for efficiently grouping them into so-called Planning Support Systems (PSS).

Over the years, several scientific contributions in the area of PSS have been made to improve decision-making in urban planning practice. In a preceding paper (Saarloos *et al*. 2001) we have distinguished two types of systems being developed: those that focus on data analysis and combine capabilities of a GIS with purpose-built decision support models and procedures (e.g. Klosterman 1999), and those that focus on visualization and integrate capabilities of a GIS with realistic, real-time, interactive visualization (e.g. Van Maren and Moloney 2000). Although convergence of these two types into one system is considered to deliver the ideal PSS (e.g. Bishop 1998), we argued that this ideal should also include a Multi-Agent component since that would enable incorporating the knowledge of multidisciplinary experts and applying it synergistically for complex problem-solving. Moreover, it would contribute to the system's user-friendliness by enabling intelligent user support. Consequently, we introduced MASQUE, a PSS under development for local urban planning that will utilize Multi-Agent technology, and defined the types of agents needed, based on an anthropomorphic approach.

This paper will further elaborate on the concept of MASQUE. First, the characteristics of the plan development process at the municipal or local level will be described (section 2). Then, the possibilities for computer-assistance in urban planning are discussed (section 3). Subsequently, the organizational framework of MASQUE will be presented, including a description of the way in which the agents will fit into the overall system (section 4). Finally, future work will be described (section 5).

2 LOCAL URBAN PLAN DEVELOPMENT

Basically, the urban planner is concerned with balancing the supply and demand for land use. He assembles and shapes the urban environment by deciding about the composition and spatial configuration of geographical objects ('geo-objects'). As such, he affects the opportunities and constraints for individuals, households, companies and institutions with regard to the use of the urban environment, whether or not intentionally. Although this implies he can influence these users' behavior, this is only the case to a certain extent because, based on the activities they need or want to perform in the urban environment, there will be certain basic demands that they will try to pursue anyhow. If the environment is found to be not (fully) suitable for performing these activities, problems like traffic congestions, sub-optimal performance of facilities, or discontent among the population might occur. It is the planner's task to control the situation by optimizing the supply according to the demands. This section will describe urban plan development at the local or municipal level, i.e. the instruments that are used, the process that is taking place and the factors making it complicated.

2.1 Instruments

Urban planning embraces many different interests and deals with issues at different levels of scale, even when only looking at the local level. To cover this broad area of attention the urban planner makes use of various 'policy instruments' or 'urban planning instruments', each serving a particular purpose. In the Netherlands the most frequently used instruments at the local level are:

1. *Structure plan.* Urban plan indicating the outlines of the overall urban development policy and covering the whole municipal territory or a large part of it.
2. *Thematic plan.* Urban plan pointing out the development policy with regard to one specific land use, e.g. green space or traffic, and covering the whole municipal territory or an even larger area.
3. *Land use plan.* Urban plan laying down legally-binding regulations for permissible land use in designated zones, either generally or more detailed, and covering specific parts of the municipal territory that can range in size from a city district to a building block.

Usually, every policy instrument consists of maps and text documents. Maps are more or less indispensable because of the geographical nature of the plan. At least one map is needed to indicate the boundaries of the area the plan is referring to. Text documents are used to give background information and to describe the policy, usually with map references.

The general purpose of these instruments is to document the policy and to make it operational. In order to implement changes to the urban environment based on those plans further elaboration has to take place. There are some 'urban design instruments' available to go into more detail, like the *(re)development plan* that, based on given land use plan regulations, graphically shows the intended (re)development of an area by indicating the arrangement of buildings and public spaces.

2.2 Process

The *urban plan development process* is defined here as the process that will lead to the plan in its physical form. When it has been decided that a plan should be developed, the following three general stages constitute this process (Rutledge 1971)[1]:

1. "Survey, or an assembling of facts and data which might have consequences for the design's outcome.

[1] Although Rutledge focuses on the 'site design process' in the light of recreational area planning, he points out that the phases described can in fact be identified in any process that aims at solving some kind of land use problem, the primary difference just being the inputs which are analyzed towards solution.

2. Analysis, or the making of value judgments about the effects of one fact upon another.
3. Synthesis, or the weaving of the results of analysis into a comprehensive form and organization solution to the problem."

Rutledge defined several parts within each phase. In the *Survey* phase a "Program" is prepared to express the early requirements of the project. Also, an "Inventory" is made to gather facts and data about both the study area and its surrounding areas. In the *Analysis* phase one or more so-called "Relationship Diagrams" are developed that reflect the various ways in which the program items could be mutually arranged according to their functional relationships, irrespective of the site's characteristics. Besides this, "Site Analysis" is performed to visualize the opportunities and constraints offered by the study area and its surrounding areas. In the *Synthesis* phase each relationship diagram is fitted to the study area, resulting in one or more "Design Concepts". Finally these concepts undergo "Refinement and Finalization" in order to make them presentable to the parties concerned.

As can be deduced from this it is possible that during plan development it turns out that a number of alternative final plans should be developed because "several equally desirable relationship diagrams have been found or because a single diagram could be fitted to the site in a variety of ways" (Rutledge 1971). When emphasizing this scenario-based way of working and also including the actions following plan development, i.e. implementation and monitoring, the outline of the general *planning process* becomes visible. This process is usually represented as consisting of the following phases (e.g. Arentze 1999):

1. Problem identification and definition.
2. Formulation of goals and objectives.
3. Formulation of alternatives.
4. Analysis of alternatives (forecasting).
5. Evaluation of alternatives and making a choice.
6. Implementation.
7. Monitoring and early warning.

2.3 **Complicating Factors**

As described above, it is the urban planner's job to balance supply and demand by adjusting the supply according to (expected) changes in the demand. However, the demand, both on the aggregate and individual level, tends to change faster than most changes to the urban environment can possibly be made. Because of this, urban plans should be made flexible or robust enough to account for changes that could not have been foreseen during the plan development.

Nevertheless, the given outline still presumes more straightforwardness than there actually is, in that practice shows a process with many irregularities (e.g. Batty and

Densham 1996) of which basically two kinds can be distinguished. On the one hand, numerous iterations between phases may take place in order to tune interrelated decisions, for example when, as part of the evaluation, the plan is offered for consultation to the public and resulting legitimate objections make it necessary to change the design. On the other hand, particular phases may be skipped, for instance when the planner just wants to test the feasibility of an idea for a design that came to his mind rather spontaneously.

Besides these procedural irregularities urban plan development is also complicated by 'the nature of the problem'. Urban planners are faced with "high complexity, uncertainty, and subjectivity" (Yeh and Shi 1999). First, the planner is dealing with multidisciplinary problems involving many interwoven factors and relationships. Because one person cannot possibly oversee all of this, the urban planner usually has to consult different experts during plan development. "Planners rarely, if ever, solve problems or develop proposals in isolation" (Tweed 1998). These multi-player situations cause great complexity because the different parties will have conflicting "beliefs (observations and perceptions) and desires (goals and expectations)" (Ligtenberg *et al*. 2002), which should be resolved by negotiation and cooperation. Second, many of the cause-effect relationships between the planner's decisions and the quality of life are unclear in advance. The underlying mechanisms are for a great deal unfathomable because of the large number of aspects involved. Moreover, the mechanisms are strongly location-specific, making it hard to derive generally applicable rules. Third, creativity is considered to be a vital prerequisite during plan development in order to get a high quality design that fits to its environment in every possible aspect. Many decisions in urban plan development are still based on intuitive thoughts of the planner. So, although an urban plan often looks quite simple in its final appearance, the planner is in fact faced with many complicating factors during its development.

3 COMPUTER-ASSISTANCE IN URBAN PLANNING

When thinking of the impact changes to the urban environment can have on the quality of life, it is obvious that urban plan development should be based on well-informed decision-making. As described above, however, there are many factors complicating the development process. This section discusses the possibilities of utilizing computers to improve urban plan development.

3.1 **Potentials and Difficulties**

The two basic questions faced in urban planning are "What location is most suited for this land use?" and "What land use, or combination of land uses, is most appropriate for this location?". For answering these questions information about land suitability has to be combined with information about land use characteristics, which includes information about both quantitative and qualitative properties of land uses, as well as the (in)compatibility of land uses with one another on the same location, on adjacent or nearby locations. It can be very complicated to develop a spatial configuration of land uses while taking all of these interrelated aspects into account. The combinatory nature of the problem, however, makes it possible for computers to assist in finding solutions. They can, at least, help the planner with enumerating alternatives as well as with decreasing the solution space by systematically evaluating the alternatives.

However, the development of computer applications for design and decision support requires insight into the nature of the problem at hand. As mentioned above, it is still difficult to gain a clear understanding of the typically multifaceted and location-specific mechanisms taking place in the urban environment, which makes creativity and intuition indispensable in urban plan development. Even though some mechanisms can be described in sets of rules that are understandable to the computer, it is this urge for creativity and intuition that causes the planner to be very critical, at best distrustful, towards computer assistance (Geertman 2001) because the computer's approach is considered to be too systematic. This is a major hurdle since user acceptance is a key issue in the successful deployment of any computer system (Yeh and Shi 1999).

3.2 **Prospects of Artificial Intelligence**

In order for a PSS to get accepted by the urban planner it should be beyond doubt that the system is capable of improving the quality of decision-making[2]. This can only be established by incorporating multidisciplinary expertise and a wide variety of methods and techniques in the system, which will prevent users from having to 'mask' their lack of information and methodological abilities any longer when having to solve the many ill-structured problems that they are faced with in practice (Saarloos *et al.* 2001). So, a PSS should offer both knowledge and methodological tools to enable well-informed decision-making.

These two prerequisites are already recognized for years and have functioned as the guiding principles in the development of Expert Systems (ES), or more broadly knowledge-based systems, and Decision Support Systems (DSS) respectively. According to Darlington (2000), the former attempt "to mimic human expertise by applying inference methods to a specific body of knowledge", usually within a narrow and clearly defined problem domain, whereas the latter attempt "to support decision makers using data processing and/or operational research techniques", which allows a wider scope. As Arentze (1999) points out, another field of research has emerged from these two, where ES techniques are used within a DSS framework for enhancing the modeling capabilities of the system or improving the intelligence of the system in various components including data management, model management and user interface. This indicates that Artificial Intelligence (AI) can improve a system in multiple ways. It could be the key factor for the acceptance of Planning Support

[2] Besides this, it is of course also important that the system fits into the organization.

Systems because it "can be used to facilitate and improve the quality of decision-making by reducing information overload and by augmenting the cognitive limitations and rationality bounds of decision makers" (El-Najdawi and Stylianou 1993).

In recent years, it is the so-called Multi-Agent (MA) technology, a particular branch within the AI field, receiving much attention. Considering the complicating factors in urban planning as discussed above, the most interesting aspect of this technology is that it enables the development of Multi-Agent Systems (MAS) that are "ideally suited to representing problems that have multiple problem solving methods, multiple perspectives and/or multiple problem solving entities" (Jennings *et al*. 1998). It enables different types of interactions between the multidisciplinary experts ('agents') inside the system, like cooperation, communication and negotiation. Jennings *et al*. (1998) state "it is the flexibility and high-level nature of these interactions which distinguishes MAS from other forms of software and which provides the underlying power of the paradigm". The technology shows great promise towards the field of PSS as it can offer the functionalities that are still missing. It can serve both simulation and problem-solving purposes (Ferrand 1996). Although in urban planning MA technology is still mostly applied for micro-simulation, it has already been demonstrated that it can equally well be used for simulating multi-actors decision-making processes (Ligtenberg *et al*. 2002) or for improving user interfaces (Rodrigues and Raper 1999).

4 MASQUE, AGENTS EMBEDDED IN A LOCAL PSS

Recognizing the need for a comprehensive Planning Support System at the local level, the Urban Planning Group and the Design Systems Group of the Eindhoven University of Technology initiated a research program called MASQUE, which stands for a Multi-Agent System for supporting the Quest for Urban Excellence. The acronym is meant to reflect the intention that the computer system should support designers, planners and other decision-makers to improve the quality of their plan-making, i.e. their decision-making in shaping urban environments. This section will describe the organization of the system, first its subdivision in phases and then the positioning of agents within this framework.

4.1 System Framework

In principal, a computer system will become more complicated to use when it offers more functionalities. In the case of MASQUE, which is meant for local urban planning purposes, the following requirements are defined (Saarloos et al. 2001):

- Use of height-related data
- Use of time-related data
- Scenario-based working
- Support of task- and process-related decisions
- Access to multidisciplinary knowledge
- User support throughout the system

These requirements imply offering a ‘rich’ set of functionalities. This richness brings along the risk that the system might be overwhelming to the user. In order to prevent this from happening and make the system as understandable and easy to use as possible, a distinction is made between six 'system phases’, which is both a refinement[3] and an extension of Rutledge’s framework of the urban plan development process. (see Figure 1). Hence, MASQUE consists of the following system phases:

1. Inventory
2. Program
3. Analysis
4. Synthesis
5. Implementation
6. Monitoring

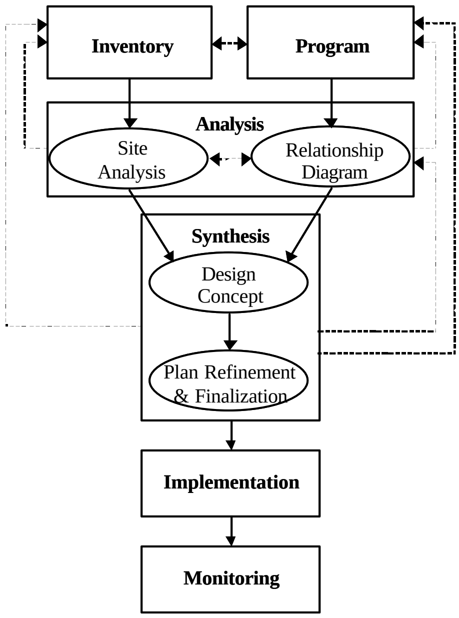

Figure 1: **The urban plan development process (free after Rutledge 1971)**

[3] Both the Inventory and Program, which Rutledge described as parts of the Survey phase, are ‘upgraded’ to phases in order to emphasize their fundamental differences.

The purpose of the *Inventory* phase is to build up the databases that contain all the geographic and non-geographic data available about the study area and its surroundings. In order to fulfill this task the component is equipped with functionalities to import data from different sources. During the plan development process anyone, either the human user or a software agent, can query the databases for information with which questions can be answered or problems can be solved. Obviously, it is possible that the information requested turns out to be missing. In these cases the component can be accessed again in order to extend the databases. The Inventory is the only phase that does not support scenario-based working, because all data can become useful to all scenarios at some time. In this respect the Inventory serves as a common base for all scenarios.

The purpose of the *Program* phase is to put together all goals and objectives of the different parties involved in the plan development process and extract an overall set of goals and objectives from it that reflects the future ideal. Basically, there are two potential obstacles hampering this task: difficulties with encoding abstractly formulated goals and objectives so that the system and its agents can understand them, and difficulties with finding compromises in case of conflicting goals and objectives. Besides the goals and objectives that are defined outside the system, goals and objectives can also emanate from one of the other phases. Then, the Program component has to be re-accessed to incorporate these 'endogenous' goals and objectives into the overall set, tuning them with the 'exogenous' goals and objectives already entered.

The *Analysis* phase elaborates on both the Inventory and Program phases, although in a separated fashion. On the one hand, the Inventory is used as the basis for "Site Analysis" in order to determine the opportunities and constraints offered by the study area and its surrounding areas. The driving force for this is the 'absolute location', reflecting the suitability and feasibility of the land with concern to different uses. On the other hand, elaboration on the Program takes place to generate one or more "Relationship Diagrams", i.e. alternatives for the mutual configuration of land uses without (!) taking scale and site information into account. The driving force here is the 'relative location', reflecting the functional relationships of land uses and the lines of travel between them. Of course, interaction between the two elaboration tasks can take place at any time, giving direction to one another, "with a growing knowledge of Program needs directing the search for particular site qualities, and a rising feeling for the site illuminating what can be done to satisfy the Program's demands" (Rutledge 1971).

The purpose of the *Synthesis* phase is, first of all, to put together the Inventory elaboration and the Program elaboration to get a "Design Concept". For this task the planner is free to "manipulate the diagram elements in whatever manner needed to see that all use units end up on desirable portions of the site in a pattern which retains the essential relationships implied in the abstract diagram" (Rutledge 1971). To start the procedure the planner can choose to (i) select perfect or preferred locations for particular land uses (i.e. diagram elements), or (ii) select perfect or preferred land uses for particular locations. From this point on he can elaborate by rolling the other units from it. Then, "he may relocate land uses whose initial positioning violates the sense of the relationship diagram or revise the whole to ameliorate the negative effects of the relocation, and then turn to refinements that satisfy a single criterion" (Rutledge 1971).

The *Implementation* phase is used for determining an "Implementation Plan" based on the final design that resulted from the Synthesis phase. This means that functionalities are offered for making decisions about all financial and time-related issues of developing the land according to this final design.

The *Monitoring* phase offers diagnosis functionalities for enabling the user to detect and anticipate any changes in land use demands that (could) lower the performance of the urban environment when the final design would be implemented. When unacceptable decay is detected or anticipated, this information will be used as input to re-access the Program phase and subsequent phases to find remedies or repairs.

In all phases of MASQUE except for the Inventory phases, it is possible to define scenarios whenever decisions have to be postponed because their effects cannot be (exactly) foreseen, or in other words, whenever it is necessary to leave multiple options open because it is not possible to tell which one will work out best. The scenario tree in the system gives access to information about all scenarios defined within a project.

4.2 Positioning of Agents[4]

Within MASQUE two agents are operational from startup to closedown, monitoring the user in order to offer support when needed. The *'system guide'* is responsible for giving information about what functionalities are offered, where they can be found, and how they can be used. The *'process guide'* gives support with concern to the organizational issues of the plan development process, using the scenario tree as a guideline. Both agents are part of the graphical user interface and are therefore called 'Interface Agents' (see Table 1). Also belonging to this type of agents is a group of *'phase guides'*, of which one is assigned to every system phase in order to assist the user while working in that phase. The modifications that are made during a phase are documented by the 'phase guide' and, in a summarized form, passed through to the 'process guide' to let this agent keep the scenario information up-to-date. Whether on their own initiative or on the user's behalf, the 'phase guides' can contact both *'tool managers'* and *'domain managers'* who can assist with finding agents (*'operators'*) that have knowledge about certain (kinds of) tools and (sub-)domains respectively:

a. *'Tool operators'* are responsible for either dedicated tools, which can be used during a specific phase, or generic tools, which can be applied at any time during the plan development process. Hence, their involvement in system phases (see

[4] A description of the different types of agents defined within MASQUE can be found in Saarloos *et al*. (2001).

Table 1) is determined by the range of applicability of the tool they are responsible for.

b. *'Domain operators'* are experts on particular aspects of one particular land use, i.e. aspects of location, quantity, quality and implementation of residential areas, commercial areas, etc. Their involvement in system phases depends on the kinds of knowledge required and the kinds of aspects studied during these phases (see Table 1):
   i. During the Inventory phase 'domain operators' can become needed for giving advice on matters like the definition of categories when storing information about certain (aspects of) land uses, or the identification of different kinds of problems in the current urban environment.
   ii. In the Program phase 'domain operators' can be asked for assistance with interpreting and encoding goals and objectives, and with identifying any fundamental (in)compatibilities between goals and objectives that are referring to different (aspects of) land uses.
   iii. In the Analysis phase the involvement of 'domain operators' depends on the task to fulfill. When relationship diagrams are developed it is possible to consult 'domain operators' that have knowledge about aspects concerning the *relative* location of land uses. They can assist with identifying synergies and conflicts occurring between land uses on the same, adjacent, or nearby locations. For performing site analysis support can be offered by 'domain operators' that have knowledge about aspects concerning absolute location of land uses. They will be able to tell for which use(s) the land is most suitable.
   iv. The 'domain operators' that may be contacted during the Synthesis phase are those that are concerned with quantitative and qualitative aspects of land uses. Based on their knowledge the physical feasibility of each relationship diagrams will become clear. Because of the fact that this may result in a need for making (minor) changes to the relative and/or absolute location of certain land uses, also the 'domain operators' concerned with location can become involved.
   v. Obviously, during the Implementation phase the user can consult the 'domain operators' that have knowledge about implementation aspects of land uses. They know about the time needed for developing a certain land use, as well as the costs and benefits.
   vi. During the Monitoring phase all aspects of land uses should be considered again because they can all lead to problems. This means that 'domain operators' of any kind can get involved in this phase. In this phase their task is to identify future problems.

5 FUTURE WORK

This paper described the reasoning behind the organizational framework of MASQUE, a PSS for local urban planning that makes use of Multi-Agent technology.

Table 1: **Agent involvement in the different system phases**

Name		**SYSTEM PHASES**					
		Inventory	**Program**	**Analysis**	**Synthesis**	**Implementation**	**Monitoring**
INTERFACE AGENTS							
System Guide		X	X	X	X	X	X
Process Guide		X	X	X	X	X	X
Phase Guides	Inventory Guide	X					
	Program Guide		X				
	Analysis Guide			X			
	Synthesis Guide				X		
	Implementation Guide					X	
	Monitoring Guide						X
TOOL AGENTS							
Dedicated Tools Manager		X	X	X	X	X	X
Operators	Problem definition	X	X				
	Goals & objectives		X				
	Alternatives			X	X		
	Forecasting			X	X		
	Evaluation			X	X		
	Implementation					X	
	Monitoring						X
Generic Tools Manager		X	X	X	X	X	X
Operators	Information retrieval	X	X	X	X	X	X
	Information processing	X	X	X	X	X	X
	Simulation	X	X	X	X	X	X
DOMAIN AGENTS							
Domain manager*		X	X	X	X	X	X
Operators	*Location*	X	X	X	X		X
	Quantity	X	X		X		X
	Quality	X	X		X		X
	Implementation	X	X			X	X

* Based on the eight types of possible land uses, MASQUE distinguishes separate domain managers for: residential areas, commercial areas, transportation, services, landscape, recreation, technical infrastructure, and hydraulic constructions.

It explained the way in which the system will be structured, and in particular how the agents are positioned within it, in order to meet the requirements that were derived from local urban planning practice in an earlier stage of the research project (Saarloos *et al.* 2001).

The following step will be implementing the concept in order to test its feasibility and efficacy. The emphasis in this will be on the synergistic opportunities the use of multiple agents will bring along for complex problem-solving. This means that the interaction between the different types of agents will be modeled based on the different *kinds* of knowledge these agents will need to have.

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