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DESIGNING PLANS: A CONTROL BASED COORDINATION MODEL

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Designing Plans: A Control Based Coordination Model

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Abstract

In this paper we discuss artificial plan designing as a research field that deals with the development and use of computational models to support the generation of design descriptions in architecture and urban planning. We discuss some crucial methodological issues and we present a model for artificial design generation based on learning control methodologies. The design problem is defined as a search for "coordinated" solutions (changes) that satisfy distributed domain requirements and views expressed by human or artificial agents. The model is simulated for a land use and layout plan design problem seen within the context of a hypothetical urban development assignment.

1. Introduction

Designing is recognised to be a natural human activity and thus inherent in professional practice, irrespective of the scientific domain (Simon 1996:111). In this paper, we are interested in designing as it is seen in architectural and urban planning practice. In engineering and architecture there is a significant body of research around different aspects of the design activity, but urban planning practice seems somehow disconnected from research in design methods and processes. However, a lot of researchers do suggest that design is an integral part of good planning, mainly underlining the need for producing and evaluating alternative plans (Batty 1974, Harris 1998, Hopkins 1998a, Alexander 1992, Schlager 1965). Urban development problems are typically in between the architectural and urban scale and so are seen as a good paradigm for investigating common routes in design methodologies and techniques developed in the different disciplines.

On the other hand, designing is also recognised to be a potential "artificial" task. Despite the complex and elusive character of design, formal models and their computational counterparts have been developed, for some 40 years now, to simulate or to support design – "both as a cognitive activity and as a domain"(Liddament 1999: 43). The use of computational models to generate design descriptions seems to be a common ground among different research fields although their meaning, the methods used and their scope varies. Different terms have been used to describe the purpose or the nature of these models such as automatic (e.g. Steadman 1970, Cross 1977, Eastman 1973), generative (e.g. Brill, Flach, Hopkins and Ranjithan 1990, Chien and Flemming 2002) or creative (e.g. Gero and Maher 1999). In urban planning a typical application addresses the problem of land use-transportation plan design (e.g. Feng and Lin 1999, Aoki and Muraoka 1997, Anderssen and Ive 1992), while in architecture the dominant example is in building layout design (e.g. Mitchell, Steadman and Liggett 1976, Liggett 1985, Chakrabarty 1990, Jo and Gero 1998). In this paper a model for simultaneous generation of facility location and building layout plan design is presented. In the following, the terms "artificial plan designing" or "plan generation" will be used as umbrella terms to refer to all these models.

Designing, whether it is based on "artificial constructs" or directly on human decision-makers, points typically to the formulation of plans. Looking at the definitions of "plan" in different disciplines (Alexander 1992, Schlager 1965, Hopkins 1998a, Dorst and Cross 2000, Houkes, Vermaas, Dorst and de Vries 2002, and Kroes 2002), however diverse, can help us distinguish a common view. A plan by and large represents decisions to be implemented in order to satisfy current and future goals (and/or constraints); a plan is the design of actions that will lead to future changes. However, the relation among designing processes, design artefacts (plans) and real world artefacts varies across disciplines and according to the nature of the system to be designed (e.g. if it is a building or a city). This variation reveals different interpretations of designing. In some cases, designing is coupled directly with the real world artifact without the explicit mediation of a plan. Christopher Alexander's (1979) work on "pattern language" actually sets up a plan that works more like a social knowledge source, rather than a blueprint that is well established before its implementation to the real world. More recently, research on the field of intelligent (kinetic) buildings and robotics (e.g. Fox 2001), anticipate -to some degree- the reality of a tight coupling between designing and real-world reformulation (Brazier, Jonker, Treur and Wijngaards 2001: 470). In parallel, plans in the context of urban development are very much part of the problem they attempt to solve and the designing activity tends to be seen more as a positive-descriptive rather than a normative-prescriptive activity. Naturally, formal design models mirror the discrepancies among various interpretations of designing and thus a wide range of different methodologies have been developed in relation to different views of the design problem.

In the following section we will discuss some theoretical and methodological issues pertaining to artificial plan designing. The attempt will be to provide a broader picture in artificial plan designing as a vehicle to discuss some key issues, which form the basis of the argumentation for the development of the proposed model (presented in the last two sections). In this model, the simultaneous generation of land-use (facility location-allocation) and layout plan design is elaborated. The design problem is defined as a search for locations and physical layout proposals that satisfy distributed and time-variant requirements or targets. Expert knowledge for this search is not explicitly incorporated in the model but a Neural Network (NN) architecture is used instead to discover and represent knowledge captured as interdependencies among decision variables expressed by distributed sources (decision makers or their domain models). We present a model-tool that learns from user interaction and then uses this knowledge to search and generate design proposals. For the simulation of this model we take a hypothetical urban development assignment that aims to the development of a housing and retail unit. The attractive point in this framework is that we have to consider a simultaneous and constant generation of alternative plans, both in the architectural and the urban scale, from the preliminary stages of the plan design. Additionally, requirements and targets are typically distributed among different teams and vary in time according to the emergence of new conditions (Cadman and Topping 1985).

2. Artificial plan designing

Before we proceed with the presentation of the model it would be useful to see the broader picture in artificial designing and discuss some crucial theoretical and methodological issues. We will discuss in more detail three key hypotheses that form the basis of our argumentation: distribution, coordination and learning.

2.1 Some typical methodological approaches in artificial plan generation

Optimisation has been the predominant approach to automated plan design, in urban planning as well as in architectural and engineering design (Gero 1985, Harris and Batty 1993). The design problem is translated into a search for design(s) that represent optimum solutions. Thus appropriate methodologies need to be devised to generate and choose solutions that optimise some utility or cost function under a number of constraints. There are different formulations that fit to this paradigm which employ techniques ranging from mathematical programming (e.g. Anderssen and Ive 1982, Mitchell et al 1976) to multi-objective (e.g. Balling, Taber, Brown and Day 1999, Chakrabarty 1990) and genetic programming (e.g. Aoki and Muraoka 1997, Caldas and Norford 2002).

An extended view of the above paradigm includes the development of search-based or heuristic models. The design problem and formulation emphasizes the exploratory view of designing. Those approaches might include optimisation concepts and techniques but are mainly associated to the concept of "systematically navigating in a space of possibilities" (Akin and Sen 1996: 421). For instance, Akin's et al (1992) search based model puts into practice a quite comprehensive interpretation of design problem solving based on a "generate and test" search paradigm. Another early but lucid example includes Steadman's work (1970) on small-scale layout plans based on the exhaustive search of all possible topological dissections of rectangular layout plans. Other heuristic methods vary from the simple overlay of spatial constraints (Alexander 1962) to its more sophisticated weighted analogue -the so-called potential surface technique- (e.g. Haubrich and Sanders 2000), and to averaging conflicting factors based on probabilistic Markovian processes (Batty 1974).

A third paradigm emphasizes the fact that plan design is a creative process. Evolutionary search, based on the biological analogy of the natural evolution of species, has been the predominant approach on creative design in architecture, art and engineering (e.g. Bentley 1999, O'Reilly, Testa, Greenwold and Hamberg 2001, Frazer 1995). The emphasis here is on replicating the creative process of designing rather than replicating the searching activity, which more formally is associated with a process of evolving the number of the decision variables together with their values (Gero 1994, Bentley 1999: 38-42). Unfortunately, in the planning domain -as far as the authors are aware- not much attention has been paid to creative aspects of plan generation. Evolutionary algorithms in planning have been used mainly for optimisation rather than for creative search. For example a tool called Sketch Layout Model (Feng and Lin 1999) combines a genetic algorithm with multi-objective programming in order to produce a set of alternative land use plans. In the context of planning the search for alternative plans that satisfy multiple criteria or objectives comes as a consequence of the social nature of decision-making rather than as a quest for creativity. However, research on sketch planning does signify an attempt to support in some formal way the intuitive and innovative aspects of plan designing (Harris 2001, Hopkins 1998b, Singh 1999).

Shape grammars constitute a distinctive approach in artificial plan generation, based on generation rules expressed as algebras or formal grammars. Typical shape grammars are founded on a "vocabulary of shapes and arrangements of these shapes into spatial relations" (Knight 1994: 705). This is another potential plan generation process based on selection, creative exploration and emergence (Stiny 1994) but unlike the above paradigms the emphasis is on the morphology and attributes of the design artifact itself rather that on the design or decision making process.

Arguably, creativity and innovation are important issues in plan designing which usually relate to a task of employing known solutions to a new context (Gero 2000). Case Based Reasoning (CBR) deals with such issues of creativity. CBR as has been used in design automation, starts from the recognition that knowledge is distributed to design cases which can be adapted and reused in similar contexts to support creative reasoning (e.g. Maher and Pu 1997, Yeh and Shi 1999). In this sense, learning is also an implicit function supported by the continuous adaptation and re-evaluation of cases.

Research in Multi-Agent Systems (MAS) has brought to light another critical issue in design; that is the distributed and collaborative nature of the design activity. In most design projects, the interaction of different experts and stakeholders, or more generally, the concurrent interplay among different knowledge sources, is paramount. Even though other models such as CBR systems deal with issues of design reasoning and knowledge distribution, these models do not "explicitly model the reflective reasoning required for multi-agent distributed design" (Brazier, Moshkina and Wijngaards 2001: 138). The concept of agency and the ideas behind MAS have been adopted to model design activity (e.g. Gero and Fujii 2000, Brazier, Jonker, Treur and Wijngaards 2001, Liu, Tang and Frazer 2001), usually by integrating knowledge level models. The focus is on the development of autonomous design agents capable of reasoning about their own plans and targets, and capable of reflective reasoning about other agents and needed interactions. A wide range of issues is associated with the development of MAS such as emergence of new structures from local interactions, coordination of conflicting partial plans, and learning.

The plethora of methodologies briefly reviewed in this section discloses a plethora of ways to understand designing. In this paper we will consider plan designing as a search for "coordinated" solutions (changes) that satisfy distributed domain requirements and views. Learning control is seen as a method to search for solutions that direct partial descriptions to follow their (dynamic) targets despite conflicting requirements. There are three hypotheses behind this view: the first is that decision making is distributed among multiple agents, the second is that some kind of coordination needs to be reached among these diverse requirements and purposes; and the third is that domain knowledge cannot be defined a-priori in this context, but some learning mechanism needs to be devised to capture distributed knowledge and effectively use it to generate plan designs.

2.2 Three critical hypotheses for the proposed model

The first hypothesis is related to methodological issues. Current practice in research related to design and planning support indicates a shift from designing based on individual action to designing based on collective-distributed action. Designing is a distributed activity that involves multiple agents (human or artificial) which are sources of diverse and often conflicting knowledge, and express individual views and goals. Design and planning as social phenomena have been typically discussed in positive-descriptive terms. On the other hand, designing from the viewpoint of the individual designer has been mainly addressed through normative approaches (Batty 1984: 280). As Batty (1984) suggests, these two viewpoints are not necessarily in opposition. Designing as a process of collective or distributed decision making implies that the normative activity of change is set under the weight of a collective dynamic, which also underlines the fact that plans are not only prescriptions for the future but they are also descriptions of future changes.

In this sense, it is probably fair to notice that we have moved from the use of computational models and machines as automatic design devices to the use of computational models that support the generation of designs through user interaction. In the context of multi-agent design this interaction is distributed in networks as can be documented by current interest in collaborative design and planning and Computer Supported Collaborative Work (CSCW) (e.g. Coyne, Sudweeks and Haynes 1996, Simoff and Maher 2000, Kvan 2000, Dickey and Vernon 1998, Gordon, Karacapilidis, Voss and Zauke 1997, Shiffer 1992). The hypothesis of the distribution of decision making suggests that knowledge is also distributed, not only because plans are collectively formed by communities (or multidisciplinary groups), but also because even expert reasoning is fragmented into diverse goals, criteria and evaluations.

Naturally, in the context of distributed decision-making, plan design involves searching for configurations that reduce or resolve conflict among distributed goals. Broadly speaking we can distinguish three typical structures in distributed systems. The first appoints a collective function that needs to be optimised for the sake of a "social welfare", the second leaves the dynamic among the involved parts to determine the distribution of welfare, and the third directs the distribution of welfare equally among the involved parts. In decision sciences formal definitions include concepts of bargaining, negotiation, conflict resolution, social choice, consensus or cooperation (Kleindorfer, Kunreuther and Schoemaker 1993). Similar approaches have been developed in the context of artificial intelligence (Ossowski 1999) and some relevant examples in operational research can be found in Batty (1984).

In this research, plan designing, in the light of distributed decision-making and conflict resolution, is seen as a coordination problem. Coordination is extensively discussed in the context of organisational decision support systems (Grandori 2001, Malone and Crowston 1990) and is a recurring issue in the literature on distributed artificial intelligence and multi-agent systems (Ossowski 1999, Jennings 1996). Whether talking about actors or agents, human or artificial, coordination is what makes them act as a distributed system and reach solutions on the basis of managing interdependencies among individual requirements. In the following we will introduce the idea of coordination as a learning control problem. Learning corresponds to a process of capturing interdependencies among decision variables, while control corresponds to a process of using this knowledge to generate control actions (plans) that meet time-variant individual targets, despite endogenous uncertainties or exogenous disturbances expressed by distributed agents. In this context creativity and innovation lies in the possibility of unforeseen solutions emerging through agent interaction and learning.

Finally, the third hypothesis relates to the question of how domain or descriptive knowledge about the system to be designed is incorporated within the model. Very often, domain knowledge is seamless with the proposed model. For instance, facility planning has been extensively addressed with respect to studies on user behaviour, thus building models (e.g. gravity based models) that represent this behaviour. So the design of optimum location-allocation plans is strictly depended on this predefined formulation of user behaviour. On the other hand, in MAS this knowledge is distributed to local agents and global patterns of behaviour emerge by local interaction. Thus, knowledge about the system behaviour is not a priori defined but rather it emerges as the collective design process progresses. In CBR systems domain knowledge is incorporated in cases and it is also dynamically updated by user interaction. In those two last paradigms learning is an implicit function of the system that supports the maintenance, reuse and adaptation of knowledge (Liu et al 2001). In parallel, learning is also an implicit function of design especially when it is conceived as a problem of coordination among distributed plan formulations. So, learning is a source of plan actions for design, which is enhanced in the course of the design process. In this research, learning is seen as a natural way to reduce conflict in distributed systems. Learning associations among decision variables that keep design descriptions of individual agents (human or artificial) within their dynamically defined targets, can be used as a mechanism to produce plan descriptions that coordinate conflicting requirements and views. We use distributed neurocontrol as a paradigm for artificial plan generation based on learning.

3. Plan description

We consider that plan descriptions are built on distributed domain problems and/or partial proposals developed and controlled by agents (human or artificial). For instance, a trivial location and space layout problem may involve various groups of agents: one that defines the appropriate location, another that designs a suitable distribution of volumes, a third that designs a potential spatial distribution of rooms and a last one that is involved in the structural engineering of the building. Each agent is self-interested and represents a partial component of the overall description. Agents' proposals are considered to be partial not only because they convey domain-specific knowledge about the design problem, but also because these proposals are incomplete and change in time according to changing situations and new knowledge gained in the process.

In the context of this paper, plan descriptions are generated within a virtual reality (VR) world and are composed by aggregated objects introduced by users. Objects are justified on the basis of a "purpose" for the design assignment. For the simulation described in this paper we used three objects (initially in the form of three cuboids) located in a hypothetical virtual city, which represent the preliminary development goals for a housing unit, a retail facility and an open space (figure 1). Plan descriptions and hence object specifications, are dynamically generated and modified through the interaction between human actors (or their computational models) and artificial agents that act as controllers. Controllers-agents are also justified on the basis of a "purpose" (namely the "purpose" of the corresponding objects) and will be described in more detail in the next section. So, plan descriptions work as an interface among human operators and artificial controllers-agents (an outline of the model structure and the relation among plan descriptions, objects, users and artificial agents is given in figure 3). The extend to which the overall model for plan generation is working autonomously from human operators, depends mainly from the degree to which formal models are incorporated as domain knowledge sources. Apparently, another issue that relates to the autonomy of the model is the definition of the objects. The way to which objects are defined determines the subject of control wielded by human operators or their models. In other words, the "granularity" of the objects may determine the scale to which we study the design artefacts, and the depth to which we manipulate their characteristics through human-model interaction.

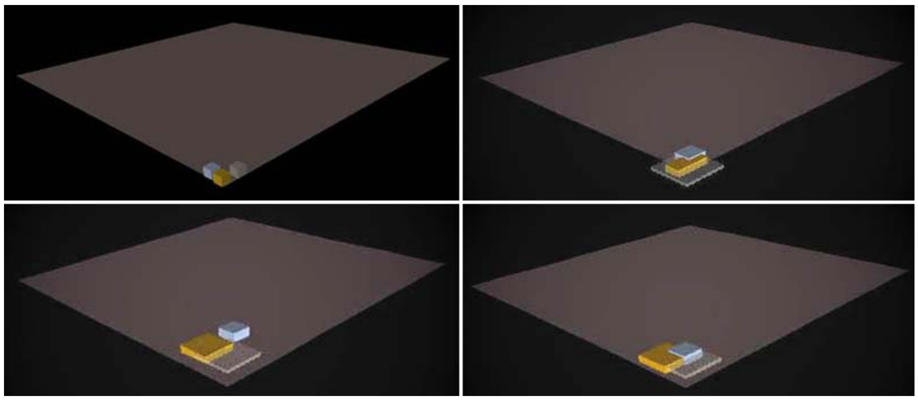

Figure 1: Snapshots from the evolution of the plan description within a VR environment. The blue cuboid represents housing; the yellow represents retail and the grey represents open space. The three objects change continuously dimensions and position in order to reach their functional requirements. Note for instance that the retail volume tends to grow so as to cover larger ground floor area in comparison with the housing volume. Also, the open space tends to "follow" the retail cuboid rather than the housing.

The objects within the VR environment are built on three classes of information: Structural, Behavioural and Functional (SBF). The meaning of the SBF framework for the plan design has been extensively discussed in literature and in a variety of different contexts (e.g. Gero 2000, Gorti, Gupta, Kim, Sriram, and Wong 1998, Szykman, Racz, Bochenek and Sriram 2000, Narasimhan, Sykara and Navin-Chandra 1997). In this paper we will only discuss briefly how this framework is adopted in the context of urban development.

Formally, each object is specified as a row matrix: $A_i = [S_i, B_i, F_i]$. The overall plan description is the column matrix $P = [Ai]$ of all these objects. Structural information specifies the elements of the proposed plan, their attributes and their relations. For the simulations presented in this paper structural information depicts the physical components of the objects and their topological relations. So, for instance, for an object A_h (housing), structural information includes location $[x, y]$, volume dimensions $[z_x, z_y, z_z]$ and relations with other objects such as: distance to other facilities -like retail and open space- $[dr, do]$ and adjacency to north, south, east and west, with other buildings. Behavioural information specifies the way each object reacts to changes of its state and its environment. Behaviour is a description of change of the design objects in order to reach their intended functions. For instance new land uses tend to be developed close or far from other existing land uses in order to fulfil their functional requirements. The Newtonian function of "motion" has been used to model this behaviour, as will be described later. Also, other formulations (like fuzzy inference systems) have been used to describe the tendency to develop more extended, detached building surfaces facing south, or the tendency to maximize ground floor area for retail uses. Development cost is also used in some cases to describe tendency to profit from cheap land prices and exploit larger floor area. Finally, we consider that functional information represents the ontology and purpose of the proposed objects expressed as land use –in our case housing, retail, and open space. The above formulations are given mainly as examples rather as strict definitions of the SBF framework in the context of urban development.

4. Artificial plan designing as control-based coordination

The design problem is formulated as a coordination problem among self-interested agents (which are represented as cuboids in the VR world) and is addressed via a distributed learning control methodology. In general the idea can be summarised as follows: a learning algorithm is used to train a neural network to discover associations among Structural, Behavioural and Functional attributes (in this paper we use off-line training). This knowledge is then used to generate plan descriptions, based on partial information presented to the NN, which will satisfy a temporal (preliminary) reference target for the SBF attributes. For each agent we assign a control architecture which seeks to stabilise SBF interdependencies under internal variations and external disturbances presented by the other agents. Even though there are several different control-based formulations that might be reasonable for coordination problems (for a different formulation refer to Alexiou and Zamenopoulos 2001), we will present here one, which addresses coordination as a self-control problem aiming to satisfy temporal targets, despite conflict expressed as disturbance in the control framework. More analytically, each self-interested agent carries out two combined control-based activities: the first alludes to a synthesis-analysis-evaluation route expressed as a function among Structural Decisions S, Expected Behaviour B_e and Actual Behaviour B_s. The second activity alludes to an evaluation-formulation-reformulation route expressed as a function of Actual Behaviour B_s, Expected Function F_e and Actual Function F_b.

The objective of each agent is to find a suitable path of structures S that lead the behaviours B_s, to follow a reference (expected) behaviour B_e, despite uncertainties and despite exogenous disturbances *Sd* produced by other agents' decisions. The expected behaviour B_e is defined by a reference model, which is developed following a similar control process. The objective in that case is to find the appropriate behaviours B_e that lead the function F_b, to follow a reference (expected) function F_e, despite uncertainties and despite exogenous disturbances *Bd* (figure 2). Hence, the desired performance of the synthesis-analysis system is evaluated (denoted by E in the figure) through the reference model (formulation-reformulation) which is defined by its input-output pair {F_e, B_e}. The control system attempts to make the plant model follow the reference output B_e asymptotically:

$$\lim_{t \to \inf} \left| B_e - B_s \right| < \varepsilon \qquad (1)$$

where ε is a positive integer.

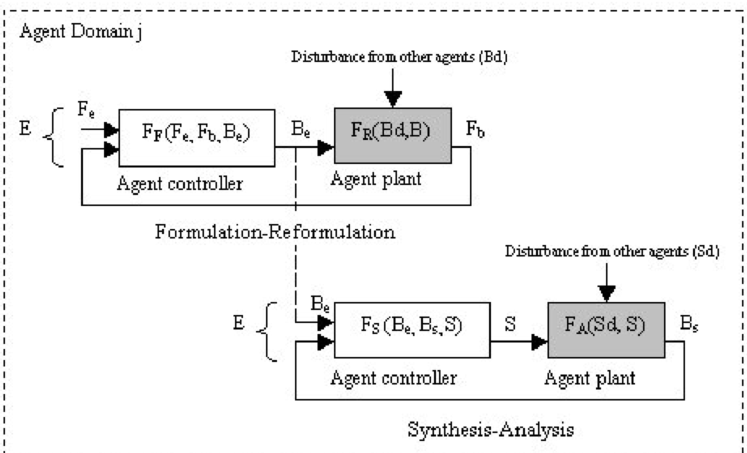

Figure 2: Plan generation as a control process.

From Figure 1: Each agent carries out two control-based activities: the first alludes to the Formulation-Reformulation activity and the second alludes to the Synthesis- Analysis activity. The objective of each agent is to find a suitable path of structures *S* that lead the behaviours B_s, to follow a reference (expected) behaviour B_e, despite uncertainties and despite exogenous disturbances *Sd* produced by other agents' decisions.

Notation: *B= behaviour, F= function, S= structure,* F_A*= Analysis function,* F_S*= Synthesis function,* F_F*= Formulation function,* F_R*=Reformulation function and E= Evaluation.*

To sum up, what we call *synthesis* is the control process that aims to stabilise the state space (behaviour) of an agent according to a reference value for the behaviour B_e; and *formulation* is the control process that aims to stabilise the state space (function) of an agent according to a reference value F_e. *Evaluation* is the process of measuring the degree of "matching" between the two control systems. The control signals $S_t, \ldots, S_{t+n}$ produced by this combined control process consist a set of evolving plans (proposals) for the design and planning problem in hand. The process of artificial generation of plans based on learning control is a process of self-adaptation of agents that leads to coordination of their distributed descriptions. Going back to the methodological issues discussed in the previous sections, we visualize here the possibility to formulate plan descriptions using knowledge acquired and learned through the interaction of human and artificial agents. This can potentially extend the role of "design tools that learn" (Gero 1998) to support collaboration and coordination in distributed decision making environments.

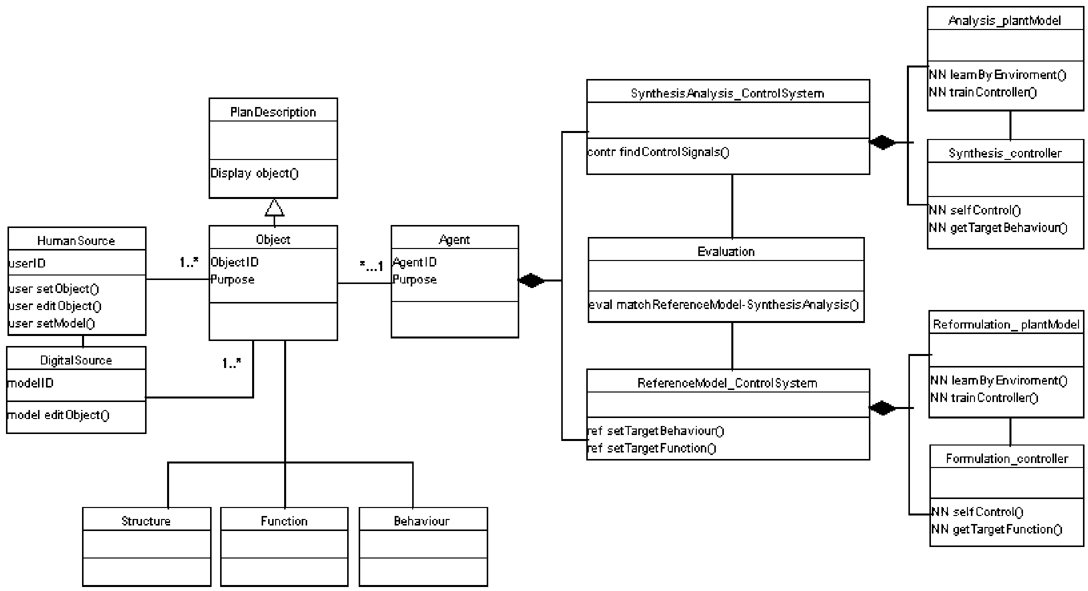

Figure 3: UML-like diagram that outlines the basic structure of the model.

Plan descriptions are built on aggregated objects introduced by users. In the centre, the class *Object* is an interface among users (or their digital counterparts) and the agent society. Objects are built on three classes of information: *Structure*, *Function* and *Behaviour*. Each user has (i.e. can set and edit) a number of objects that are organised in different groups according to their purpose. Each group (that is an instance of the class *Object*) corresponds to an *Agent*. Agents are artificial entities that act as controllers. They are composed on two levels of classes that represent the Synthesis-Analysis and the Formulation-Reformulation design activities respectively and are implemented as two control systems (Synthesis-Analysis and Reference Model). On the first level we have the Analysis and Synthesis classes (which correspond to two neural networks). The Analysis class is responsible for a learning process based on user interaction while the Synthesis corresponds to self-control process that aims to keep individual requirements within their targets. On the second level we have the Formulation and Reformulation classes, which are similar to the Analysis and Synthesis classes. Evaluation is the process of measuring the degree of matching between the two control activities.

5. Simulation

The above model is developed and simulated in a MATLAB-SIMULINK (Mathworks, Inc) environment. We are experimenting with Adaptive Backthrough Control architectures. These structures typically use two neural networks: the Controller (the system that controls) and the Plant Model (a model of the system to be controlled) (figure 4). First, the plant model is trained to approximate the plant by learning, on-line or off-line, input-output patterns of the agent behaviour. Then, these patterns are used “backwards” as a guideline for the controller (Kecman 2001). In our case the plant has been implemented as a compact block of three objects that represent the design and planning reasoning of the three agents that stand for the different development goals. For the purposes of this simulation we do not introduce human operators but we rest on formal descriptions to represent them. The plant model identifies the behaviour of those agents and this knowledge is used to train the controller to find appropriate patterns that can be used to satisfy the goals directed by the reference model. The reference model is essentially a prototype of the system that produces time-variant goals (target behaviours) for the controller, and corresponds in our case to the formulation-reformulation phase of the design description. The structure of the reference model as described previously, is a control architecture similar to the one focused on the synthesis-analysis process.

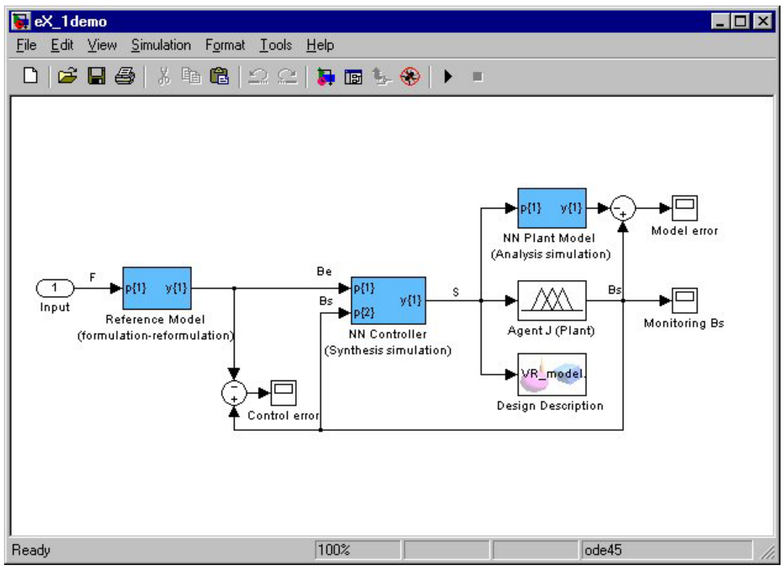

Figure 4: The control model of a generic agent in Matlab-Simulink.

Each box in the diagram represents a subsystem of the entire model. The Controller and the Plant Model are two subsystems that contain feedforward neural networks used to simulate the Synthesis-Analysis control process. The Reference Model box is another subsystem built on a similar control architecture which represents the Formulation-Reformulation process. The Agent (or Plant) represents the system to be controller and can be a human operator or a formal model. The system is connected with a VR sink which is used to visualise the evolution of the Design Description as seen in figure1.

We have experimented with mathematical formulations that model agent behaviour (like motion, shape transformation and costs) based on state space methodology, as well as with fuzzy systems. As an example, the "moving behaviour" of the land use *j* is described by n equations (for *n* land uses) as follows:

$$m_j x''_j = \sum_{i=1}^{n} k_{ij}\left(x_i - x_j\right) \qquad (2)$$

where m_j is the floor area of the land use j, x_j is position, k_{ij} is the interaction matrix between land use j and i, and x''_j is the second derivative of the distance. Fuzzy systems are built on the basis of fuzzy IF-THEN rules, which for example may represent qualitative evaluations about the fitness of a specific location based to criteria of proximity with neighbouring facilities (figure 5).

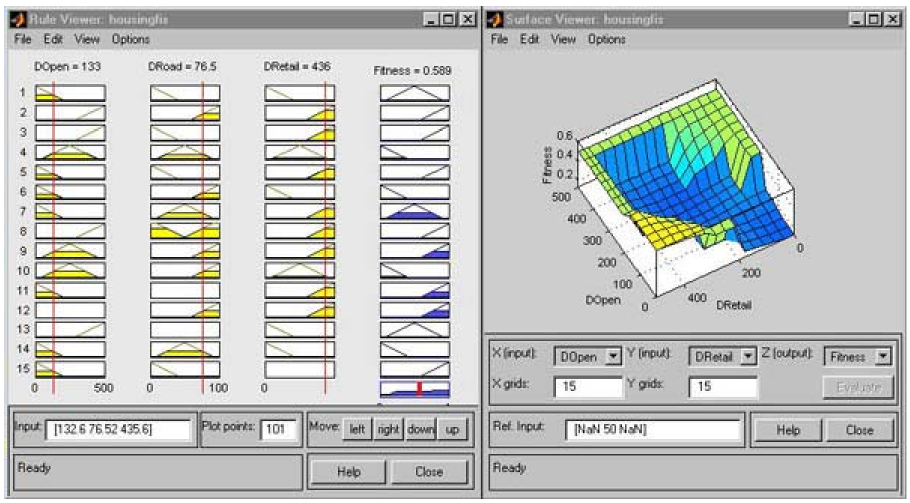

Figure 5: Agent reasoning as a fuzzy system.

The Rule Viewer on the left and the Surface Viewer on the right are used for displaying the fuzzy inference system; that is illustrating inputs and outputs and their relations in a two and a three dimensional space.

The Virtual Reality toolbox offered the possibility to visualise the evolution of the design-decision space. We can directly retrieve and manipulate the location and shape variables of the three objects and view the conflict as it evolves in the three dimensional space (figure 1). So far we have focused on the interaction among the three objects within a neutral (void) space, so the next step is to build an environment that allows interaction to be extended beyond the three objects alone and poses further restrictions and requirements. We are currently working towards two different directions: one is to connect the VR world with a spatial database, and the other is to attach sensors to the three objects so that they can recognise their environment. Those two directions represent two alternatives: to incorporate a model of the environment in a knowledge base for the agent, or to equip agents with the ability to recognise their environment at any given time.

6. Conclusions

We presented a model for artificial plan designing in architecture and urban planning based on learning control methodologies. The control-based approach in artificial plan designing is developed with the intention to address three crucial issues pertaining to current research on the field: distribution of knowledge and decisions, coordination and learning. The work presented here is a first attempt to develop a model that supports decision making and generation of design descriptions using knowledge captured dynamically through agent interaction. The aim of this paper is not to understand human design cognition or explain the design process, but rather to explore the meaning and the scope of artificial plan designing in architecture and urban planning. To this end common methodological routes are explored from the computational intelligence perspective.

Testing and validating such computational constructs is an important issue. One approach is to have the resulting plan descriptions evaluated by domain experts. Another possible approach is to stage different conflict scenarios and review the rationality of the results for each specific case. The efficacy of the model is very much related to its learning performance and mode (e.g. on-line or off-line), so further research has to be done to this direction.

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