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Modeling process knowledge in architectural design: a case-based approach

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Abstract. The paper presents on-going research aimed at the understanding and support of process knowledge in architectural design, from early and not sufficiently defined, to satisfactorily-defined phases. Today, technical, planning, management and environmental issues have created a scenario of such complexity that traditionally efficient control tools (e.g. technical manuals) are inadequate and there is a demand for new, integrated instruments to handle the decision process underlying architectural design. We assume design as a recursive and incrementally specified intentional planning activity, involving goals, constraints and their relationships. The essence of architectural design is thus encapsulated in the continual recursive transformation of the initial model, in order to map the desired state onto the enacted one. On the basis of this concept of design we describe the model of an environment aimed at progressively representing the enlarging space of acquired knowledge, and at supporting the designer's central role in the management of complexity.

Introduction

The paper presents on-going joint research efforts in the areas of cognitive science and architecture, aimed at the understanding and support of architectural design.

Architectural design is a complex decision-making process, which is generally referred to as an ill-defined problem area because of its character: the influence of several related variables, most of which vague and underspecified, and the continual and recursive evolution of requirements and strategies.

There are a number of factors which typically generate the complexity of the architectural design and connected building process: the heterogeneous nature of the knowledge domains and technical skills involved, the constraints of building regulations, the simultaneous activity of an increasing number of different subjects participating in the process, and finally the density of interferences among decisions related to different domains and roles.

The nature of this complexity can be summarized in the following features:

- The poor and inadequate description of the object of the design process, of which the intentional features expressed by the client are known, but the nature of the actual technically articulated content of the goals is unknown. A reasonable configuration of this object has to be searched for by the design process, and its feasibility has to be verified in front of a network of goals, the incidence of which is only partially identified.

- The lack of a conventional representation system for architectural values, able to declare without ambiguity the nature of knowledge-domains assumed as the reference points of the design process; these values are chosen cultural issues or technical and economical requirements and are the expression of objective goals connected with resources optimization.
- The lack of a conventional language able to describe and communicate to a community the relationship between the assumptions of the different knowledge domains composed in the design, i.e. the transfer of design intentions into results.
- The lack of a codified representation-system for the relationships among the semantic, functional and topological components of a project along its generation steps; for the interferences among the involved knowledge issues.
- The lack of a conventional procedure to represent the decision making process.
- The widely prevalent specificity of design subjects, i.e. the unique configuration of requirements, due to factors such as a very fragmented market demand (e.g. Italy), individuality of clients, unskilled in their expression of a technologically qualified demand.

Architectural design as a decision activity

Design is an intentional planning activity in which both the rules governing the process and the required properties of the final solution are subject to permanent refinement, substitution and review. A decision taken in one area will necessarily impact on the configuration of the process as a whole; therefore any sequential solution approach seems to be necessarily inadequate.

In such a knowledge context, the decision-making activity requires the adoption of an incrementally refinable model of reality, aimed at progressively incorporating all possibly relevant issues. In other words, in a context of "turbulent complexity" (Maldonado, 1992) -as specificity and variation are the main characters for architectural design today- the decision-making process should abandon sectorial approaches, to be founded upon the application of a methodology able to incorporate the largest possible number of significant issues since the very first heuristic phases of design, so as to define a preliminary solution model.

In this view, the design process may be seen as the planning of a path among increasingly accomplished configurations of the preliminary model, which develops as the involved issues win higher specification and integration levels. The consequent increasing complexity should be validated by incremental evaluation tools to ensure the truth-maintenance of the network of relationships among constraints, rules and goals.

The observation of the skills of project managers has led to the conviction that decision-making in design is an information intensive activity, largely relying on the availability of quality-oriented and readily-accessible information sources, supporting the experience and reasoning skills of the decision-maker.

This is to say that effective solutions to complex problems are seldom developed from scratches and that decision makers build on knowledge and expertise acquired in the solution of previous similar problems related to contexts, or cases. Decision making, thus, requires refinement, mutual adaptation of evaluation components and intuitive combination of solutions to previous problems, leading to an incrementally configured hybrid solution model.

On the basis of these distinctive characters of architectural design activity, we analyze the underlying process knowledge with the aim of obtaining a cognitive model of the space of intention and decision-making in architecture. Then this cognitive phase of the work leads to the modeling of a set of tools aimed at supporting the design process from the very beginning, aiding designers in the specification of the problem, in the evaluation of alternative solutions, in the retrieval and adaptation of relevant cases and in the overall representation of the decision-making process.

To accomplish these tasks is the goal of PatriArch, a system conceived as a platform -better, as a wide comprehensive environment- of integrated and evolving tools and agents, aimed at the description of the design work in its process nature.

The architectural design process

Some authors converge on a definition of the design process as a "global activity occurring in a contemporary and non-linear evolution of the requirements and design state through continuous reciprocal adaptation" (Smithers, 1991)

This conception configures an architectural project as the progressive definition of a model apt to solve the design subject's specific requirements, based on the resources of the designer's, producing a synthesis -the final solution- of which the designer is the one responsible 'agent of proposals', together with the cooperative coordination of the other concurrent specialized domains. It is during the evolution toward the intended level of quality -satisfaction of requirements- that the designer carries out the full application of his intelligence of correlations, which may be defined as his ability to know, to describe and solve in a model the contents -and the possible conflicts- of the interfering decision factors.

Building on the conception of design we have just outlined, we analyze architectural design as a process path leading from an initial configuration toward a desired situation by means of an incremental specification of the goals, constraints, rules of evaluation and verification and involved variables. In this view, design becomes a continuously recursive -and revisable- decision path among increasingly detailed and developed versions of the initial model.

The model represents and tackles the decision path both in its globality and in its constitutive elements, i.e. steps/sequences of steps at different abstraction levels, treated as unitary autonomous sub-processes.

We represent the process on three levels of abstraction:

- the first level comprises all the potentially acceptable solutions ("chosen", in an intentional model such as that of Cohen & Levesque, 1990). This level regards the mapping of goals and constraints (where goals are viewed as a subjective subset of constraints, i.e. they are not environment-driven but intention-driven constraints). At the outset, a certain number of goals and constraints are specified by the designer. These allow the description of the initial configuration of the model, which is necessarily incomplete and underdefined but already presents the specific character of the "creative" design activity: produces a hybrid between the nature of abstract intentions and an object;

- the last level comprises the set of decisions/objects actually adopted ("intended", again in terms of an intentional model) which, once taken together, make up the actual solution;

- the intermediate level comprises the space of all decision nodes explored along the process making up the path leading from the space of "possible" solutions to the final "intended" solution. Decision nodes are viewed as the building blocks of the process. They are elementary units flexible enough to govern the complexity of each single step, at whatever level of abstraction, in the process (see description of Galathea, Bottelli and Fogh, 1995). This level is constituted by the decisions/objects needed to combine the elementary units forming the adopted solution (second level) coherently with the evolving map of goals and constraints (first level).

The executed solution represents the actual intention taken out of all chosen possibilities. The intermediate levels are based upon an evaluation system, in its turn. When reasoning on any sub-level, its higher and lower boundaries are kept stable, while the space in between is modified. The results achieved may eventually reflect on either boundary, and the whole process may iterate on both the hierarchically superordinate and subordinate levels. Thus, the whole process is recursively analyzed.

This three-level model proves very useful because it may be equally applied to the process as a whole, when designers need to look at a project from afar, considering just the landmarks; and to any specific phase or sub-phase when it is necessary to descend in the process details.

Consider the following example: an architect, setting out on a new project assignment, is searching for knowledge deriving from previous projects apt to help him/her in the definition of a general layout. He/she may thus look back on the knowledge acquired from a previous project, just considering general basic decision nodes, i.e. viewing it in its globality. At this stage, in fact, it is useless and uninteresting to retrieve knowledge pertaining to specific decisions, e.g.

the choice of floorings. At later stages of the same project, instead, the architect might search for knowledge suitable to aid him/her in the decision-making process of a specific domain area (e.g. choice of structure or windows or floorings etc.) and look back on the same previous project entering the desired level of detail of specific lower order decision nodes.

The decomposition of decisions, based on the chosen evaluation system, in such a model is therefore not pre-defined but leaves designers free to explore different abstraction layers, according to the task in question.

Constraints are heterogeneous in their nature, origin and weight:

- Nature: they may refer to extremely different domains, all of which interact in the decision process. They may have quantitative or qualitative nature, or both. They are an expression of the several specialist areas contributing to a successful design solution. For instance, they may refer to the areas of costs, of environmental issues, of aesthetical values, of technical performances etc.

- Origin: some constraints are context-dependent, i.e. they are variables on which designers have no power of choice (legal domain, functional issues, client requirements, site features etc.); others are subjectively driven, i.e. they are a function of the culture, experience and values of the designer; others again are an expression of both;

- Weight: not all constraints have comparable importance in the determination of the design process. Moreover, the weight of constraints may vary and change considerably during a project.

Typically, some constraints are wholly unknown or disregarded at the outset, but acquire importance during the process, or vice-versa. For instance, incomplete information regarding the noise level of a building site at the beginning of a project may induce an architect to give an inadequately small weight to noise reduction techniques. Information acquired during the process will modify the relative weight of this variable in the mapping of constraints and consequently the project will progressively incorporate noise reduction techniques such as insulation, choice of windows etc.

Planning: a key for design-decision activity

We view design as a form of intentional planning. Schematically, an agent can be described as an intentional system capable of analyzing and evaluating the current world situation in terms of a number of characters, assigning each of them a causal role in the overall likeability of the situation itself, and deliberating and acting in order to change one or more characteristics, so as to make the situation more to his/her likings. (Pollock, 1992, 1993) By the likeability of a situation, we simply mean the extent to which it is judged valuable by the agent.

From this point of view, an agent exhibits the following basic set of cognitive abilities:

- the ability to analyze the current world situation; each agent will subjectively analyze the situation according to his/her previous structure of knowledge and goals; the analysis itself will in turn modify such structure;

- the ability to evaluate the causal role of the characteristics, allowing the agent to decide which of them can and should be modified in order to bring about the desired changes in the overall situation;

- the ability to deliberate about the actions which are likely to bring about these changes; this requires that the agent knows what its possibilities for action are, how the world constrains such possibilities, etc., which takes us back to the analysis of the situation.

Given these abilities, to make a plan means to decide how to transform a certain world situation, by modifying one or more of its defining characteristics, so as to make it expectedly more to the agent's likings.

To plan means to select, among the possible world of configurations the expected likeability of which is higher than the current one, i.e. the configuration exhibiting the most satisfactory expected value in terms of costs/benefits. A distinction needs thus to be drawn between what, in principle, an agent thinks he/she would like and what he/she actually decides to (tries to) bring about, the latter obviously being a subset (as large as possible) of the former.

The difference is that an agent will commit only to the latter subset; we will use the term choice for any potentially likeable situation, and the term intention for the one to which the agent is actually committed. If an agent cannot achieve his/her goals (i.e., if he/she cannot satisfy his/her intentions), he/she will possibly fall back to the larger set of what would be likeable (i.e., of the previously discarded choices), thus committing to a different course of actions.

Resource-bounded agents cannot decide in advance all the details of their intended courses of action, because they simply cannot foresee all the tiniest consequences, side-effects, etc., of their plans. Furthermore, the world is dynamic, i.e., it is likely to change before an agent has completed the execution of a plan; this would make an excessively careful deliberation a waste of time.

At each moment in time, therefore, a plan should be neither more nor less detailed than is needed at the current stage of development. This idea is known in the planning community as least commitment. (Weld, 1994) A plan can be viewed as a complex network of interdependent nodes of knowledge and goals, large areas of which are initially blank and will be progressively detailed as the agent proceeds in deliberation. Parts of the network might be still underspecified even at the time when other parts are already being executed.

The links of the network are the constraints (of space/time, knowledge, priority, etc.) which the nodes impose to one another. A change in a node may consist in a further development of its details, or in a real revision; revisions may be due e.g. to information feedback from other areas of the plan which have undergone further development or execution. The consequences of a change in a node may propagate, through the different constraint links, to other nodes, so that they may be accordingly modified in their turn. The plan is therefore a continually evolving structure of knowledge and intentions, which undergoes dynamic revision under the action of internal as well as external pressure.

This model of planning applies straightforwardly to design. A project may be viewed as a complex network of knowledge and decisions (although these will not be actions in the usual, "behavioral" sense, they will be decisions anyway), each of which has, or may have, an influence on the others. To fully specify a project means to develop all the nodes down to the desired level of detail. In this process, each piece of knowledge and intentions may reverberate its effects to the others. Starting from scratch, and from an analysis of the initial goals and constraints, the designer's task is to transform an initial situation into a more likeable one, by recursively modifying the appropriate characteristics of the progressively evolving situation.

This conception of planning is crucial in our analysis of design and, coupled with our conception of case-based reasoning, dealt with in the following paragraph, constitutes the cognitive framework for the design process model we propose.

PatriArch: an integrated environment for architectural design support

The main paradigm for an integrated computer-based support environment for architectural design consists in the opportunity of conceiving and representing projects as networks of relationships which progressively assume their identity, composing in a well-structured framework the designer's research for an optimized solution.

In this conception the design activity is a process guided through the following steps of evolution of knowledge contents:

- designer's interpretation of the theme and requirements submitted by the client;

- building project's feasibility verification;

- progressive identification of the fragments of solution that the designer evaluates to be of mature formulation;

- proposal for assembling solutions that configure a satisfactory synthesis for the set of requirements;

- parallel activation of a verification procedure of their validity and respect of regulations, or of constraints and goals given by the designer;

- adaptation procedures allowing the solution to comply with the newly formulated relationships between rules and goals, the description of which has been increased;

- reiteration of the validation procedures of the solution in the assembling of the different members in a general space configuration;

- control of the client's satisfaction degree.

A further paradigm is to conceive the design solution as a network of relationships among constraints and goals that takes shape in the dimension of space and functions, the validity of which can be verified along its same drawing up, although this form is only partially defined.

On the contrary, exactly because of its provisional and partial definition, the validation of an in-progress solution can point out a new more satisfactory direction of development which can save time and energies, requiring a smaller and more acceptable sacrifice in abandoning a not yet accomplished solution for more promising ones.

Another important point consists in enabling the practice of the designer's intelligence to be supported in its ability to operate and compare a number of solution models competitive among themselves, to choose the most satisfactory technical and architectural language potentialities.

A final topic for the "designer's intelligence" is to see a project as a phase in the definition of a process, the nature of which is intimately connected with its material feasibility.

The essential requirements on the basis of which PatriArch is being conceived are the following:

- the ability to represent, operate, validate design solution models during their progress, at the reached level of definition;

- to allow models' elaboration by different tools and agents at their state of definition, and to add new acquired quanta of technical information that can be assumed in the definition of the model;

- to describe the design models by the technical languages and reasoning schemes currently assumed by human designers;

- to support by continuity the representation of the increasing levels of definition of the knowledge contents implemented in the solution model;

- to support a well structured set of integrated evaluation tools;

- to store and retrieve relevant cases of process knowledge, i.e. fragments of relationship among the design decision factors that have determined the drawing out of previous successful design experiences;

- to activate the agents able to operate the "building regulations application control", the "truth maintenance systems", the "design procedures planning agents": that is to say the entire population of tools and agents that, by successive generations, enrich the design supporting environment.

Summary

We have outlined a cognitive approach to architectural design based on four main knowledge areas:

- the general complex, ill-defined context characteristic of design activity today;
- our approach to design as a recursive, incrementally defined process;
- our approach to design as an intentional planning activity.

We have thus proposed a model for design activity based on three levels of abstraction applied to the process.

These three levels of abstraction develop into the model of an environment aimed at supporting the design process.

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