GALATHEA: A CASE-BASED PLANNING TOOL FOR KNOWLEDGE NAVIGATION IN THE ARCHITECTURAL DESIGN PROCESS

VaIeria Bottelli and Christian Fogh

Politecnico di Milano, Facoltà di Architettura, Dipartimento di Programmazione Progettazione e Produzione Edilizia, Milano, Italy
tel. -39-2-23995125 fax. -39-2-23995150
email: arlati@cdc8g5.cdc.polimi.it

Abstract

We report on an on-going Ph.D. research aimed at the analysis of the nature of process knowledge in architectural design and the development of a conceptual model for a case-based navigation tool for its support. We describe architectural design from a process viewpoint and assume it as a form of intentional planning, leading from an initial state configuration toward a desired situation, by means of an incremental specification of goals, constraints and involved variables. We consider the very essence of design and of the specific professional skill characterising designers as the continual recursive transformation of the initial solution model, in order to map the desired state onto the enacted one and the capability to govern a number of continually changing variables in this direction. On the basis of this general concept of the design process, we describe the model of Galathea, a case-based planning tool, aimed at progressively representing the enlarging space of acquired knowledge, and at supporting the designer's central role in the management of the design process.

Introduction

This paper reports on the current state of an on-going Ph.D. research aimed at the investigation of the nature of process knowledge in architectural design and at the development of a case-based tool for its support.
The theoretical background to this research has been the analysis of the scenario characterising the decision-making activity of architects in Italy today. The past decades have brought a brisk increase in complexity in technical, planning, management and environmental issues involved in the design process, thus creating a new demand for integrated instruments apt to support the management of the different knowledge domains with an appropriate qualitative result.
Our research has focused from the beginning on the role of information, experience and memory within the management of the design process. In order to gain insight into this complex problem, we started out on this research project investigating the architectural design process under two distinct but complementary points of view. On one side we have followed the historical evolution of the nature of decisions in manuals and treaties, that is the only formalised instrument utilised throughout the centuries for their management; and on the other side the evolution of cognitive models aimed at the investigation of knowledge and memory in the design process.
The birth of architecture manuals as encoded classifications of building practices and techniques, accepted and approved by entire communities, owes much to the affirmation of a scientific method, of a "modern" relationship between information, planning and project, which renounces the description of a unitary conception of artistic and technical issues, as occurred previously in the great treaties of the renaissance and baroque eras. The story of architecture manuals, therefore, starts out as a result of the renewed philosophy of science characterising the rationalist period of the 1700's.

The 19th century marked the growing affirmation of a positivistic and taxonomic attitude toward architecture, which is translated in manuals in their progressive transformation into catalogues of exemplary procedures and solutions, with a wide presence of figures showing examples of building details and architectural solutions to the new typologies characterising towns, such as museums, markets, prisons, etc. apart from the growing interest in hygiene connected to housing. We envisage this transformation of the knowledge contained in manuals as a precursor of the concept of cases, in that a complex interrelation of specific knowledge domains is presented as contained in unique but potentially repeatable architectural solutions. This period marks the largest fortune of manuals, especially as didactic instruments aimed at transmitting the necessary knowledge to a growing number of new professional roles involved in the dramatic expansion of towns.

At the turn of the century, the acceleration of industrialisation and urban development, with the consequent rise of new building techniques, new social needs and organisational issues, progressively led to a separation between the conception and realisation of architecture. This considerably weakened the weight of traditionally accepted building techniques.

With the Modern Movement from the 1920’s onwards, a deep change occurred in the relationship with technical issues and the organisation of work, characterised by the search for the utopia of standardisation and industrialisation of architecture. This led to a definitive loss of attention for consolidated building procedures and a growing attention for a typological and abstract conception of architecture.

The last thirty years in Italy, as in the rest of Europe, have been characterised by an exponential development of a number of complex factors influencing the architectural process, such as the proliferation of new building products, the growth in complexity of building regulations and legal issues, the differentiation of professional figures involved in project management etc.

All this has progressive led to the crisis of the foundation of the professional role of architects, thus opening up a demand for new control tools, apt to aid designers in representing and following dynamically the knowledge and expertise-intensive decision- making process underlying architectural design. This is the space in which we believe research on design support tools may find its main usefulness.

On the other hand, we followed the development of formal methods utilised in the past decades to analyse process knowledge in architecture. This has meant studying the path leading from the first essentially deterministic conceptions, aimed at modelling human processes, along the path of disillusionment and the progressive rise of a new conception of systems research, which is only informed by human behaviour but does not necessarily attempt to model it (Oxman, 1995). This has led to an increasingly central role of flexible and recursive models, right down to the present knowledge and memory intensive theories, aimed at reconstructing a unitary idea of design from the very first heuristic phases of the process. We have also followed the evolution of models in the domains of planning, project-management and decision support systems, along the progressive weakening of rigid algorithmic goal-oriented plans up to the present state of the art in terms of ill-defined context planning.

This introductory analysis has guided our research in its first phases, aimed at investigating the nature of knowledge and memory in the architectural design process as it is today, trying to develop a useful model for the assistance of the professional role of architects for its control.

Architectural design as an intentional, progressively defined, knowledge-intensive process

In this work, architectural design is viewed as a complex, ill-defined decision-making process, operating as an exploration activity (Gero, 1995) in a context characterised by a number of different related information domains, mostly vague and underspecified in constant change. In such a context, the essence of designers’ skill is the ability to continually and recursively modify the decision-making strategy in a restricting solution space, in order to obtain a satisfying solution model.

In other words, design is a planning activity aimed at producing a change (Gero, 1995), in which both the rules governing the process and the required properties of the various steps of solution are subject to continual refinement, substitution and review. A decision taken in one domain will reverberate its consequences on the other domains building up the configuration of the process as a whole; therefore any sequential solution approach is methodologically inadequate.

In the problem context we have just outlined, the decision-making activity requires the adoption of an incrementally refined, model of reality, apt to progressively incorporate all possibly relevant issues as they arise. That is to say that the decision- making process should be founded upon a method incorporating the highest possible number of issues from the very first heuristic phases of the project, so as to reach a preliminary solution model. The design activity thus becomes the planning of a path between increasingly accomplished configurations of the initial model, which evolves as variables reach higher specification levels.

Moreover, decision-making in design is an information and expertise intensive activity largely relying on the availability of information sources and on the experience and reasoning skills of the decision-maker. In fact, qualified solutions to complex problems are seldom developed from scratch and decision-makers constantly build on knowledge and expertise acquired in the solution of previous similar problem contexts, or cases. Moreover, there are many different kinds of information and memory necessary in design; thus a model for design activity is necessarily hybrid. Decision making in design thus requires the refinement, modification and intuitive combination of solutions to previous problems, leading to an incrementally configured hybrid solution model.

Case-based reasoning

The central role of memory and experience skills in design is a wholly accepted concept in AI and cognitive psychology. (Kolodner, 1991)

Memory and experience in complex, ill-defined problems rely on the efficient manipulation of relevant knowledge units acquired in previous similar situations in order to enhance and ameliorate the task of making decisions in underconstrained and ill defined problem contexts.

In fact, when tackling a new design problem, it is known that designers strongly base their exploration path upon previous professional experience: they browse memory of precedents for a relevant example (or *case),* recall the solution process, and thus adapt the previous solution procedure to the new project context.

Case-based reasoning (CBR) is a 'weak' paradigm based upon the modelling of memory and experience. It is characterised as a problem-solving approach inferencing from previous solutions, which are adapted to current situations. In contrast with the expert system paradigm, case-based reasoning stores past experience as individual problem solving episodes, representing exemplary solutions to complex problems, much in the same way as in architecture manuals of the 1800's (see Introduction). This paradigm has proved useful in domains where experience is strong but the domain model is weak, as is certainly true of architectural design.

After a first generation of knowledge-based studies utilising CBR concentrated research efforts into trying to replicate human knowledge, current work is primarily directed at a partnership between the human and machine agent. Thus, the main aim of such systems is to enhance human decision-making by suggesting alternatives, predicting consequences and pulling together the information that goes into decision making, the underlying principle being that of external cognition.

In our view, a case-memory is thus to be conceived as a case-container in which designers themselves manage the nature and semantic connections of cases, according to their personal professional method. This is necessary in a domain like design, in which the entire management of the process, and consequently the exploration strategies underlying it, do not follow any predetermined scheme and vary considerably according to specific tasks and to the personality of the designer.

A case in design KBS literature is generally viewed as a design solution (unitary self- contained problem solving episode), however well-defined. In our work, primarily focused on the nature of process knowledge in design, we have tried to adopt a different perspective on cases, which owes much to a relatively new theoretical approach coupling CBR, planning and general problem solving issues (Carbonell, 1986; Veloso, 1994).

This is to say that the matter we have assumed as most relevant in the design process, which is the resource of our case-base, is not the *episodic* nature of memory, i.e. that contained within specific project solutions, but the *conceptual* nature of memory, i.e. the strategic exploration underlying these solutions (Profeti, Zitti, 1995). In other words, since we have assumed design as an incrementally defined knowledge-intensive planning and decision-making activity, we have tried to focus precisely on these aspects when trying to answer the fundamental question: "What's in a case?" (Rosenman et al., 1991) In this view CBR allows the retrieval, evaluation and adaptation of sub-processes (or *design moves* - Oxman, 1995) obtained from previous design experiences and judged pertinent by designers themselves, in a new problem context, rather than tackle it from scratch.

In our view, the usefulness of this approach to CBR is twofold:

1. the adaptation of microprocesses, or design moves, stored from past projects in new contexts
2. the planning out of a general reference framework for projects, tailored to personal skills and habits of designers.

A case in this work is thus viewed as the process *trace* of a choice, however complex, adopted within the process. Conceptually, this bears some resemblance to the "foot- printing" model (Carbonell, 1986), although the recursive and progressively defined nature of design implies that the foot-printing approach cannot but be extremely loose and 'weak'. This is to say that, unlike the problem solving domains studied by Veloso (Veloso, 1994), architectural design, especially in its early phases, is not subject to any "strong" planning normalisation method, for there is no fixed sequential path leading to the final solution, since extremely different courses of action may be adopted according to the nature of the task and the personality of the designer.

Retrieval in such a CBR planning model is based upon the evaluation of the current problem (or sub-problem) configuration compared to similar process (or sub-process) traces of previous design contexts. The degree of

similarity reflects some resemblance to the concept of "derivational analogy" proposed by Cabonell, or in another way to the concepts of "design moves" and "strings of moves" (Oxman, 1995). The basic idea consists in the comparison of new and previous process configurations, where the relevant characteristics allowing comparison are the general problem configuration, the prefiguration of a more satisfactory configuration and the trace or string of traces necessary to map the first into the second.
Thus, sub-processes, i.e. decision traces, may be stored, retrieved and adapted in new project contexts as cases, on the basis of process analogy. In this view, CBR allows the application of incrementally detailed relevant sub-processes from previous projects, and helps designers to clarify the terms of a project and to plan out a framework of reference tailored to personal skills and habits. The question of how such a case-memory should be indexed is open, although we believe that, in order to meet the nature of designers, some kind of visual indexing method should be pursued, as demonstrated by the Fabel project (Bartsch-Spoerl, 1994).

A cognitive process model for architectural design

On the basis of the view we have just outlined of the nature of knowledge in the architectural design process and of case-based reasoning, we here propose a model of the design process and of a tool for its support.
We consider design as a form of intentional planning (Cohen, Levesque, 1990), in which the architect is viewed as an intention-driven agent, exhibiting the following basic set of cognitive abilities:
the ability to analyse at any stage of the process, the current world situation in terms of a certain number of characteristics (goals, constraints and their relationships). This ability reflects the subjective expertise-intensive structure of knowledge pertaining to each specific architect;

- the ability to define a more satisfactory project step configuration, by means of the evaluation of the causal role of the characteristics, and therefore the nature of their modification, in order to bring about the desired changes in the overall situation;
- the ability to deliberate about the actions which are likely to transform the current project situation into a more satisfactory one, by means of the evaluation of alternative courses of action.

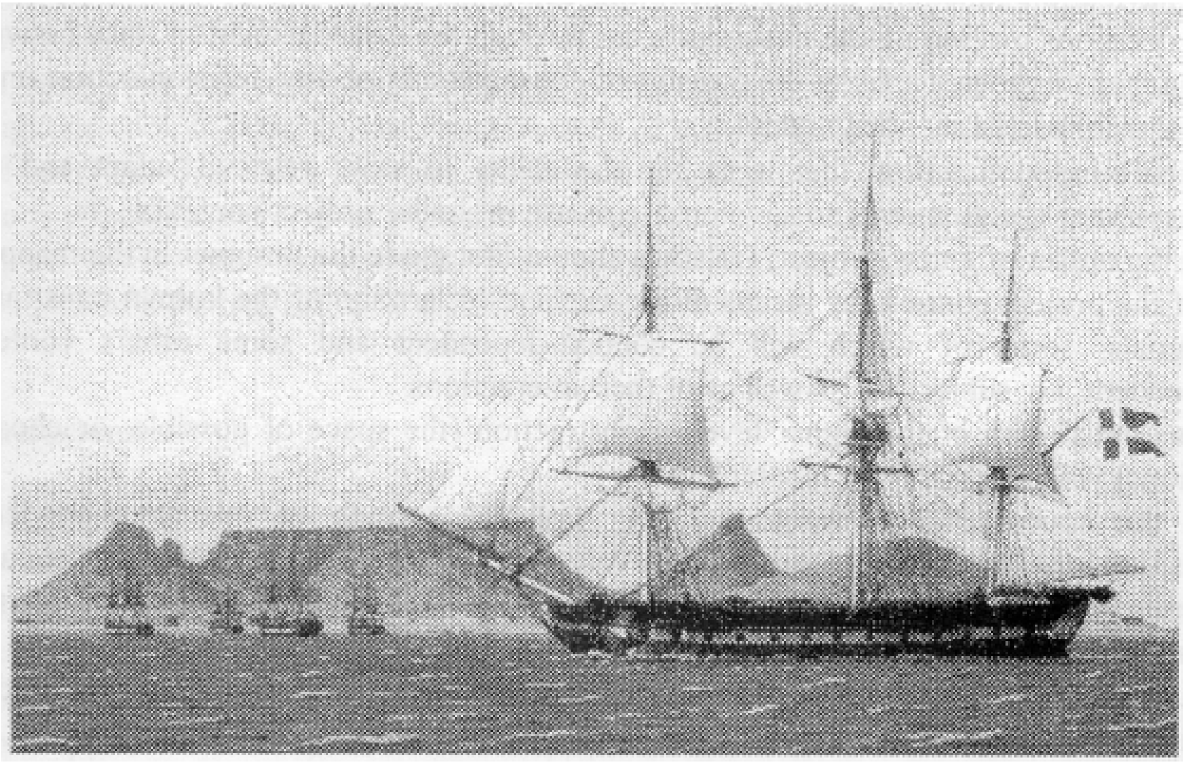
Given these abilities, the decision process underlying design involves the ability to transform a given project situation, by modifying one or more of its defining characteristics in the direction of a higher level of satisfaction. This is to say that, given a project context, to plan means to select, among the possible preferable configurations ("chosen" in an intentional model such as that of Cohen and Levesque, 1990) the one exhibiting the most satisfactory expected performance, and therefore executing it ("intended", again in an intentional model). In case the adopted course of action does not achieve the given goals, then architects generally return to previous decision nodes, committing to a different solution.
Given the incremental specification of design, a plan in any given moment 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 specified as designers proceed in deliberation. Parts of the network will still be underspecified when other domain areas will have already been totally solved and executed. A typical example of this is that structural issues in a building plan are designed, verified and executed long before details referring to windows and doors may not have even been designed.
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 satisfactory 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 previous paragraph, constitutes the cognitive framework for the design process model we propose for Galathea.
Summarising, we represent the architectural design process on three levels of abstraction:

- a higher level, comprising the space of all potentially acceptable solutions. 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 incomplete and underdefined.
- a lower level comprising the set of decisions/objects actually adopted, which taken together construct the actual solution;
- an intermediate level comprising the space of all decision nodes making up the path leading from the space

of possible solutions to the final executed solution. Decision nodes are viewed as design moves, i.e. the elementary building blocks of the process, flexible enough to govern the complexity of each single step, at whatever level of abstraction, in the process.

This level is constituted by the decisions/objects needed to combine the elementary units forming the adopted solution (lower level) coherently with the evolving map of goals and constraints (higher level). The executed solution represents the actual intention taken out of all chosen possibilities.

Galathea: a knowledge navigator for the support of architectural design activity



Galathea, a scientific research Danish royal navy corvette devoted to geographical and naturalistic discoveries, in Capetown in 1846 (painting by C.W. Eckersberg).

Based upon this overall concept of design, the structure of Galathea, a tool aimed at supporting design activity, is currently under development. This model may be envisaged as a partner to the architect; the underlying principle being that of external cognition (Winograd & Flores, 1986). This is to say that we see it as a valid knowledge navigating consultant, aiding designers in making decisions quicker and with a broader and clearer knowledge and experience base. Such a tool is conceptually viewed as a part of an integrated, open, flexible environment, devised to adapt to, and grow with, the architect.

We have chosen Galathea, a scientific research Danish royal navy corvette, which, in 1845, left Copenhagen for a two year round-the-world trip devoted to geographical and naturalistic discoveries, as metaphor for our model, for a number of reasons:

- the conceptual analogy between architectural design activity and navigation in new lands is not new (Koberg, 1974). In this view, a designer is like an explorer, who, basing his search on previously acquired knowledge (experience), traces a goal- directed path in a new and unfamiliar landscape, still managing to maintain a reasonable degree of control
- since this work is primarily concerned with the process knowledge underlying design activity, it is only too natural to envisage the overall process as a set of single steps, each constituting a design move, which will reverberate its effects on the entire "map"
- in this view the "map" which is traced during any project becomes a guide for future explorations; the knowledge it contains may be used by the designer himself or by other designers to save time and use acquired and explicit design experience. Galathea is aimed at the satisfaction of the following three functions:
- map-making function: that is to say the ability to explicitly describe the evolving project configuration, through the declaration of characteristics (goals, constraints and their relationships) defining any specific design move

- navigation function: that is to say the ability to explicitly represent the path of decisions making up the design process through the establishment of links between decision nodes, enabling the transfer of consequences of any decision/action on all the connected mapped nodes
- case-based function: that is to say the ability to save, retrieve, adapt and use relevant design moves so as to enable re-use in similar project contexts.

At the outset of a new project, Galathea should first guide the designer in the mapping out of the project context, by means of the explicit declaration of the known constraints and goals, some of which will be context-dependent and some others context- independent, i.e. subjective, as well as of their interactions.
This initial map of the higher level of abstraction (the space of possible, or chosen, decisions) will necessarily be incomplete.
In the course of the design activity, with the growth of relevant knowledge acquisition, the map will progressively evolve, and the nature, weight and origin of constraints will change continually and recursively, as new decisions are taken, starting to configure the lower (or intended) level of abstraction.
During the project, Galathea will moreover report the results of temporary candidate solution evaluation on the basis of the map of constraints, testing the effect of the candidate solution on the whole configuration of the process.
Again, whenever designers feel they need it, it will be possible to refer to previous cases, on the basis of the degree of similarity between the process configuration of the new problem to previously solved ones. The design support tool may therefore be viewed as a planner, capable to map out the complete process path by means of the dynamic representation of the relationship between goals, constraints and the decisions taken at specific nodes. We also view it as a navigator, or map-maker, since it enables designers to explore their own personal route which, in the space of possible, or chosen, solutions, leads to the temporary adoption, evaluation, adaptation and final execution of the intended one. In this view, the tool is a navigator skilled in the exploration and construction of a route (characterised by its being unique and unrepeatable), rather than a driver skilled at choosing the most appropriate previously defined road.
This model is currently under feasibility analysis. The next steps we are currently planning are the transfer of this conceptual model into a formalised structure, and subsequently the choice of the most appropriate techniques.
For the moment we conceive an environment comprising Galathea in association with a versatile agent, apt to perform a number of individually chosen verifications, according to specific needs of an individual/project. (Arlati et al,, 1995)
In other words, the model of Galathea has been developed within an environment comprising an object-oriented CAD system endowed with a large number of intrinsic characteristics (geometrical, weight, light performance, cost etc.) and a flexible user-programmable agent, able to apply verification algorithms onto these characteristics.
For the moment, we are therefore planning a prototype of Galathea, in which we will focus on the following two main areas:

- the modelling of Galathea, the map-making tool able to describe the decision-making process underlying design
- the enlargement of the number of variables intrinsically present in the object-oriented CAD data base to define parametric components;
- the modelling of the agent, able to apply verification algorithms onto the said variables.

The results of the simulations effected by the agent will be input and used by the navigation tool, in order to test consequences of actions/decisions on the general process configuration. The links between situation configurations, desired configurations and actions effected are stored as procedural cases, which may then be indexed, retrieved and adapted in new problem contexts. The organisation of the resulting case-base, i.e. the principles of indexing, retrieval and adaptation have not yet been analysed.

Conclusions

We have outlined a cognitive approach to architectural design based on four main knowledge areas:
a general cultural background defining the complex, ill-defined context presently characterising design activity

- our approach to design as a recursive, incrementally defined process
- our approach to design as an intentional planning activity
- our approach to design as a knowledge intensive activity strongly based on memory and experience, hence the case-based reasoning paradigm.

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 Galathea, a tool aimed at supporting the design process in its globality and constitutive elements.
This tool may be viewed as a navigator, supporting designers to construct an original decision-making path amongst incrementally defined process configurations, up to the final solution.
This path is constructed with the aid of reference to previous similar project configurations on the basis of analogy between the current and past mapping of evolving goals, constraints and interrelations.
Current work in this research is centred upon further conceptual analysis of the thresholds of abstraction in the design process, so as to enact a smooth and free possibility of exploration of decision nodes from general down to very detailed levels.
The feasibility analysis is also beginning to focus on the simplifications necessary in order to plan a first implementation scheme.

References

Akin, Ö. 1986. *Psychology of Architectural Design.* London: Pion.

Arlati, E., Bottelli, V., Fogh, C., Tirassa, M., 1995. 'Modelling process knowledge in architectural design - a case-based approach." *Proceedings of Intersymp 95, 8th International Conference on Systems Research, Informatics and Cybernetics, Baden Baden, .4 August 1995 (in press).*

Bartsch-Spoerl Brigitte, 1994. "Representing and using cases in visualisation-oriented design". *Proceedings of the 2nd European Workshop on Case-Based Reasoning, Chantilly, November 1994.*

Bottelli, V., Drago, P., Fogh, C. 1994. "Can preconditions of architectural projects be considered as cases? Development of a case-based tool" *Pohl J. (ed.), Advances in knowledge-based building design Systems, Windsor: Windsor School of Computer Science.*

Bottelli, V., Fogh, C. 1995. -Galathea: a case-based knowledge navigator for the support of the architectural design process." *Proceedings of Intersymp 95, 8th International Conference on Systems research, Informatics and cybernetics, Baden Baden, 4 August 1995 (in press),*

Carbonell, J.G. 1986. "Derivational analogy: A theory of reconstructive problem solving and expertise acquisition" *Machine Learning,* no.2.

Cohen, P.R., Levesque, H.J. 1990. "Intention is choice with commitment." *Artificial Intelligence* no.42: 213-261.

Colajanni B., De Grassi M., Di Manzo M., Naticchia B. 1991. "Can Planning be a Research Paradigm in Architectural design?" *Proceedings of the 1st International Conference on Artificial Intelligence in Design* Edinburgh, 1991.

Gero, J.S., 1995. "Exploration, redescription and design creativity" *Research Directions for Artificial 1ntelligence in Design* (ed. by J.Gero and F.Sudweeks), Sydney: University of Sydney.

Koberg, D. et al., 1974. *A soft-systems guide to creativity, problem-solving and the process of reaching* goals, Los Altos (CA): Kaufmann,

Kolodner J.L, 1993. *Case-based reasoning* San Mateo (CA) : Morgan Kaufmann

Oxman R.E., Oxman R.M., 1995. -Visual reasoning in design" *Research Directions for Artificial Intelligence in Design* (ed. by J.Gero and F.Sudweeks). Sydney:University of Sydney.

Pohl, J., Myers L., 1994 "A distributed co-operative model for Architectural Design", *Knowledge-based Computer-aided Architectural Design,* (ed. by Carrara G. and Kalay Y.), Amsterdam: Elsevier

Profeti, M., Zitti, G., 1994. *Un modello di memoria integrato per un sistema di progettazione architettonica,* Ancona: CNR-Progetto Finalizzato Edilizia.

Rosenman M.A., Gero J.S., Oxman R.E., 1992. -What's in a case?" *CAAD Futures 1991 - Education Research Application,* Wiesbaden: Vieweg.

Veloso, M.M. 1994. *Planning and Learning by Analogical Reasoning,* Berlin: Springer-Verlag.

Weld, D.S. 1994. "An introduction to least commitment planning."AI *Magazine,* Winter I994: 27-61.