Applying CBR to the teaching of architectural design

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Abstract

This paper presents an approach to the analysis and description of the nature of process knowledge in architectural design, the development of a conceptual model for Galathea, a case-based navigation tool for its support, and the application of this theoretical foundation to the teaching of design to a group of about 100 second-year architecture students.

Design is assumed as a globally coherent information, memory and experience-intensive process in which professional skill is the capability to govern a large number of continually evolving variables in the direction of desired change.

This viewpoint on design has guided the development of Galathea, the model of a tool aimed at describing architectural design through the description, mapping and management of the complete decision-making path of projects by means of the dynamic representation of the relationship between goals, constraints and the decisions/actions adopted at specific nodes and through the creation of a case-base aimed at the storage, retrieval and adaptation of relevant design moves in similar project contexts.

This conceptual model is applied to educational activity at the faculty of Architecture of Milan, with the aim of teaching how to govern a project from the outset considering it as an evolving but coherent map of design moves, which allow the adoption of the correct decisions involving the most disparate types of information, experience and memory, and which altogether conduct to the desired goal. The resolution paths of the students, all applied to the same architecture problem, result in a design move case-base, the further utilisation and interest of which is open to collegial discussion.

Key words: knowledge-based design; case-based reasoning; design process control, design moves

1. Introduction

This paper reports on the current state of theoretical research conducted at the faculty of Milan on the analysis and description of the nature of process knowledge in the design process and its formalisation into the conceptual model of Galathea, a tool aimed at its support, and on the application of these studies to educational activity on a group of second-year students.

The theoretical approach to the analysis of design as an intentional and progressively defined map of variables, heavily relying on the role of information, experience and memory is briefly outlined in paragraph 2. The role of experience and memory in particular are developed in paragraph 3, and the transposition of this approach into the model of Galathea is outlined in paragraph 4. The application of this background work, object of two Ph.D. theses[2], to educational activity, is described in paragraph 5. Our conclusions and discussion for further research are presented in paragraph 6.

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[2]Valeria Bottelli, *Informazione Esperienza Memoria. Verso una formalizzazione della conoscenza del processo progettuale con Galathea*, tutors:Ezio Arlati, Antonio Scoccimarro, Faculty of Architecture of Milan, 1992-1995; Christian Fogh, *Modello di navigazione nella conoscenza processuale della progettazione architettonica: tracciarne le mappe con Galathea*, tutor:Ezio Arlati , Faculty of Architecture of Milan, 1992-1995.

The aim of the work presented in this paper is twofold: a **research** aim - i.e. the need to apply the results of a theoretical approach which has been developed for the past three years by our group to teaching has the scope of testing its foundations and refining its formalisation in the direction of implementing a first prototype of Galathea; an **educational** aim - i.e. the need to stimulate and develop the ability of young students to reason on method while performing a design task.

The results of the application outlined here should therefore yield two effects: on one hand stimulate the modification and refinement of the structure of Galathea, on the other hand bring about changes in the educational strategy on design and method.

2. The nature of design knowledge

We view architectural design as a complex, ill-defined exploration activity,[3] the essence of which is a decision-making process operating in an evolving context characterised by a number of different related information domains, mostly vague and underspecified. The very nature of professional skill in architecture may thus be defined as the ability to envisage a decision-making strategy at the outset of a new project which takes into account all known variables, and to continually and recursively modify this strategy in a restricting solution space, in order to obtain a satisfying solution model. [4]

In other words, design is a planning activity aimed at producing change[5], in which, however, the rules governing the process and the required properties of the various steps of solution are subject to continual refinement, substitution and review, and in which the role of the subjective approach of the designer is very significant. Any decision taken in any domain at any point of the process will reverberate its consequences on other related domains building up the configuration of the process as a whole. (see figures 1 and 2), therefore any sequential solution approach is methodologically inadequate.

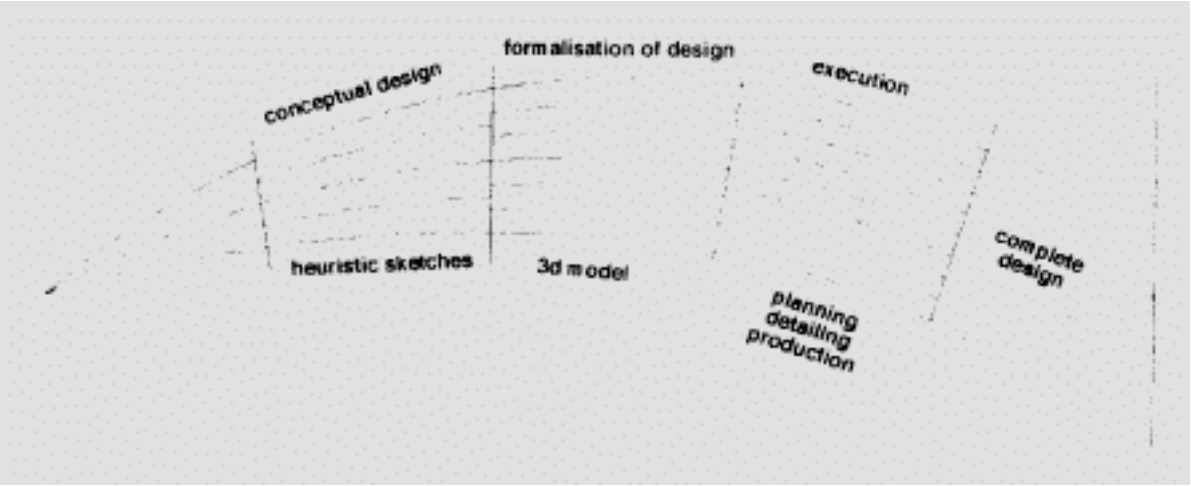

Fig 1 - Representation of the design process as an incrementally defined knowledge-intensive process leading from briefing to complete design

[3]J.S. Gero, *Exploration, redescription and design creativity*, in: "Research Directions for Artificial Intelligence in Design, eds. J.Gero and F.Sudweeks, University of Sydney, Sydney, 1995
[4]E. Arlati, V. Bottelli, C. Fogh, M. Tirassa, *Modelling process knowledge in architectural design - a case-based approach.* in: Proceedings of Intersymp 95 (ed. J.Pohl), 8th International Conference on Systems Research, Informatics and Cybernetics, Baden Baden, August 1995
[5]J.S. Gero, *cit.*

In such a problem context, any sequential or pre-defined solution strategy is bound to fail, and it is necessary to adopt an incrementally specified model of reality, apt to progressively incorporate all possibly relevant issues as they arise and thus to guide a coherent and aware design strategy. In other words, decision-making 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 object of design activity thus becomes the planning of a path between increasingly defined and specified configurations of the initial model, conducting from the briefing phase to the final complete project, in a progressively restricting solution space and in a progressively defined and mature design solution.

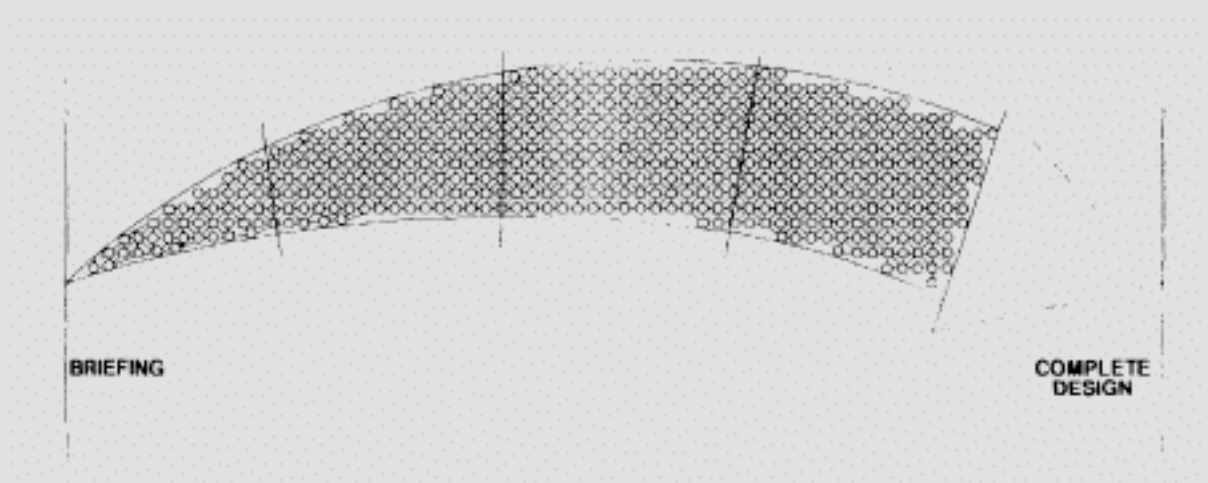

Fig 2 - The design process as an evolving map of interdependent decision nodes (design moves)

Moreover, the decision-making activity in design relies heavily on information, experience and memory - that is on the availability of information sources, on the expertise and reasoning skills of the decision-maker, and on the ability to refer to decisions and actions taken in other past similar contexts, or cases.
The role of memory in design is a complex subject and it is not easy to describe how architects operate cross-links between apparently distant design problems[6]. In our view, memory in design is a hybrid composed of at least two different kinds of memory: episodic memory relates to analogies formed with design solutions form other contexts; conceptual memory relates to analogies formed with design solution strategies. In the design process it may be useful to utilise one of the two kinds but in most cases the use of an analogy with previous solutions implies a hybrid of the solution and the solution path which has generated it.[7]
The central role of memory and experience in the formation of an efficient design solution strategy and the recognised inadequacy of 'the whole repertoire of logically sound AI methods' owing to the ill-defined and ill-structured nature of design[8] have brought us to focus on case-based reasoning (CBR) as the main reference paradigm for the formalisation of the nature of design process knowledge.
Thus, design activity is an intentional, experience and memory-intensive progressively defined solution path in a restricting solution space and it is first of all an activity directed at producing a change. This is to say that, in its globality and in its constituting steps, design implies the ability to describe the current state of the design problem, envisage a more desirable situation and perform a design act, apt to transform the given project situation by modifying one or more of its defining characteristics, in the direction of a higher level of satisfaction.

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[6]B. Bartsch-Spoerl, *Representing and using cases in Visualisation-Oriented Design Domains,* in: "EWCBR94-Proceedings of the second European Workshop on Case-Based Reasoning", eds. M.Keane, J.P. Haton, M.Manago, Acknosoft press, Paris, 1994
[7]M. Profeti, G. Zitti, *Un modello di memoria integrato per un sistema di progettazione architettonica,* Ancona, ed.CNR-Progetto Finalizzato Edilizia, 1994.
[8]B. Bartsch-Spoerl, *cit.*

In other words, any design project may be seen as an evolving network of transformation acts (or **design moves**) at many different levels of abstraction (from highly complex moves down to simple and straightforward ones) operating the desired change from the outset of a project to its successful completion.

3. Design moves as cases

A case in knowledge-based systems regarding design is generally assumed to be as a design solution or a fragment of a design solution, that is, a unitary self-contained problem-solving episode, generally but not necessarily at an advanced stage of solution. This is the approach which characterises ARCHIE[9] and CADRE[10], and in a different way also FABEL[11] and A.S.A.[12], just to name the best-known case-based design systems. The concept which somehow unifies the approaches of these systems is that architects work on the analogy existing between forms achieved in past projects and current situations, so that what is most interesting is the possibility to retrieve or adapt relevant forms.
This work has chosen to concentrate on a different point of view on the nature of design knowledge, i.e. a solution is considered as an act taking a given project from a given point to a more desirable one, i.e. a design move. A case in this work is therefore not a design solution but a design move, or strategic exploration act, underlying the solution.
In this view CBR may be useful in guiding the design process from the earliest phases by allowing the retrieval, evaluation and adaptation of relevant design moves from previous experience, at various levels of abstraction, taking a project from the outset to the complete design.
'Design move' is a wholly accepted and widely employed term in design studies, utilised with different shades of meaning to identify discrete design transactions producing state transitions in the representation of design. In other words it may be considered as a unit composing the increment of change occurring during the design process - a basic unit of change.
Thus, if a design process is an incrementally defined and evolving map of interconnected design moves, one may argue that a design process itself is a design move, taken at a very high level of abstraction, transforming the given context into the final project. This is certainly true, and leads to the need to break down the whole process into a number of classes of design moves at various levels of abstraction, according to complexity criteria.
Oxman[13] proposes a taxonomy of design moves in connection to visual reasoning, including: design move (the basic unit), design episode (connected string of design acts discernible as an ensemble in a particular design task) and network of strings (connected set of episodes apt to yield insight into design heuristics).
We have decided to adopt this conventional three-level taxonomy which brings us to characterise a **design move** as a discrete basic action of change; a **design episode** as a set of

[9]A. Goel, J.Kolodner, M.Pearce, R.Billington and C.Zimring, *Towards a case-based tool for aiding conceptual design problem solving*, in: R. Bareiss (ed.), "Proceedings of DARPA Case-based Reasoning Workshop, San Mateo, Morgan Kaufmann, 1991
[10]B.Dave, G.Schmitt, B.Faltings, I.Smith, *Case-based design in architecture*, in: J.Gero and F.Sudweeks (eds.), "Artificial Intelligence in Design 1994", Dordrecht, Kluwer Academic Publishers, 1994
[11]B. Bartsch Spoerl, *cit.*
[12]A.Giretti, L.Spalazzi, M.Lemma, *A.S.A. an interactive assistant to architectural design*, in: J.Gero and F.Sudweeks (eds.), "Artificial Intelligence in Design 1994", Dordrecht, Kluwer Academic Publishers, 1994
[13]R.M.Oxman, R.E. Oxman., *Visual reasoning in design*, in: "Research Directions for Artificial Intelligence in Design" (ed. by J.Gero and F.Sudweeks), Sydney, University of Sydney, 1995

moves which globally brings about a discernible change in a significant decision node; and a **network of episodes** as an complex group of interconnected design actions composing one of the basic ensembles of change in the process.

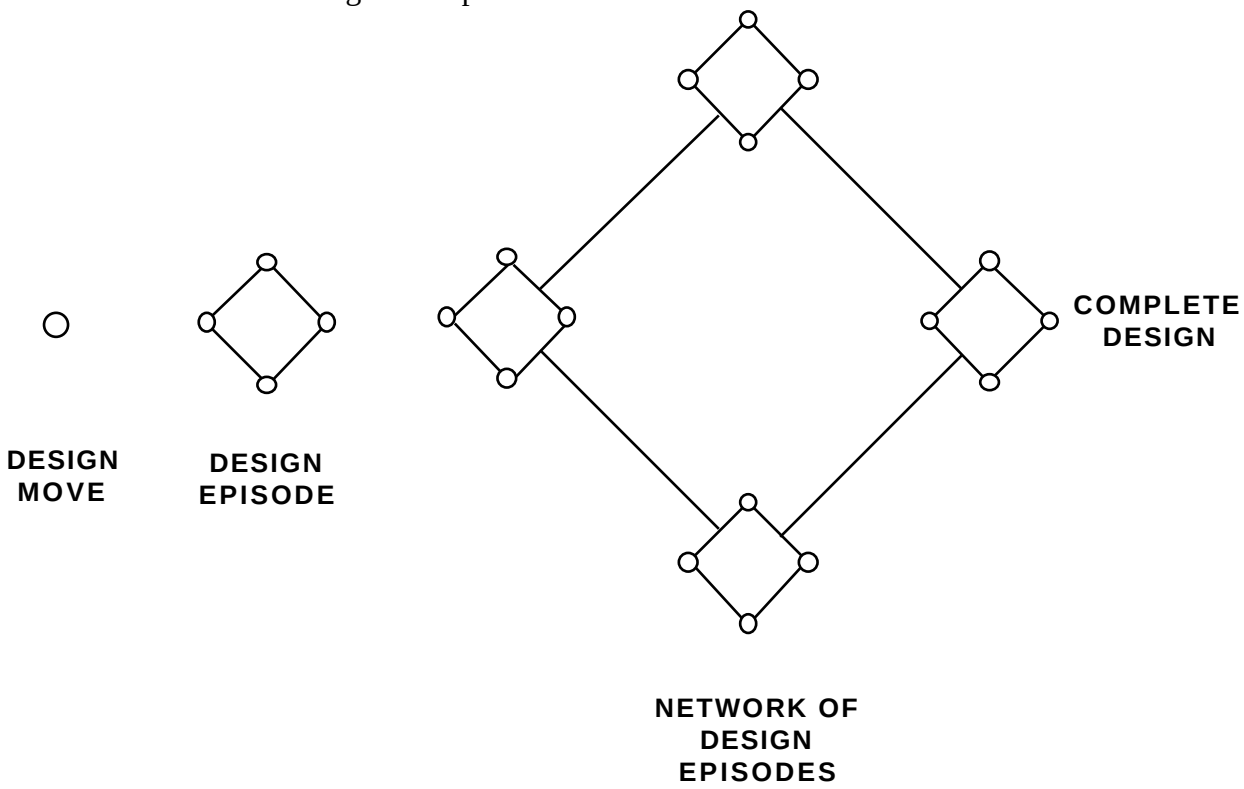

Fig. 3 - Representation of the three abstraction levels of the units of design knowledge adopted in the model of Galathea

This means a design process will be composed of a small number of networks of episodes, composed of a large number of design episodes, composed of an enormous number of design moves. In reality there is a seamless transition between levels, but in order to formalise a usable case-base such a partition is necessary.
The usefulness of this approach is manifold:

- it allows an explicit representation of the decision-making process of a specific project
- by generalisation, it allows the explicit representation of a general framework of decision-making pertaining to a specific designer's design method
- it allows the flexible and non predefined description of past experience in a way which may be stored, retrieved, compared and adapted in other design contexts
- it allows the use of past decision-making experience to other architects (in the hypothesis of an enlarged case-base, e.g. on the web)

In such a CBR model, the focus is on retrieval, which is based upon the evaluation of the current problem (or sub-problem) configuration compared to similar process (or sub-process) previous design contexts. The basic idea consists in the comparison of the general problem configuration, the prefiguration of a more satisfactory configuration and the design move necessary to map the first into the second, expressed in terms of a number of intrinsic characteristics.
Relevant design moves, episodes or networks of episodes may thus 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.
Such a model poses a number of implementation questions, especially regarding which characteristics intrinsically present in an object-oriented design effectively allow a description of

any current state apt to allow comparison and retrieval of similar states. In the following paragraph there is a succinct description of one simplified but feasible hypothesis which has been explored for the Galathea model.

4. The model of Galathea

On the basis of this concept of design, the structure of Galathea, a tool aimed at supporting design activity, is currently under development.[14] This model may be envisaged as 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.
Galathea is aimed at the satisfaction of the following three functions:

- **map-making** function: 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: the ability to explicitly represent the path of decisions making up the design process through the establishment of links between decision moves, enabling the transfer of consequences of any move on connected ones
- **case-based** function: the ability to save, retrieve, adapt and use relevant design moves so as to enable re-use in similar project contexts.

When setting out on a new design assignment, a designer, in using Galathea, should first be guided in the mapping out 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.
During design activity, with the growth of relevant knowledge acquisition, this initially incomplete map will progressively evolve, and the nature, weight and origin of constraints will change continually and recursively, as new decisions are taken.
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 candidate solutions 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.
Galathea 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. It may also be seen as a navigator, or map-maker, since it enables designers to explore their own personal decision-making route which, in the space of possible solutions, leads from the brief, along the complete path of adopted design moves, to the completion of a coherent and successful project.
At the present state we are reasoning on a feasible way to formalise design moves on the basis of measurable defining characteristics and on their subdivision in the hierarchy outlined in paragraph 3, so as to implement a first prototype comprising Galathea in association with 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.

[14] V. Bottelli, C. Fogh, *Galathea: a case-based planning tool for knowledge navigation in the architectural design process,* in: Proceedings of the 13th European Conference on Education in Computer Aided Architectural Design in Europe, Palermo, 16-18 November 1995

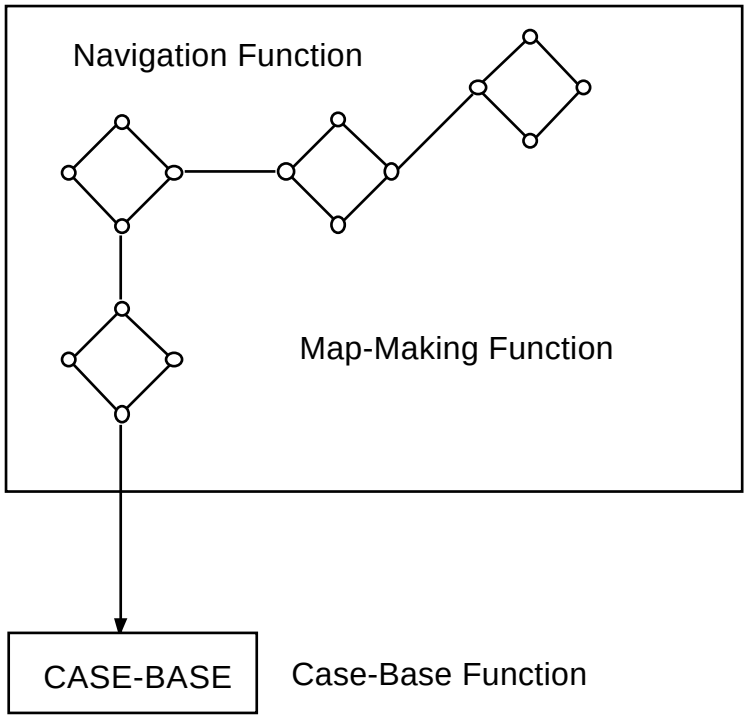

Fig. 4 - The three functions of the model of Galathea

5. *Diarium* - an educational application

The model described in the previous paragraph needs to be further studied and described in order to allow a first implementation plan for a working prototype. In the meantime, a number of questions are arising regarding the need to verify the theoretical assumptions made in real-life design working sessions, so as to gain further insight into the theme of design method, and the taxonomy of design acts.

In order to do so, and in order to allow a transposition of the research work into educational work, we have studied an educational application of our theoretical approach to design, tailored to a class of about 100 second-year students, aimed at stimulating a reflection on design method and awareness during the development of a project.

The class object of this experimental teaching module is composed of about 100 second-year students working on a common design problem in groups of about 3, yielding about 30 final solutions to the same problem. The characteristics of the students are a general design background and some specific knowledge obtained during the first year, with this project often being the first complex design task they have met.

Thus we have decided to assign a design problem apt to be interesting and complex but not to an extent that would create confusion, and the rehabilitation of an existing building rather than the project of a new building, enabling us to collect a lot of documentation beforehand which would allow a thorough and detailed knowledge of the building under its many different aspects, and due to the prevailing characteristics of architecture jobs in Italy today. The basic idea behind the first briefing phase is that if design is an intentional activity directed at producing change, the first task is certainly the acquisition of a rich knowledge base regarding the design context, so as to envisage a preferable situation.

At the outset, students are thus given a brief as well as theoretical and practical instruments to **evaluate** the building in terms of a number of parameters (or **values**), so as to obtain an initial complex and rich perception of the context. A collegial discussion with all teams of students is aimed at deciding a fixed number of values which will be used to monitor all design acts through the process. Of course it is made clear that values may be substituted by others during the process, if they result unnecessary, insufficient or inadequate.

This first part of the work gives students the notion of design as an incremental process of change, initiating in a richly studied map of characteristics building up the state of the art, a desired state envisaged by the brief and a notion of the distance separating the two states, which will be filled by the exploration process and design moves they will choose to adopt.

The values chosen by the class are used as reference parameters in a simple monitoring data-base which is given out to all students, and using which they will record any design moves they judge relevant. Design moves are recorded both verbally (description of the problem, description of the desired state, description of the design act performed) and by means of the parameters (buttons identify values involved in the design move and relative weights 1 to 10 judged by the students, the existence or not of conflicting values and date and time of recording). (See fig. 5)

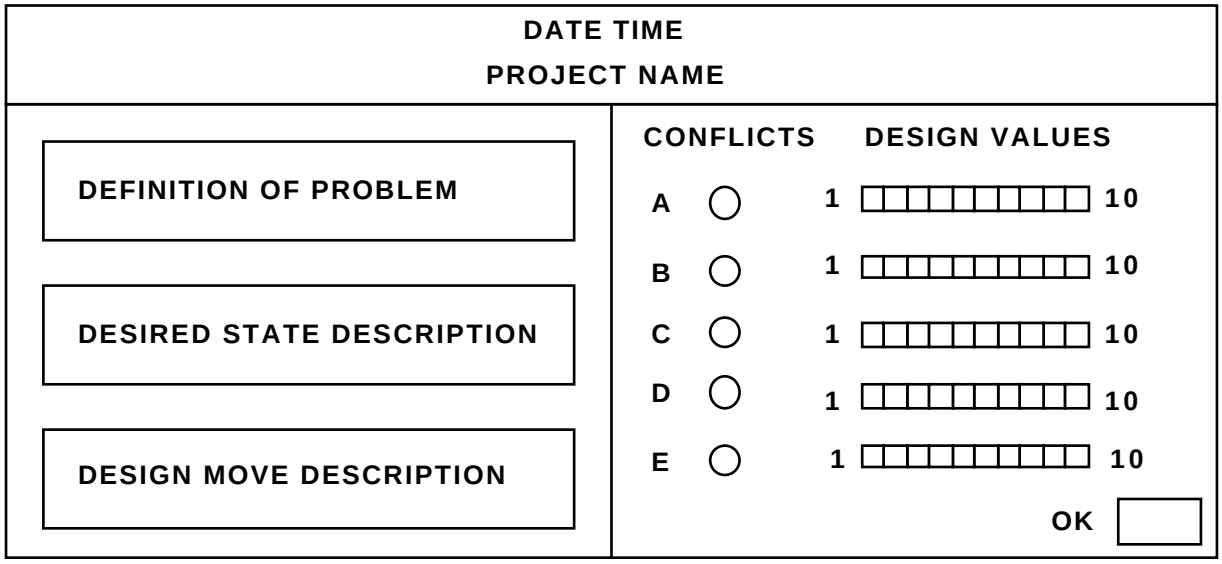

Fig.5 - Fac-simile of screen layout for the recording of design moves

This manual recording of design moves is of course a very simplified notion of the possibilities envisaged by the model of Galathea, and at the same time, is in no way a proposal for real-life designers, since it is an intolerable burden which no designer, justly, would ever accept. But in an educational context, it is useful to oblige young students to reason about their first design acts and about methodology, and it is also useful for periodical collegial revisions, identifying topical points, incorrect decisions etc.

From this point on, all design teams start the design process using any media they prefer, from sketches to CAD drawings, to 3D-models to physical models and photographs to express their ideas. During weekly revisions of the state of the project, student groups are asked to hand in graphical descriptions of the current state of their projects as well as a print-out of their design moves recorded in the navigation book - hence called *Diarium.*

At the end of the year, all design teams hand in a complete design and a complete *Diarium* and a seminar of collegial discussion occurs. All verbal descriptions compose an ”experience-base” for students to refer to, in case of need, when thinking back on the causes which have triggered certain design acts. All the representations of design moves in terms of values, compose a final graph of the global process navigation route.

Of course, the quantity and quality of information yielded by this graph on the nature of knowledge and decisions in the process is very poor if compared to the possibilities envisaged by Galathea, but may still prove useful, especially to enhance collegial discussion and point out areas of success or causes of error in the decision-making process of students.

The graph resulting from the yearly *Diarium* offers a good way for students to defend and criticise their project or other students' projects other than by using the projects themselves, and making use of transparent, unambiguous and collegially decided units of measurement. Of course the graph's closeness to reality depends upon students' ability to correctly evaluate the function and characteristics of design moves. This ability, generally poorly formed in second-year students, is in our opinion an important factor of growth for architects.

The graph thus allows a rough representation of the relative weights of values guiding the development of the project, as well as the identification of conflicting values in specific project phases. This is useful in judging whether, for example, the incorrect adoption of a value at a certain point, e.g. due to prejudice, triggers a series of problems and errors along the process; or, on the contrary, it is useful to identify a neuralgic point of success in which the adoption of a correct and inspired decision has made life easier in later project phases.

One other important point that this educational experiment makes clear is the central role of memory and experience in architectural design. The compulsion to record all relevant design acts yields quite a weighty case-base of design moves which may often be of use during the project; this communicates unequivocally and in a manner which is of immediate comprehension to the students the central role of past experience in forming aware decisions in design. This leads to an experimental comprehension of the usefulness of the CBR paradigm in design.

6. Conclusions and further work

In this paper we have outlined a theoretical approach to the description of the nature of knowledge in the design process based on an incremental decomposition of the process in discrete acts called design moves, resulting in a model for a tool supporting decision-making called Galathea.

Furthermore, we have described an experimental application of these concepts in the teaching of architecture by means of the keeping of a navigation book, or Diarium, recording design moves judged relevant by the students, resulting in a rough but useful case-base of design moves. The scope of this experiment is twofold: it enhances the ability of students to reason on design method and on the central role of past experience in decision-making in design, and it gives us a first practical framework to value the usefulness of the Galathea model in the direction of a first prototype implementation.

Further work we intend to carry out is a reiteration of this experiment on other design classes working on different project scales, e.g. product design, and the formulation of a first implementation plan for Galathea, as well as, possibly, the activation of this experiment between classes in different towns connected via the web, so as to share the usefulness of this first, rough case-base of design moves with other design students.

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