A TRICHOTOMIC SEGMENTATION PROCEDURE TO EVALUATE PROJECTS IN ARCHITECTURE

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ABSTRACT. This paper illustrates a model used to construct the evaluation module for 'An Interface for Designing' (AID), a system to aid architectural design. The model can be used at the end of every cycle of analysis-synthesis-evaluation in the intermediate phases of design development. With the aid of the model it is possible to evaluate the quality of a project in overall terms to establish whether the project is acceptable, whether it should be elaborated ex-novo, or whether it is necessary to begin a new cycle to improve it. In this last case, it is also possible to evaluate the effectiveness of the possible actions and strategies for improvement. The model is based on a procedure of trichotomic segmentation, developed with MCDA (Multi-Criteria Decision Aid), which uses the outranking relation to compare the project with some evaluation profiles taken as projects of reference. An application of the model in the teaching field will also be described.

1. Introduction: Design Process and Evaluation

Under the pressure of social needs and the desire to address the complex problems of today's world, the 60s and the early 70s witnessed the birth of a number of methods and techniques intended as aids in the design process. Many of these methods sought to break down the barriers between disciplines and to demonstrate the applicability of the scientific method to the fields of artistic research and design (Alexander 1964; Archer 1965, 1968; Broadbent 1970; Gregory 1970; Jones 1963, 1970; Luckman 1967). The intrinsic limits of the methods proposed, together with the declining interest in a more systematic way of projecting, led architects in the mid-70s to concentrate on the language and form of architecture.

In recent years, however, the widespread diffusion of computer technologies, the emergence of the so-called environmental crisis, and the growing complexity of the decision-making context have led architects to reconsider method. They came to think of it as an important tool to manage the design process, from a technical point of view as well as from an organizational one. In fact, the architects' tasks seem to be growing more and more difficult as time passes. Architects are finding themselves in situations where they have to coordinate multidisciplinary working groups, where they have to identify design actions to protect human and environmental values and, at the same time, keep in mind the limits imposed by the decision-making context.

A number of methods consider designing to be a process that consists of a sequence of cycles of analysis-synthesis-evaluation (Archer 1965; Jones 1963; Luckman 1967; Maver 1977, 1988). Such methods usually differ from one another owing to the number of cycles in the process or the number of steps in each cycle. The basic idea is that every cycle must be repeated several times before completing the project. This way of conceiving the design process is useful in some kinds of projecting (for example, in mechanical engineering), but it is much less useful in architecture. In fact, the designing of architecture - especially in the early stages - appears as an ill-structured and ill-defined problem, one that's difficult to control. We can encounter alterations in the sequence as well as in the duration of the various steps in a cycle. A procedure based on

H. Timmermans (ed.), Design and Decision Support Systems in Architecture, 189–200.

successive cycles of analysis-synthesis-evaluation proves to be useful only in the more advanced phases of the design process, when the solution has reached relative stability.

Whereas methods of analysis are fairly numerous and efficient, methods of synthesis are virtually absent. In fact, this step in the cycle depends entirely on the capacity for synthesizing on the part of the individual architect. As far as evaluation is concerned, the methods available refer to very specific aspects of the process. What we are talking about, in general, are methods regarding technical control. It would be inexact, in our opinion, to consider them as real tools of evaluation, because they do not allow us to evaluate a project from an overall point of view.

This paper describes an evaluation method that is based on MCDA (Multi-Criteria Decision Aid). This method is particularly suitable to a process with different 'actors' (designers, consultants, users, etc.). But MCDA can also be used by the individual designer who intends to simulate the decision-making context. The method allows direct comparison of the performances related to building efficiency in terms of environmental comfort, costs, etc., with other intrinsically qualitative aspects, such as the relationship between the project and the landscape or the historical and cultural context. The model helps the designer evaluate the project in an explicit and global manner without overlooking qualitative aspects. It aids him in making choices which imply complex trade-offs between performances of different types. The method has been used to construct a module of evaluation that forms part of a design support system named 'An Interface for Designing' (AID), which is in the working stage (Mortola 1988, 1989a, 1989b, 1990; Giangrande et al. 1991). This system, which can be applied to different phases of the design process, was developed with the aid of Hypercard. It is made up of a number of modules, some of which can be interfaced with other commercial systems and programs frequently used in CAAD or in scientific fields.

2. Evaluation and MCDA

In many disciplines, including economics, statistical theory of decisions, operational research, games theory, etc., the rationality of a choice is guaranteed when the decision-maker, knowing all the feasible alternatives and their consequences, selects the best alternative on the basis of a single criterion (e.g., profit maximization). This paradigm of decision-making went into crisis in the 50s as a result of studies carried out in the social choice theory (Arrow 1951), in the behavioural sciences, and in organization theory (March and Simon 1958). These studies have progressively led to a lack of conviction about the possibility of explaining and forecasting decision-maker's behaviour according to codes of rationality (Simon 1957). These studies questioned the validity of many classical evaluation models and favoured, from the mid-60s, the development of a new field of research which put to good use the theories of the previous decade: the Multi-Criteria Decision Aid (MCDA) (cf. Jacquet-Lagrèze et al. 1978; Roy 1968, 1985). The methods and techniques developed in MCDA furnish the actor with the tools that help him to make a decision in the light of multiple and often conflicting points of view.

According to this approach, the term 'optimization' loses its meaning. In contrast with some evaluation techniques developed in the field of operational research, such as MOLP (Multiple Objective Linear Programming), the MCDA methods do not lead to the 'objectively' best solution, which, in fact, does not exist. In MCDA, the decision is seen not so much as a result but as a process with various steps in which one or more dominant points of view prevail. The rationality of the decision process is evaluated as 'coherence with the objectives of the decision-makers' (Sfez 1973). In this point of view, it is important that a method accommodates the complex game of interaction between the different elements of the decision-making process.

The 'hard' models of operational research are substituted by 'soft' ones (less mathematical but equally rigorous). This allows the actors to interact directly and more easily with the evaluation tool. In MCDA, concepts such as actor, action and criterion assume particular importance. The actor is an individual (or a group of individuals who participate in a homogeneous and coherent way in the process) who can directly or indirectly influence the decision. By action, we mean the representation that an actor constructs of a solution (or of an element which helps to obtain a solution). In the architectural design, the action is the entire project or a design decision that modifies it. By criterion, we mean a 'model' (indicator, objective function, etc.) that allows us to compare more actions and to evaluate their effectiveness in an explicit way.

In MCDA, the criteria are usually multiple and conflicting. In any case, the criteria used to evaluate the action (or the actions) must make up a coherent 'family', i.e., a set of exhaustive and not redundant criteria (Roy 1985, p. 310). Another fundamental concept is problem formulation. Four problem formulations are considered in MCDA: α, β, γ, δ, (Roy 1985) The objective of the problem formulation is to help in choosing one action considered the 'best among those studies (selection procedure). In the problem formulation β, the objective is to help to sort out all those actions that are "good' (segmentation procedure). In the problem formulation γ, the actions are ranked in order of decreasing preference (ordering procedure). The objective of the problem formulation is to analyze the actions and their consequences to help the decision-maker make a choice. This problem formulation does not necessarily lead to ranking the actions, nor to choosing the best action(s). The applications of MCDA are numerous in the planning and management fields but are less diffuse in architectural fields (Calderaro et al. 1986). In the following sections, we will illustrate the method we used to develop the evaluation module for the AID system. We will then give an example of its application to an experiment in architectural design in a didactic context.

3. The Evaluation Method

The evaluation method is based on problem formulation β. In this problem formulation, the objective is to help to sort out all those actions that are 'good' (segmentation procedure). This is the only MCDA usable problem formulation when we need to evaluate an action not according to a set of alternative actions but with respect to absolute references. In this specific case, we used a trichotomic segmentation procedure (Moscarola and Roy 1977; Roy 1981) to establish if the action is good, bad or uncertain. The procedure assigns the action to one of three categories: K^+ (action accepted), K^- (action rejected) and $K^?$(the action merits an additional examination). The action is evaluated with respect to n criteria by l actors ('judges'). The n criteria are represented by the same number of semantic differentials (Osgood et al. 1957) which correspond to all those aspects, and only those which are meaningful to evaluate the project with reference to the design theme, the context, and the level of definition of the project itself. A semantic differential consists of one or more pairs of adjectives or statements of antonyms. These are the polar terms or factors which have to be used in judging the objects presented. In order to increase the precision of the responses, a range of choices is allowed between each extreme.

In our case, every semantic differential is defined on a scale of 7 levels. The two extreme levels of the scale, 1 and 7, represent respectively the negative and the positive polar terms of the differential. The meaning of every polar term is defined by a sentence and some images, maps, or diagrams of exemplary projects. Every judge assigns the project to a level on the scale which will be all the more close to the positive (or negative) polar term as the project is judged better (or worse) in respect to the considered criterion. In this manner, the judges define l vectors with n components $a_j^k (j=1,2,\dots n;\ k=1,2,\dots l)$. The jth component of this vector represents the level of the project on the criterion j in the opinion of the judge k.

In the applications which interest us, the judges can be the designers and the consultants of a professional studio, the jury of a competition, the members of a building commission, or a board of examining professors. To guarantee a correct evaluation of the project with respect to all the criteria, it is necessary that the jury be composed of experts in different sectors. In a no-conflict situation, the evaluation of the project can be carried out by the judges in collaboration. In the didactic context, a student can simulate the judgments of a board of examiners to identify the aspects (criteria) where his project is weaker. Every judge assigns afterwards the weights w_j^k (j=1,2,...n; k=1,2,...l) to the criteria. These weights are coefficients which reflect the importance that each judge, on the basis of his own system of values, assigns to the different criteria, considering the design theme and the context. The sum of weights assigned by a judge to all the criteria must be equal to 1.

The procedure asks, moreover, that each judge define a pair of vectors with n components: b_j^k, c_j^k, named respectively the upper and the lower profile. These profiles represent two sets of reference projects which discriminate between acceptable and uncertain projects (b_j^k) and between uncertain and unacceptable projects (c_j^k). Therefore, for every criterion, the level of the upper profile must be greater than that of the corresponding lower profile. If the project is over all upper profiles (or under the lower ones) the project can be assigned, without hesitation, to the category K^+(or K^-). If these conditions are not met, as often happens, it is necessary to compare the project with all the profiles by the outranking relation S defined as follows. Given two actions, a_1 and a_2, we observe that a_1 S a_2 (a_1 outranks a_2) if a_1 is at least as good as a_2 (Roy 1985). To establish if project a outranks a specific profile p (or vice versa), the indexes of concordance $C^k(a,p)$ (Roy 1968) have to be calculated. This is done as follows:

$$C^k(a,p) = \Sigma_j w_j^k c_j^k(a,p) \qquad (k=1,2,...l) \qquad (1)$$

where,

$$c_j^k(a,p) = \begin{cases} 1 \text{ if } g_j^k(a) >= g_j^k(p) \\ 0 \text{ if } g_j^k(a) < g_j^k(p) \end{cases} \qquad (j = 1,2,...n; k = 1,2,...l) \qquad (2)$$

$g_j^k(a)$ and $g_j^k(p)$ are respectively the levels of a and p on criterion j. The condition $g_j^k(a) >= g_j^k(p)$ is fulfilled if the project is assigned to a level of the semantic differential equal to or higher than the level of the reference profile. The index of concordance can vary between 0 and 1: the closer this value is to 1, the greater is the comprehensive weight of criteria which agree upon the sentence 'a is at least as good as p.' To calculate the symmetrical indexes $C^k(p,a)$, it is sufficient substitute a with p in (1) and (2). In general, $C^k(p,a) \neq C^k(a,p)$.

To be able to assert that a outranks p, it is not sufficient that $C^k(a,p)$ assumes values near 1. If the difference $g_j^k(p)$ - $g_j^k(a)$ is considerable, even for only one criterion, the outranking could not occur, or it would not appear very credible, aside from the value of $C^k(a,p)$. The procedure asks that every judge assigns a veto threshold v_j^k to each criterion (Roy 1978). v_j^k represents the maximum value of difference $g_j^k(p)$ - $g_j^k(a)$ that judge k could accept for criterion j in order to attribute a high credibility to the outranking aSp. The veto thresholds are used to calculate the 'fuzzy' indexes $S^k(a,p)$, which represent the credibility degrees of outranking asp. To calculate these indexes, we must calculate the indexes of discordance $D_j^k(a,p)$.

These are defined as follows:

$$D_j^k(a,p) = \begin{cases} 1 & \text{if } g_j^k(p) > g_j^k(a) + v_j \\ 0.5 & \text{if } g_j^k(p) = g_j^k(a) + v_j \\ 0 & \text{if } g_j^k(p) < g_j^k(a) + v_j \end{cases} \quad (j = 1,2,\ldots n;\ k = 1,2,\ldots l) \quad (3)$$

The indexes $S^k(a,p)$ are calculated in the following way:

$$S^k(a,p) = \begin{cases} C^k(a,p) \text{ if } D_j^k(a,p) \leq C^k(a,p), & (j = 1,2,\ldots n) \\ & (k = 1,2,\ldots l) \\ C^k(a,p) \prod_j \{[1 - D_j^k(a,p)] / [1 - C^k(a,p)]\}, & \end{cases} \quad (4)$$

where, $\prod_j$ is extended to all the values of j for which $D_j^k(a,p) > C^k(a,p)$.

In general, the smaller the thresholds of veto v_j, the lesser the degree of credibility of the outranking. Comparing the project with all the profiles, upper and lower, for each judge we obtain four indexes: $S^k(a,b)$, $S^k(b,a)$, $S^k(a,c)$, $S^k(c,a)$.

To assign the project to the category K^+ (project accepted), K^- (project rejected) or $K^?$ (the project needs improvement), we use the decision tree shown in Figure 1 (Scharlig 1985; Vansnick 1979), where B^+, B^-, C^+ and C^- represent respectively the number of judges for which the indexes $S^k(a,b)$, $S^k(b,a)$, $S^k(a,c)$ and $S^k(c,a)$ exceed a threshold T. This threshold is chosen empirically. The more it grows in value, the more severe the 'filtering' of the corresponding index and the fewer the number of judges for which the corresponding outranking relation assumes credibility.

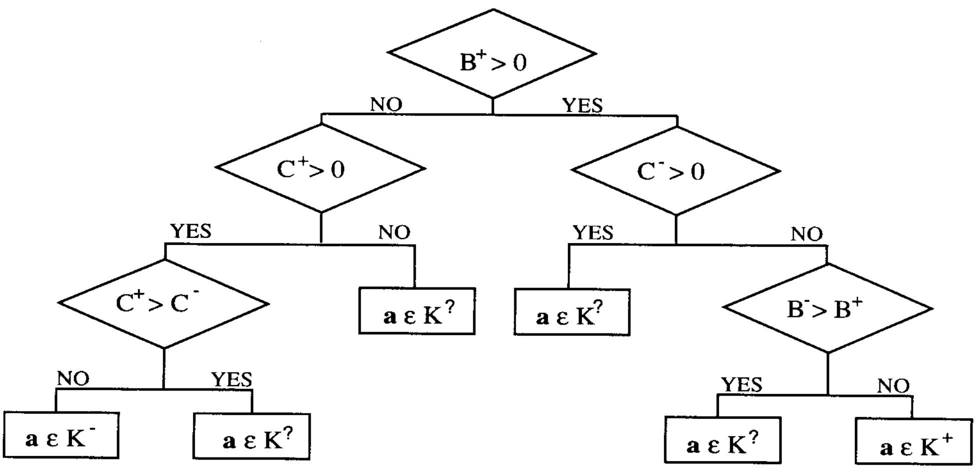

Figure 1. The Decision Tree

Considering that the choice of the threshold is arbitrary, it is necessary to conduct a sensitivity analysis, varying its values in a suitable range (e.g. 0.6 - 0.9) in order to verify the stability of the results of evaluation.

4. An Application of the Evaluation Model

The procedure of evaluation has been applied, as a didactic exercise, to one of the projects of the

Italian students who participated in an inter-school competition sponsored by Strathclyde University in Glasgow for European students of architecture. The theme of the competition was the design of a Media Lover House, a home for the 21st century. This competition intended to celebrate an important event in English architecture. This was the competition proposed in December 1900 by the German magazine 'Zeitschrift für Innendekoration' for the design of an Art Lover House ('Ein herrschaftliches Wohnhaus eines Kunstfreundes'). One of the participants was the architect C.R. Mackintosh. His project is now taking shape in BellaHouston Park, for the occasion of the celebration of Glasgow architecture, which marked the European City of Culture for 1990. The building is intended for habitation. Some of its characteristics are connected with the kind of user (a media lover). Specifically, it should provide for collateral activities to satisfy professional, social, and cultural needs, to promote hobbies, and to encourage communication and meeting at the professional and family level, with the aid of advanced technologies. In addition, the

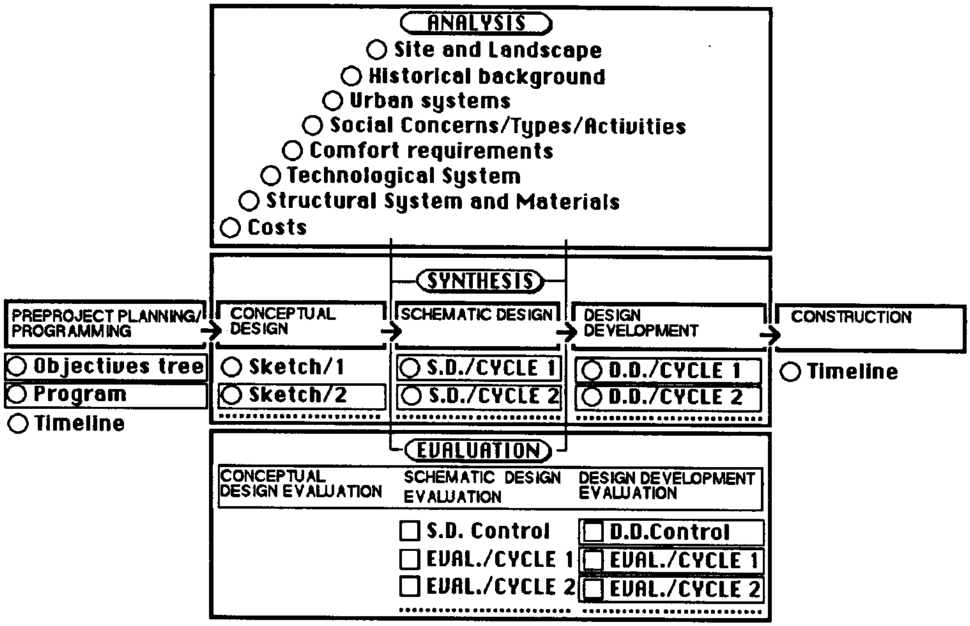

Figure 2. The menu of an interface for designing (AID)

project should propose innovative solutions for the management of the building, in order to obtain the energy to be used from the natural surroundings. The resident group consists of six permanent inhabitants, not necessarily linked by family ties, and two guests. The participants in the competition could also determine the localization of the house.

In the following, we will describe the application of the evaluation procedure to the project developed for this competition and successively for the 'thesis of laurea' by the students Francesca R. Castelli and Anna Gadola (Chairman: Prof.Arch. Elena Mortola; Co-chairman: Arch. Maurizio Clarotti). In developing their project, the students used the AID system. The project was emblematically located in BellaHouston Park, in front of the Art Lover House of Mackintosh.

The evaluation procedure has been applied by the students to the last two cycles of analysis-synthesis-evaluation of the development design phase (Figure 2). With the aid of the procedure, in

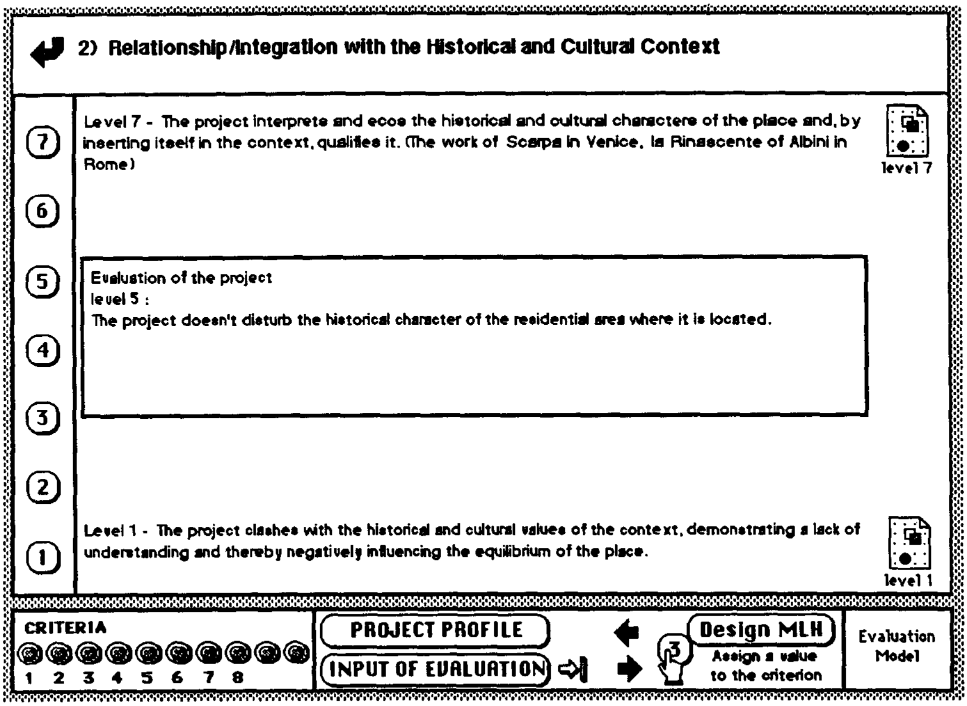

Figure 3. An example of a semantic differential (criterion 2)

the next-to-last cycle, the students defined a strategy to modify the project. A strategy is the prefiguration of a set of design actions which could improve the project with respect to one or more criteria. To evaluate the efficacy of the strategy, it is sufficient to apply the evaluation model to the vectors which represent the estimated performances of the modified project.

To choose the best strategy, the students considered only the actions that do not lead to the total transformation of the project and that allow the minimum design effort. The choice of the evaluation criteria was made jointly by the students and six professors (see Annex). The lack of a criterion on the quality of the formal aspects is justified by the fact that every criterion takes this requirement into account (see, for example, criterion 5). In order to choose the examples that would clarify the meaning of the polar terms of the semantic differentials, many projects were analyzed and evaluated in relation to the different criteria (Figure 3). This helped the students develop a multicriteria mentality, i.e. the capacity to consider together many different aspects of designing. The weights of the criteria were assigned separately by every judge (Figure 4), who successively evaluated the project in collaboration. This evaluation is a result of a preliminary discussion which allows the judges to reach agreement. The judges decided to use the same reference profiles, i.e. $b^k = (5,5,5,5,5,5,5,5)$, and $c^k = (3,3,3,3,3,3,3,3)$, for $k=1,2,\dots l$. The profiles are 'flat', that is, the levels are the same for every criterion. At the end of the considered cycle, the project is evaluated as follows: $a = (5,5,4,5,4,4,3,4)$. Considering the results of evaluation, we deduce that the technological systems are not innovative (level 3). Moreover, we deduce that the relationship with the urban context (in functional terms), the comfort in the

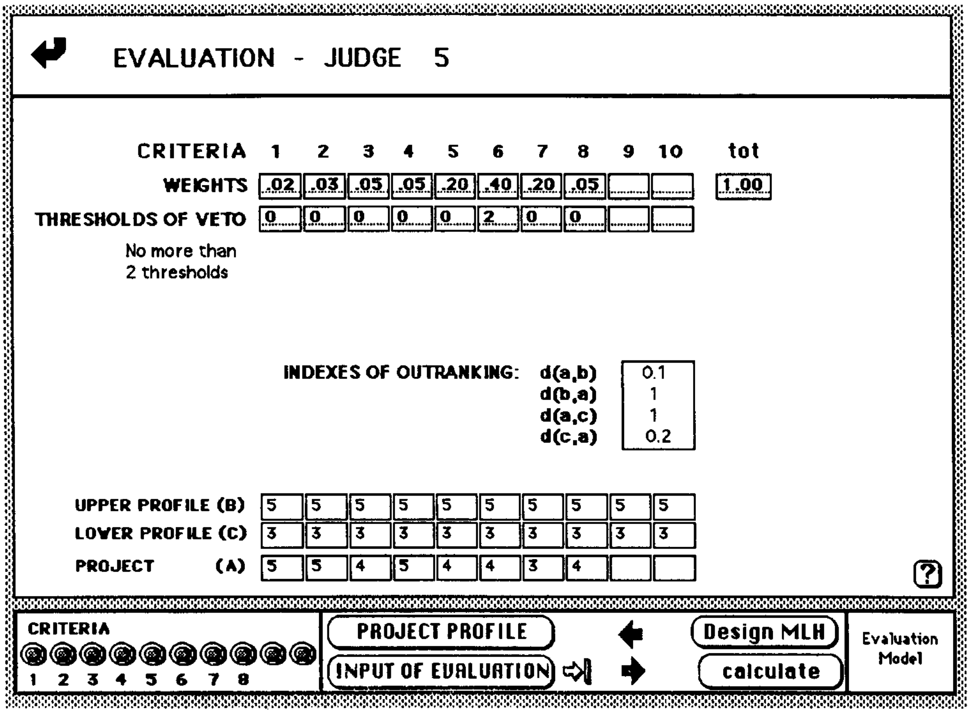

Figure 4. The evaluation of a judge

building, the static solution, the construction, and the maintenance costs cannot be considered satisfactory (level 4). The performances referred to by the other criteria are sufficient (level 5). The project, as evaluated with the trichotomic segmentation procedure, is assigned to the category $K^?$. The sensitivity analysis showed that the evaluation result was stable.

With the aid of the model, the students explored some strategies to improve the project. A strategy is the prefiguration of a set of design actions which could improve the project in respect to one or more criteria. To choose the best strategy, the students considered only the actions that did not imply a revolutionary transformation of the project and allowed the minimum design effort. A first strategy was intended to improve the originality of the technological solutions, especially concerning techniques to obtain the energy to be used for the management of the building from the natural surroundings (from level 3 to level 4), the relationship with the historical pre-conditions, through a study of English houses and the architectural language of Mackintosh (from level 5 to level 6), and the layout problems (from level 5 to level 6).This strategy should improve the project as follows: a = (5, **6**,4,**6**,4,4,**4** ,4). These modifications are not sufficient to change the evaluation of project from category $K^?$ to category K^+. The students decided to explore a strategy which considered other improvements, in addition to those considered previously (Figure 5). The new improvements are related to the static solution (from level 4 to level 5) and the comfort conditions inside the building (from level 4 to level 6), i.e. a = (5,6,4,6,**5** ,**6** ,4,4). The evaluation model, with these performances, assigned the project to category K^+ (Figure 6).

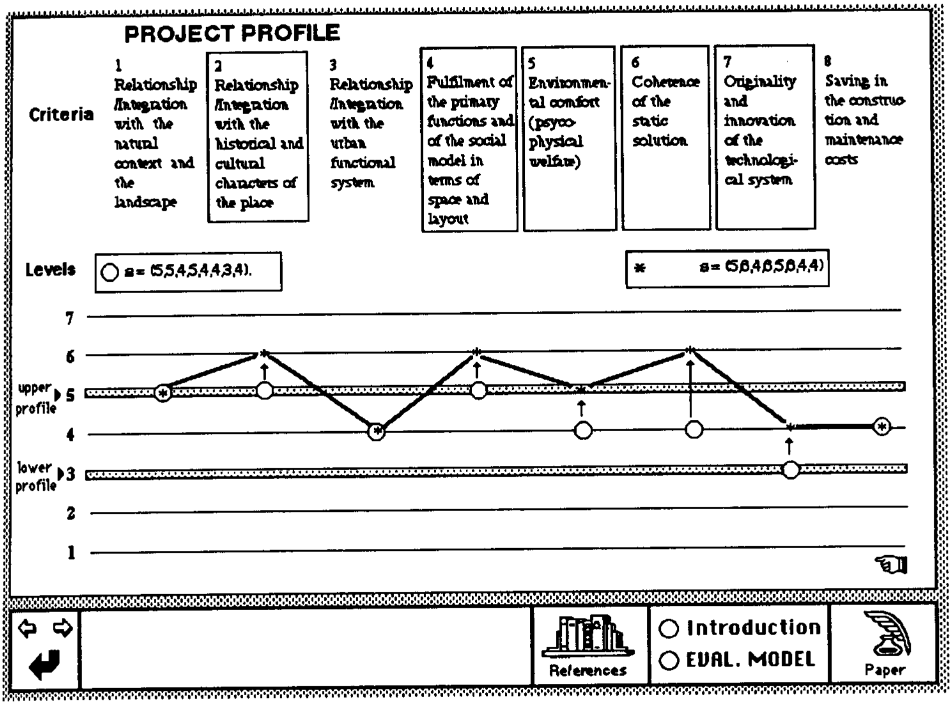

Figure 5. Searching for strategies to improve the project

5. Conclusion

The AID system can be used interactively in a very easy way. It can help the designer, not only in the last but also in the first phases of the design process. It allows the designer to make a direct comparison between the performances related to building efficiency (in terms of environmental comfort, costs, etc.) and other intrinsically qualitative aspects (such as the relationship between the project and the landscape or the historical and cultural context). Therefore, the AID system helps the designer to evaluate the project in an explicit and global manner without overlooking qualitative aspects. It assists him in making choices which imply complex trade-offs between performances of different types.

With the help of the evaluation module of AID, it is possible to simulate how some design decisions will affect the project before deciding to carry out these design transformations. These simulations, achieved with the aid of this module, allow the designer to identify the paths to be taken in order to improve the global quality of the project. In other words, the simulations help him to elaborate strategies, i.e. prefigurations of a set of design actions, which can improve the project with respect to one or more criteria. To choose the best strategy, it is better to consider only those actions that did not imply a revolutionary transformation of the project and at the same time produce the best results with the minimum design effort.

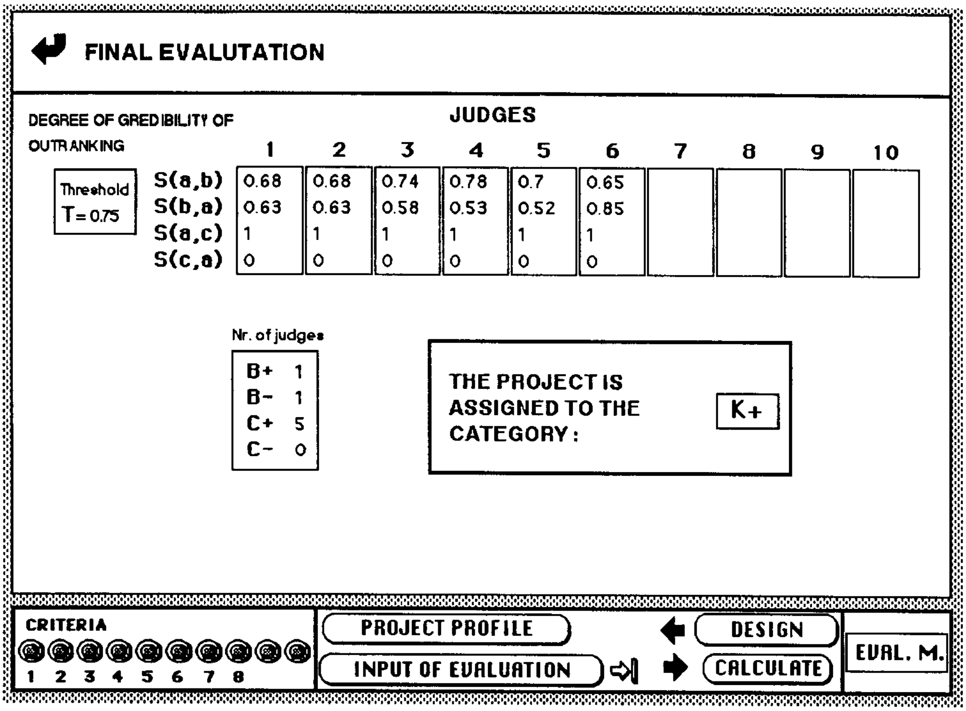

Figure 6. The final evolution

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Annex: Criteria

1. Relationship/integration with the natural context and the landscape

Level 7: The project takes into account the characteristics of the place and its natural aspects,itself becoming an important element of the place and/or improving its quality.

Level 1: The project contrasts with the landscape, altering its characteristics.

2. Relationship/integration with the historical and cultural character of the place

Level 7: The project interprets and recalls the historical and cultural character of the place and, inserting itself in the context, qualifies it.

Level 1: The project puts itself in contrast with the historical and cultural values of the context.

3. Relationship/integration with the urban functional system

Level 7: The project matches closely the hierarchical structure of the road network and urban services. In addition, this integration is plainly rendered in the project's solution.

Level 1: The project neglects the problems of the urban functional system, hindering its function.

4. Fulfilment of the primary functions and of the social model in terms of space and layout

Level 7: The layout and the dimensions of the spaces take into consideration the needs of the users. Different activities and possible changes with time of the needs are alsoforecasted. In addition, the project represents an innovative solution.

Level 1: The layout and the spaces do not take into consideration the needs of the users.

5. Environmental comfort (psycho-physical welfare)

Level 7: The environmental comfort performances are satisfied and do not contrast in any way with the formal solution.

Level 1: The project does not take into consideration the comfort requirements, necessitating extraordinary interventions or costly installations that, nevertheless, do not guaranteea complete solution to the problem.

6. Coherence of structural solution

Level 7: The project points out a precise correspondence between the structural typology and the materials utilized. The static solution shows its structural clarity and coherence.

Level 1: The structural typology is not coherent with the formal solution and contrasts with the materials.

7. Originality and innovation of the technological system

Level 7: The project includes the most advanced technological systems, meeting the highest level of quality neds without altering the architectural image itself.

Level 1: The project does not take into consideration any innovation concerning technological systems. The systems used are out of date and do not integrate with the formal solution.

8. Saving on the construction and maintenance costs

Level 7: The cost level is contained in this respect and takes into consideration the obsolescence problems, security and environmental comfort. Costs fit the resources of the users.

Level 1: The project presents elevated costs and low quality because of erroneous solutions from the financial point of view.