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The paper illustrates a model used to construct the evaluation module for "An Interface for Designing" (AID), a system to aid the 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 better it. In this last case it is also possible to evaluate the effectiveness of possible actions and strategies for improvement. The model is based on a procedure of trichotomonic segmentation, developed within the MCDA (Multi-Criteria Decision Aid), which uses the outranking relation to compare the project with some evaluation profiles taken as projects of reference. In the paper an example of application of the model in the teaching field will also be described.

Introduction: Design Process and Evaluation

Under the pressure of social needs and a will to cope with the complex problems of the today's world, the 60's and the early 70's witnessed the birth of a number of methods and techniques intended as aids in the design process. In many cases these methods sought to break down the barriers existing among the disciplines and to verify the applicability of the scientific method to the fields of artistic research and design (Alexander 1964, Archer 1965 and 1968, Broadbent 1966, Gregory 1966, Jones 1963 and 1970, Luckman 1967).

The intrinsic limits of the methods proposed together with the decline of interest in a more systematic way of projecting, led architects in the mid-70's to become more interested in 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 think about method again as an important tool to manage the design process, both from a technical point of view as well as from an organizational one. In fact, the architects tasks seems to be growing more and more difficult as time passes. Architects are finding themselves in situations where they have to coordinate multidisciplinary work group, where they have to identify design actions to protect human and environmental values and yet, at the same time, keep in mind the limits imposed by the decision making context.
A number of methods consider designing a process that consists in a sequence of cycles of analysis-synthesis-evaluation (Archer 1965, Jones 1963, Luckman 1967, Maver 1977 and 1988). Such methods usually differ one from the others owing to the number of cycles in the process or for 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 both in the sequence as well as in the duration of the various steps in a cycle. A procedure based on successive cycles of analysis-synthesis-evaluation proves to be of a certain usefulness 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 nil: in fact, this step in the cycle depends entirely on the capacity for synthesizing of the individual architect. As for 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 real tools of evaluation, because they don't allow us to evaluate a project from an overall point of view.

In this paper a evaluation method is described that is based on MCDA (Multi-Criteria Decision Aid). This method is particularly suitable to be used in a process with different "actors" (designers, consultants, users, etc.), but can also be used by the individual designer who intends to simulate the decision making context. The method allows us to directly compare the performances related to the building efficiency in terms of environmental comfort, costs, etc., with other intrinsically qualitative aspects as the relationship between the project and the landscape or the historical and cultural context. The model helps the designer therefore to evaluate the project in explicit and global manner without overlooking qualitative aspects and aids him in making choices which imply complex tradeoffs between performances of different type.

The method has been used to construct a module of evaluation which is part of a design support system named "An Interface for Designing" (AID), which is in the working stage (Mortola 1988-1989a-1989b-1990, Mortola and Sansoni 1990, Giangranda et al. 1991).

This system, which can be applied to different phases of the design process, has been 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 field.

**Evaluation and MCDA**

In many disciplines as economics, statistic 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. the profits maximization).

This paradigm of decision making went into crisis in the '50 as a result of the studies carried out in the social choice theory (Arrow 1951), in the behavioral sciences and in the
organizations theory (March and Simon 1958) . These studies have lead progressively to a lack of conviction about the possibility of explaining and forecasting decision makers behavior according to codes of rationality (Simon 1957).

These studies questioned the validity of many classical evaluation models and favoured, from the middle '60, 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) (cfr. Jaquet-Lagrèze et al. 1978, Roy 1968 e 1985). The methods and techniques developed in MCDA furnishes 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 the 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, doesn't exist.

In the MCDA the decision is seen not so much as a result, but as a process with different steps, in which are prevalent one or more dominant points of view: 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 allows us to take into account 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), which allows the actors to interact directly and in easier way with the evaluation tool. In the MCDA some concepts as actor, action and criterion assume particular importance. The actor is an individual (or a group of individuals which participate in homogeneous and coherent way in the process) which 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 help 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 explicit way.

In MCDA the criteria are usually more than one and in conflict: 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. The problem formulations considered in the MCDA are four: [] , [ ]  , [ ]  (Roy 1985, p.75). The objective of the problem formulation a is to help to choose one action considered the "best" among those studied (selection procedure). In the problem formulation b the objective is to help to sort out all those actions that are "good" (segmentation procedure) In the problem formulation g the actions are ranked in a decreasing order of preference (ordering procedure). The objective of the problem formulation d is to analyze the actions and their consequences to aid the decision maker to make a choice. This problem formulation doesn't lead necessarily to rank the actions, nor to choose the best action(s).

The application of the MCDA are numerous in the planning and management fields but are less diffuse in the architectural one (Calderaro et al. 1986).

In the following pages we will illustrate the method we used to realize the evaluation module for the AID system and its application to an experiment of architectural design in a didactical context.
The evaluation method

The evaluation method is based on problem formulation b (see above). This is the only MCDA problem formulation usable when we need to evaluate an action not according to a set of alternative actions, but respect to absolute references. In the specific case we used a trichotomous 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) e $K_0$ (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 antonyms. These are the polar terms or factors which have to be used in judging the objects presented. In order to increase precision of responses, a range of choices between each extreme is allowed.

In our case every semantic differential is defined by 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 of the scale which will be all the more closer to the positive (or negative) polar term as the project is judged better (or worse) respecting the considered criterion. In this manner the judges define l vectors with n components $a_j^k$ ($j=1,2,...,n; k=1,2,...,l$). The j-th 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 from time to time the designers and the consultants of a professional studio, the jury of a competition, the components of a building commission, a board of examining professors.

To guarantee a correct evaluation of the project 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 defines 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 ever 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, as often happens, aren't met, 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 \( a_2 \), \( a_1 \) outranks \( a_2 \) (or vice versa) if \( a_1 \) is, at least, as good as \( a_2 \) (Roy 1985, p.122). To establish if the project \( a \) outranks a specific profile \( p \) (or vice versa) the indexes of concordance \( C^k(a,p) \) (Roy 1968) have to be calculated as follows:

\[
C^k(a,p) = S_j w_j k c_j^k(a,p), \quad (k=1,2,...l)
\]

where

\[
c_j^k(a,p) = \begin{cases} 
1 & \text{if } g_j^k(a) \geq g_j^k(p) \\
0 & \text{if } g_j^k(a) < g_j^k(p)
\end{cases} \quad (j=1,2,...,n; \ k=1,2,...l).
\]

\( g_j^k(a) \) and \( g_j^k(p) \) are respectively the levels of \( a \) and \( p \) on the criterion \( j \). The condition \( g_j^k(a) \geq g_j^k(p) \) is fulfilled if the project is assigned to a level of the semantic differential equal or higher to the level of the reference profile. The index of concordance can vary between 0 and 1: the more his value is near 1, the more 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 change in (1) and (2) \( a \) with \( p \). In general \( C^k(p,a) \neq C^k(a,p) \).

To assert that a outranks \( p \) it isn't sufficient that \( C^k(a,p) \) assumes values near to 1. If the difference \( g_j^k(p) - g_j^k(a) \) is considerable, also for only one criterion, the outranking couldn't occur, or, eventually, appear not very credible, aside from the value of \( C^k(a,p) \).

The procedure asks that every judge assign 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 the judge \( k \) could accept for the criterion \( j \) in order to attribute to the outranking a Sp a high credibility. The veto thresholds are used to calculate the "fuzzy" indexes \( S^k(a,p) \), which represent the credibility degrees of outranking a Sp.

To calculate these indexes we must calculate the indexes of discordance \( D_j^k(a,p) \), which are defined as follows:

\[
D_j^k(a,p) = \begin{cases} 
1 & \text{if } g_j^k(p) \geq g_j^k(a) + v_j \\
0.5 & \text{if } g_j^k(p) = g_j^k(a) + v_j \\
0 & \text{if } g_j^k(p) < g_j^k(a) + v_j
\end{cases} \quad (j=1,2,...,n; \ k=1,2,...l)
\]

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

\[
S^k(a,p) = \begin{cases} 
C^k(a,p) \text{ if } D_j^k(a,p) \leq C^k(a,p), V_j \\
1 - D_j^k(a,p) \text{ if } D_j^k(a,p) > C^k(a,p)
\end{cases} \quad (k=1,2,...l)
\]

\[
\text{if } C^k(a,p) P_j \frac{1 - D_j^k(a,p)}{1 - C^k(a,p)} \]
where $P_j$ is extended to all the values of $j$ for which is $D_j(k,a,p) > C(k,a,p)$. In general, the smaller are the threshold of veto $v_j$, the lesser is the degree of credibility of the outranking. Comparing the project with all the profiles, upper and lower, we obtain for each judge 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 the fig. 1 (Scharlig 1985, Vansnick 1979).

![Figure 1. The Decision Tree](image)

where $B^+, B^-, C^+, C^-$ represent respectively the number of judges for which the indexes $S_k(a,b), S_k(b,a), S_k(a,c), S_k(c,a)$ exceed respectively the thresholds $S, S', T, T'$. These thresholds are chosen empirically, considering that the more are growing their values, the more severe is the "filtering" of the corresponding indexes and lesser is the number of judges for which the corresponding outranking relation assumes credibility. 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.

**An Application of the Evaluation model**

The procedure of evaluation has been applied, as a didactic experience, to one of the projects of the Italian students who participated to an inter-school competition, proposed by the 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 of the English architecture: the competition proposed in december of 1900 by the german revue "Zeitschrift fur 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, in the occasion of the celebration of Glasgow architecture, which marked the European City of Culture for 1990.

The building is intended for habitation with some characteristics connected with the kind of user (a media lover). Especially, it should provide for collateral activities to satisfy professional, social, and cultural needs, to promote hobbies, and to encourage communication and meeting at professional and family level, with the aid of advanced technologies. In addition the 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 is made up of 6 standing inhabitants, not necessarily linked by familiar ties, and of two guests.

The participants to the competition could moreover choose the localization of the house. In the following we'll 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)

![Figure 2. The design of a Media Lover House (Thesis in Design Methods). The project of the students compared with the Art Lover House of C. R. Mackintosh.](image)

The students, in developing their project, used the system AID. The project, was emblematically located in BellaHouston Park, in front of the Art Lover House of Mackintosh (figure 2). The evaluation procedure has been applied by the students to the last two cycles of analysis-syntesis-evaluation of the development design phase (figure 3).
Figure 3. The Menu of An Interface for Designing (AID).

Figure 4. The Evaluation criteria.

With the aid of the procedure, in the last but one 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 a strat-
egy it is sufficient to apply the evaluation model to the vectors which represent the estimated performances of the modified project. To chose the best strategy the students considered only the actions that don't lead to the total transformation of the project and that allowed the minimum design effort.

**Figure 5a.** An example of semantic differential (criterion 2).

**Figure 5b.** The Architecture of C.R. Mackintosh is the main historical reference of the project.
The choice of the evaluation criteria was done together by the students and by six professors (see Annex). The lack of a criterion on the quality of the formal aspects is justified by the fact that every criterion take into account this requirement (see, for example, the criterion 5). To choose the examples to be used to better explain the meaning of the polar terms of the semantic differentials, many projects were analyzed and evaluated in relation to the different criteria(figure 5a, 5b and 6).

![Figure 6. Another example of semantic differential (criterion 5).](image)

This contributed to develop in the students a multicriteria mentality, i.e., the capacity of considering together many different aspects of designing. The weights of the criteria were assigned separately by every judge (figure 7), who, successively, evaluated the project in collaboration. This evaluation is a result of a preliminary discussion which makes an agreement between the judges a norm for this procedure.

![Figure 7. The Evaluation of a judge.](image)
The judges decided to use the same reference profiles, i.e.

\[ b^k = (5,5,5,5,5,5,5,5) \quad (k=1,2, \ldots l) \]

\[ c^k = (3,3,3,3,3,3,3,3) \]

The profiles are "flat", i.e., 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 aren't innovative (level 3) and that the relationship with the urban context (in functional terms), the comfort in the building, the static solution, the construction and maintenance costs can't be considered satisfying (level 4). The performances referred to the other criteria are sufficient (level 5). The project, evaluated with the trichotomic segmentation procedure, is assigned to the category \( K^2 \). 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 oriented to improve the projects:

- the originality of the technological solutions, with particular reference to the use of 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-existences, through a study on the English houses and the architectural language of Mackintosh (from level 5 to level 6);
- the layout problems (from level 5 to level 6).

This strategy should improve the project as follows:

\[ a = (5,6,4,6,4,4,4,4) \]

The components in bold style indicate the changed levels. These modifications aren't sufficient to change the project from the category \( K^2 \) to the category \( K^+ \). The students decided to explore a strategy which consider other improvements, in addition to those considered before. 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 the category \( K^+ \) (figure 9).

In conclusion, these simulations, done with the aid of the evaluation model, allowed to identify the directions in order to improve the global quality of the project. The necessary controls and modifications were done successively by the students using the AID system.
Some significant drawings of the project generated during the synthesis phase are shown in the figures 10 – 12.

**Figure 8.** Searching for strategies to improve the project. The actions that do not imply a revolutionary transformation of the project and allow the minimum design effort are considered.

**Figure 9.** The final evaluation.
Figure 10. The step of synthesis (conceptual design): The images contained in the designer’s memory help produce the first sketches.

Figure 11. The step of synthesis (last cycle of developing design). The geometric model of the project is elaborated with the aid of a 2D drafting program.
Figure 12. The step of synthesis (last cycle of developing design). A 3D model helps to define volumes, spaces and materials.

References:

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Jones J.C. 1970. Design Methods, N.Y. : J.Wiley & Sons
Luckman J. 1967 "An Approach to the Management of Design", Operational Research Quarterly , 18 , 4
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 (Wright’s Kaufmann House, some examples of Castles in Scotland or France)
   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 characters of the place and, inserting itself in the context, qualifies it (the work of Scarpa in Venice, la Rinascente of Albinì in Rome).
   Level 1 - The project puts itself in contrast with the historical and cultural values of the context, demonstrating a lack of understanding and thereby negatively influencing the equilibrium of the place.

3. RELATIONSHIP/INTEGRATION WITH THE URBAN FUNCTIONAL SYSTEM
   Level 7 - The project matches very well the hierarchical structure of the roads network and urban services. In addition, this integration is plainly rendered in the projectual solution (the Crescent in Bath, l'unité d'habitation of Le Corbusier, some Dutch and German projects of '30).
   Level 1 - The project neglects the problems of the urban functional system, hindering its function.
4. FULFILLMENT OF THE PRIMARY FUNCTIONS AND OF THE SOCIAL MODEL IN TERMS OF SPACE AND LAYOUT
Level 7 - The layout and the dimensioning of the spaces take into consideration the needs of the users. Different activities and possible changes with time of the needs are also forecasted. In addition, the project represents an innovative solution (Existenz Minimum of Gropius, Siedlungen of Ernst May and Bruno Taut, the Weissenhof).
Level 1 - The layout and the spaces do not take into consideration the needs of the users, making the carrying out of personal activities difficult and revealing a total absence of spacial flexibility.

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, can not guarantee a 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, coherent with the formal solution, shows its structural clearness and coherence.
Level 1 - The structural tipology is not coherent with the formal solution and contrasts with the materials.

7. ORIGINALITY AND INNOVATION OF THE TECHNOLOGICAL SYSTEM
Level 7 - The project owns the most advanced technological systems (related to construction technology, security, recycling of construction materials, production of energy, management of equipments, etc.) meeting the highest level of quality’s needs without altering the architectural image itself.
Level 1 - The project does not take into consideration any innovation concerning technological systems: the systems used are surpassed and do not integrate with the formal solution.

8. SAVING IN THE CONSTRUCTION AND MAINTENANCE COSTS
Level 7 - The cost level is contained with respect to the choice of materials and construction elements which take into consideration the obsolescence problems, as well as the security and environmental comfort; in addition, the 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.