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THE IDENTIFICATION
OF ARCHITECTURAL DESIGN CRITERIA
BY COMPUTER: AN EXPLORATORY STUDY

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INTRODUCTION

Integral to the architectural design process is the means by which a designer operationally defines the goals of a problem. Seldom, if ever, is a design problem received which includes in its initial statement specific considerations for materials, environment, or human factors. Most often the information given is the identification of room types (i.e., bedroom, office, chemistry laboratory) and/or activities for which they are to be designed (i.e., reading, typing, general research). From such initial types of information, and from refinements he is able to elicit of them, the designer is required to define those criteria for materials, space needs, space relationships, human factors, and other types of considerations necessary for making the design decisions involved in completing the project.

Only the gross outlines of the traditional process by which architects carry out this definition is known. It seems certain that the specific considerations are produced via a psychological mechanism similar to "association". The designer's experience with the effects of materials and form on various activities allows him to "associate" those materials or forms, or qualities of them, with the desired activities. Whether he calls his procedure "association", or "projecting himself into his client's shoes", or "applying his experience", the central cognitive activity seems to be one of recalling and applying observed interactions between desirable activities or functions and the space or its qualities that helped produce them. Both general "scientific" criteria and subjective unique criteria are determined in this manner. It is by recalling experienced interactions that the designer operationally defines the goals of his problem. The process can be described as being intuitive.

This traditional problem-defining process has been found to be weak for two reasons. Because science, particularly engineering and the behavioral sciences, is continually identifying more interactions between behavior (i.e., activities) and qualities of the environment, designers have the responsibility of applying an ever larger number of considerations to their design problems. While the traditional process was appropriate when design considerations were primarily a product of the designer's individual experience, it has not been found competent for recalling scientifically derived criteria. Such criteria, with its qualities of being detailed, measurement-oriented, and less observable to direct experience, do not possess the learning and experiential cues relied upon by the traditional intuitive approach. Thus, architecture has been slow to incorporate scientific considerations in its endeavors. And while science is making design problems more complex, the business environment in which architects work demands that design criteria be identified in shorter time and for continuously larger scales of projects. Thus, relatively fewer considerations have time to be recognized; less comprehensive design is the result.

A second weakness in the architect's traditional intuitive means for identifying design goals is the limitations it often imposes on his own creativity. In the hurried associational search of his memory for relevant considerations, an architect is likely to associate a previously seen solution rather than the criteria determining that solution. Instead of generating considerations for the development of his own solution based on its own context, a designer may associate a physical solution that, in some other context, worked well. Yet without generating criteria, he has no means for evaluating the worth of any proposed solution. Thus fewer original alter-

natives are created. Because of the pace by which modern architectural design must be produced, the re-applying of someone else's solution without thoroughly analyzing its consequences has become a common practice. This habit is even reflected in our building codes where partial solutions, i.e., materials and quantities, are specified rather than performance criteria.

Computer technology offers the potential means for correcting the faults now existing in our present means for identifying appropriate criteria for architectural and other types of design problems. Its capabilities as an information retrieval device are well known. And recently means have been developed for internally restructuring information automatically so that it may be retrieved in any desired form. What is suggested here is that it presently seems feasible for the general, commonly known goal criteria relevant for any typical type of design problem to be stored in computers in more detail than is humanly possible, and to be comprehensively retrieved in a manner that recognizes all the possible combinations of activities and all the material, space, and environmental criteria that are presently known to affect these activities. In essence, such a system would be able to retrieve in comprehensive form appropriate performance criteria, given any set of building functions. Such an automated system is a necessity if design is to reflect our present and future knowledge concerning the effects of the environment on human well-being, and if it is to continue providing creative alternatives for environmental problems.

REQUIREMENTS FOR SUCH A SYSTEM

A computer-based retrieval system for identifying performance criteria would be required to handle human and mechanical systems constraints for any activity or group of activities. Because supporting equipment systems for a project may be "given" or their design may be part of that project, retrieval should be possible at several levels of detail.

Other criteria for such a retrieval system would be:

1. The system must be able to retrieve information using input traditionally available in the presentation of a design problem. It should be able to respond to various amounts of input detail. More detailed input should produce more refined output;
2. It must produce as output operational criteria that can be applied directly to the design problem. It must be able to produce performance criteria in the form of physical measures or other well-defined formats that can be unambiguously applied by a competent designer;
3. It is expected that designers will rely on computers in the future for a wide range of design activities, including analysis, decision-making, and alternative generation. The system outlined in this research should have the capability of being integrated with other design-oriented computer systems. Thus, its output should be in a format that can be directly applied to computer-based analysis and decision-making. The results of various analyses should be capable

of being stored within this system as relevant criteria for future problems.

THE PROPOSED PROJECT

The proposed project concerns the development of an automated retrieval system for identifying general, scientifically derived design criteria in performance terms. Such a system would allow more comprehensive consideration of generally known criteria and would free designers to generate new alternatives and recognize those unique subjective criteria existing in any project.

This exploratory project would involve the conceptual development of such a system. It would identify what the organization of such a system might be in terms of its information files and processing routines. It would also explore the feasibility of such a system.

The results of such a study would be presented in a report to the funding agency. Included within the report would be:

1. An introduction stating the need for such a system, along with a review of the relevant literature concerning the problem;
 2. The development of a general cognitive model of the problem specification system traditionally employed by designers. The relevance of this model is that any new tool to be utilized by designers should be compatible with their present mode of thought;
 3. The general design for an automated performance specification retrieval system. This system would be capable of storing and
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retrieving appropriate scientific or commonly known information for any type of architectural design problem. The system design would be presented in written and diagrammatic form, and would reflect the requirements presented in this proposal;

4. An evaluation of the operational capabilities of such a system. This would include an estimate of the size, in core and secondary storage of the system for different capabilities, and a discussion of the information formats that might be used.

In general, the system will be developed so as to be compatible with the general model of the design process presented in Appendix A.

The proposal requests funds for Mr. Eastman for a period of eight weeks and for a secretary half-time for the same period. It is requested that the project begin February 1, 1968; the final report will be in the hands of the funding agency before 5 June, 1968.

APPENDIX A

A section of a forthcoming research article titled "The Strategies of Design". This section describes the general model of the design process now being developed by Mr. Eastman.

PART ONE: THE MODEL

There have been several attempts to generate a working model of the design process. Some have been for the purposes of improving the rigor of design by making sure no steps were omitted (Archer, 1965; Matousek, 1963; Hall, 1962, Ch.4), others for logically strengthening some of the procedures designers unselfconsciously utilize (Norris, 1963; Alexander, 1964). All of the existing models have been developed for purposes other than computer application or simulation. Thus, no model has responded to the essential capability of computers and has approached design from an information processing point of view. Such an approach seemed profitable, also, because other studies of complex problem-solving behavior have fruitfully applied this perspective (Feigenbaum and Feldman, 1963; Kleinmumtz, 1966). Thus, approaching design from an information processing viewpoint allows design processes to be compared with other types of complex mental processes.

From the initially available protocol, many insights were possible that suggested an approach for generating such a model. It was clear that design is a special kind of problem-solving task. That is, it requires the transformation of information from one form into another (Reitman, 1964, pp. 282-314). It was also clear that design is a serial procedure where only a few considerations are applied at a time. In the protocol, each physical aspect of design is considered numerous times from such points of view as structure, fabrication, maintenance, human factors, and esthetics. Each goal consideration has a form consequence which the designer attempts to integrate with the partially complete design. In a general sense, it was seen that the procedure of design was one of multi-variate, multi-stage,

decision-making (Bellman, 1961, p.52; Mikhalevich, 1965).

Yet it was clear that designers do not simply apply criteria against a set of alternatives in a random serial fashion. Such a notion would wrongly assume that each decision is independent from others. One physical change in a design may affect many design considerations.* Design problems have a structure; the resolution of one consideration influences other considerations via the alternatives chosen. Thus, each alternative is chosen with consideration of the goal constraints determined at the outset of the problem, and the constraints imposed upon it by already chosen alternatives. Besides these explicit constraints, the designer must also consider how each alternative will integrate with yet-to-be chosen alternatives fulfilling as yet unresolved considerations. This factor is based upon the designer's prior experience with resolving this type of problem and can be considered as a subjective likelihood ratio (Manheim, 1966).

These points may be summarized thus. The value of any alternative (V_{a_n}) is equal to the inverse of the sum of the distances between its parametric values ($v_{1...m}$) and those values initially desired or determined by other alternatives, plus the sum of its likelihood of being compatible with yet-to-be chosen alternatives times the probability that the alternatives will be included in a final solution ($w \cdot P_{n...r}$). Thus, the total value of any alternative in a particular decision-making situation is

$$VA_m = \frac{1}{\sum d(v_{1...m})} + \sum (\bar{w} \cdot P_{n...r})$$

* In many respects design is similar to dynamic programming. The principal difference is that, while the restrictions for each decision moment is independent in dynamic programming, design involves a constraint structure within a decision series. (Mikhalevich, 1965, p. 168)

Since $\sum(\bar{w} \cdot P_{n...r})$ can vary significantly according to which decisions have already been made, the order of decision-making significantly varies the value of any alternative. Thus, the order of decisions is of central importance in design. Indeed, there is much to suggest that designers rely on the likelihood ratio for determining the order for making decisions. Several strategies for applying this ratio were observed in the protocol and in the experiments to be discussed. It will be shown that the likelihood ratio, the sequence of decisions, and the "style" of the design solution are all interdependent.

The total value of any alternative will vary during the decision sequence, before and after a decision concerning it has been made. Though this likelihood ratio seems to be a minor aspect of the total value of an alternative (from all analyses of present studies) it does vary enough to alter some decisions. Thus, any serial set of decisions can hardly be optimal. And as significant variations in the likelihood ratio are produced during the decision sequence, reiterations of previous decisions become desirable. These points will be elaborated later.

The two explicit types of constraints, those of goals determined outside of the design problem, and those resulting from the interaction between alternatives, emphasize that a design problem can be defined at any level of detail. For example, certain components of an electrical system or building may be prescribed at the outset of the problem. Thus, the incorporation of these total units is a design goal; their interface with the thing to be designed are the constraints. A similar design problem may also involve the design of these components. In this case, not the resulting interfaces but the constraints that prescribe these components would

be the goals of the problem. Thus, the physical world can be considered as made up of hierarchical sets of components. A particular design problem may involve within its realm any set of these components in several hierarchical levels. The limits of the problem are determined by its goal constraints, which identify the constraints imposed by those aspects of the world outside the scope of the problem, and hence define the boundaries of the problem.

The central decision-making aspect of design seems to easily fit into this multi-variate, multi-stage decision process. Numerous examples in the first protocol showed the designer comparing over time several alternative schemes against a set of criteria. Though these criteria were sometimes accidentally discovered and hence randomly applied, more often they were structured into a predetermined decision sequence, into a decision strategy. The alternative schemes were integrated and compared at several levels of detail, from general considerations of the overall project to specific considerations concerning component alternatives. The comparing of alternatives followed procedures generally called analysis, the determining of relationships between parameters of the alternatives.

But decision-making alone does not include nor explain other important activities of design. While some criteria given to the designer was explicit, it was seen from the protocol that others were very general. Others were not even mentioned in the problem statement given to the designer, but were identified by him as he resolved the problem. Thus, designers are not passive translators of goal criteria into specifications for form, but are also active in specifying goal criteria.

Thus, another sub-system in the design process concerns goal specification. This system translates needs, desires, implications, or other relevant

information into a mode that can be related to physical form. Indeed, the very definition of relevant information for design is determined by whether it has form consequences. Goal specification generally proceeded from a specification of inputs, which might be the activities or room types, through all known variables affecting performance and/or well-being to physical parameters that could be related to known attributes of a physical design. Goal constraints consist of a continuum between generally known, universally applicable "scientifically derived" constraints and unique, subjective constraints only applicable to the particular problem.

The final form of goal constraints were found to take one of three forms.

1. The most common form of constraint in the original protocol is a threshold, and can be represented by a line separating equally acceptable values from those unacceptable. It may also be represented by two lines between which are equally acceptable values and outside of which are unacceptable ones. Threshold values seem particularly suited for treating discrete alternatives, and have been examined by Simon who calls them a "satisficing function" (Simon, 1957, Chapt. 14).
2. Other constraints in the protocol are specific, and represent a goal that a solution must exactly achieve. The degree to which any alternative fulfills a consideration of specific form depends on its ability to approximate its value. Examples of specific constraints in the protocol are the departmental units and the visual form constraints. Specific constraints vary in their sensitivity -- the influence of variation on acceptability. Constraints absolutely sensitive allow no variation, while others

vary widely (Asimow, 1964, p.26).

3. Directional constraints are also encountered. They represent maximizing or minimizing goals; maintenance, cost or time of travel are possible examples. While the first two types of constraints do not necessarily require optimization, the superlative nature of directional constraints does. Because one directional constraint among specific and threshold constraints greatly limits solving for the others, designers often attempt to re-define directional constraints into one of the other forms.

Another aspect of any model of design is that it must include some means for generating alternatives. Some decisions are made from among relatively discrete choices; i.e., materials, manufacturing operations, beam sizes. On the other hand, some of the most important decisions concern continuously varying alternatives; shape and spatial relationships are the two most obvious examples. Both types of alternatives must be included in any comprehensive model of design. As a result, various routines for generating shape and spatial alternatives have to be included within any model of design.

It may be helpful to introduce at this point definitions of the units used in this study and reiterate the structure between them. Design has already been defined (see footnote, page one). Goal constraints are those constraints predetermined outside the object or system being designed, and are expressed in qualitative or quantitative terms. They may be "given" or may be identified by the designer. Human factor, organizational inputs, environmental criteria, may all be examples of goal constraints.

In this paper the qualitative or quantitative dimensions defining potential goals represent parameters, the relevant types of considerations for the entity being designed. A parameter and its required value or form thus defines a goal constraint.

A material configuration considered as part of a design solution is here called an alternative. Each alternative has values for the parameters relevant to the design problem, that is, each influences some goal or goals. Those alternatives whose values of relevant parameters best meet the goal constraints become part of the potential design solution.

Another type of constraint develops when some alternative is accepted as part of the design. An accepted alternative not only affects certain goal constraints, but also other alternatives that can go with it. The structural system of a building constrains the kinds of exterior wall panels that can be used, materials constrain joints, one piece of electrical or mechanical equipment constrains others in the same system. These kinds of constraints become part of the design problem as soon as the first material decisions are made. In this paper they are called alternative constraints.

A third type of constraint influencing any design decision is the estimated likelihood of ultimate compatibility for each alternative considered. These three types of constraints - goal constraints, alternative constraints, and compatibility likelihood ratios; all influence the decisions of the design process.

(Insert Figure One)

In summary, the preliminary information processing model gained from the initial protocol of the design process took the form shown in Figure One. At the most general level of organization, it is simply the traditional

decision-making paradigm of relating constraints to alternatives by a decision strategy. At a more detailed level, the dynamic and material aspects of design introduce unique variations. There are three types of constraints. Figure One indicates that alternatives are of at least two kinds, discrete and continuous. Different procedures must be included for each. The binding system integrating the whole process is the design strategy. This system orders and integrates sequential decisions.