

UC Berkeley

IURD Reprint Series

Title

Some Principles for the Design of an Educational System for Design

Permalink

<https://escholarship.org/uc/item/65s2n9r1>

Author

Rittel, Horst W.J.

Publication Date

1966-04-01

Peer reviewed

Reprint 54

Some Principles for the Design of an
Educational System for Design

Horst W. J. Rittel

University of California at Berkeley
Institute of Urban and Regional Development

Reprint 54

**Some Principles for the
Design of an Educational
System for Design**

Horst W. J. Rittel

April 1966

**University of California at Berkeley
\$10.50**

SOME PRINCIPLES FOR THE DESIGN OF AN EDUCATIONAL SYSTEM FOR DESIGN

Horst Rittel

University of California, Berkeley, California

INTRODUCTORY REMARK

I shall discuss the intellectual tools I think an architect should have and suggest ways of providing them. I shall try to deal with this subject, in spite of the fact that I am not an architect myself, because I have been "living among" architects and other kinds of designers for several years - trying to understand what their problems are and how they deal with them, observing their work, attempting to theorize about their activity, and occasionally even proposing a trick for overcoming some particular difficulty in their work.

This role is that of a methodologist, i.e., someone who is concerned with the procedural aspects of an activity, in approaches to problems and their "logic." Methodology is "rational" in the sense that it aims at explicit, communicable, and plausible descriptions and rules of the What? Why? and How? of the activity under study.

This ambition engages the methodologist in a permanent struggle with the proponents of "common sense," in particular because his endeavor gives rise to peculiar side effects: it tends to make things even more difficult than they already are. Raising the level of consciousness must be paid for with a loss of innocence and naïveté--without at all guaranteeing better solutions. The bicyclist who consciously applies the theory of the gyroscope to control the movements of his limbs will not automatically win the Tour de France.

In fact, it is argued that any rational intrusion into the creative process must lead to its frustration, that the essential creative events during this process take place beyond the reach of rational understanding and control, and depend on uninhibited, freewheeling, preconscious imagination.

While this objection sounds serious, it is not to the point. First, designing is not an incessant stream of creative events; it is highly patternized and organized labor, only occasionally interrupted by sudden insights and ideas. Second, it cannot be taken for granted that those rare "creative events" are necessarily mysterious and beyond comprehension. On the contrary, there is evidence that good ideas can even be produced systematically, and, without much exaggeration, it can be postulated that a good designer is almost never a naive one. Further, the main difficulties of designing may not lie in lack of ideas, but in developing concepts and ideas toward a solution and its implementation.

I shall first try to identify various doctrines of architecture and to analyze some of their implications for architectural education, hoping to arrive at principles for the design of educational systems for architects. Teachable abilities can be grossly classified into:

- a. Skills and dexterities, like freehand drawing, making an appealing cardboard model or extracting a square root. They are best trained by some kind of conditioning, by demonstration and exercise.
- b. Judgmental capabilities, as about harmony, becomingness, appropriateness. They are best transmitted by "ostensive" procedures, i.e., by pointing at good and bad examples.

- c. Factual knowledge about bricks and beams, the building code and construction cost. It can be taught by textbooks and lectures and lends itself to automated instruction which is most appropriate for rote learning.
- d. Knowledge of problems and of ways to go about them. Knowledge of this kind requires and builds up a high level of consciousness and critical ability. It is acquired by "insight," not by rote learning.

Only the last category deserves the label "intellectual," and I shall focus on this category.

APPROACH

I propose a point of view which might be called that of a "systems designer," an approach characterized by the strategy of "working backward," i.e., of first trying to identify which purposes the object to be designed has to fulfill, and from this description of the "mission" of the "system," drawing implication for its design, working gradually toward more and more detail. In our case, the task is to design an educational system for architects.

What is the mission of this system? A simplistic, though not useless, answer is: "To prepare and to equip people for a life as a professional." We must then determine the present tasks of that profession, and what these tasks will be in the future. This question answered, one would proceed to identify the typical difficulties of dealing with these tasks. Based on these findings, one would establish the catalog of skills and knowledge the professional needs in order to

overcome these difficulties. Finally, techniques, strategies, and institutional devices would be developed which are suitable to transmit and to train these capabilities.

But in applying this approach to the problem of designing an educational system for architecture, serious difficulties are already encountered in the first step: unfortunately, there is no agreement at all as to the role of the architect, or his tasks and responsibilities. There is a continuing controversy between the representatives of substantially different self-images, each naturally having different implications for the design of the educational system.

What Are The Architect's Tasks?

So, to sketch some of these "archetypes":

- "The architect is a coordinator of construction projects who integrates the knowledge of many disciplines into one solution, reconciling conflicting demands and preferences. He is mainly a manager and a mediator."
- "The architect is a man who designs buildings."
- "The architect is an environmental engineer who knows how to provide desired controlled conditions of human environments."
- "The architect is a specialist for designing and manufacturing building construction and component systems."
- "The architect is and will remain mainly an artist, some kind of sculptor of the void, using buildings as his medium. He creates spatial images relying on his knowledge of intrinsic "architectural values." In this category, several variants can be distinguished:

- the man whose job it is to make the world more beautiful,
- the sculptor for whom structural hardware is mainly a means for self-expression,
- the visionary who wants to produce tomorrow's imagery,
- the social realist who wants to depict the state of society in terms of buildings,
- the mysticist of "form," by which he means some substrate that has the tendency to become physically manifest. He only liberates it.

And so on and so forth. There does not seem to be one single conceptual framework which fits all of these points of view, and no educational system could account for this diversity.

These discrepancies notwithstanding, most people do agree that the profession of architecture is in transition. Almost everybody expects major changes; unfortunately, the direction of this change appears to be most uncertain.

The reasons for this attitude are obvious. They lie in the history of this profession, which--for a century--has become more and more of a mongrel offspring of engineering and the beaux arts. No wonder that architecture is lost between the worlds of real estate and esoteric taste, of cultural change and cultural romance. The 1300 American architectural firms form a charming subculture, controlling a small and shrinking share of the total investment in building construction.¹ Most of the jobs of building design are carried out by

other people: engineers, developers, construction firms, manufacturers of prefabricated systems, and amateurs.

Many architects claim that most of these people do not do their jobs very well; e.g., that the desolate landscapes of suburban tracthouses clearly demonstrate their lack of architectural involvement. Such protests seem futile, and the majority of architects seem pushed into a more and more restricted role, to wit, that of designers of:

- representational buildings,
- "custom built" residences for those who can afford them either as a means of conspicuous consumption, or as living pieces of art (or both).

Perhaps this dim picture is not valid for that successful minority of leaders and pacemakers of the art and for the large offices. But it applies to the army of ordinary architects, in their mini-offices, struggling for a micro-existence.

One might conclude: "So what? Subcultures come and go. Witch-doctors, blacksmiths and custom tailors have vanished or lost their significance, their tasks taken over by other people. Why should architecture be immune against this fate?" Why not, indeed!

Whether such a development will occur depends decisively upon the policies and strategies of the profession. Of course, the architects are not the only players in the game about the future of the profession. But in order to improve their chances of settling in an interesting and rewarding territory in the professional landscape, they better ought to formulate their claims and better advertise what kind of service they will offer.

In this development, the position of the schools will be very important. Here the self-images of the future members of the professions are molded (in the USA, at a rate of almost 2,000 graduates per year), and therefore, here a reform of the profession ought first to become effective.

Yet the ideals which the schools cherish do not seem realistic, progressive, or consistent. Consequently, the syllabi are often implausible, faculties perplexed, and many students adopt as a naive goal the role of smart independent practitioner, who starts his career in his own small office, creates a little gem of architecture, becomes "published," and enjoys recognition manifested in large commissions. They learn the hard way, and often late in life, how inadequate this ideal is.

THE MASTER-APPRENTICE SYSTEM

It might be argued that the situation is not so dramatic at all, because education does not terminate with graduation. Afterwards starts another kind of learning process, that of gathering professional experience. Therefore, why not continue the operation of the existing educational facilities, modify them wherever appropriate and leave to practice the adaptation to the changing conditions of practice? But this proposal does not help us. First, the value of professional experience is overestimated. Much of professional experience consists only of a record of painful mistakes without insights for future usefulness. We do not automatically learn from past mistakes. Furthermore, the ability to adjust to changing conditions is overestimated.

We tend to stick to our habits, and increasing experience means increasing rigidity. Finally, if professional experience were really the best school, why not abandon academic education for architecture and return to the master-apprenticeship system? Why fill the heads of the students with materials which will become obsolete within a few years anyway, as, e.g., technological details? But a retreat into this system does not offer a solution. Even today's masters of the art cannot be prototypes for tomorrow's architects; mastership must be paid for with a decreasing capability for re-learning.

LEARNING HOW TO LEARN

Although it proves not to be meaningful at present to undertake the design of an educational system for architecture, one might investigate the more general problem of designing an educational system for design. One could at least search for principles pertinent to the education of all kinds of designers--including those types of architects which can be considered as designers and not as artists (in the sense to be discussed below). Very likely, such principles are not specific, but since we are interested in implications for designing educational systems which produce designers for a varying, uncertain class of future tasks, a wide scope of generality is desirable. We want initially to determine features of designing likely to remain invariant over a long period of time.

One principle of design education likely to serve this purpose efficiently is "teaching the student how to learn" rather than filling his brains with piecemeal knowledge which can be expected to become obsolete within a short period of time. K. Boulding points out that:

"...the academic world generally goes on the assumption that the more we know of everything the better. . . . The student has always known better than this. He has usually operated on the principle of knowing as little as he can get away with. It is time, perhaps, for this principle to be made respectable. We must reexamine the whole process of formal education from the point of view of what is the minimum knowledge, not the maximum, which must be transmitted if the whole structure is not to fall apart. Any economizing of learning, therefore, is highly desirable.²

This sounds simple and straightforward, and Boulding elaborates how to implement this policy:

"If a single theoretical principle can be shown to apply over a wide area of the empirical world, this is economy of the learning process."³

Naturally, any good theoretical principle replaces the necessity of knowing a great number of piecemeal details. Thus learning about a particular air conditioning device will be facilitated by the knowledge of the laws governing all air circulation, which in turn becomes easier to grasp if one knows some principles of gas mechanics and physiology. Certainly we can operate and use devices without understanding "why" they work the way they do. But only by general principles we do not have to become familiarized with them one by one--analogies as well as significant distinctions are revealed, and we can transfer knowledge from one particular case to another.

This is not new. It is the way physics or philosophy are taught. The question is: "Can powerful principles and laws be found for the designer, providing aids for 'learning how to learn'?" My answer is affirmative--although some warnings are in order. General laws and principles are not panaceas, but intellectual economy blending

piecemeal knowledge and general theoretical knowledge into a balanced diet. The understanding of the laws of Newton and Hooke is sufficient to derive the critical inequalities for most of the cases of structural design. But it is a very time consuming procedure to derive the "formula" for each specific case. Therefore it is useful to know the frequently used formulae by heart, or at least to know where to find them in a handbook when needed. Moreover, general laws are not eternally valid; they are changed by research and development. Fortunately, they do not change rapidly, and very often they do not become obsolete at all. The old law becomes only a special case of a new, more general law (as happens frequently in the natural sciences). But even if some law is abandoned as untenable, understanding the reasons for this event is supported by the understanding of the rules for corroborating or refuting hypotheses.

General principles and theories are powerful means for learning, allowing for adaptation under widely varying circumstances. The program for the institution Science consists in boldly formulating universal statements, safeguarded against over-generalization by the rule that every hypothesis should be as sweeping and even provocative as possible--in order to challenge its refutation--but also so specific that its refutation is possible, at least "in principle," i.e., it must be possible to design a crucial test or an experiment, one conceivable outcome of which would clearly demand the refutation of the hypothesis under test. What is known as "the scientific method" is nothing but a set of rules for formulating, corroborating and refuting hypothesis, none of which can ever be positively proven.

In ordinary life, and in many of the professions, there is no equivalent guarantee for permanently challenging established truths. Therefore, there are in fields like architecture few general theories and little testable knowledge.

To design a viable educational system for design, some analogy to the scientific strategy would be helpful, some set of rules of how to test a solution of a design problem against a list of predictions the designer has made in developing the solution.

These considerations suggest a further principle for educational systems for design: "Do not only teach general rules but also rules for the changing of rules!" Teach how to design a theory and how to test it. Philosophy belongs in the design studio; it is not sufficient to have it listed in the curriculum under "general electives."

GENERALISTS VERSUS SPECIALISTS

One group of design educators claims that the designer must be a "generalist," the others say that he must be a specialist. "Education in breadth" versus "education in depth" is a favorite topic, discussed through maxims like, "Everybody must possess profound knowledge in one field plus a broad idea of all other fields impinging on his work," "Specialization first," "General education first," "The architect must be able to communicate to everybody with whom he has to cooperate in his work," "Architecture is a discipline of its own right and the architect should not try to be a jack of all trades," etc. (analogous arguments are found in other disciplines, such as engineering). The existing curricula of the schools are compromises between these doctrines, and the battle goes on.

However, the alternative, 'breadth versus width,' seems to be based on a spurious dichotomy. It is of little use to pile up 'width' by prescribing a long list of so-called non-professional prerequisites and electives which mainly consist of mutually unrelated introductions into a field. The capabilities of the students to "synthesize" these bits and pieces into a coherent body of knowledge, the various parts of which support and reinforce each other, are overestimated (the teachers cannot do it either!)

On the other hand, there is no evidence that specialists have to be narrow-minded and ill-educated. In defense of the specialists, Y. Bar-Hillel writes:

"... specialization has become a dirty word among many people, scientists included. . . (they) are emotionally convinced that specialization is evil and even resent its being regarded as a necessary evil. Though every scientist knows perfectly well that in order to remain an expert in some area he has to cut down the width of his interests more or less continuously, he has been exposed for such a long time to the propaganda of the so-called humanists, perhaps best expressed in the silly saying about 'knowing more and more about less and less' that he has become sub-consciously convinced of its truth."⁴

The regrettable narrow-mindedness of many specialists is due, not to their specialization, but to the fact that they have forgotten to question the foundations of their specialty, and because they consider themselves members of an isolated and internally justified sub-culture.

'Breadth' is meaningless apart from the capability of particularizing knowledge to a specific case, and 'depth' is possible only with the help of very general guiding principles.

The notions of generality and specialization are relative to the conventional landscape of entrenched disciplines which are the product of a very peculiar historic development. No logical reason could be derived, from the nature of the subject matters of these disciplines that would justify the present map of specialties. The issue is not, width versus depth, but plausibility and connectedness versus piecemeal scattering and superficial encyclopedic universalism.

CHARACTERISTICS OF DESIGN

In order to develop more specific implications for the design of educational systems for design we must ask "What is understood by design?" What is a designer, the product of such a system, supposed to do?

Designing is an ubiquitous human activity. A man designs whenever he has a purpose in mind and devises a scheme to accomplish this purpose. The outcome of designing is, not the accomplishment of the purpose, but a plan for its accomplishment. For instance, architects make plans for buildings but do not build buildings. The execution of the plan is expected to produce a situation with desired characteristics: this situation ought to contain what was to be accomplished, and--besides this--it should not incorporate undesirable and unforeseen side effects.

Designing means thinking before acting. A designer tries first to develop a set of alternative courses of action, then to figure out their potential outcomes and their likelihood, and then to evaluate them, finally to decide in favor of one of them. The designer intends to change a segment of the universe (what the scientist who is mainly interested in explanation of the universe, tries to avoid!)

His motivation is consequential action, not understanding or explanation. His desire to control the consequences of his actions means that he tries to behave responsibly (as does the scientist, though in a different way) and not capriciously. He worries about the potential effects of what he proposes to do.

Many of these features seem typical of all kinds of decision making. The distinctive property of designing lies in the--frequently very long--time interval between the design process (i.e., the construction of the plan) and the 'feedbacks'--the effects of the execution of the plan. "How good a plan was," will be found out later--during a future of indefinite length, reaching as far as causal chains can be and are constructed.

Design projects tend to be one-shot operations; there is not the opportunity to approach solutions by trial and error. There is nothing like experimentation with real situations. Once a plan is being carried out, it has become an essentially irreversible affair. It is impossible to try out a solution "a little bit," and then, if one does not like the outcome, to erase its consequences and to try something else instead. Plans in the process of execution are essentially definitive. In other words: a theory of design cannot be built on the assumption of repeatability and non-intervention with affairs that matter (in contrast to the theory of scientific experimentation).

As a result of these characteristics, the designer operates in a world of imagination. He has to anticipate, to guess, to judge what might happen if a certain contemplated action will be carried out.

Therefore, he relies on techniques which support "vicarious perception" of that what might happen as a consequence of his deliberated plans. Introspection, analogy, simulation, mockups, cardboard models, extrapolations, etc., are his aids to imagine what might occur and how desirable it would be.

DESIGN PROBLEMS ARE ILL-BEHAVED

Design problems have another feature: they are "ill-behaved."

In contrast to problems of arithmetic or chess, for example:

- they are not well-defined, i.e., every formulation of the problem is preliminary and incomplete. It changes in the course of solution. The reason for this is that each formulation of the problem is already made in view of some particular solution principle. If the idea of the solution is elaborated or even changed during the design process, new aspects become relevant and new kinds of information become pertinent. Different solution principles will lead to different questions about what is the case in the particular situation and about what is desired or acceptable. Since nobody can anticipate all conceivable design possibilities before design starts, nobody can list all potentially relevant data in a complete, well-defining problem formulation.
- for design problems there is no criterion which would determine whether a solution is "correct" or "false." These are meaningless labels which cannot be applied to solutions of design problems. Plans are judged as "good," "bad," "reasonable," but never "correct" or "false." And a plan that looks "good" to Mr. A. may be most objectionable to Mr. B.

- for design problems there is no rule which would tell the designer when to stop his search for a better solution. He can always try to find a still better one. Limitations of time and other resources lead him to the decision that "now it is good enough."

This ill-behaved nature of design problems frustrates all attempts to begin a project with an "information phase" or an "analytical phase" at the end of which the problem would be well described, including a complete list of objectives, which then would become the basis for a "synthetic" phase in which--in monastic isolation-- a solution could be worked out. Designing requires a permanent "feedback" with the problem environment, i.e., a perpetual information exchange about the conditions of the situation and about the "ought-to-state" which is to be accomplished.

DESIGNING AS SEQUENTIAL PROBLEM SOLVING

The resulting picture of the design process shows the designer "arguing" toward a solution with himself and with the other parties involved in the project. He builds a "case" leading to a better understanding of what is to be accomplished; in its course solution principles are developed, evaluated in view of their expected performance, and decided upon. The parties commit themselves to specific courses of actions and to the risks involved in them. In this way, better formulations of the problem are being developed simultaneously with a clearer and clearer "image" of the solution.

This process can be interpreted as an alternating sequence of two kinds of basic mental activities, followed by periods of unproblematic routine work (like converting a working drawing into a contract drawing). Every time a problem comes up, i.e., a difficulty that cannot be resolved in routine fashion, a cycle of the following kind will be triggered:

- initially, a phase of "generating variety": the search for a set of relevant possibilities which might solve the problem at hand. (This is the process of developing ideas. It ends with a set of alternatives which contains at least one element.)
- this is followed by a phase of "reducing variety": the alternatives are evaluated for their feasibility and desirability, and a decision is made in favor of the most desirable, feasible alternative, which is incorporated into the plan until another or the same difficulty arises, which gives rise to another cycle.⁵

In any real case, these problem-solving cycles will not form a linear sequence but a proliferating and nested network. In the early stages of a project in its conceptual phase, the cycles will apply to problems of determining the very general concept of the solution, its "morphology" ("To build or not," "Type of construction?"). Later on, more and more detailed problems will occur ("paint of ceiling in bathroom?"). This is the parametric phase, where the values of already identified variables are determined. Particularly in the conceptual phase, several alternatives may be pursued in parallel until finally one of them proves to be clearly superior. In many real design problems it would be desirable to follow this practice

more frequently, i.e., "to avoid to know too early what kind of a solution to aim at." Many a good solution is missed because of the fixation of the designer to a "pet idea."

This picture of the design process is simple, and the attempt here will be, not to develop it in all its detail, but to find implications about the kind of knowledge which guides the designer in this process, and which enables him to solve his problems.

INSTRUMENTAL KNOWLEDGE

In order to be "instrumental," i.e., useful in the process outlined above, an item of knowledge must have the form (in the simplest deterministic case):

"Under circumstances C, action A will lead to state T." If, in a particular situation, C is given and T is compatible with the situation to be accomplished, then A offers one possibility to solve the problem at hand. Apparently, the basis of instrumental knowledge are causal relationships. Whenever the causes are under the control of the designer, they are potential means, and the effects become potential ends. "Generating variety" can be considered the activation and construction of pertinent instrumental knowledge, each alternative representing a "cognitive system" made up of items having the form indicated above.

Instrumental knowledge relates three kinds of entities with each other. These three entities, which can be described as variables which can assume different values, are:

- a. Performance variables which express desired characteristics of the object under design, and in terms of which the object will be evaluated ("Construction cost," "Esthetic appeal," "Overall quality," etc.).
- b. Design variables which describe the possibilities of the designer, his ranges of choice, his design variables ("Height of ceiling," "Shape of door knob," "Type of heating," etc.).
- c. Context variables which are those factors affecting the object to be designed but not controlled by the designer ("Land price," "Height of people," "Likelihood of earthquakes," "Type of eating habits," etc.).⁶

If we call $P(O)$ a specification of the performance of an object O , i.e., a statement about the (observed, desired, or predicted) performance of O , if we write $D(O)$ for a specification of design variables of O (as intended or actual), and if $C(O)$ describes a particular constellation of the context of O , then the general format for an item of instrumental knowledge becomes (in the simplest case):

"Under context $C(O)$, design configuration $D(O)$ will lead to performance $P(O)$."

In the symbolism of formal logic, this can be written:

$$C(O) \& D(O) \rightarrow P(O)$$

(read: "If $C(O)$ and $D(O)$ then $P(O)$."). In case that the variables occurring in the terms are continuous, it might be possible to write the relationship as a mathematical function:

$$p = f(d, c)$$

where P indicates a vector of performance variables or an overall performance measure, which is a function, f , of design variables d and contextual variables c .

This formulation reveals the bothersome fact that the designer alone does not control the performance of his creations: how O performs depends on which performance aspects p are applied and under which context O is functioning. To give an example:

O is a window, and if $C(O)$ and $D(O)$ then $P(O)$, where

$D(O)$: "The ratio of height over width of O equals the golden ratio."

$C(O)$: " O is looked at by a representative of the classical beaux arts."

$P(O)$: " P has beautiful proportions" (for the beholder).

From $D(O)$ and $C(O)$, $P(O)$ can be predicted.

All formulae of structural design can be written in this instrumental form. Here the design variables are the dimensions and the material of a truss, e.g., loads, gravity conditions form the context, and the performance variable is "structural soundness" which assumes one of two values, say, " O collapses" or " O does not collapse."

Usually, knowledge is not taught in this form. It is documented and learned in terms of causal relationships without differentiating between the three types of constituents. Knowledge becomes instrumental in a particular situation, and the variables occurring in a particular item of learned causal knowledge are reclassified whenever this item is utilized: once the material of a beam has already been decided upon, its tensile strength is a "given," a contextual specification. If the material is still undecided, tensile strength is a design variable to be decided upon by the choice of the material.

Knowledge is reclassified over and over again, guided by associative processes which are not yet well understood.

Some instrumental knowledge is derived from systematically structured theories (as frequently in structural design). Much knowledge, however, is just heuristics, i.e., rules of thumb without theoretical foundation but which have proven to be helpful in more than the average number of cases. ("If you provide two bathrooms per dwelling unit in a subdivision, your sales chances in California are pretty good," or "If you build on a slope, don't cut the slope.") Particularly knowledge about social and aesthetic phenomena, as well as most of the tricks of the trade, are of the heuristic type.

RECURRING DIFFICULTIES OF DESIGN

This picture of the design process and the structure of the designer's knowledge is abstract and not very sophisticated. Therefore one cannot expect any one of its implications to be specific for any particular area of design. What can be derived from it must be independent of the particular object to be designed, whether it is a bridge, an urban renewal policy, an airplane or the curriculum for a school.

Nevertheless, the model is a framework for the identification of those typical "intellectual" difficulties which are repeatedly encountered by a designer in his work. It is important to enumerate some families of these difficulties--without claiming completeness or that the various items are independent from each other:

1. To assess the worthwhileness of a project. Since everybody's problem-solving capacity is limited he must allocate his

resources to the most worthwhile projects--otherwise, he would incur heavy "opportunity costs." This, however, is easier said than done. Whose and which costs and benefits should be included in this assessment? How to discount future benefits into present assets? Answering these questions requires a distinct and sophisticated "ought-to image," explicitly describing what one wishes to become the case, together with a clear picture of the "opportunities." Every project requires the construction of a "case" to which the participants in a project commit themselves.

2. To determine the appropriate level of a problem. A problem originates from a recognized discrepancy between what is and what ought to be. Any attempt to solve it consists in the search for removing this discrepancy. But every discrepancy can be considered a symptom of a higher order discrepancy. And there are many ways of explaining one and the same discrepancy, since there are many explanations which construe a "because of." The apparent discrepancy may be the deficiency of housing in a blighted area, and one might think of doing something about it. But this deficiency may be better understood as being only a manifestation of social imbalances, the removal of which would automatically take care of that blight. And, in turn, social imbalances can be explained as resulting from a particular social value-structure, the adjustment of which would do away with those imbalances. And so on and so forth. This escalation of explanations is not at all uniquely

determined. Blight can also be--and occasionally is--understood as the product of the inhabitants' malevolence or negligence. Each explanation will lead to entirely different types of problems, and, therefore solutions.

There is no logical, natural, or objective level on which to settle the problem originating from a discrepancy. The solution level is a matter of judgment and self-confidence.

3. To determine the nature of the solution. Assume that agreement has been achieved as to the formulation and explanation of the discrepancy which has given rise to the problem and its explanation. Then a multitude of different principles can be developed--"morphologies" as they have been called above--which also promise to lead to a solution. The problem of a congested freeway may be attacked by adding a few lanes, by diverting a portion of the traffic through a new artery, or by a rapid transit system. Each of these morphological alternatives leads to entirely different information needs and sub-difficulties." How to find reasonable morphological alternatives and how to choose among them?

A related aspect is the appropriate naming of the object to be designed. This is decisive for the class of solution possibilities conceived of by the designer, and also for the "image" of the final product in the eyes of its users. A "dwelling" is not necessarily a "house," and the connotations of "public housing" are very different from those of "economy

apartments," even if the "physical" design is the same. So-called physical objects--like buildings--do not have an independent objective meaning. They are what they are taken for, and this determines their fates.

4. To construct an evaluation system. In order to do his work, the designer needs an evaluation system to guide his search for a solution. What ought to be accomplished? This system should incorporate all the aspects and viewpoints under which the object will be evaluated. Normally, there will be a multitude of performance variables to be considered. But a mere list of these variables is not sufficient:

- they are not all of equal importance.
- they are not independent from each other. It is seldom, if ever, possible to maximize all performance values at the same time, since an improvement on one aspect usually reduces the performance of another aspect.
- ideally, the solution ought to perform well in everybody's eyes. But normally, different people assess the same object from different standpoints, and even if they agree on the relevance of a particular performance variable, they might disagree on how to score a certain object on this scale ("How beautiful!" says A, "How trite!" says B). The owner, the neighbors, the architectural profession--all have a "say" about the quality of a building; an investor wants to maximize the return on his investment while

the prospective tenants are likely to want to pay as little rent as possible.

Therefore, the designer must:

- a. identify the relevant performance variables for each of the parties to be taken into account,
- b. find out the relative importance of the various aspects for the various parties considered,
- c. "settle" somewhere in the field of conflicting interests, e.g., by assigning weights of influence to the various parties,
- d. construct a measure of "overall performance" for evaluating alternative solutions.

All of these items present considerable difficulties. Particularly the last one is most decisive: in view of performance aspect P_1 a solution A may be better than a solution P_2 , but for performance factor P_2 the solution may be just the other way around, etc. This situation is known as a dilemma, and any two solutions under consideration will present a number of them. Which is to be preferred? In order to make up one's mind in favor of either one of the solution possibilities, one needs a procedure that enables one to aggregate the various performance aspects--properly balanced--into one overall judgment of the form "B is better than A," for example. This can, for instance, be accomplished by determining weights of importance for all of the relevant performance aspects, or

by finding a common measure of utility into which the scores under each of the aspects can be equally converted. Such an overall-performance measure can be constructed for each individual party involved in the project, or it may be tried to accomplish agreement on one particular evaluation system. The rationale of these procedures is to replace "offhand" overall judgments (I just like it!), by sets of detailed evaluations which are then recombined into another overall judgment--which is hoped to represent a more rational and balanced evaluation.

5. To anticipate the context of the object. As discussed above, the performance of something is not a function of the design characteristics alone but also and decisively of the conditions under which it operates and the purposes for which it is used. There are almost no single purpose objects around. A building has to function as a commodity on a market, at the same time it is somebody's house, people "circulate" in it, it has to be cleaned, presents a fire hazard, and it is looked at with the eyes of the connoisseur. Each of these functions takes place under conditions which may change over a time, and even the set of purposes for which the object is used may change (a bedroom might be converted into a living room, e.g.). It is a major difficulty to anticipate the relevant characteristics of the context under which the object will perform. Not only have the contextual variables to be identified, but also their

values have to be estimated, together with the ranges of variation to be provided for. Frequently, the performance variables are not independent from each other but form nests of functional relationships. Thus, real estate value will depend on demand, on the character of the neighborhood, the state of deterioration, which, in turn, is a function of usage and investment into maintenance, etc.

Of course, in this category belongs also the anticipation of "environmental factors:" should one design for earthquakes in Missouri, for an H-bomb holocaust, for a social revolution in the United States? If not, why not? Again, answers are a matter of judgment and of the willingness to accept risks, and of the degree of optimism of those who run the project.

6. To identify a relevant solution space. Each morphology determines a set of design variables, representing the range of variation for the design decisions. This is the problem of retrieving the appropriate technological data. Which materials are available? Is it possible to make a glue connection between metals a and b which withstands x degrees of heat over y hours?
7. To constrain the solution space. Not all combinations of the design parameters defining the solution space are meaningful: a beam with span x and dimensions u, v, w, made of material y may not be feasible, because in the "context" of load z and gravitation t it would collapse. Or, a prefabricated component may be structurally elegant but useless because it cannot be

transported or because it violates the building code. Therefore, it is essential to exhaustively identify the constraints which reduce the variety represented by the solution space. Constraints originate from contextual conditions (building code, weight of people. . .) from relationships between the design variables (the interior dimensions of a room cannot exceed its exterior dimensions), and from the so-called qualitative objectives, i.e., those performance specifications which are expressed in terms of a binary performance variable ("A garage is either provided or not; it is required to have one").

Constraints are, however, not at all "givens" which just have to be accepted. Whether something is under a constraint or not depends largely on the decision maker. The building code can be accepted as given and thus become a source of constraints, or one can decide to do something against some of its paragraphs. In this case "changing the building code" has become a part of the design project. Every accepted constraint is an indicator of resignation: the decision maker has given in and decided to leave a segment of his reality as it is instead of trying to change it.

8. To construct a system of functional relationships which connect design variables, context variables, and performance variables with each other. This may be called the central difficulty of designing. In almost no case will one succeed in setting up one big model that represents a whole, realistic problem. Usually, one starts out with a crude overall model, representing

the idea of the solution principle. This model, along with increasing elaboration of the solution, is fragmented into sub-models for partial problems which can be treated somewhat independently, etc. By "model" is here understood any "mental" construct which is assumed to be homomorphic to that which it is meant to represent. It may be a cardboard model, a system of equations or a narrative: it is the picture somebody makes for himself about something. In any real design problem the great number of variables and the fuzziness and the complicatedness of the relations between them makes the construction of complete, communicable models extremely difficult, if not impossible. Nonetheless, the "rational designer" must feel obliged to attempt the construction of such models which tell him how a certain configuration of design-decisions, if the object is subjected to a certain context, will perform with respect to the overall-performance measure (since he is trying to anticipate the consequences of his design decisions). In addition--as the discussion of the nature of the design process has shown--such a model is incessantly subjected to modification and revision, due to the steady stream of new information during the whole design phase of the project.

9. To find an appropriate solution in the solution space. If the system of accepted constraints is not contradictory (which happens often enough) the number of feasible solutions is very large. Which of them yields a good overall performance? How does one know that, if solution A is good, that there is not

another solution B in another area of the same solution space which is considerably better than A? Occasionally, this difficulty presents itself as the task of optimization. However, because of the aforementioned difficulties overall optimization almost never occurs in design. Optimization requires three conditions:

- a. that there is a manifold of well-defined solutions,
- b. that there is a criterion which enables one to compare the performance of any two solutions of that manifold leading to the judgment about which of them will perform better,
- c. that, if optimality for a certain solution is claimed, it can be proved that--according to the criterion--there is no better solution in the manifold.

In design, usually none of these conditions is fulfilled. As discussed before, it is normally impossible to construct a comprehensive solution space for the whole problem (which would include all models belonging to all conceivable morphologies of the whole and its parts). Second, even if one succeeded in setting up an overall-evaluation system, it will frequently be impossible to "read" the future performance of every particular solution from its representation in the solution space. The reason for this is that we simply do not know what the impact of an additional inch in the width of a room will be for its use as a bedroom. Finally, who knows of a solution proposal to a design problem and can prove that one could not

have done better? Therefore, categories like "acceptable," "good enough," etc. are commonly used to terminate the search for a solution.

10. To avoid undesired side-and-after-effects of a plan. A plan may literally accomplish what it was intended to, but it may produce additional effects which come as unpleasant surprises. They are due to forgotten factors or to cumulative effects which none foresaw. To apply DDT to the extermination of insect pests is a good idea; to find insecticides 15 years later as a stable and harmful compound in almost every organism on earth is alarming. It is a "scale-effect" caused by the ubiquity of insect pests. A freeway, designed in order to take care of traffic congestion, leads to a further dispersion of residential, commercial and industrial locations and therefore "generates" even more traffic than there was before, thus stimulating its own suffocation. There are many dramatic examples of unforeseen after-or side effects. How can they be avoided or at least made to occur less likely? The larger the scope of the project, the more consequential they tend to be.
11. To implement a solution proposal. It was said that the result of the design process is a plan which if carried out is expected to lead to the desired result. But the best plan is of no value if it is not carried out. It has to be implemented in two ways: first, it has to be accepted by the decision maker; second, it has to be realized. Therefore, a good designer has

the implementability of his plans in his mind all the time. It is useless to make "Platonic" plans which look promising but which cannot be realized because of the deficiencies of this bad world.

12. To test the results. In order to learn for the future, the designer has to rely on a careful review of what he has accomplished in the past. Ideally, he would check a list of hypotheses against that which actually happens later on. But because of the independence of performance from both the design decisions and the context, how can he attribute a particular deficiency to either of them? Is the present system of assigning legal liabilities a sufficient testing device for the designers and the other parties? Is a housing project which turned into a slum badly designed, or was it subjected to the unforeseeable intervention of new social factors?

All these complexes of interlocked difficulties, which could only be adumbrated here, deserve further analysis and more detailed classification. They are familiar to every designer. In everyday practice they are overcome "somehow," more or less consciously. For each of them, there is a host of negative examples. Positive examples are harder to find because they do not show up: good design is unobtrusive.

For the purpose of this paper, two questions arise:

- is it possible to master these difficulties systematically or, at least, more consciously?
- if yes, is it possible to teach this mastery?

GRAND APPROACHES

All those difficulties are different expressions of a basic dilemma of human existence: if one tries to be rational, i.e., tries to anticipate the consequences of one's doings, there is no beginning and no end to reasoning. One can think a further step "backward" and also another step forward. The more one tries to anticipate and to justify one's actions the more difficult it becomes to act. On the other side, non-rational spontaneous action on a large scale is likely to get the actor and others into trouble: it is irresponsible. Thus both extremes have little survival value.

For all of these reasons there cannot exist anything like "the" design method which smoothly and automatically resolves all those difficulties. Those people who claim the existence of such a device postulate nothing less than the solution of all present and future problems of this world. They are likely, however, to produce nothing but "Platonic" schemes, impossible to implement.

Everybody knows the patent-ideologies which are meant to overcome the difficulties "by principle." There are those who say that the designer is a "need fulfiller," a reaction-jar into which people pour their needs. The designer is just a catalyst for the crystallization of the solution. These people forget that the designer commits himself in his work. Knowingly or inadvertently, he uses his judgment all the time, as does anybody else. Every constraint is a matter of decision. If he tries to remain neutral and uninvolved he is likely to do the job of some middle-class opportunist or even that of a reactionary: "Whose bread I eat, his design I do."

A related doctrine demands the belief in the existence of a list of basic human needs, common to all people at all times. The designer has just to identify them objectively and to design accordingly. There are numerous attempts to list basic needs, one and for all and for everybody. Unfortunately, in these lists "food" becomes "protein," "carbohydrates," and "fat," breathing requires "oxygen," a house becomes a "shelter," measured in terms of square feet. Because of their generality, such lists tend to oversimplify the problem: it is easier to provide protein than beef. Such lists wipe out the enormous diversity between peoples and cultures (even if they list "privacy as a basic need.") thus erasing the unique and specific constellation of values in which every design project takes place and leading to solutions which cannot be implemented because people want beef and not algae. It takes a long and difficult argument to convince people that they should better have algae. Therefore, it is hopeless to attempt the construction, for instance, of a standard catalog of performance specifications for all buildings or even only for a particular type of building--say schools. Behind any such list is somebody's particular "ought-to image" of schools in response to a particular "is-state," and not at all timeless objectivity.

Another variant is the beloved doctrine that "form follows function." If this comes together with the "need fulfiller" doctrine, its triumphs are the jeep and other forms of military equipment. If the designer believes that technical perfection automatically provides optimum usefulness, he forgets that "technical" criteria have no independent meaning, and that lists of requirements do not at all

determine a solution (otherwise Russian rockets would not look Russian and American rockets American). The list of requirements may be long: they either prescribe no solution at all or an infinite number of them. And "form" is no opposite to function: "To be looked at" is just one function of an object, which has many other functions.

BETTER DESIGN

Does this mean that nothing can be done to master those difficulties better than before? I refuse to believe it. It must be possible to design better.

But what does "better design" mean? Let me use a weak definition, based on the pragmatic criterion that since the quality of a plan will be proved only after its execution--it is "better" to the extent it has accomplished that which it was meant to accomplish, and the fewer undesirable side-and-after-effects to which it has given rise. Then a designing system is the better (in its own terms) the less frequently it produces bad plans. This does not preclude the possibility of good designing systems, which are evil for somebody else, since this definition does not evaluate the particular moral or political commitment of the system. Then, on a very modest level, we might search for tools, techniques and methods which are likely to enhance the designer's capability to make better plans in view of his own commitment. Naturally, as with all tools, such aids are "value free." A hammer can be used to drive a nail or to hit somebody's head.

Perhaps even this simplistic understanding of how to improve design capabilities can have a desirable net effect. Most bad plans are the result of ignorance and fallibility, and not of bad will. If, therefore, the capability of a design system "can be improved in its own terms," it is not unlikely that the number of bad plans and the impact of their consequences can be reduced.

It may even happen that a higher degree of reasonableness, sophistication, and communication in the production of plans leads to less "evil" plans.

METHODS, TOOLS, AND TECHNIQUES

Certainly, the harder one tries to cope with those difficulties in a conscientious and rational fashion, the more intellectual capabilities are required, i.e., reasoning, understanding, argument and critical ability. But, besides, they demand power of judgment and commitment. The more one intends to understand one's decision, the greater the number of decisions to be made, and the more complicated the relationships to be handled. What was an offhand judgment or a routine, turns into a set of nasty problem complexes, leading to deeper causes and requiring more, and more fundamental, assessments and decisions. It is a matter of judgment and basic conviction where to stop proliferating complexity and intellectual penetration, to settle the problem at hand. No methodology can substitute for this judgment.

There are methods, techniques, and tools, however, which can aid the designer in structuring and manipulating a problem. As weather forecasting, structural engineering, or market research benefit from

the use of rational procedures (and thereby improve their performance in the sense defined above), the designer can also employ more conscious and sophisticated modes of approach which allow the controlling of more factors and more complicated relationships on which to base his decisions. These do not guarantee better plans. The most sophisticated mathematical model can be useless or even detrimental if applied and interpreted unwisely.

At present, the set of methodologies is by far insufficient for mastering all those difficulties (and there is good reason to postulate that the difficulties can never be removed by any method), yet there exists a considerable "tool-chest" to aid the designer in his work. Statistical techniques may support his predictive efforts; procedures of systems analysis can be used for interlocking a greater number of variables than the "unarmed mind" can manipulate; symbolic logic can serve as a means for describing and analyzing the structure of a problem; techniques of operations research will find the optimal solution in a fixed solution space with a given performance measure; one can employ a simulation model in order to better anticipate how a certain solution will perform under a variety of conditions; techniques of empirical research can generate more reliable knowledge about "what there is;" combinatorial techniques may support the search for solution principles, etc.

Besides, there are many procedural systems to attack and carry through a design project. They are not really methods, but disciplines of procedure, which suggest when to do what, and checklists reminding the designer of those things he should take into consideration.⁷

Perhaps the least developed but the most important family of design-aids can be subsumed under the name of "social technology."⁸ These are methods of providing for social interactions and events in view of a specified goal. They are meant to apply to problems of instruction, forecasting, coordinating expert opinions, organizing a group, obtaining corporate decisions, implementing solutions, and legislating. Many of these center around the problem of appropriate "display": how to communicate one's way of understanding to others? how to display one's value-structure? Although many systematic devices for setting up evaluation systems have been developed, much research remains to be done for their improvement. Likewise, it ought to be investigated how to better display alternative plans, together with their pros and cons, in order to provide a basis for understanding the implications of the alternatives and a debate about their acceptance.⁹ Such displays could have just the form of graphic materials, but also--and this would perhaps be more interesting and useful--they could be rules for stimulating controversy and debate which hopefully lead to the detection of concealed weaknesses and to wider and better founded bases of agreement among the participants. How badly this aspect is mastered is impressively demonstrated by the failures of almost all urban renewal projects, rapid transit systems and the like. Persuasion and secrecy seem to dominate the decision making process instead of attempt to argue with each other on reasonable grounds. It seems that the basic assumptions of the decision makers or the designers, their intentions, ideologies and beliefs (which are decisive for the outcome of design projects as discussed above) tend to remain implicit and unargued. But a necessary

condition for improving our capability to plan lies in clearly recognizing and spelling out the foundations of the participants' positions. Otherwise, planning degenerates into "muddling along," and it would be surprising if the results of this practice would be not unpleasantly surprising.

One might argue that this critique is directed against basic "inbuilt" faults of human nature, and that nothing can be done about them. But the existence of Robert's Rules of Order, of the decision making procedures of democracy, the rules of legal proceedings show that it is not impossible to "engineer" social technologies of the "dialectic" type.

IMPLICATIONS FOR DESIGN EDUCATION

I had assumed that an educational system for design should prepare and equip the student for practice, and that, therefore, it should focus on the typical and recurring difficulties of designing, on ways to overcome these difficulties, and on that knowledge necessary to obtain the knowledge needed for a particular project.

It was the purpose of the preceding considerations to demonstrate that such fundamental difficulties can be formulated in a way pertinent and valid over a long period of time. The significance of these difficulties is increasing because of the changing nature and the widening scope of design projects, which allow the designer less and less frequently to rely on precedents or habitual ways of doing a job.

These procedural aspects of designing offer a principle for the design of a curriculum, since they provide a plausible framework for selecting and relating the host of factual knowledge and skills to be transmitted. Some implications of this strategy are:

- the student should be exposed to and familiarized with those typical difficulties as articulately as possible.
- design problems should be developed which emphasize one difficulty at a time. ("The influence of different measures of performance on a solution," "To generate relevant morphological alternatives to a given problem," "To anticipate the performance of a proposed layout for a supermarket," "Set up the system of relationships between the design variables, the patterns of use and the performance of a lecture hall," "Determine A's image of building B1," "Compare the social costs and the benefits of the alternative plans for School S.")
- "software" technologies which are apt to support the work toward the solution should be taught systematically and thoroughly exemplified ("methods of prediction," "procedures of evaluation," "theory and model construction," "the division, organization and scheduling of design labor," . . .).
- the principles and the present state of theories of environmental systems should be conveyed to the students and their further development encouraged ("theory of floor plans," "theories of growth, rehabilitation, decay, and obsolescence," "environmental control," . . .).

- whenever possible, the emphasis on the knowledge of present "hardware" technologies should be reduced to the principles of these technologies. How should one obtain the particular technological knowledge required in a particular situation? How should one keep abreast of the change of technological principles (the organization and the use of data banks and experts)? How should one determine the technical feasibility of a solution idea?
- the vast areas of factual knowledge should be taught in a problem-oriented way (i.e., as relationships between design, contextual- and performance-variables).
- it should be shown how to mesh the factual knowledge of many disciplines and slices of reality into one system (how do the dimensions of trucks, the building code, production facilities, material properties and wages affect the design of a prefabricated concrete slab? . . .).
- it should be discussed and demonstrated how cultural, social, economic and political factors influence design, and how these factors themselves can become subjected to design.
- particularly in the more advanced segments of the curriculum, real design problems should be given

instead of mock-up projects, because--as discussed before--design problems are notoriously "ill-behaved" and cannot be formulated exhaustively and definitively. Therefore it is difficult if not impossible to simulate the conditions of real-world problems in the studio. Public design projects, competitions and industrial corporations might be considered as sources of realistic design problems.

This list of teaching items can easily be extended in width and detail. It is more essential, however, to point to their implications for the basic attitudes and the foundations of this strategy. It requires that the designer be fully aware of the unescapable dilemmas produced by his attempts to design responsibly. He must know that his results are "political" by necessity because they are based on his and others' images of how the world is and how it ought to be. The more a project matters the more crucial its political implications will become ("political" without the derogative American connotation but in the Aristotelian sense: every act is political if it affects the affairs of the community, if it reaches beyond the boundaries of privacy). The good designer will know that he shall never find the best solution, but nevertheless he will continue to search for better ones. For him it is at least as important to be familiar with today's unsolved problems as with yesterday's approved practices. He will have learned to live with the fact that everything he is doing is due to his own free decisions, that there are almost no necessities, that almost everything--including values, habits, and beliefs are subjected to potential change,

and that this change can be designed. He should be prepared for the change of accepted values and he must learn to live with the thought that the more systematic and rational he tries to be, the wider the scope of possibilities becomes and the heavier the burden of ethical commitment.

One might ask whether a person with such an extent of awareness can still be capable of designing. Can anybody make design decisions in face of the universe of possibilities and consequences? The answer lies in the pattern one can observe in the behavior of design students. As a freshman, full of naive enthusiasm, they are dedicated to the redesign of the whole world, fast and thoroughly. They ask for the real problems and attack them impatiently, though not very realistically or efficiently. Some students get stuck to this phase; they are disillusioned the hard way, after school. Others enter a second phase: accidentally, or by instruction, they stumble into the difficulties of designing, and they find out that they do not know enough to overcome them. They look for reliable knowledge and appropriate procedures. The result is often resignation or cynicism; they lose courage to draw a base line on a blank sheet. Some give up the idea of becoming designers and switch to a science (preferably psychology), or go into business. A few survive this period of frustration without quitting, resigning or resorting to opportunism. They learn to design inspite of difficulties, paradoxes, and dilemmas. They also deduce that balancing masses against the void, sequencing spaces, considering buildings as "statements" of esthetic preferences, glass-bead games with "megastructures", are only one group of factors in the much richer context of building design, urban planning and construction.

Perhaps an educational system for design is the "better" to the extent that it increases the number of students who attain this view of architecture.

NOTES

¹In 1959-60, ca 30,000 architects were counted in the labor force of the United States, the median representative of them being 41.5 years of age and earning \$8753.00 per year. Between 1957 and 1965 the number of architectural firms decreased from approximately 1600 to 1300, their relative share of the new construction market shrunk from 23% to 14%, although their absolute share increased from 6.7 to 7.1 billion dollars. (U.S. Bureau of the Census, Statistical Abstract of the United States, 1964-1965, Table 308, Progressive Architecture, Nov., 1965; Bureau of the Census, Value of New Construction Put in Place, 1946-1963, and others).

²K. E. Boulding, The Image (Ann Arbor: The University Press, 1961), p. 162.

³Ibid., p. 163.

⁴Yehoshua Bar-Hillel, Language and Information (Reading, Massachusetts: Addison-Wesley Publishing Co., 1964), p. 367.

⁵Several types of strategies can be observed in this process. E.g., the problem solver could just take the first solution possibility that comes into his mind and carry it out, instead of developing several alternatives in parallel and then to select one of them. This is the most frequently encountered approach. It runs the risk, however, of leading into a dead alley or of missing superior solutions. In case the first solution does not work out, the "next" idea is developed, etc. Another strategy is to develop alternatives over several steps and to select among the branches of the resulting "tree" of alternatives, analogous to the chess player who tries to think several moves ahead. All optimization techniques as developed in operations research are of this kind: they aim at finding the best solution in a solution space containing a very great number or a continuum of solution alternatives. That these strategies are actually applied can be demonstrated by having a designer "think aloud" during his work and analyzing the protocol afterwards.

⁶The terminology used is widely identical with that of operations research, as developed in R. L. Ackoff, Scientific Method: Optimizing Applied Research Decisions (New York and London: J. Wiley & Sons, 1962).

⁷For industrial design, such a system has been worked out in painstaking detail by L. Bruce Archer, Systematic Methods for Designers (London: Council of Industrial Design, 1965). From the standpoint of engineering design, such a procedure is presented in the article of J. Ch. Jones in J. Ch. Jones and D. G. Thornley (eds.), Conference on Design Methods, (Oxford: Pergamon Press, 1963). Almost any textbook on systems analysis or operations research contains in one of its first chapters at least a crude enumeration of steps to be taken in a design problem.

⁸ Social Technology is the title of a book by Olaf Helmer, Social Technology, (New York: Basic Books, Inc., 1966). Here, the term is used to designate methods of obtaining expert opinions about future technological, political and social developments. In the context of this paper, the term is used in a wider sense, including all methods, techniques and tools which can be deliberately applied to accomplish specific, goal-directed modes of social behavior.

⁹ For a comprehensive analysis of the various forms of display and their uses, cf., C. W. Churchman, The Use of Research in the Preparation of Decisions, pp. 255-270, in H. Krauch (ed.), Wissenschaft und Politik, (Studiengruppe für Systemforschung: Heidelberg, 1966). This essay emphasizes "dialectic display" as a most appropriate device "to make sure that the decision maker has the opportunity of scanning the most plausible alternatives in a forceful manner."