Chapter 3
Science of the Artifice

> *The central task of a natural science is to make the wonderful commonplace: to show that complexity, correctly viewed is only a mask for simplicity; to find pattern hidden in apparent chaos... the designer is concerned with how things ought to be -- how they ought to be in order to attain goals and to function.*
>
> Simon, 1981, p.3, 7

Justification

Unlike the natural and social sciences the sciences of the "artifice" are just beginning to be taken seriously. Its history is brief; yet, its recognition is primarily due to the legacy of Herbert Simon and his seminal work: *The Sciences of the Artificial* first published in 1969. Simon's work on human cognition and the Sciences of the Artifice emerged from an area which at first appears to be unrelated to architectural design and even the artifice for that matter; namely, decision-making, particularly in the area of economics, in which Simon has been awarded his Nobel Laureate.

Throughout its relatively brief existence as a field of study, decision-making has been occupied with two fundamental tasks: one, developing a sound basis upon which to construct its theories, and two, defining valid and practical domains for the application of these theories. In turn, the development of theoretical models in decision-making has followed two distinct paths, reminiscent of the Rationalist vs. Empiricist dichotomy in scientific reasoning. These are known as *normative* and *descriptive* models of decision-making.

Normative models are involved with indisputable principles that underlie decision-making. Their aim is to discover formal methods, including mathematical ones that demonstrate the application of these principles to specific problems in the form of deductive reasoning. One such approach to decision-making, which has dominated the early debate in the field of economics is based on "...the rational man conception."

In essence, this conception holds that (1) people have preferred structures that obey certain axioms of well-behavedness so that (2) a mathematical representation can be rendered of these preference structures and (3) choice can be modeled as maximizing an imputed objective function, e.g. expected utility, subject to certain economic constraints.[95]

Descriptive models on the other hand are based on the assumption that decision-making is a result of the specifics of the human cognitive process and can be represented as a stochastic phenomenon originating from the way humans "perceive, process, and evaluate probabilities of uncertain events." This position is related to the empiricist philosophy and the method of induction. Research on "intuitive statistics" by Peterson and Beach[96] points, for instance, to an optimistic conclusion on this subject:

> *...man gambles well. He survives and prospers while using... fallible information to infer the states of his uncertain environment and to predict future events. Experiments that have compared human inferences with those of statistical man show that the normative model provides a good first approximation for a psychological theory of inference. Inferences made by subjects are influenced by appropriate variables in appropriate directions.*[97]

We must observe that this dichotomy, while a fundamental one, is not manifested in absolute terms in the models that have been developed for decision-making. As is the case in classical philosophy, the normative and descriptive positions are idealized positions. Feldman and Lindell drive this point home in a recent article:

> *Investigations in... rational decision making... have frequently sought to contrast a normative model of decision making with a descriptive model. The distinction is somewhat misleading, since current normative models.... are implicitly descriptive. That is, the model is defined in terms of specific parameters... and associated operations by which these parameters can be estimated... By eliciting the appropriate judgments of likelihood and preference, the investigator*

describes an individual's decision-making process in terms of the parameters of the proposed normative model.[98]

It is against this background of interrelations between normative and descriptive theories that we must now consider each. It is for the same reason that this should emphasize and sharpen their differences.

Normative Models of Decision Making

In decision theory, normative decision-making implies the selection of an alternative from among multiple, possible alternatives based on economic utility, or some "value" convertible to economic utility, associated with each selection. The estimation of the Expected Utility (EU) of this selection is contingent, naturally, on the selected alternative's attributes.

Principles of this approach were first stated in their axiomatic form, in 1947, by von Neuman and Morgenstern (vN-M) as an underpinning of the Economic Theory of Games.[99] While this was directed at solving problems of economics, the *vN-M* theory of decision-making provides an excellent benchmark and a point of departure for studying many other decision-making applications.

The vN-M Theory models the world of decisions in terms of a set of outcomes, called X, and the set of probability distributions on X, called P. Given two possible payoff schemes, one, called p, with outcomes X' and probabilities P' and the other, called q, with outcomes X" and probabilities P". The vN-M theory defines mathematically expressible axioms, which attempt to articulate immutable truths about decision-making. Consider for example:[100]

Axiom 1 if $p \leq q$, $q \leq r$, then $p \leq r$

Axiom 2 $p \leq q$ implies that $\alpha p+(1-\alpha) r \leq \alpha q+(1-\alpha)r$

Axiom 3 if $p \leq q \leq r$, then $0 \leq \alpha p+(1-\alpha)r-q \leq 1$

Axiom-1 states the principle of transitivity between payoff schemes. If the payoff scheme p is preferable to q and q is to r; then it is necessarily so that p must be preferable to r. Axiom-2 represents the principle of *value conservation* over *identity* operations. Given two preference ordered payoff schemes, their ordinal value is conserved under multiplicative and additive identity operations with the probabilistic reciprocals (α and $1-\alpha$) with respect to a third payoff scheme: r. Axiom-3 represents the principle of *ordinality*. Given three ordered payoff schemes, the difference of the sum of the probabilistic reciprocals of the largest and the smallest schemes, from the median value, remain within the probability range.

Based on these axioms it is possible to construct theorems that can show mathematically which choices in these types of problems are more likely to yield greater utility:[101]

<u>Theorem 1</u>:

A decision maker's preferences for lotteries in P satisfy the axioms iff there exists a function such that $p \le q$; iff $\lambda u(x)p(x) \le \lambda u(x)q(x)$ [102]

According to this theorem, given the expected outcomes of $1000, $200, and -$500 with associated probabilities of .5, .25, and .25, for p; against $500, $470, $350, and -$1000 with associated probabilities of .6, .17, .13, and .1, for q; we can state that:

$$p \le q, \text{ iff } .5u(1000) + .25u(200) + .25u(-500) \le 6u(500) + .17u(470) + .13u(350) + .1u(-1000)$$

The underlying assumption of this approach is that decision makers can make the correct decisions about choices so long as they behave as predicted by the principle of "rational economic men" represented by these mathematical models. While this point of view has dominated the modeling of economic behavior for a long time, modifications of this theory have been introduced from time to time in order to overcome the discrepancies between the predictions of the model and the actual behavior of decision makers.

Savage (1954), for instance, expanded the vN-M Theory to include *subjective uncertainty*. During the 60's, others[103] developed versions that take the middle road in quantifying uncertainty. All of these modifications attempted to cast the normative Theory of vN-M as a descriptive one. It is this effort, which ultimately led to the recognition that decision-making, must take into account subjective assessments of utility and cannot be solely based on the assumption of rational behavior. This, in turn, gave rise to concepts such as Bounded Rationality, Satisficing Solutions, and Information Processing Theory.

Descriptive Models of Decision Making

Under this category, we will review three kinds of theories that have been developed by various research efforts. The first covers efforts that try to diagnose the shortcomings of normative Theories and suggest corrections that will take into account the non-rational behavior of human decision makers. We will call these *modified* normative models. The second one represents a more radical departure from the normative models. It includes models in which the complexity of the decision-making process employed by the decision maker, not to mention the underlying cognitive "mechanism," is a precedent. These we will call Information Processing models of decision-making. The third category is similar to Information Processing models in the sense that it treats decision-making as a sequence of transformations, such as in cognition, based on heuristic rules of decision-making and choice. These we will call heuristic models.

When normative models were used as descriptive tools, they fell short in accurately predicting decision makers' behaviors. Early experimental tests found the vN-M Utility Measure to be operational and capable of predicting choice behavior. Somewhat later, however, there appeared formulations of choice situations in which people systematically violated its axioms.[104]

This led to the inclusion of subjectively measured factors of utility and probability in decision models. Kahneman and Tversky,[105] in proposing such a theory, summarized the shortcomings of normative models, using three concepts, Certainty, Reflection, and Isolation.

People generally do not weight the utilities of outcomes by their respective probabilities (as is assumed in EU theory). Instead, they tend to overweight outcomes they consider certain relative to those they consider merely probable. This tendency is referred to as the Certainty Effect. When a choice between two positive prospects, i.e., gains only, is compared with its mirror-image choice between two corresponding negative prospects, i.e., losses only, individuals typically reverse their preferences. This tendency is termed the Reflection Effect. To simplify decision-making, people typically disregard common components between alternatives, focusing instead on elements that distinguish the alternatives. This is called the Isolation Effect.[106]

In order to remedy these shortcomings Kahneman and Tversky proposed the Prospect Model, which differs from the normative model in five distinct ways. It: (1) uses a value function, rather than the utility function of the vN-M theory; (2) uses decision weights instead of objective probabilities to account for low probabilities, which are generally over-weighted, and high probabilities, which are underweighted; (3) treats choice situations involving strictly positive or negative outcomes differently than those involving zero and/or both positive and negative outcomes and factor out sure gains and losses; (4) edits the gambles in order to simplify the choices presented; and (5) uses a relative reference point for the value function emphasizing changes in assets and not the final asset position.[107]

A well-known shortcoming of normative models is to account for the non-rational behavior of human decision makers. The assumption is that cognitive and psychological limitations rather than some innate desire to be irrational are the cause of this behavior. This position is substantiated by an abundance of research findings that describe the cognitive capabilities and limitations of humans.

A certain amount of sensory information from the external world enters the human sensory system on a routine basis and is briefly stored there.[108] During this interval the perceptual system discovers patterns in this information and attends to those patterns that are relevant based to the problem at hand and on previous perceptual or cognitive experiences.

Newell and Simon offer a simple model to describe the key elements of such systems (Figure 3.1). Given such a structure, the human information processing system has several key functionalities: (1) a number of primitive information processes that operate on the information contained in the system, (2) a set of rules for combining these processes into larger sequences that perform certain functions for the overall system, and (3) a control mechanism that governs the overall goal direction of the system.[109]

There seems to be specific cognitive structures that enable the processing of incoming information. First, these patterns are translated into symbolic code that is stored in Short Term Memory (STM). This is temporary until the information is either incorporated in Long Term Memory (LTM) or discarded to make room for new information being admitted into STM.[110] Human LTM seems to provide both "unlimited" capacity for storage and a complex retrieval storage mechanism for ease of information access.

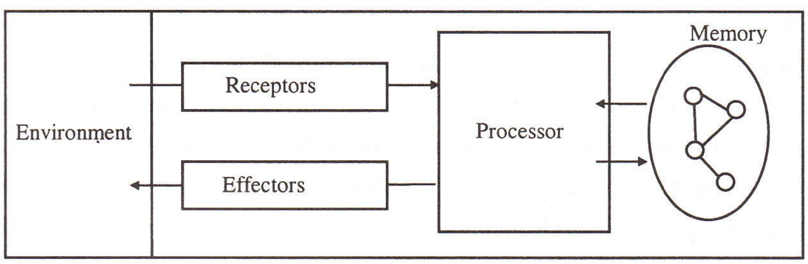

Figure 3.1 Information Processing model of human cognition (From Newell and Simon's, Human Information Processing).

Within the parameters of these mechanisms, there are several functional limitations that are insurmountable for human decision makers.[111] First, there is the inherent sequentiality of operations. Second, there is the limitation of the span of STM, which is around seven chunks, or units of information. Third, there are latencies involved during storage of information in LTM, which is in the order of five to ten seconds.

Simon[112] has argued that given these limitations the "decision-making man" cannot be expected to behave like the "rational economic man." He proposed an alternative theory called Bounded Rationality "which holds that all intendedly rational behavior occurs within constraints, including cognitive ones. Most decision rules that people use are sensible when viewed in the presence of these constraints, but not otherwise... The theory of bounded rationality suggests that a distinction be made between objective rationality (as assumed in economics) and subjective rationality."[113] This implies that people have the capacity to select satisfactory alternatives, or "satisfice" within a problem context rather than maximize or minimize some overall objective function, as is the case in optimization.[114] In satisficing, human decision makers limit their problem domains using constraints and rely on heuristic rules to facilitate decision-making.

Tversky and Kahneman have defined several human biases that apply to these situations. In addition they have also shown how some heuristic strategies can lead to systematic biases: *anchoring, representativeness, availability*, and *causal quality*.[115]

Anchoring is the tendency to derive final judgments by making adjustments to an initial point assumed at the onset. The tendency to favor the probabilities of occurrence of items and events that are perceived as representative of classes of items and events is called Representativeness. Availability is the tendency to favor items or events that seem to be most available in the context of the problem at hand. Causal Quality has to do with hierarchically ordering causal, diagnostic, and incidental relationships between events and items in that respective order. These heuristic tendencies seem to bias the probability judgments in decision-making.

Decision Sciences and Architectural Design

The process of architectural decision-making brings to the table the full complexity of building design problems as well as that of the designers' knowledge and skills that are applied to these problems. Students of this field of study have recognized that it is the very nature of the building design problem, which, incidentally, has been called many things from "ill-defined" to "wicked," that contributes most to this difficulty. Here we will describe some recent approaches to design decision-making, which recognize and exploit the ill-defined viewpoint. In this approach, we will consider architectural design as less of a problem to be solved and more of a cognitive process with changing parameters and variables.

In general the results of research on design indicate that: 1) the design process exhibits characteristics that are shared by other information processing phenomena, 2) certain behaviors of designers can be adequately described using various cognitive and problem solving models, and 3) some aspects of design behavior go beyond those that can be demonstrated by simple, algorithmic procedures. It is this final category of results in which we will be interested since they reveal the most about distinctions between decision-making in design and decision-making with more confined problem domains.

Primarily, designers are also bounded by all of the limitations that apply to decision makers in general. The span of STM is comparable to those found in other problem solving domains. Information stored in LTM is grouped into semantic "chunks" for later retrieval. The storage latencies for LTM are substantially greater than those for the STM, and the processing of information in general is sequential.[116]

Added to this picture is the large set of disciplines that get involved in making decisions in architecture. It is inevitable, then that building design problems present new and unanswered challenges to cognitive models of decision-making. Three major parameters of design decision-making stand out among the ones that have been articulated. One is the decomposition of the domain of decisions into smaller ones. Two is the sequence of issues to be considered and the decisions to be made. Three is the integration of individual and independent decisions into comprehensive ones.

Decomposition is the breaking down of building design problems into smaller sub-problems. This is evident in almost everything that we have reviewed up to this point: reasoning, decision-making, design and so on. This is also the case for the individual designer facing a design problem, regardless of how small or trivial the problem might be.

The designer organizes the architectural entity into "meaningful" chunks, or patterns that have some semantic homogeneity, so that this information can be manipulated in memory, with ease. In a chunking-recall experiment[117] simple floor plans were found to be decomposed into 20-40 graphic chunks; collectively, consisting of several basic categories: wall segments forming corners, exterior linear walls, interior linear walls, exterior-interior-combination linear walls, exterior non-linear walls, steps, furnishings, and structural elements.

It is not at all surprising that formal schemes of decomposition are recognized at many levels of the building delivery process: for the drafting board (classical orders, Sweet's Catalog, drawing conventions), for the construction site (building elements, labor unions, critical path charts) and for the building manager's use (furniture inventories, occupancy plans, zones of maintenance).

One of these, the one intended for the drafting board, can be discerned from talk-aloud protocols. Akın, in his book entitled *Psychology of Architectural Design,* defines a representation called "problem description graph" (PDG), which depicts the decomposition of small design problems into design issues. He found the number of issues defined by designers in these protocols, typically lasting around 150 minutes, to be on the order of 160; and the organization of the PDG to be hierarchical.

Decomposing a large problem into smaller, more manageable sub-problems undoubtedly makes the problem easier in some respects. In other respects however it complicates issues. There are two categories of complications: the sequence in which sub-problems must be tackled, and the re-composition of the sub-solutions into a single overall solution. Let us now consider the findings in these two areas.

With a large number of issues to which one must attend in a relatively short period of time, designers have to find efficient strategies so that the decomposition strategy does not end up making the problem less manageable. One of these strategies has to do with the order in which the design issues are tackled, which appears to be hierarchical.[118] The two basic choices that immediately present themselves to the designer are whether it is more efficient to traverse this hierarchical tree breadth-first or depth-first.[119]

In Breadth First Search each issue at the top node of the PDG is considered before any of the issues in any of the lower nodes. This procedure is applied in a top-down fashion until all nodes are exhausted. In Depth First Search, the first "sibling" of each successive sub-set is considered prior to the next node at the same level, recursively, until a bottom-most node is reached. After which the process is repeated with all of the remaining branches. There are obvious advantages and disadvantages to both search strategies.

In Depth First Search, each alternative branch of the tree is considered in detail before the next branch is even looked at. In building design problems, this can leave important design issues out of consideration while some other issues get a lot of attention. Other inefficiencies can also occur. Where there are inherent dependencies between issues, the decisions made about one issue may be violated by decisions made in the case of another. Looking at issues depth-first, before other issues are tackled, can provide an understanding of the sub-problems in considerable detail. This has the advantage of insuring greater precision in establishing agreement between sub-solutions. In Breadth First Search, the advantages and disadvantages are reversed. One gets an overview of issues at first but lacks the in-depth understanding until quite late in the search process.

Designers seem to prefer a combination of these two strategies. It appears that, in the early stages of design, experienced designers are involved in Breadth First Search, canvassing as many of the global issues as possible, before they select a single issue to consider in depth. This cycle is repeated until all nodes of the tree are traversed.[120]

In a separate study, Chan (1990) systematically altered the explicitly stated constraints of a design problem and obtained a set of protocols in which the same designer generated a series of design solutions.[121] The results of these experiments demonstrate that the sequence in which design issues are tackled is also a function of the constraints of the problem at hand. As these constraints were changed the sequence in which issues were considered also changed.

In most cases, where some sequence of design issues is a consideration, the designer seems to take multiple passes while traversing the entire tree-space. Due to the dependencies that bind these decisions to one another laterally, singular passes through the tree-space in a top-down or bottom-up manner hardly improve the synchronization of the independent decisions that are taken at each step. This is probably why multiple passes need to be taken through the search space, in order to coordinate results both "laterally" as well as "vertically." This brings up the question of how to integrate independent decisions.

Theoretically, solving a problem in parts and then combining these parts to form wholes is an effective way of making an unmanageably large problem, more manageable. Alexander, in his seminal work, *Notes on the Synthesis of Form*, argued for a method of design which generally followed a similar logic.[122] In this approach the decomposition of the design problem into sub-parts is done in such a way that the number of links, or dependencies, between issues that are separated from each other, are minimized. While theoretically acceptable, the approach is flawed. Often the links or dependencies between design issues are unpredictable. At other times, they arise due to the particulars of a solution developed. In other words, decomposition makes greater sense when it is *a posteriori* rather than *a priori*.

Needless to say, there are complex mechanisms that contribute to the process of integrating independent decisions. When the entire decision process is divided up into smaller parts, each part can be posed as a mini-problem. In fact Simon, in his discussion of the structure of the design process alludes to this process as the primary remedy to the unruly nature of ill-structured problems.[123]

The whole design then begins to acquire structure by being decomposed into various problems of component design, and by evoking, as the design progresses, all kinds of requirements to be applied in testing the design of its components. During any design episode, the architect will invariably find himself working on a problem, which begins in a state of ill-structure, and is soon converted into a well-structured problem.[124]

Making these sub-problems workable, in and of themselves, and giving them sufficient structure takes more than just finding the right decomposition scheme. Each sub-problem must be defined in terms of the domain of probable solutions, operations to be applied to the problem states and a set of criteria to indicate the acceptability of alternative solutions. In essence, each sub-problem must become a problem in is own right. This process has been called Problem Structuring.[125]

Once the sub-problems are solved, these solutions suggest alternative ways of reformulating them into a comprehensive solution. In other words, it seems to be possible to build the inherent dependencies that exist between sub-problems into the body of each sub-problem so that their integration will be aided by the agreement of many if not all aspects that define them. There is sufficient evidence from all fronts of problem solving that the process of problem structuring is a crucial ingredient that plays an important role in the integration of sub-solutions.[126]

Methods of Descriptive Modeling

Empirical studies of design are based on the assumption that we can derive general principles from specific examples or cases. This proposition has several immediate implications. First and foremost, it is necessary that the evidence resulting from the design process be manifested in the external world.[127] Secondly, the evidence thus found should be accessible to objective onlookers for their study and analysis.[128] Finally, this evidence may reveal information about a number of different aspects of design: design decisions made, process of making these decisions, and their consequences.

In studying this evidence, a causal relationship between design decisions and their manifested outcomes is assumed. Inherent in this relationship is the problem of understanding the mechanics of how a design decision yields a resulting word, an action, a design, or an object. This is the process of inferring design decisions from the results at hand, or simply, induction.[129]

Appropriate methods and techniques are needed for studying the relationship between design and its overt manifestations. One of these is the Case Study Method. In this method, the particulars of a given result and associated cases are described in detail. Based on these, inferences about the general principles of design are made. Both historic and other descriptive approaches in management science, medical science, law, and architecture, constitute well-known applications, in this category.

Another method that is widely used, especially in decision-making research, is the experimental testing of *a priori* models of design against human behavior. Through the comparison of design decisions made by human designers against normative decisions, discrepancies are detected. Based on these results, general rules used by decision makers are inferred and normative models are developed.

In other experiments, evidence about the design process is collected in order to verify hypotheses about the process itself. Specific methods designed to observe the design process as it is in progress are used. This is done in two ways, either in a laboratory or in the "natural" setting of the design act. Most social and political science research falls into the latter category. Cognitive psychology among these has been instrumental in developing particularly effective methods for the former area. These include reaction time, eye-fixation, and protocol analysis techniques. For example, Russo and Dosher[130] used "eye-fixation sequences and verbal protocols to demonstrate that subjects estimate dimensional utility differences and combine these estimates across dimensions."[131] Verbal protocols, among these methods, appear to yield the richest and the most direct data about the decision-making process itself.

Let us now consider this method and its application to the study of the building design process in some detail.

Protocol Analysis is a term invented by Allen Newell referring to a method used in studying human problem solving. In its most basic form, Protocol Analysis involves the posing of a problem to be solved in the laboratory where recordings of the problem solving process are made for later analysis.[132] The problem is constructed to resemble, as closely as possible, the conditions, which are under investigation. If problem-solving behavior in Chess, for example, is under study, subjects are seated before a chessboard and are asked to perform predetermined Chess tasks. Usually, subjects are also asked to speak aloud, to make drawings, or their eye-fixations are tracked in order to get at their problem solving processes more directly.

Consequently, protocol studies come in various forms: such as, "Motor Protocols," "Eye-movement Protocols," and "Verbal Protocols,"[133] where each term indicates a different form of data collection and analysis technique. The setting and the task are selected in such a way that the subjects are involved in performing the task with minimum distraction or sense of artificiality. The data collected at the end is called the "protocol" referring to the "original draft or record"[134] of the experiment produced through these recordings.

Several objections have been raised against this method, largely on the grounds that: "(1) subjects may not be able to report accurately on their own mental processes, (2) even if [they] could... the act of reporting may distort those processes, and (3) because verbal protocols are extremely complex, one may wonder whether [their] analysis... is objective and factual or simply the projection of the analysts' biases."[135]

A careful review of the literature on protocol analysis shows that some of these concerns are based on misrepresentations and the others can be remedied quite easily.[136] First, subjects seem to be perfectly capable of talking about what they are doing as they perform a task.[137] Secondly, subjects in the process of solving a problem, especially one which involves verbal processing are no more adversely affected by this method than by reading aloud, lets say, instead of reading silently.[138] Finally, in the analysis phase, several safeguards must be taken in order to assure reliability. These include "coder reliability," "independence," and "differentiating among alternative theories."[139] In each study using Protocol Analysis, independent and multiple coders of the protocol have to be used and their encodings must be compared for consistency and reliability. Judgments of coders must be kept independent of the theory being tested in the study; and each analysis must show a level of agreement between data and tested theories.

Since the late 1960's, the building design process has been explicitly studied using Protocol Analysis.[140] Inspired by developments in management science, cognitive psychology and computer science,[141] Eastman conducted the first known protocol study in the Industrial Design domain.[142] In this study, experienced designers were asked to redesign the interior of a given residential bathroom based on orthogonal drawings and user evaluations of the current situation.

This was followed by a number of important studies. Krauss and Myer[143] tracked the design actions of a team of architects designing a school building over a period of 18 months. The collective design behavior in this architect's office was observed in the form of an unabridged design delivery process. In the early 1970s, Adel Foz[144] completed a master's thesis on the process of designing an architectural *parti* for a small institutional building, both by experts and novice designers.

These early studies of the architectural design process were concerned with characterizing it in its most general form: identifying the operations and representations that are responsible for the development of designs, calibrating the human cognitive system, describing a general taxonomy of tasks, and doing all of this within the context of Information Processing Theory.[145] Subsequently, researchers seasoned by this initial encounter as well as others entering the field from related areas, especially Engineering Design, built upon this early foundation.

These studies represent the beginning of a diversification in research agendas in the area of design thinking. Some of these studies deal with the internal and external representations of designed objects,[146] others with the issues of design generation,[147] others with the knowledge base of design thinking,[148] others with the formulation of design problems,[149] others with the thought processes that apply to learning,[150] and yet others with refining the general descriptions of the design process offered by the initial group of studies.[151] Currently, Protocol Analysis and other similar techniques it has inspired, such as Ethnographic Studies represent the core of descriptive approaches to design research.

Collective Design and Information Processing

The rich body of literature, briefly cited above, has been making inroads into the discovery of the nature of the individual designer's process. Yet our knowledge about the nature of design practices, in comparison to our knowledge about the nature of things around us, such as social systems, natural systems, and mechanical systems, is considerably more meager. It might be instructive, here, to revisit some of the high points of design research, particularly in the context of teamwork that usually produces it and the social systems within which they function.

The cognitive viewpoint argues that the basic anatomy of the human design process consists of three phases: initiation, development, and refinement.[152] This can be easily discerned from the behaviors exhibited by designers. They work in distinguishably different ways as they initiate their designs, as opposed to developing, refining or concluding them. Thus we structure our discussions here in three parts, respectively: conceptual design, design development, and design implementation.

Conceptual design, what is also known as initial design, is widely accepted in educational settings, as an introduction for students to the global context of architecture and building design, efficiently and effectively. The primary function of the conceptual design mode is for designers to establish the domain of design discourse, which is to follow in later stages. More tangibly, this means that they: (a) identify an inclusive set of requirements, (b) prioritize these requirements, (c) develop preliminary solution instances for these requirements, (d) evaluate these solution instances, and (e) thus, establish a final corpus of design requirements, preferences and evaluation criteria to be used in future stages (design development and design implementation).

Design development involves the further elaboration of design ideas into feasible ones, testing the validity of intentions developed in the initial stages against the realistic parameters of the design problem. This is usually addressed in more advanced years of architectural education. The designer, typically, is engaged in fully developing designs established in the conceptual design stage. The principal concern is one of insuring feasibility of the direction chosen in conceptual design and clarifying issues of cost, timetable, and performance expectations, *vis a vis* this direction. If any surprises arise in this stage, there is always the possibility of returning to conceptual design to revise the parameters of the solution space.[153] A revision of this kind can come in two distinct ways: irresolvable conflicts, and new opportunities. Conflicts arise when one set of prioritized requirements of design are impossible to realize without violating another, equally important set. This is a possibility because solutions developed during conceptual design are not sufficiently specific and do not permit accurate assessment of their downstream implications. Emergence of new, unrecognized opportunities is also possible for similar reasons of inability to predict all consequences of early design assumptions.

Design implementation, the third stage, refers to the translation of designs into constructed objects including working drawings and construction at the site. Here all technical issues are resolved and the translation of the design into a tangible object is completed. Before reaching the design implementation stage, most feasibility concerns are put to rest and the architect is in a mode of carrying out what is clearly known as likely-to-succeed strategies established during conceptual design and design development. Here, techniques of detailed specification are applied predictably, and accurately. Backtracking is not as prevalent as in design development, particularly if the earlier stages of design have been relatively successful. We regard the decision-making issues in each of these steps to be both equally demanding of and different from the others.

When viewed as a process involving multiple actors and stages, design consists of several distinct and progressively more complex layers of decision-making. The professional view of the building design delivery process has greater granularity than our cognitive abstraction of the design process: programming, schematic design, design development, working drawings, bid documents, and construction. These are predefined phases of practice with clear implications about the sequence of work, client reviews, payment schedules for services, and contents of documentation. They are sanctioned by professional organizations like the American Institute of Architects (AIA) and the Royal Institute of British Architects (RIBA). Furthermore, affiliated organizations, laws, and regulations support them.

While this breakdown is both realistic and organizationally useful, when we map these into the cognitive view of design, they appear to be less useful. In fact, research on the collective design process is hard to come by. The first refereed publication dedicated to collective design processes (*Codesign*) was launched only in 2003. Decades after Krauss and Myer's early study, precious little has been done in the area of collective design. Other than one carefully constructed case study in England,[154] we can cite only one other study that deals with collective design in architecture.[155] The latter, employing the Protocol Analysis techniques reviewed earlier, reports that:

(1) the "state space" representation which has been successfully used in modeling the individual's design process also applies to the collective design process

(2) decisions in the collective realm exist at different levels of information management: the profession, the firm, and the design team

(3) there are interdependencies between decisions taken at these different levels and these are regulated through people and policies

(4) quality of the decisions taken is a reflection of the quality of the decision mechanisms in place

These results are merely suggestive of both similarities and differences that arise in trying to extend our understanding from the domain of the individual designer to that of the design team.

The building design problem, by nature, is a very large problem.[156] It involves an extraordinary number of independent knowledge domains: ergonomics, sociology, cultural anthropology, urban design, economics, electrical engineering, mechanical engineering, civil engineering, soil mechanics, law, political science, and art, to cite a few.[157] Very large design problems are usually defined through large bodies of implicit requirements that spring from such knowledge domains. In parallel to this, there is also a kernel of relatively well-defined data sources that are as, if not more, relevant to the design problem at hand. These include information about site, upon which the architectural design must be placed, the client organization and its functional-spatial needs, the budget allowed, and the construction materials and techniques locally available.

To the untrained eye the very large design problem is definitely an endless maze of interrelations between vast sources of data and knowledge. To the trained designer, however, it merely constitutes the set of ingredients that are necessary for the development of a wholesome design. To both, the problem is overwhelming in its initial form. Yet, both apply specific and distinguishable approaches in dealing with this difficulty.[158] Here we are interested in the behavior of the experienced designer, who has a particular strategy, which he or she follows in order to make the very large design problem more manageable.

Initially, as we discussed earlier, a Breadth-First search is conducted which is converted into a Depth-First strategy as the architectural design work matures. In this context, the design team first examines as broad a set of alternative views of the design problem as it can manage within the time that is available. This requires the collaboration of different design professionals. For example, the options available for spatially organizing the functional elements of an architectural program, and the alternative access possibilities, alone, may provide an adequate basis for this step. If access is a determining factor, then the designers generate several alternative solutions based on the traffic and movement analysis. If the program is complicated, alternatives based on the interrelationships of the functions and their behavioral implications for the building's users would be considered. Thus, the overall strategy followed, at first, resembles the searching of the upper-most nodes of a decision tree, where all possibilities are identified without detailing each possibility beyond what is needed to clearly define them.

Once the design team identifies all significant alternatives and their spatial parameters, one or more of these are taken to the next stage and developed in greater detail. For example, multiple structural systems identified as viable alternatives would be boiled down to one or two suitable ones for the project and studied with the help of engineers. This often involves the selection of appropriate values for constraining the choice of materials, spans, construction methods, and so on.

After a solution in response to such an issue is developed, designers return to the initial set of issues and select a new one to develop into a new schematic solution. For example, if during the development of a solution to the circulation problem the possibility of a centrally organized floor plan arrangement is recognized, then it may be necessary to modify the current structural and mechanical solution accordingly. To satisfy the new requirements, the designer may find it necessary to incorporate a central HVAC concept into the design and introduce a radially organized structural grid, thus reinforcing the circulation idea through the structural and mechanical systems. In any event, a new solution emerges. This requires an active and iterative collaboration between several design professionals.

A difficult aspect of very large design problems illustrated by the above example is the integration of partial solutions into comprehensive ones. Comprehensive solutions are ones that satisfy a large set of design criteria at once. During the process of developing such solutions partial solutions are inevitable, because it is not possible to exhaustively search the entire design solution space. We already alluded to the large scope of these requirements and indicated how building systems, such as circulation, structural and mechanical, can suggest different layout solutions. Experienced designers and design teams first find partial solutions that satisfy individual criteria and then combine them into one or more comprehensive solution(s). Evidence from manual design protocols indicate that this is accomplished through a pair-wise integration strategy.[159]

Based on this, some general conclusion about design integration can be proposed: (a) design criteria are first satisfied individually, through partial solutions, in isolation from other criteria, (b) partial solutions are integrated piece-meal in a pair-wise fashion into comprehensive solutions, and (c) in developing the comprehensive solution some partial solutions may be revised and adapted to the constraints related to other partial solutions. Such a strategy is not only logical, but it also provides a structure for the collaboration of independent experts working on the same design problem.

Another strategy in collective design situations, which has been documented in literature, is the tendency of experienced designers to introduce new problem formulations during the course of design.[160] These studies report that experienced designers, compared to novices, show significant differences in structuring their problems.

Using Protocol Analysis, a series of experiments were conducted based on three different site shapes and three levels of subject expertise. It was observed that in solving the problem designers redefined their earlier definitions of the problem by altering the constraints applicable to the solution being developed. There were five distinct categories of problem redefinition or "restructuring" documented for all subjects: (1) re-order the sequence of constraints applied to functional elements, (2) eliminate a constraint previously applicable to functional elements, (3) apply new constraints to functional elements, (4) modify a set of constraints applicable to functional elements, and (5) apply a new design approach that changes relationships and constraints systematically.

This result indicates that on the average, designers (architects in this case) restructure the design problem consistently and significantly more often than others. The data also suggests that designers restructure the problem not only when they are stuck but also in cases when they find solutions. This undoubtedly is a strategy that can also assist in the innovation of design.

In fact, the tendency to reformulate problems by changing the *frame of reference* of the problem has been connected to the process of design *creativity*.[161] The sudden onset of a realization that a new frame of reference can help yields a theretofore unrecognized solution. Also known as the "Aha!" response, this phenomenon has been demonstrated in different domains of innovative cognitive activity, including puzzles, scientific discoveries, industrial design, and architectural design.

The third aspect of the design process applicable to large design problems is the role that human interaction plays within design decision-making. Due to the diversity of design agents (designer, consultant, client, developer, occupant, contractor, financier, and manufacturer) and the diverse roles they play, there are complex forms of "reasoning" that enter the picture. In addition to formal reasoning mechanisms, these include things such as, human judgment and constituent advocacy. In general, we refer to these as *negotiative* rather than *formal* or normative reasoning, as would be the case with induction and deduction.

Judgment depends on experience over a long period of time in a particular domain, as well as common sense and moral-ethical norms. In contrast to the formal reasoning approaches under the Positivist viewpoint, in which the validity of premises are less important than the validity of the derivations from them, here, premises are of utmost importance. Judgment implies correctness of premises.

The goal of the designer, then, is to seek compromise or consensus as opposed to searching for unequivocal truths, as is the case in formal logic, which is a primary tool of the sciences. This aims to bring into synthesis disparate even conflicting positions. This inherently problematic situation for logical propositions, as carried out by humans, is where the power of informal reasoning or design lies.

Advocacy as opposed to the "skepticism" of the sciences is the modus operandi of the designer or the artist for that matter. The scientist wishes to disprove hypotheses in order to make sure that the relationships she or he finally derives have withstood all tests and are as irrefutable as possible. On the other hand, the designer finds herself or himself in a position where many viable alternative relationships and solutions are possible. Here the task is one of choosing one alternative, which represents the consensus among all agents and is the best solution attainable in the designer's judgment. Once a candidate solution is found, the task of the designer is to advocate it as the solution until those who are to carry it out agree.

Suggested Readings: Chapter 3

3.1. Feldman, J. and M. K. Lindell (1990)"On rationality," in *Organization and Decision Theory*, ed. by I. Horowitz, Kluwer Academic Publishers, Boston, pp. 83-165

3.2. Simon, H. A. (1981) *The Sciences of the Artificial* MIT Press, Cambridge, MA

3.3. Akın, Ö. (1986) *Psychology of Architectural Design* Pion, London

3.4. Schön, D. A. (1983) *The Reflective Practitioner: How Professionals Think in Action*, Basic Books, New York