MODELS OF EXAMINING ARCHITECTURAL PROBLEM SOLVING ACTIVITY; A DESCRIPTIVE STUDY

by

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Chapter I: Introduction

Architectural design is a problem solving activity. There is no single path to the solution, neither is there any one correct answer to the problem (Lawson, 1989). Architectural design involves rational as well as tacit processes (Schon, 1985). Tacit processes are executed at a subconscious level and hence they are difficult to articulate. Furthermore it is difficult to evaluate the validity of such subconscious processes. All these reasons have hindered the objective study of architectural design activity. Recent developments in cognitive psychology (Bruner, Goodnow, & Austin, 1956; Miller, 1956;) and the Information Processing System (IPS) (Newell & Simon, 1972) have opened the door to the study of these tacit (cognitive) processes involved in problem solving activity. Following from such advances, several models have been developed to study the cognitive process of architectural design (Akin, 1984; Chan, 1990; Eckersley, 1988; Goldschmidt, 1990).

The models under study are based on the premises of the information processing theory (IPT). This theory posits a set of processes that produce the behavior of a thinking human. The IPT focuses on the individual, in order to identify the information that the individual has and the manner of processing it. As a result, verbal behaviors are used as data, and the analysis of verbal behavior has come to be the hallmark of the information processing approach to problem solving (Newell & Simon, 1972). Consequently, the models under study are based on verbal data generated by individuals involved in architectural problem solving activity. All the four models mentioned above use 'think-aloud' verbalizations. Think-aloud verbalization is the verbalization uttered by the problem-solver at the time of solving the problem. In all the models, the recorded verbalization is transcribed into typewritten form, assigned to predetermined categories defined by the respective models, and then analyzed. This study will describe and compare these models using a single architectural design problem. The content of the verbalizations collected will be examined and the inter-coder agreement in assigning the verbalizations to the predetermined categories of each model will be evaluated.

Significance

Architectural design is the backbone of architecture education (Dinham, 1986; Dutton, 1987;). Thus, a better understanding of the process of architectural design is central to improving architectural education. This process is of particular relevance in light of the crisis in the profession at the moment, and the series of attempts to uncover the processes of architectural design. With advances in technology, architectural design has become a complex socio-technical process (Schon, 1985). Many areas of design that traditionally were under the jurisdiction of architects are now controlled by professionals from other disciplines (Gutman, 1988). This shift has resulted in disenchantment with the profession, and awareness of the need to re-address the problems faced by the profession. Books like Brolin's *The Failure of Modern Architecture* (1976), Blake's *Form Follows Fiasco* (1974), and MacEwen's *Crisis in Architecture* (1974) are testimony to the crisis in the field of architecture. A brief overview of the context of American architectural education in this century and recent developments in design methods in response to this crisis will help to establish the need for greater understanding of the process of architectural design.

American Architectural Education

American architectural education in the nineteenth and early twentieth century was modelled after the French Beaux-Art tradition.

Consequently, architectural education in America at that time was characterized by the importance given to ateliers (studios), the tradition of older students helping the younger students, the teaching of design by professional architects, the commencement of design studies as the student entered the institution, and the system of the 'esquisse' (competitions) for evaluating student design (Escherik, 1983). After the first World War, American architects like Edward Stone, Louis Kahn, and Louis Skidmore toured Europe. This was the time when the Bauhaus movement had swept across Europe, and works of architects such as Le Corbusier, Mies Van der Rohe, Moholy-Nagy, and Walter Gropius, strongly influenced these American architects (Wolfe, 1981). They returned to America filled with ideas of the socialist architecture of the Bauhaus movement. The architecture for the working class seemed to echo the philosophy of America - 'the land of opportunities'. Then in 1937, in the wake of Nazi rise to power, Walter Gropius, founder of the Bauhaus School, came to America. Soon Marcel Bruer, Mies Van der Rohe, Moholy-Nagy and other architects of the Bauhaus movement followed in Gropius' footsteps. Both Gropius and Mies were offered positions of leadership at American architectural schools. Moholy-Nagy opened the New Bauhaus, which evolved into the Chicago Institute of Design (Wolfe, 1981). Thus, these European architects influenced the architecture profession and education in America for the next few decades. The reverence for classical order was replaced by a reverence for simplicity and mass produced 'machines for the living'. Architectural education changed rapidly under their guidance. The Beaux-Art tradition of classical order made way for the machine architecture of the International Style (Wolfe, 1981).

The architecture of the 'new world', which was directed towards an architecture of the working class, did not live up to its name. It was an irony of fate that at a time when America was at the zenith of power, it espoused an architecture whose tenets prohibited every manifestation of exuberance, grandeur or high spirits (Wolfe, 1981). This architecture of the working class was characterized by crisp straight edges, stark facades, and match box structures in the likeness of machines for the living. The buildings were harsh and devoid of any individual or humanistic touches. There was a growing conviction that the built environment had far reaching effects on people and their work (Juhasz, 1981). It was believed that "the architect properly educated could contribute far more to the construction of a humane world" (Kay, 1975, p. 36). Since no systematic inquiry had been conducted in this area, this was a realm of growing interest in the 1960's. Thus began the trend towards an union of traditional architectural education and social sciences in the 1960's and 1970's.

In order to execute this merger of architecture and the social sciences, it was necessary to restructure the architecture curricula as well as modify the methods/theory of pure social sciences. It was at this time that environment-behavior research/studies (EBR/EBS) was established. Schools hired social scientists to make the connection between building design and its effects on the buildings' users. Courses in the social sciences were introduced in architectural curricula. These courses were primarily theoretical, without much emphasis on their applicability in the context of architecture. A part of the problem was that the empirical methodologies of the social sciences did not lend themselves easily to generalization. Thus, the ideas and theories taught in classes were not integrated in the studio. Many of the courses attempted to introduce the architecture students to the concept that buildings should be designed to facilitate positive human behavior. Another group of social science courses was intended to familiarize architecture students with the methods of research. In some instances, social science research was utilized to develop programs for buildings, but only in very few instances was environment-behavior research used to structure design projects (Seidel, 1981). This fragmented approach paid lip-service to the concept of incorporating social science studies in architectural design. Thus, the impact of environment-behavior research on architectural design was much less than that which had been hoped.

The Need for Research on Design Methods

The inability of design professionals to successfully integrate knowledge from the social sciences with architectural design resulted in disillusionment with the profession, and more specifically with the prevailing education system. The social sciences did not prove to be the panacea for the ailments of the profession. There was widespread feeling among architects that architecture education needed to be revitalized. The efficiency and adequacy of the design studio in imparting architectural education was questioned by both professionals and academicians (Beckley, 1984; Dutton, 1987; Hurtt, 1985; Rapoport, 1984; Saunders, 1986; Schon, 1985;). These writers called for greater emphasis on the process of design, rather than on its end product.

At the same time, the second half of the twentieth century witnessed rapid technological advancements in the construction industry. New materials were invented and quick construction methods perfected. Taller structures could be built, and wider distances spanned (Gutman, 1988). Greater scale and complexity of structures increased the need to involve a broader range of new disciplines and professions in the design process. New domains of technology such as building diagnostics and energy management began to play important roles in the design process. According to the AIA, there are now as many as twenty-five disciplines whose expertise the architect may need for designing a building (Gutman, 1988). Thus, the architect is required to have a wider knowledge base to control the design process (Gutman, 1988; Schon, 1985;). Although there have been significant shifts in the realm of architectural practice in the past forty years, the architectural education system has not reflected much change. Thus, practitioners and educators began to doubt whether the existing architectural education system could equip students to face the challenges of the profession.

First Generation Design Methods

An active interest in architectural design developed amongst academicians and professionals as a result of the changes in practice described above. The success of the National Aeronautical and Space Administration in solving military technological problems led to the notion that a systems approach might be applied profitably to civilian design areas (Cross, 1984). The early 1960's witnessed the development of systematic procedures for the overall management of the design process based on the success of systems approaches in solving military technical problems (Cross, 1984). The models proposed within this paradigm dealt primarily with the sequence of design decisions, the generation and evaluation of alternatives, and the optimization of choices (Alexander, 1964; Jones, 1970). The objective of these methods was to find a set of rules that produced an optimal solution to a problem. The use of these methods presupposed that the goals to be achieved were precisely defined. However, since in architectural design the goals are complex and ill-defined, the systematic approach did not prove to be as successful as expected (Heath, 1984). Alexander (1971) publicly announced his retreat from his earlier position of systematic design as the solution to good design. Within a few years, the major exponents of the 'first generation' design methods (Alexander, Eastman, Jones), had withdrawn from the field.

Second Generation Design Methods

The early demise of the first generation design methods led to the rise of 'second generation' methods. Procedurally different from their predecessors, these methods visualized design as an argumentative process, rather than as a sequence of well defined steps (Rittel, 1984). With the second generation methods, expertise as well as ignorance about a problem was assumed to be distributed over all the participants (i.e. user, client, architect, other consultants) involved in the design process. Design was conceptualized as a counterplay of raising issues and deciding in favor of or against various positions on each issue (Rittel, 1984). Consequently, maximum participation was sought from architects, consultants, clients, and other interested groups in order to activate as much knowledge as possible. Conferences and seminars generated a large amount of literature on participation. The concept of participation was widely acknowledged by users and design professionals. However, the actual implementation of participation in the design process proved to be the weak link in the system. Criticisms of participatory design processes included: (a) disproportionate amounts of time and effort spent on reaching consensus on particular design issues, (b) users not aware of the complexities of the design process, (c) users not educated to participate in design decision-making effectively, and (d) products of participatory design processes not differing much from buildings designed in traditional way (Broadbent, 1982). Thus, the second generation methods also failed to have any overreaching effect on architectural practice.

Development of Focus on Cognitive Processes in Design

The failures of the expert mathematical and optimization techniques of the first generation methods and the argumentative design process of the second, convinced designers the design process is different from scientific processes. Because a design problem does not include an explicit set of requirements, its solution is usually one of a set of possible solutions. The requirements of the problem are obscure, and the task of design is one of minimizing misfit between emerging requirements and developing provisions. Consequently, much of recent work in design method deals with the study of the logic and reasoning of the designer and their strategies for generating information and arriving at solutions. This trend was influenced by developments in cognitive psychology and information processing theory.

Developments in Cognitive Psychology/Information Processing System

Traditional approaches to modeling human cognitive performance are based on the stimulus-response, or behaviorism models (Akin, 1984). These models assume that behavior of a person can be explained only by studying his/her response to observable external stimuli. The internal mechanisms responsible for developing solutions suitable to the initial stimuli are considered to be a black box, into which researchers should not pry (Lobell, 1975). On the other hand, the information processing theory developed by Newell & Simon (1972), asserts that people are information processing systems, at least when they are solving problems. The theory attempts to explain behavior in performing a particular task by describing the manipulation of information to a level where an interpreter can convert the description into an effective process for performing the task. Thus, the information processing theory provides a viable framework for studying the cognitive processes behind problem solving activity.

Omer Akin (1984), at Carnegie Mellon University, laid the foundation for the study of the cognitive processes involved in architectural design activity. Following Akin, several other researchers have attempted to develop models of studying architectural design activity in the hope that they will give insights into the design process. None of these models has been developed to study the design process from the point of view of formulating an effective theory of design education. Neither does any of them provide a time-tested means of examining architectural problem-solving activity. However, these models do provide ways to study the process of architectural design. This situation underscores the need to evaluate the reliability of the data obtained through the use of these models, and to examine the extent to which such models can yield insights about architectural design processes in order to improve design education. If shown to yield reliable and valid information, these models can be used to identify important components of the design process, strengths and weakness of different design strategies, and other influences on design. In the next step, data from these models could be used to examine causal relationships (if any) between student design capabilities and type of design instruction. These findings could then help to develop a more effective theory of design education.

The present study represents the first, exploratory step in the process outlined above. On the basis of the comparison of the models that have been developed to study the cognitive processes involved in architectural design, two models were chosen for further study. These two models were those of Eckersley (1988) and Goldschmidt (1990). The study evaluates the agreement between data obtained via the two models, and the usefulness of the inferences that can be made from the analyses of such data. If dependable, these models could be used to gather data about design processes which could generate generalizable principles or ideas. If information yielded by the models is not dependable, then refinement and modification of one or both of the models is essential.

Objectives of Study

The objectives of this study are three-fold:

1. To examine the content of verbalizations of students involved in architectural problem-solving activity. Such data will illustrate how different people structure a solution to a specific architectural problem.
2. To compare the quality of data collected and analyzed by the two chosen models. This process compares protocols for the agreement in encoding and ease of encoding by the two different models.
3. Explore ways in which the models studied could be improved.

In order to achieve these objectives, the following questions were posed:

1. How do different students structure the solution to a given design problem? What kinds of information are used to structure and solve the design problem?
2. a) How dependable are the two models (Eckersley, 1988; Goldschmidt, 1990) in terms of structural and categorical agreement?

   b) How much time is required to encode the protocols using the different models? What kinds of problems are encountered during encoding?

3. In what ways may these techniques be modified or further developed so that more relevant information about the cognitive processes involved in architectural design activity may be obtained?

Chapter II: Information Processing Theory in Design Process

The study of the process of architectural design has developed along two paths. Both approaches examine the process of architectural design, but vary in the methods of doing so. In the first instance, the process of architectural design is examined by following closely the student-teacher interaction in the context of the studio environment. The way in which a student explains his/her design, and articulates the difficulty he/she is facing in developing the scheme, and the instructor's response to the student is studied to gain insight into the process. Schon (1983, 1985) is the main exponent of this method of inquiry into the design process. Another mode of inquiry into the design process is based on the information processing theory. According to this approach, architectural design is considered to be a type of problem solving activity which can be analyzed by examining the verbalizations of a problem solver. Following the methods of information processing theory, an individual is asked to solve an architectural design problem and to think-aloud while he/she is engaged in solving the problem. These verbalizations are the data for analysis.

Since these modes of inquiry approach architectural design as a specific kind of problem solving activity, the concepts of problem solving, information processing theory, and more specifically design information processing systems (DIPS) are central to these strategies. This chapter includes a brief description of the salient features of problem-solving, information processing theory, and the design information processing system. Next is a description of the four models under study, followed by a comparison of the models.

Problem Solving

A problem is described as a source of difficulty or trouble, or a question proposed for solution or discussion. Problem solving is the act of finding the answer or solution to a particular question. The desired answer may be very tangible, like the solution to a simple mathematical problem, or abstract, like a design problem. The goal may be a physical object, or just a set of symbols (Newell, & Simon, 1972).

Problem State and Problem Space

Human problem solving is a continuous process. The process begins with the initial problem representation, goes through a series of intermediate stages, and ends either with a solution or admission of failure. For the purpose of studying problem solving behavior, problem solving is represented as a series of discrete events, rather than a continuous process. Each of these events are termed problem states. According to Akin (1984), a problem "...state is the totality of all the information relevant to the problem solving process and available to the Information Processing System (IPS)..." (p. 14) at any time. These problem states constitute the problem space. The problem space consists of the initial situation presented to the problem solver, the desired goal, various intermediate states, and concepts used to transform the initial state to the goal state (Akin, 1984).

Human problem solving takes place by search (for the desired goal state) in the problem space (Newell, & Simon, 1972). The given conditions of the problem and concepts of the problem solver are used to transform the initial state to the desired goal state through a series of intermediate stages. Thus, the task of problem solving is one of minimizing the difference between the initial and goal state, until a satisfactory fit is achieved (Akin, 1984).

The example of the fifteen puzzle problem (Neisser, 1976) illustrates the problem space representation. Figure 1 provides a representation of an initial state, some probable intermediate states, and the final goal state. The object of the problem is to achieve the goal state from a given state by moving the numbered cells of the grid into the blank cell position (represented by a dark square in the figure). Each intermediate step can be represented by specifying the positions of all the cells. This can be done graphically, or by specifying the coordinates of all the cells. The set of all probable states constitutes the total problem space. It can be seen that the problem space is large, even in the case of a simple problem like this. Only one of the possible states in this case is the goal state. The goal state is that particular state in which all the cells are arranged in a left-to-right, top-to-bottom ascending order, with the blank cell occupying the bottom right corner position.

Ill-structured and Well-structured Problems

Problems can be broadly categorized as being ill-structured (ill-defined) or well-structured (well-defined). Reitman (1965) uses the term ill-defined to designate those problems which lack a systematic basis for solution. Such problems have open ended constraints. Because a wide range of knowledge can be used for formulating such constraints, no universally accepted solution is generated. These problems are solved by general rules of thumb or heuristics methods. Newell (1969) uses the term ill-structured to refer to problems that do not have a well-defined method for solution. He emphasizes the relationship between problem structure and problem solving methods. The generality of a problem solving method is determined by the size of the set of problems that it is able to solve. Within the specified domain of a method, the ability to produce solutions is a measure of the power of the method. There is an inverse relationship between the

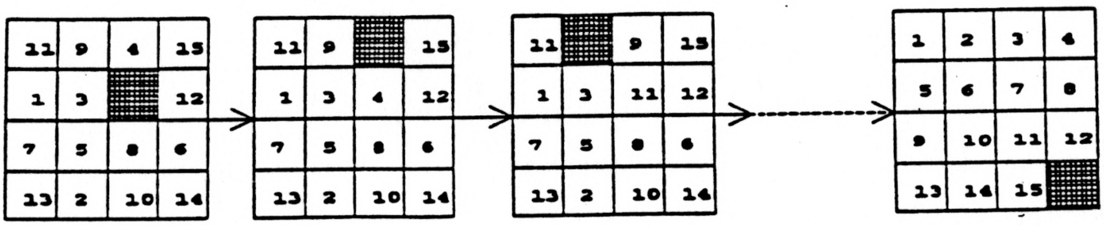


Figure 1: 15 puzzle problem

Source: Neisser, 1976 from Akin, 1984, p. 14

generality and power of a problem solving method. General methods of solution are also weaker methods of problem solving. Thus, "a problem solver finds a problem ill-structured if the power of his methods that are applicable to the problem lies below a certain threshold" (Newell, 1969, p. 375).

Ill-structured problems are characterized by very large problem spaces. They are open ended and lack a systematic solution path. The initial problem statement itself is not well defined. During the process of solution, the problem solver evokes goals and constraints from his/her knowledge base to structure the problem. The solution of an ill-structured problem thus involves as much problem formulation as problem solution. The domain of ill-structured problems is considered one in which only weak problem solving methods are available (Newell, 1969).

Well-structured problems (WSP) have definite criteria for testing proposed solutions and a mechanizable process for applying each criterion. For example, during a simple addition problem, one can obtain the solution by following the necessary steps or algorithm. If the steps are executed correctly, an universally acceptable answer is generated. Well-structured problems have a finite problem space. The initial state and the goal (final) state are well defined. The operators which can be used to transform the initial state to the required goal state through intermediate steps are known. The initial state, final state, and transitions necessary to transform the initial state to the goal state can be represented in the domain of the problem space (Simon, 1984).

<u>Architectural Problem Solving</u>

Architectural problems are characterized by being ill-defined in a number of ways. "The problem space is not defined in any mechanizable way, for a definition would have to encompass all kinds of structures the architect might at some point consider" (Simon, 1984, p. 152). There are no set solution paths, nor are there any definite testing criteria. Design problems are broken down into sub-goals during solution. As the design progresses, requirements/constraints are applied to solve the sub-problems. These requirements are either set by the client or retrieved from the designer's knowledge base. Since a person's knowledge base is the sum total of his/her past experiences, differences can be expected between the knowledge bases of different people. These differences, as well as variance in problem solving aptitudes, result in different solutions to the same design problem. In a short period of time, the architect working on an ill-structured design problem converts it into a series of well-structured sub-goals by using appropriate constraints. Inter-relationships between different well-structured sub-goals may often be neglected or overlooked. Solutions to certain sub-goals may be affected by later moves, when new aspects are reviewed. The skill of the architect is used to eliminate or reduce such inconsistencies. The sequence in which design constraints are applied may contribute significantly to the direction of the search and hence the designed product. Global parameters established in the early stages of design can operate later as constraints on relevant components. Differences in product between different designers (in response to the same problem) can result from different organization of the design process. Thus, the components of design and their inter-relationships can give meaningful insights into the design process. Consequently, a significant portion of recent research in design methods focuses on various parts of design and their relationships to one another and the design process as a whole.

Information Processing Theory

According to the information processing theory, human beings can be represented as information processing systems. "An Information Processing System (IPS) is a system consisting of a memory containing symbol structures, a processor, effectors, and receptors" (Newell & Simon, 1972, p. 20). Symbols are elements, while a symbol structure consists of instances (i.e. occurrences) of symbols connected by a set of relations. An information process has symbol structures for its inputs and outputs. As shown in Figure 2, receptors gather information from the environment and effectors manipulate the environment through motor behavior.

A processor is a symbol manipulator which converts the information provided by receptors into a code that is consistent with the internal symbol structures of the system. Processors also transform internal symbols and their relations into codes that can be transmitted to the external world and environment by effectors. Memory is a component of an IPS that is capable of storing and retaining symbol structures. The processor consists of atomic processes (elementary information processes), working (short term) memory and an interpreter that determines the sequence in which the processes are performed. This sequence is a function of the symbol structures present in the working memory. The working memory is responsible for retaining the input and output symbol structures of the atomic processes, which are the basic functional or molecular units of the processor. When atomic processes are activated in particular sequences, the functions for which the processor is responsible are performed. Working memory is the representational medium for these operations - very much like the architect's sketch pad. The interpreter oversees the proper functioning of the processor by ensuring that the atomic processes are executed in a correct sequence.

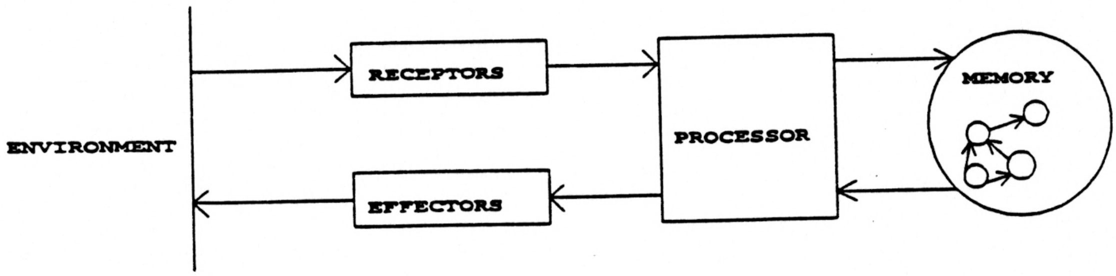


Figure 2: General structure of an information processing system

Source: Newell & Simon, 1972, p. 20

In order to follow the process of architectural design through the medium of the information processing system, some assumptions have been developed (Akin, 1984). These assumptions are:

1) Design is a form of problem solving where individual decisions are made towards the fulfillment of objectives.

2) The designed product is a direct consequence of the preceding cognitive activity and not some arbitrary process that is independent of such activity.

3) Although designers' knowledge and behavior may vary, their basic information handling capabilities, such as encoding, manipulation, and recall of information, are essentially similar to the capabilities observed in other task contexts.

Design Information Processing System

Architectural design is a rational and intuitive process. It is part science, part art. As mentioned earlier, architectural design is an example of ill-structured problems. The premises are open-ended, objectives are not specified and the process (of design) involves problem setting as much as problem solving (Goldschmidt, 1989). In order to develop a codifying system for the cognitive processes involved in architectural problem solving, a basic understanding of knowledge structures is necessary.

Research in knowledge engineering indicates that there are two basic types of knowledge: declarative and procedural. Declarative knowledge is used to describe how things are (Anderson, 1981). This is done by identifying objects, their attributes, and the relations between them. Procedural knowledge is used to describe and predict actions or a plan of action. Knowledge may also be specific or general in nature. When one refers to a bathroom or bedroom in a generic fashion, one is referring to the general information conveyed by the term bedroom or bathroom. References to a specific bathroom or bedroom would have some information pertinent to the specific bedroom/bathroom. References to a specific object is termed a token, while reference to a general class of things is known as a schemata. Declarative knowledge also is used to convey information regarding the relationship between objects. General purpose relationships between schemata are called rules of inference. When applied to a specific instance (token), the relation is termed as an attribute. Procedural knowledge contains specifications for action. Heuristics is the general form of procedural knowledge, and transformations is the term applied to specific problem solving intentions. This taxonomy of knowledge is represented in Table 1.

Since architectural design is an open-ended process, designers usually face problems without clearly defined objectives, methods or evaluation criteria. Akin (1984) developed a model of Design Information Processing System (DIPS) based on the IPS model of Newell and Simon (1972). The following description of DIPS is based on the work of Akin (1984).

Figure 3 represents the most general form of DIPS. The environment consists of knowledge pertaining to the design problem and the solution to be developed. The receptors help in the acquisition of information (from the environment) required for the problem solution. The processor is responsible for the transformation of the information acquired with the assistance of memory. Memory consists of the long-term knowledge necessary for design. Memory is built up with exposure to the process of design and with experience. The transformations that take place in the processor alter the content of the memory as well as the external environment in terms of the solution to the problem at hand. The effectors are responsible for encoding the information developed internally in the

Table 1 A taxonomy for knowledge representation

	Specific knowledge	General knowledge
Declarative 'thing'	tokens	schemata
Declarative 'relationships'	attributes	rules of inference
Procedural	transformations	heuristics

Source: Akin, 1984, p. 34

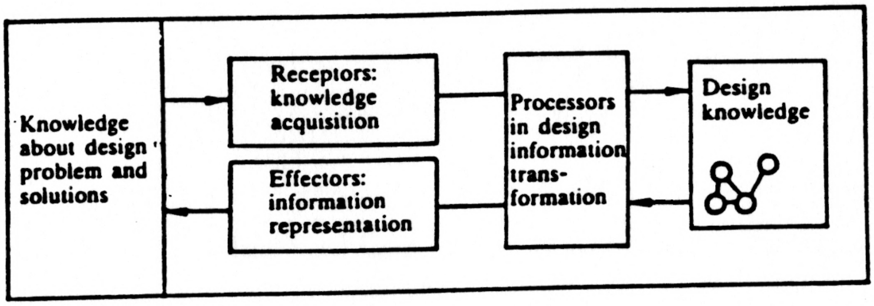


Figure 3: Design Information Processing System

Source: Akin, 1984, p. 56

processor in a suitable form to produce transformations until the goal state is achieved.

Figure 4 gives a more detailed account of DIPS. It focuses on the general attributes of DIPS under three headings: external representations, design processes, and organization of memory. Design is a lengthy process involving several participants with different skills (for example, architect, structural engineer, HVAC consultant). Since several professionals or consultants are involved in the process, design is often the process of compromise between the requirements of the different groups rather than one of perfect agreement. In order to be able to communicate with each other, conventions governing the exchange and transformation of information are necessary. The background information consists of codes and conventions used by the designers. During problem definition, information from the former phase is used to define the problem with input from the client/user. The problem definition forms the basis of the design problem. Problem structure consists of the individual formulation of the problem definition by the architect. This is a function of the individual designer's process and leads to a solution based on priorities given to the different requirements by the architect. Since different designers will probably have various ways of structuring the problem, different solutions will be evoked in response to the same problem. The preliminary design documents are used to communicate the design to clients/users and other professionals involved in the design process. Large scale projects often have two stages of preliminary design documents: schematic design, and design development drawings. Once the design is finalized construction drawings and documents are prepared. These documents include working drawings and specifications necessary for the

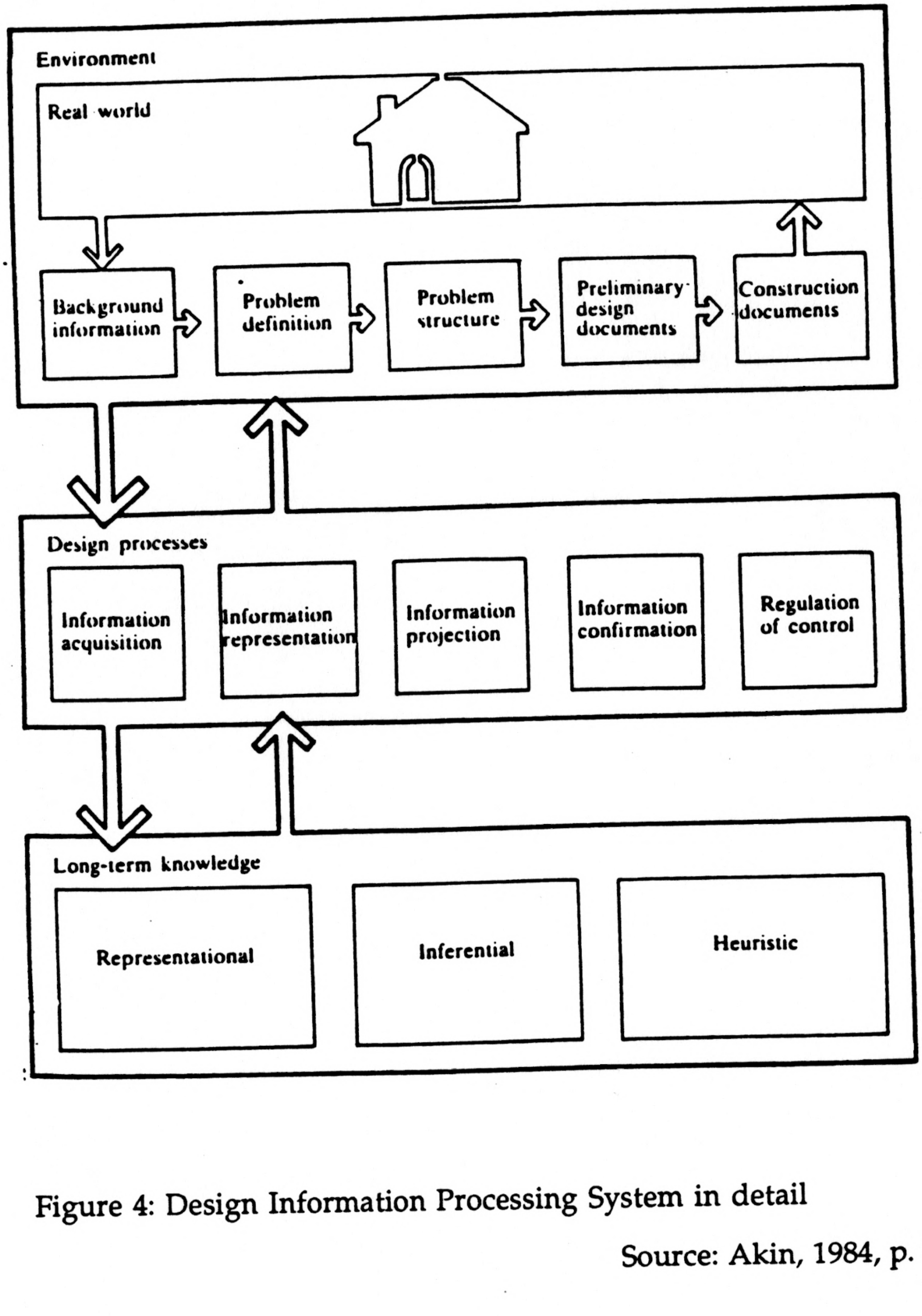


Figure 4: Design Information Processing System in detail

Source: Akin, 1984, p. 57

construction of the project. The construction documents form the basis of contractual agreement between the designer, client, and builder.

The information necessary for formulating and structuring a design problem is not contained within the long-term memory of the designer. Many of the codes and conventions, as well as other pertinent information, are obtained from external sources of information. These external sources serve to extend and augment the designer's memory. During the process of design, the external memory is adjunct to the current knowledge state. When required, the designer searches the external memory to access the information necessary to proceed with the solution. The design processes which are responsible for the transformation of information with the help of the processor and memory are influenced by inputs from the environment and long-term knowledge (as represented by Figure 3).

Description of Four Models for the Architectural Design Process

Akin (1984) was one of the first researchers to investigate the cognitive processes involved in architectural problem solving, based on the information processing system (IPS). He studied the different processes used in architectural design and provided the most extensive theoretical background of the IPS with reference to architecture. The other three models (Chan, 1990; Eckersley, 1988; Goldschmidt, 1990) are based on the theoretical framework developed by Akin. Consequently, the model developed by Akin will be described first, followed by those of Eckersley, Chan, and Goldschmidt.

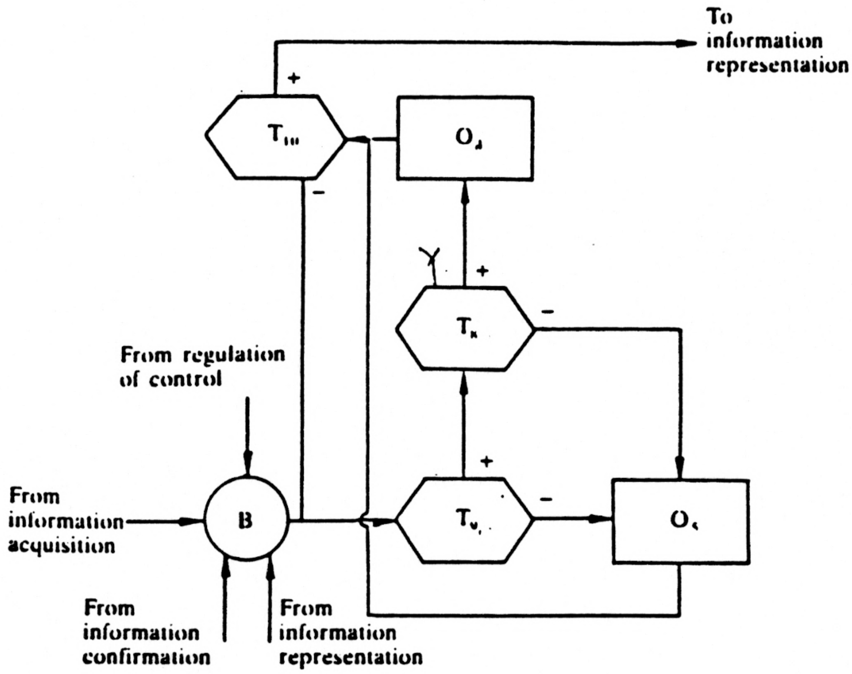
Model Developed by Akin

The process of architectural design involves several kinds of transformations. The problem is structured and then transformed from the initial state to the final goal state through a series of intermediate states. Akin (1984) has proposed a model that allows the representation of the design process at a very detailed level. He has identified five elemental processes (transformations) consistently used to alter problem states during the process of architectural design. These are: projection of information (P_p), acquisition of information (P_a), representation of information (P_r), confirmation of information (P_c), and regulation of flow of control (P_s).

Projection of information. Information is projected from existing information through inference, deduction, or interpolation. Projection of information is the process of inductive reasoning. By this process, information is transformed from one state to the other. Figure 5 illustrates the manner in which information is transformed during projection of information. For example, spatial information is often transformed into functional relationships. Rules of transitivity and substitution are used for inductive reasoning in this process. The rule of transmitivity states: if x, then y, and if z then y; therefore x = z. For example, if space x is under space y, and space z is under space y; it can be assumed that space x and z are co-planar, or both are under space y. The rule of substitution states: if coplanarity and accessibility are taken to be equivalent, in the above case we can say that since space x and space z are co-planar, then space x and space z are also accessible from each other.

Acquisition of information. Information is acquired from external sources, such as slides, books and drawings, and from memory (based on assumptions and previous experiences). Acquisition occurs most often during the problem-structuring phase through (a) visual search, (b) verbal inquiry, and (c) search of memory contents. Figure 6 depicts the process of information acquisition.

Representation of information. Information is represented either after acquisition or after internal processing to assist in other operations and to



B Begin

T_8 Are there premises (initial states) that are applicable?

T_9 Are there implications (goal states) that are applicable?

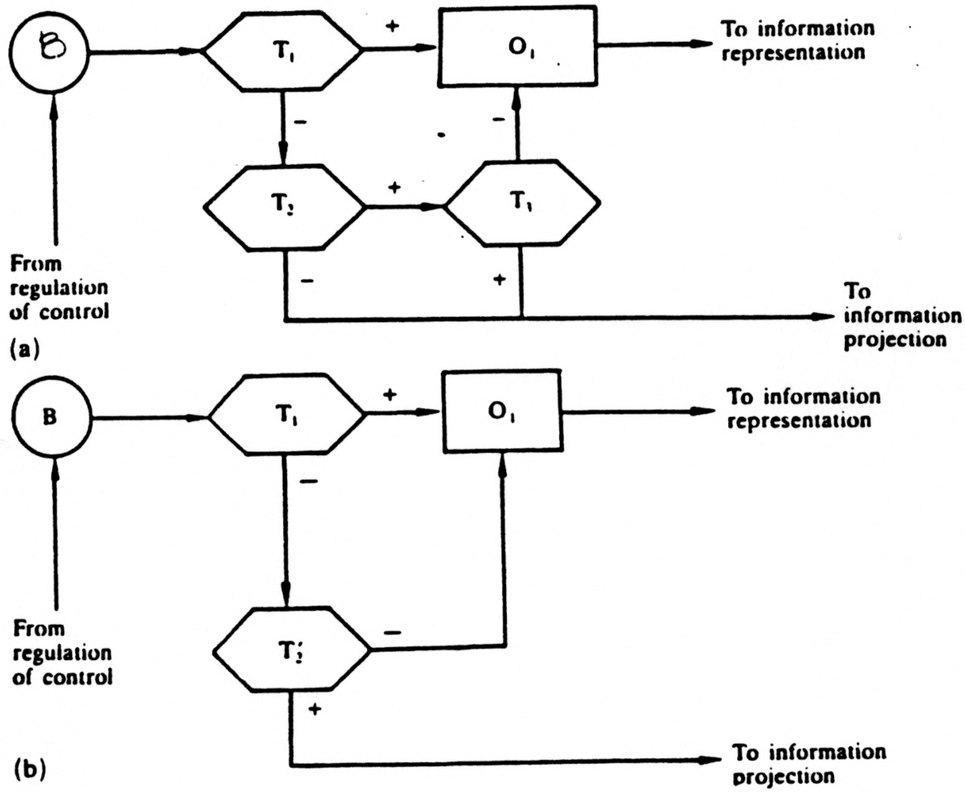
T_{10} Is the new predicate developed?

O_4 Change implication given

O_5 Change implication desired.

Figure 5: Flow diagram of information-projection process

Source: Akin, 1984, p. 77



B	Begin
T_1	Is the new information needed, in LTM (long term memory)?
T_2	Is the new information needed, in EM (external memory)?
T_3	Is there an EM?
T'_2	$= T_2 + T_3$
O_1	Retrieve from LTM or EM.

Figure 6: Flow diagram of information-acquisition process

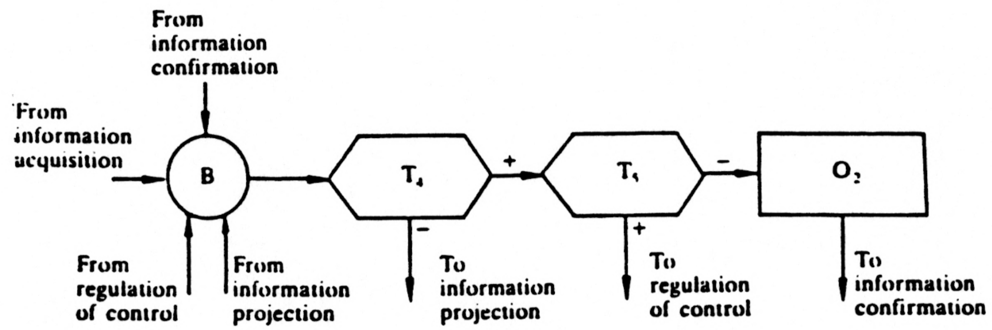
Source: Akin, 1984, p. 65

help with its retention in memory (refer to Figure 7). Representation of information usually takes place through three modes: (a) written text or spoken words, (b) graphics, and (c) memory systems.

Text plays an important part in the earlier stages of development of design and in the specifications of construction documents. Many technical attributes of materials, construction techniques, and user activities are best represented through text. Graphics are used to explain spatial relationships. In design development, graphical representation is preferred over other forms of representation because of its compatibility with physical object description. Information from short term memory (STM) is stored in long term memory (LTM) through the process of rehearsal. It is believed that representations are heuristic devices for looking at problems. Good representations are supposed to suggest good problem solving methods (Hunt, 1975). Thus, good designers acquire methods of representation suitable for the solution of the design problem successfully.

Confirmation of information. Information that is newly acquired or projected is confirmed to verify its consistency with other existing information. Each design step is not necessarily consistent with previous design requirements. The primary purpose of the confirmation process is to find previously acquired information that may potentially be in conflict with the newly acquired information, and to check for consistency between them. Figure 8 illustrates the information confirmation process.

Regulation of flow of control. Problem solution takes place in a problem space. Since design problems usually are open-ended, a designer is faced with a large number of potential alternative choices to consider during designing. Consequently, it becomes necessary to reduce the size of the



B Begin

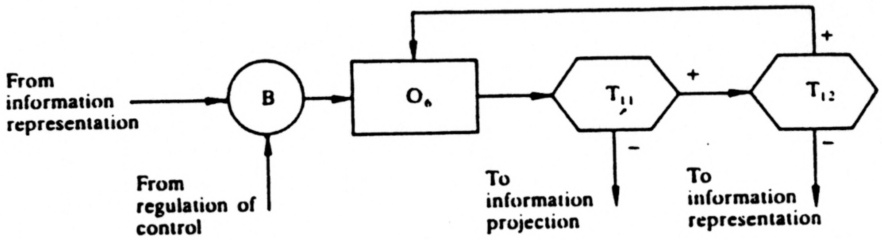
T_4 Is the new information consistent with existing representations?

T_5 Is the new information already present in existing representations?

O_2 Encode new information in external memory or long term memory.

Figure 7: Flow diagram of information-representation process

Source: Akin, 1984, p. 68



B	Begin
T_{11}	Is the new information in agreement with existing information?
T_{12}	Any other existing information against which new information must be checked?
O_6	Retrieve existing information potentially in conflict with the new.

Figure 8: Flow diagram of information-confirmation process

Source: Akin, 1984, p. 79

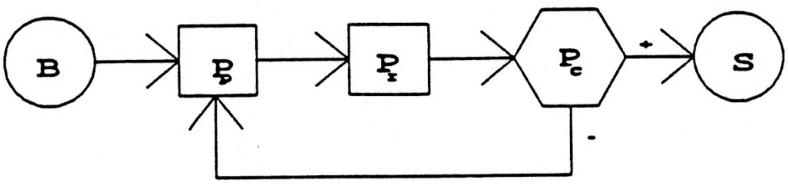
problem space during design. This is the primary goal of the process of regulation of flow of control.

Formal methods of decision making use mathematical tools such as linear programming and statistical analysis to reduce the problem space. Studies of human problem solving activity indicates that weaker methods called 'heuristics' are used to solve ill-defined problems, including architectural design problems. Heuristics are weak methods because they do not guarantee a solution. The solution reached by a heuristic is usually satisficing rather than optimal, increasing generalizability. The heuristics commonly used during architectural problem solving are: (a) Generate-and Test (GAT), (b) Hill Climbing (HC), (c) Means-End-Analysis (MEA), and (d) Induction. The structure of each of these heuristics is shown in Figures 9,10, 11, and 12.

Each of these processes is sufficient for the completion of a sub-problem, but none alone is sufficient to account for the entire design process. Figure 13 integrates these flow diagrams into a chart that links the five basic processes and accounts for the total design process.

Akin (1984)operationalized the five processes described above:

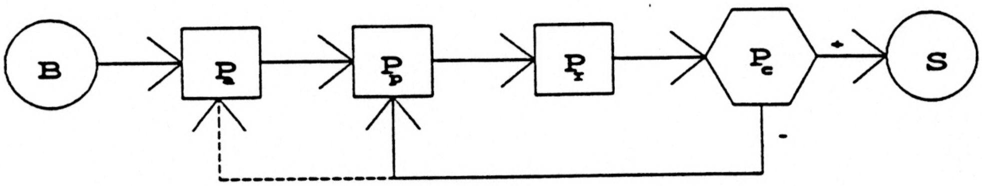
> 1) When the subject asks a question, visually examines an external source, or simply remembers a general fact from memory, for example "house costs are running in the neighborhood of $40.00 per square foot" it is assumed that he or she is acquiring information.
> 2) When the subject draws, writes, or simply verbalizes a piece of information which is used later in the protocol it is assumed that he or she is representing information.



B Begin
P_p Projection of information: generate a partial solution
P_c Confirmation of information: test if solution meets goal
P_r Representation of information: represent solution
S Stop

Figure 9: Generate-and-test process

Source: Akin, 1984, p. 99



B Begin

P_a Acquisition of information: retrieve best-so-far solution

P_p Projection of information: generate a partial solution

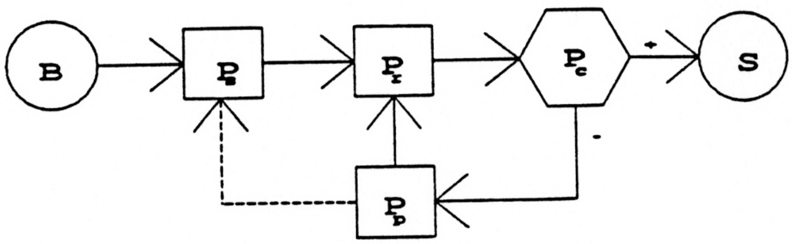
P_c Confirmation of information: test if solution meets goal

P_r Representation of information: represent solution

S Stop

Figure 10: Hill-climbing process

Source: Akin, 1984, p. 100



B Begin

P_s Regulation of control: select heuristic method

P_r Representation of information: represent solution

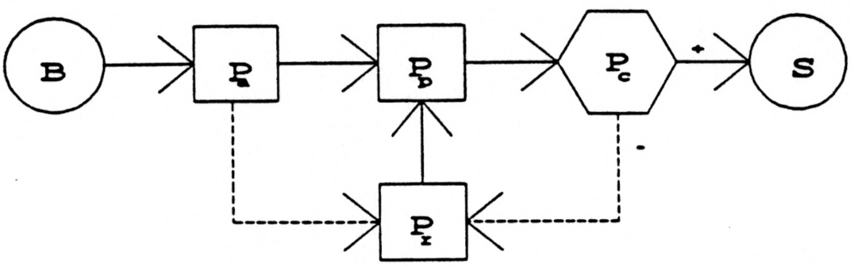
P_c Confirmation of information: test if solution meets goal

P_p Projection of information: generate a partial solution

S Stop

Figure 11: Means-end-analysis process

Source: Akin, 1984, p. 102



B Begin

P_a Acquisition of information: retrieve best-so-far solution

P_p Projection of information: generate a partial solution

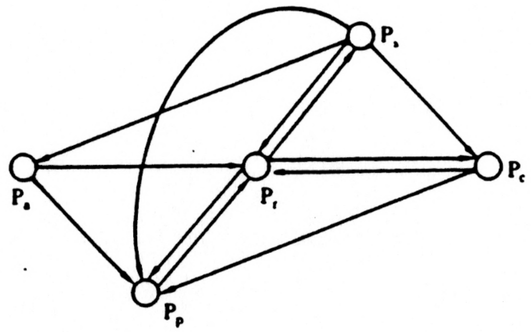
P_c Confirmation of information: test if solution meets goal

P_r Representation of information: represent solution

S Stop

Figure 12: Induction process

Source: Akin, 1984, p. 108



P_a	Acquisition of information
P_p	Projection of information
P_c	Confirmation of information
P_r	Representation of information
P_s	Regulation of control

Figure 13: Directional links showing flow of control

Source: Akin, 1984, p. 81

3) When the subject transforms a given piece of information into a different format, for example, "so 40 into 25,000", or "we can say it's a two-car garage", he or she is projecting information.

4) When the subject comments on the validity or correctness of a piece of information, for example, "it would take an assessment of the property to determine correctness of assumption", it is assumed that he or she is confirming the consistency of this information with respect to other things known. At times the subject terminates some trains of thought abruptly, for example, "Well, in the $ 1250.00 is ...", or "Well, could be figured in relation to ...". It is assumed that at such times, he or she has discovered some inconsistencies in reasoning as a result of the confirmation process.

5) When the subject comments about what must be done next with respect to the task being performed, such as "But what must I do, for lack of information, is to accept that cost of design to be $35,000.00", it is assumed that he or she is regulating control over behavior, to narrow the scope of the search space. Not all instances in this category assume explicit form.

(Akin, 1984, p. 88-89)

The think-aloud verbal protocol is recorded, and then transcribed, and coded into the five categories. When one category is immediately followed by another one without any interruptions, it is assumed that the two processes are connected. An interruption has been defined as one of the following:

1) Discontinuous data: complete inactivity exceeding five seconds, (corresponding to a break in the data and implying a similar discontinuity in the subject's train of thought).

2) Unexplained data: behavior that does not correspond to any of the criteria outlined above.

3) Nonconformity to the a priori model: the connection between the two processes does not match the set of legal process connections: that is, P_a to P_r, Pc to Pr, Ps to Pr, Pp to Pr, Ps to Pa, Ps to Pc, Ps to Pp, Pr to Ps, Pr to Pp, Pa to Pp (Fig. 12). This is attributed to erroneous categorization of data during transcription.

(Akin, 1984, p. 89)

<u>Model Developed by Eckersley</u>

Michael Eckersley describes design problems as ill-defined, "they typically exhibit poorly specified initial conditions, allowable operations and goals" (Eckersley, 1990, p. 1269). The design process is a goal-oriented activity, in which designers use technical, aesthetic, and procedural knowledge to frame and solve design problems. Since the path chosen to solve a particular design problem varies from person to person, this model aims to illustrate that "designers vary significantly in the nature and amount of information processed during problem-solving" (Eckersley, 1988, p. 86).

The methodology consists of the collection, transcription, and segmentation of think-aloud verbal protocols. Pauses, hesitations, and syntactically complete thoughts are used to segment the transcribed data. Eight types of verbal behavior are identified and used to categorize the segmented protocols. These eight classifications are operationally defined as follows:

Literal Copy - Exact or nearly exact copy of a problem statement.

Paraphrased Copy - Verbalization which captures the basic content of a problem statement.

Inference - Higher order conclusions, assertions, propositions, or justifications not given in the problem statement, but generated by the problem solver.

Intention/Plan (future-related inference) - Verbalization which indicates a decision to proceed (or not proceed) upon an intended course of action dealing with the problem or part of the problem.

Move - Statement implying the actual movement of characters. (i.e. spatial entities)

Search - Verbalization (sometimes in question form) indicating a need to gather information before acting on the problem, or portion of the problem.

Specific Assessment - Assessment, comparison, or value judgement concerning the configuration of (spatial)characters in the given problem.

General Assessment - Assessment, comparison, or value judgement concerning the general requirements of the problem.

None of the Above/Not Applicable - Verbalization so unique as not to fit into any of the above categories.

(Eckersley, 1988, p. 88.)

The information structures in design proposed by this model is illustrated by Figure 14.

Model developed by Chan

The aim of the research conducted by Chiu-Shui Chan (1990) was to explore the cognitive mechanisms and the role of design constraints involved in architectural problem solving. Chan uses 'schema' theory to explain architectural problem-solving activity. This model is illustrated by Figure 15. The key components of this model are: knowledge base, design constraints, control strategy, and search. Knowledge consists of declarative and procedural knowledge. In performing a task, the declarative knowledge is transformed into procedural form. Knowledge (both procedural and declarative) is grouped into units called schemata. Schemata consists of

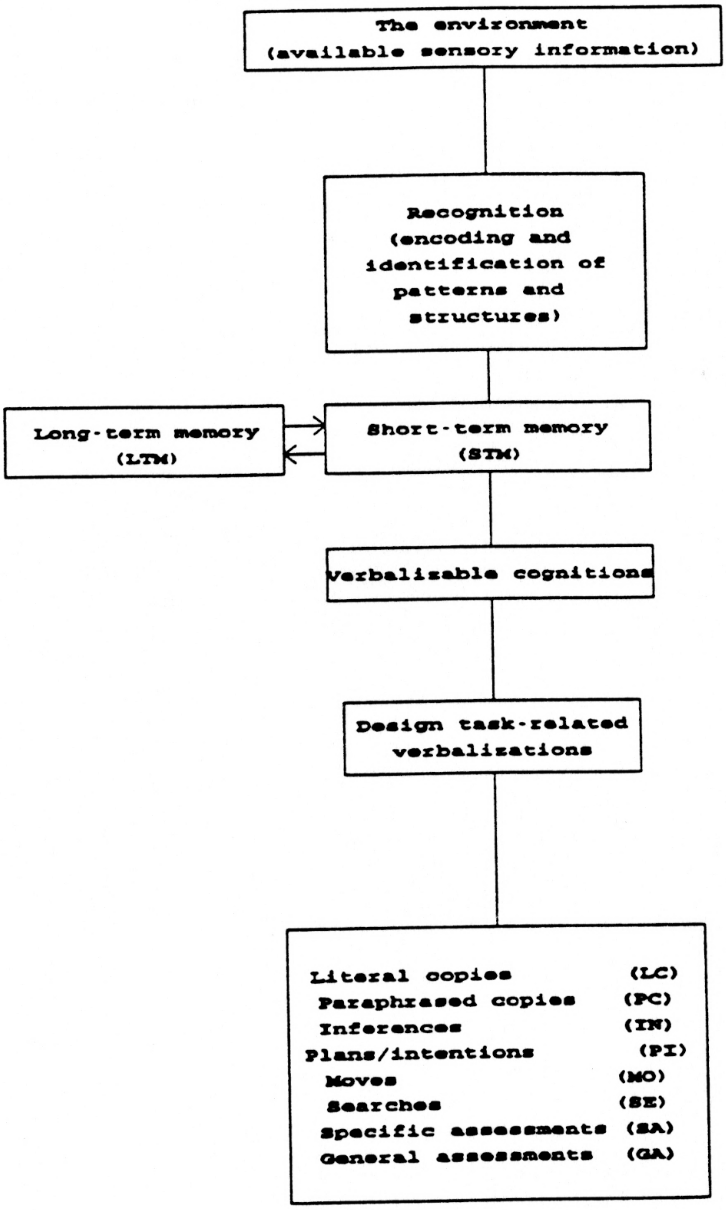


Figure 14: Model of information structures in design

Source: Eckersley, 1988, p. 88

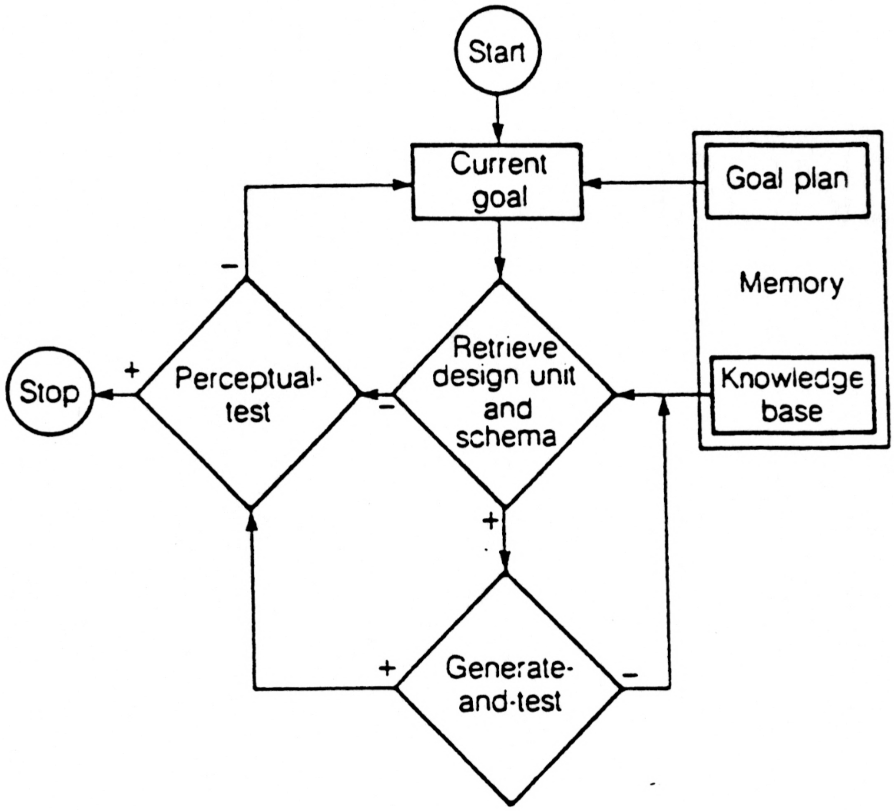


Figure 15- A general model of the design process

Source: Chan, 1990, p. 61

variables, attributes of the variables and knowledge about how to use it. Knowledge associated with design units are hierarchically organized, and this whole structure constitutes the knowledge base.

In architectural design, the problem state consists of a set of design units, operators, design constraints, and a goal. The design units are initially given by the client/user. The operators are not specified by the client; rather they form part of the designer's knowledge base. Corresponding to each design unit are a set of schemata used to structure the design solution. The design constraint schemata is assumed to be the most important one in shaping the design solution. Design constraint is defined as the requirements that must be satisfied in order to arrive at a solution to design unit(s). A design constraint consists of an identifier, a variable, a set of rules, and a value for the variable. The identifier is the name tag of the constraint. The rules consists of procedures to be followed to arrive at a solution, and the method of evaluating the value of the variable. Design constraints can be global or local. Global constraints refer to the entire problem, while local problems are concerned with specific sub-problems. Design constraints can be set by the client (for example, budget) or by the designer (for example, the spatial requirements to fulfil certain functional requirements).

Architectural problems usually have large problem spaces (the various states that a problem solver can achieve). In order to reduce the problem space, constraints are imposed on the design. The manner of structuring the solution path is called control strategy. During design, the overall problem is sub-divided into a sequence of goals. The goal plan consists of a sequence of goals that must be achieved to transform the initial problem state to the final solution state. Each goal either is retrieved from a goal plan in memory or from a perceptual-test. During solution, the schema is retrieved from memory and the constraints and rules are applied to generate the goal.

At the time of design, the designer may perceive a potential problem that has to be resolved at a particular knowledge state. In such circumstances, a sub-goal is generated. The short term memory (STM) is assumed to have the form of a stack, while the long term memory (LTM) consists of the goal plan with a list of symbols representing goals. The first symbol in the goal plan is activated and held in the STM as the current goal. In the case a goal cannot be achieved, another goal is activated in STM and the previous goal pushed back in the stack in LTM. The perceptual-test is used to verify the compatibility of local goals with global goals, to verify whether a goal is achieved, and to ascertain the problem context so that appropriate steps can be taken. When a goal is generated from a goal-plan, it is goal-driven . When a goal is developed from a perceptual-test, it is perception-driven or stimulus-driven. The method of selecting a goal is referred to as control strategy. The general structure of the design process as conceptualized by Chan (1990) is depicted by Figure 15.

This model visualizes problem solving as a search (for the solution) in the problem space, until a state is achieved which satisfies the conditions of the goal state. Chan (1990) has identified three search methods which are used for architectural problem-solving. These methods are: (a) Recognition, (b) Means-End-Analysis, and (c) Generate-and-Test. The Recognition method is defined as knowing the answer. This occurs when the problem reaches a stage at which a known process or model can be applied to the remaining steps. In the Means-End-Analysis, the required goal state is known and the difference between the existing state and the goal state can be computed. The process consists of the identification of operators which will reduce the difference between the existing and goal state till the required goal state is achieved. During the Generate-and-Test process, a generator is applied to generate objects from design units and a corresponding schemata. The test determines if the generated object satisfies the requirements for the solution. In a Generate-and-Test process, the design is assembled component by component.

In Chan's (1990) model, the verbal protocol is analyzed using the following five steps:

1) The verbal raw data is transcribed into type-written form.

2) The transcribed protocol is segmented into episodes, where an episode is "a succinctly describable segment of behavior associated with attaining a goal" (Newell & Simon, 1972; cited in Chan, 1990, p. 65).

3) Knowledge states, in which some pieces of information are activated in STM, are identified along the episodes. Any change in the knowledge state is a move, and indicates the use of an operator to effect the move.

4) A problem behavior graph (PBG) is drawn to represent the knowledge states and moves. The sub-goals are arranged in order of this occurrence along the vertical axis. The progress of each sub-goal is represented across the horizontal axis. Knowledge states are represented by nodes and moves by lines linking the nodes. The design unit being considered is shown on top of the line, while the operations responsible for state transformations are indicated below the line.

5) The problem behavior graph is then analyzed to understand the pattern of moves, the manner in which a goal is achieved, and to detect

how search methods are implemented. Thus, the PBG is used to examine the cognitive structure of the system in response to a problem.

Model Developed by Goldschmidt

According to Gabriella Goldschmidt (1990), the first step towards understanding the process of architectural design is to find the structure of design reasoning. In this model, architectural design is seen as a succession of acts called 'design moves'. A move is identified as a "coherent proposition pertaining to the designed entity, directly or indirectly" (Goldschmidt, 1990). Moves are further classified as moves during active sketching (AS), moves made while involved in contemplative sketching (CS), and moves not accompanied by any graphic output (NGI). During design, moves are used to arrive at satisficing visual representations of the designed entity. Design moves are considered to be the building blocks of design reasoning. It is assumed that understanding the sequence and nature of design moves will promote a better understanding of the design process, and that the linkages between moves will reveal the structure of design reasoning. Thus, the model developed by Goldschmidt emphasizes the links between moves, rather than the moves themselves, and assumes that the links between moves, (that is, the structure of reasoning) are independent of the content of moves.

Using this model, the moves are sequentially marked on a horizontal move-line. The duration of each move is ignored for the purpose of such notation. Link-lines departing from the moves are drawn diagonally underneath the move-line at a 45 degree angle. Thus, each move generates two link lines: a leftward line for 'backlinks', and a rightward line for 'forelinks'. Only backlinks are identified at the time of analysis of verbal protocol. The leftward line is extended until it intersects with the appropriate rightward link of the preceding move to which it is connected. A move can be linked to several other moves. No linklines are drawn when links are not identified. Since only back links are identified during analysis, rightward linklines function solely as connecting lines. Figure 16 illustrates a linkograph generated from a student's protocol.

Five parameters have been developed to analyze the linkograph: chunk, web, sawtooth track, link index (LI), and critical moves and critical path. A chunk of moves is defined as a group of consecutive moves which generates links among themselves with hardly any linkages to other moves. A chunk usually consists of 12-18 moves. Moves 35 to 49 in Figure 16, constitute a typical chunk. Chunks provide an indication of the structure of design reasoning.

A triangle formed by the horizontal move-line and linklines, and containing a large number of links in relation to the number of moves that generate them, is called a web. A typical web consists of 12-13 links generated by 7-8 moves. A web represents an unusually intense phase of reasoning, where consecutive moves are interrelated to each other. Moves 38 to 45 constitute a web in Figure 16.

A sequence of several moves, with each move linked to the one preceding it, constitutes a sawtooth track. Moves 1 to 8, and 35 to 41 are two such sawtooth tracks in the linkograph illustrated. A sawtooth track is formed when the basis for linkage is continuity rather than any other type of association. This occurs when the designer explores an aspect of design systematically, with each proposition leading to the next proposition.

The link index of a process is the ratio between the number of links and the number of moves that generate the links. Link index values lower than 1.0 indicate poor linkability, while values close to 2.0 indicate a high

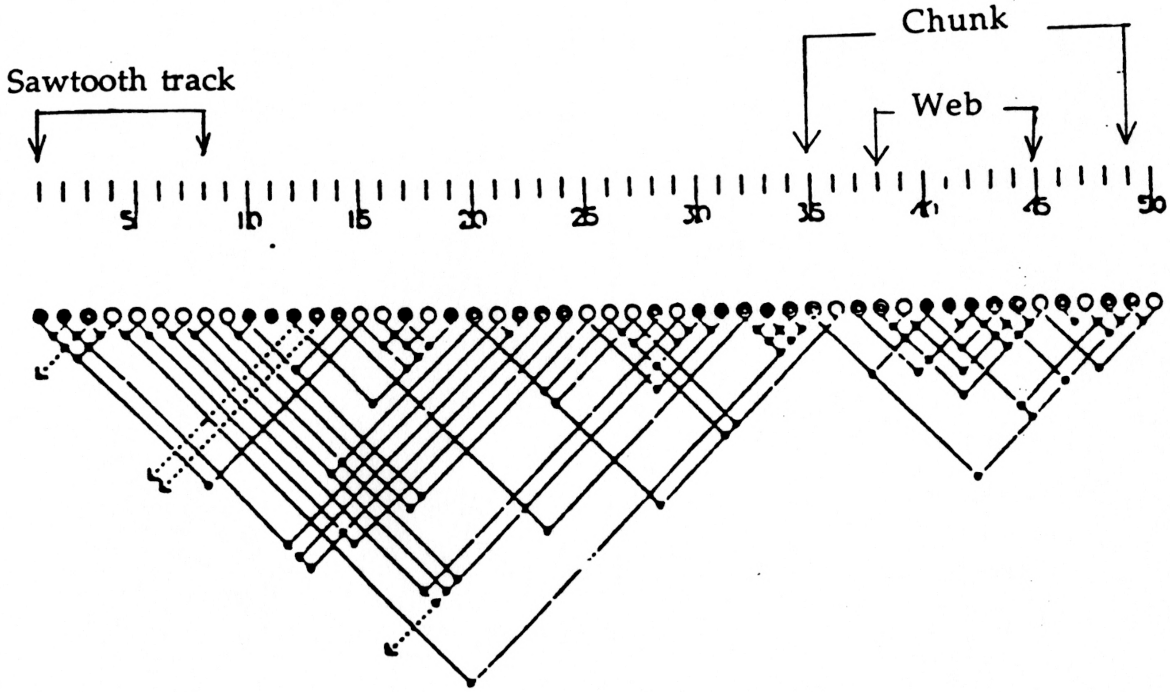


Figure 16 - Linkograph

Source: Goldschmidt, 1990.

linkaging value. Low link indexes often are found in the protocols of inexperienced designers or those having problems generating the design solution.

Critical moves are those moves which have a high number of forward or backward links. The sequence of all critical moves is defined as the critical path. The critical path reflects the essence of the reasoning process and exhibits the issues and notions that are foremost in the designer's mind.

In this model, the think-aloud verbal protocol of a subject is recorded by a video camera. The recorded protocol is transcribed. The video recording is viewed and moves are identified and marked on the transcribed protocol. Backlinks are identified at the time of analysis. Webs, chunks, sawtooth tracks, are identified; and the link index and the critical path computed. Webs, chunks, and sawtooth tracks reveal the structure of design reasoning, while, the link index indicates the productivity of the design.

Comparison of the Models

The four models studied are based on the premises of the information processing theory. All the models are essentially concerned with the identification of typical processes used during architectural problem solving activity. However, they differ in their emphasis on different components of the design process and other nuances. The models are compared across the following criteria: motivating theory driving the model, typical unit/scale of analysis, processes/components identified by the model, emphasis of the model, methodology, and the kind of information generated by the model. Table 2 illustrates the salient features of the four models in tabular form.

Motivating Theory Driving the Model

The model developed by Akin (1984) is based on the Design Information Processing System (DIPS). DIPS examines design at three levels

Table 2: Comparison matrix of the four models studied

	Akin	Category I Eckersley	Chan	Category II Goldschmidt
Motivating Theory	• Design Information Processing System • External representation, design processes, organization of memory • Elemental processes	• Information Processing System • Cognitive Science • Problem givens, obstacles interfaces with factual, algorithmic, heuristic knowledge to produce design solution	• Information Processing System • Schema theory & problem-solving theory	• Information Processing System • Structure of reasoning as critical component of design
Typical Unit of Analysis	• Elemental processes - Projection of information - Acquisition of information - Representation of information - Confirmation of information - Regulation of flow of control	• Segments of verbalization assigned to different categories - Literal copy (LC) - Paraphrased copy (PC) - Inference (IN) - Plan/Intention (PL) - Move (MO) - Search (SE) - Specific assessment (SA) - General assessment (GA) - None of the above (NA)	• Episode • Knowledge state	• Move
Process/Components Identified	• Search processes - Generate-and-test - Means-end-analysis - Induction - Hill-climbing	• Different types of verbalization (LC, PC, IN, PL, MO, SE, SA, GA, NA)	• Search processes - Generate-and-test - Means-end-analysis - Recognition	• Inter-connections between moves and other characteristics - Chunk - Web - Sawtooth track - Link Index - Critical moves/path

Table 2 (continued): Comparison matrix of the four models studied

	Category I		Category II	
	Akin	Eckersley	Chan	Goldschmidt
Emphasis	• Transformation of problem states • Elemental processes	• Transformation of problem states • 'What', 'how', 'why' of design	• Transformation of problem states • Use of design constraints in structuring and solving problems	• Transformation of problem states • Relationship between moves
Methodology of Approach	• Use of verbal protocol as data - collection of verbal data - transcription into type-written form - segmentation - assignment to categories	• Use of verbal protocol as data - collection of verbal data - transcription into type-written form - segmentation - assignment to categories	• Use of verbal protocol as data - collection of verbal data - transcription into type-written form - segmentation - assignment to categories	• Use of verbal protocol as data - collection of verbal data - transcription into type-written form - segmentation - assignment to categories
Information Generated	• Sequence of elemental processes used for search processes	• Sequence of different categories of verbalization • Frequency of occurrence of each category	• Transformation of knowledge states as the episode develops	• The type of linkages between moves • An assessment of the productivity of design

of abstraction. At the most general level, it focuses on the problem to be solved and the solution generated in response to the problem. At the next level, it focuses on external representation, different design processes, and organization of memory in order to understand the process of architectural design. At the most detailed level, it specifies elemental (primitive) processes that are used for various design processes during architectural problem solving activity. The model developed by Eckersley (1988) is based on the theory of cognitive science. This model attempts to identify differences and similarities in the cognitive styles of designers. It assumes that the problem solver brings to the task different types of knowledge, algorithms, and strategies. Such knowledge is embedded in the long-term memory (LTM). The mental representation of problems can be understood as the conceptual arena where problem givens, goals and obstacles interface with the existing store of relevant factual, algorithmic, and heuristic knowledge. Designers use technical, aesthetic, procedural, and other relevant knowledge stores to effectively frame problems and propose appropriate solutions. Differences in the way designers mentally represent and solve problems are indications of the cognitive styles of designers.

Chan's (1990) model is based on schema theory and problem solving theory. Schema theory posits that all knowledge is grouped into units called schema. A schema contains factual and procedural knowledge necessary to solve problems. Problem solving theory asserts that problem solving advances through search in the problem space until a satisfactory solution is reached. Thus, problem solving involves the identification of schema appropriate to the problem at hand, and the use of knowledge embedded in the schema to solve the problem. The model developed by Goldschmidt (1990) is based on the premise that design moves are the building blocks of design reasoning. In this model the structure of reasoning is given precedence over the content of reasoning.

Typical Unit/Scale of Analysis

In Akin's model, the units of analysis are elemental processes. These elemental processes are used to transform the initial state to the final goal state through several intermediate steps, and last four seconds on the average. In Eckersley's model, the verbalization of a problem solver is parsed into segments. A segment consists of syntactically complete thoughts, or verbalization separated by pauses and hesitations. Such segments are the units of analysis in Eckersley's model. The model developed by Chan utilizes two units of analysis. The larger (global) unit of analysis is an episode, while the different stages within an episode are called knowledge states. An episode corresponds to the strategies used for solving specific sub-problems, and lasts several minutes. A move is the basic component of the model developed by Goldschmidt; however, it should be noted that this model stresses the linkages between moves rather than the moves themselves.

Processes/Components Identified

The models developed by Akin and Chan focus on search processes used in design. Chan identifies three search processes commonly used by designers: Means-End-Analysis, Generate-and-Test, and Recognition. The search processes identified by Akin are: Generate-and-Test, Means-End-Analysis, Induction, and Hill-Climbing. The models developed by Akin and Chan are formulated with the intent of finding out the structure of search processes used during design. Eckersley defines search as verbalization indicating the need to gather information in order to proceed with the problem solution. Thus, search as defined by Eckersley focuses on the content rather than process. The model developed by Goldschmidt is also structure-oriented; however, it focuses on the structure between different design moves in order to assess the productivity of design activity.

Emphasis

Akin's model emphasizes the elemental processes used to transform the initial state to the final goal state. The model developed by Eckersley focuses on the 'what', 'how', and 'why' of design. It attempts to discern how strategy-related knowledge influences the design process. Thus, Eckersley's model attempts to find similarities and differences in the use of strategies in solving problems by different individuals. Chan's model focuses on the critical importance of design constraints in the design process and the manner in which they are evoked to structure a problem - from long-term memory or external memory. The model developed by Goldschmidt differs from the other three (Akin, Chan, Eckersley) in the sense that it is a process-oriented rather than a content oriented model. Different types of linkages between moves are identified in order to assess the productivity of design.

Methodology

All the four models use verbal protocol as data. The method involves the collection of verbal data, transcription into type-written form, segmentation, followed by subsequent assignment to different categories corresponding to the respective models. However, in the model developed by Akin, each segment is further parsed into several elemental processes. Different segments (knowledge states) combine to form an episode in Chan's model. Eckersley's and Goldschmidt's model also use segments as the basic unit of analysis. Only certain segments are identified as moves in the Goldschmidt model, and subsequent analysis deals with only those segments identified as moves. This is a major difference between the model developed by Goldschmidt and the other three models.

Information Yielded

All the models yield useful information about architectural problem solving activity. The model developed by Akin gives the sequence of processes used during problem solving. The Chan model reveals the different design constraints used to structure and solve design problems. Goldschmidt's model attempts to display the productive components of design activity. The Eckersley model is more content oriented with respect to the other three models. It assumes that the content of verbalization as well as the structure of the different components play an important part in design activity.

This review and comparison of the four models (Akin, 1984; Chan, 1990, Eckersley, 1988; Goldschmidt, 1990) indicates that the work of Eckersley (1988) and Chan (1990) are based on the pioneering work of Akin (1984). These three models assume that the design process is a sequence of discrete activities and focuses on the specific sequence of those activities. Akin conceptualizes architectural design as a series of transformations from the initial state to the desired goal state. Eckersley describes the design process as a goal-oriented activity, in which procedural knowledge is used to solve the problem. Chan's model focuses on the use of design constraints to structure and solve architectural problems. Thus, for the purposes of this thesis, these three models are considered to be variations of a larger general category (termed Category I) of models. By contrast, the model developed by Goldschmidt (1990) is based on the premise that a design can be evaluated on the basis of certain types of design activity termed 'moves'. Goldschmidt's model focuses on certain types of design activity, termed moves. According to her model, the types and number of moves are measures of the productivity of design processes. Unlike the other models, this model only concentrates on a specific kind of design activity. In this respect, this model differs from those of Category I. For the purpose of the comparisons made in this study, one model, that of Eckersley (1988) has been chosen to represent the models from Category I. This representative model is compared with the model developed by Goldschmidt (1990) to address the questions discussed in Chapter I.

Chapter III: Methodology

The first two chapters discuss the theoretical, historical and practice contexts in which the issues of design processes are generalized. This chapter describes the methodology followed in conducting the research comparing the information yielded through two models for the study of the design process: those of Eckersley (1988) and Goldschmidt (1990). A design problem was developed and used to collect video-taped protocols from under-graduate students of architecture at Kansas State University. The transcribed protocols were segmented by the researcher and then encoded by trained encoders using the two chosen models. The manner in which the different students solved the problem, as well as the inter-coder agreement in encoding the protocols, were compared. The details of the methodology followed are presented below.

Phase I

This phase consisted of the preliminary development and subsequent pre-testing of a design problem. The problem required the design of a workspace for three artists on a site near Tuttle Creek on the outskirts of Manhattan, Kansas. The problem statement included a description of the lifestyle of the three artists, their work requirements, and a site plan showing the contours of the site. Five students were asked to think-aloud while solving the problem, and the process was recorded by a video camera. Think aloud verbalizations were favored over retrospective accounts since they avoid the limitations of retrospective accounts, in which unsuccessful iterations are under emphasized, while successful trials are given emphasis (Ericsson, & Simon, 1984), and much detailed information is lost. These recorded protocols were segmented and then encoded by the researcher using the three models of Category I (i.e., that of Akin, 1984; Chan, 1990; Eckersley, 1988). The relative ease of encoding the protocols by the different methods as well as the suitability for comparison with the model developed by Goldschmidt (Category II) was used to choose the model to represent Category I.

Formulation of Problem

Design programs used in the fourth, fifth and sixth semester classes in the Department of Architecture of Kansas State University were reviewed by the researcher to gain familiarity with the type of program students were accustomed to using in the studio. The design problem was developed using the following criteria:

1) It could be completed within approximately forty-five minutes

2) A wide range of issues could be considered to generate the solution.

3) It was similar in form to those with which the students were familiar.

4) Students in the second year and above had adequate knowledge to complete the problem.

The time criterion necessitated the problem be comprehensively stated, provide all necessary information within the problem statement, and yield schematic design solutions rather than detailed drawings. The problem allowed any one or a combination of the following issues to be used to generate responses: environment-behavior, function, aesthetics, and/or energy conservation. Once the initial problem statement was developed, it was reviewed by design faculty to ensure that the problem was realistic, and could be solved reasonably within forty-five minutes. Suggested changes (by professors) were incorporated before using the problem for the pretest.

Pretest of Problem

The preliminary problem was used to collect protocols from five students in the Department of Architecture at Kansas State University. The students included one each from the fourth, sixth, and tenth semesters respectively, and two graduate students. The concept of protocol analysis and the 'think aloud' procedure to be followed was explained to the participants. The need to verbalize thoughts continuously, rather than plan out responses, was emphasized. A video-camera was used to record the protocols, and all sketches and notes made during the design process were collected. The students were asked to mention difficulties that they had faced in solving the problem, and to give suggestions about refining the problem.

All five participants took longer than forty-five minutes to complete the problem. The students often lapsed into silence, or lowered their voices, making the audio recording unintelligible at times. Due to the inaudibility of the first two participant's recorded protocols, a tie-pin microphone was attached to the video recorder for subsequent recordings. The participants expressed the view that the problem was too open-ended to be completed within the given time frame. One of the students indicated that the site plan was too small in scale, making it difficult to understand easily the site contours or the scale of the plot. This student suggested including a larger scale plan of the plot in addition to the site map already provided. This additional plan would have the added advantage of serving as an underlay for the building plan.

The pre-test indicated that the problem statement needed to be more detailed, so that the problem could be completed within forty-five minutes. Approximate areas for the different spaces, their adjacency requirements, and climatic data were included within the problem statement. A larger plan of the plot was provided in addition to the site plan. A set of instructions explaining the think-aloud procedure to be followed was attached to the problem statement. Since the participants required some time to get used to the think-aloud procedure, a small practice problem was added at the beginning of the problem statement. The practice problem introduced an opportunity to practice the think-aloud method, and any queries that the participant might have about the method could be answered by the researcher. The complete problem statement packet used to collect the final protocols is included in Appendix A.

Selection of Encoding Methods

After all participants had completed the problem and been debriefed, the recorded protocols were transcribed. The first two protocols were badly recorded and could not be transcribed. The remaining three protocols were transcribed by the researcher and excerpts from two were segmented by the researcher. The segmented excerpts were encoded using the methods developed by Akin (1984), Chan (1990), Eckersley (1988), and Goldschmidt (1990). An excerpt analyzed by the four methods illustrates the differences in the encoding processes.

The portion of the protocol given below was verbalized at a point when the participant was working on the design of the workspace for Anne (the artists who specialized in batik printing). The participant was not sure about what batik was, and the specific requirements for printing batik. After asking the researcher to clarify his doubt, he continued with his design as follows: (P is the subject/participant, and R is the researcher).

P: O.K. 5' x 5' maximum (drawing then - tapping his fingers on the board). O.K. since Anne will be working with paints and dyes. We have to segregate her over in the corner. Something like that so she doesn't splash it up on everybody else.

Fumes - ventilation for Anne (tapping)

Water and other solvents - so she needs probably a sink and all kinds of stuff (writing) and a drying space which probably may have to be as big as 10' x 10' or so.

Showroom, display, reception, book keeping etc.

Office display will be office

Main entry should be visible

So entry is also part of that (coughing)

Separate storage space for raw materials and finished products will be required.

Using Akin's model, the segment,

O.K. 5' x 5' maximum (drawing then - tapping his fingers on the board). O.K. since Anne will be working with paints and dyes. We have to segregate her over in the corner. Something like that so she doesn't splash it up on everybody else.

would be categorized as:

P_a » P_r » P_c » P_a » P_p » P_r; where

P_a is acquisition of information,

P_r is representation of information,

P_c is confirmation of information, and

P_p is projection of information.

This excerpt would be an example of a Hill Climbing type of search process (for details of Hill Climbing process refer to Chapter II, Figure 10).

Using Chan's model, the three segments,

> O.K. 5' x 5' maximum (drawing then - tapping his fingers on the board). O.K. since Anne will be working with paints and dyes. We have to segregate her over in the corner. Something like that so she doesn't splash it up on everybody else.
>
> Fumes - ventilation for Anne (tapping)
>
> Water and other solvents - so she needs probably a sink and all kinds of stuff (writing) and a drying space which probably may have to be as big as 10' x 10' or so.

would be part of the goal - design of Anne's work space. Any other verbalizations articulated later about Anne's workspace would also form part of the goal, design of Anne's workspace. This model focuses on the different stages through which the ultimate solution to a goal (Anne's workspace in this case) is achieved. Each stage of the goal is a knowledge state, and operators that are used to transform one knowledge state to another are identified to study the process of architectural design.

If the segments are categorized according to Eckersley's model, using IN to denote inference, PC to denote paraphrased copy, and PL to indicate plan or intention, they are coded as follows:

IN O.K. 5' x 5' maximum (drawing then - tapping his fingers on the board). O.K. since Anne will be working with paints and dyes. We have to segregate her over in the corner. Something like that so she doesn't splash it up on everybody else.

PC Fumes - ventilation for Anne (tapping)

IN/ PL Water and other solvents - so she needs probably a sink and all kinds of stuff (writing) and a drying space which probably may have to be as big as 10' x 10' or so.

PC Showroom, display, reception, book keeping etc.

PC office display will be office

PC main entry should be visible

IN so entry is also part of that (coughing)

PC Separate storage space for raw materials and finished products will be required.

SA got that

When the segments are categorized according to the method developed by Goldschmidt, the following categories are used: AS to indicate move made during active sketching, CS for moves made during contemplative sketching.

AS O.K. 5' x 5' maximum (drawing then - tapping his fingers on the board). O.K. since Anne will be working with paints and dyes. We have to segregate her over in the corner. Something like that so she doesn't splash it up on everybody else.

Fumes - ventilation for Anne (tapping)

CS Water and other solvents - so she needs probably a sink and all kinds of stuff (writing) and a drying space which probably may have to be as big as 10' x 10' or so.

Showroom, display, reception, book keeping etc.

Office display will be office

Main entry should be visible

So entry is also part of that (coughing)

Separate storage space for raw materials and finished products will be required.

Got that

Thus, only two of the nine segments are moves when coded by Goldschmidt's method.

After coding excerpts of the segmented protocols by the different methods, it is clear that the method developed by Akin is very detailed and documents micro level processes involved in architectural problem solving. The methodology followed by Chan results in the formulation of sequence of discrete processes and links between them. However, the sub-goals (in the case illustrated above - design of Anne's workspace) are not solved in a linear fashion, as is evidenced by this excerpt when the subject moves from the design of Anne's work space to other work spaces. The design process is a complex iterative process in which the designer jumps between the different goals, making the Problem Behavior Graph (PBG) difficult to construct using Chan's method. The model developed by Eckersley is simpler to use for encoding than those of Akin or Chan; thus it should be easier to train coders using this method. At the same time, Eckersley's method is amenable to comparison with that of Goldschmidt. The units of analysis are comparable in size, while that of Akin's are very small (a single segment yield numerous categories) and Chan's are large (many segments form a single sub-goal). All these reasons prompted the choice of the Eckersley model to be representative of the Category I models.

Phase II

This phase involved the collection of protocols based on the refined problem statement, their transcription, segmentation, and encoding.

Collection of Protocols

Participants. Eighteen students were selected from the pool of fourth, sixth, and tenth semester students in the Department of Architecture at Kansas State University. It was decided that first year students would not have developed the necessary design skills to respond to the issues of the problem statement. The majority of fourth year students in the Department of Architecture at Kansas State University spend one semester away from the University, and were not available to participate. Thus, the first (i.e second semester) and fourth year (i.e. eighth semester) students were not included in the study. The students who participated in this study were a convenience sample. An equal number of male and female students were chosen from each semester.

Instrumentation. Video equipment was used to record the protocols. An audio recorder was used as a backup measure to ensure that all verbalizations were recorded. A drafting table, paper, pencil and other basic drafting equipment were provided. All sketches and notes made by the participants were retained by the researcher.

Procedure. Each of the participants was tested individually. A convenient time for both the participant and the researcher was arranged for recording the protocol. Informed consent was obtained from each of the participants before proceeding with the study. A lecture room equipped with a video recorder and television terminals, located in the Department of Architecture, was used for recording the protocols.

The researcher briefly described the think aloud method to be followed before giving the participant the problem statement to read. The protocol of the participant's design response was recorded with video equipment that had been positioned as unobtrusively as possible prior to the beginning of the session. The video camera was focused on the subject as well as on the sketches and notes being generated. Video taping was begun when the instructions (regarding the think-aloud procedure) were being given by the researcher, so that any questions asked could be recorded. The television monitor was turned on when the instructions were being given, to insure that the data were being properly recorded. It then was turned off to reduce obtrusiveness and provide a more relaxed atmosphere.

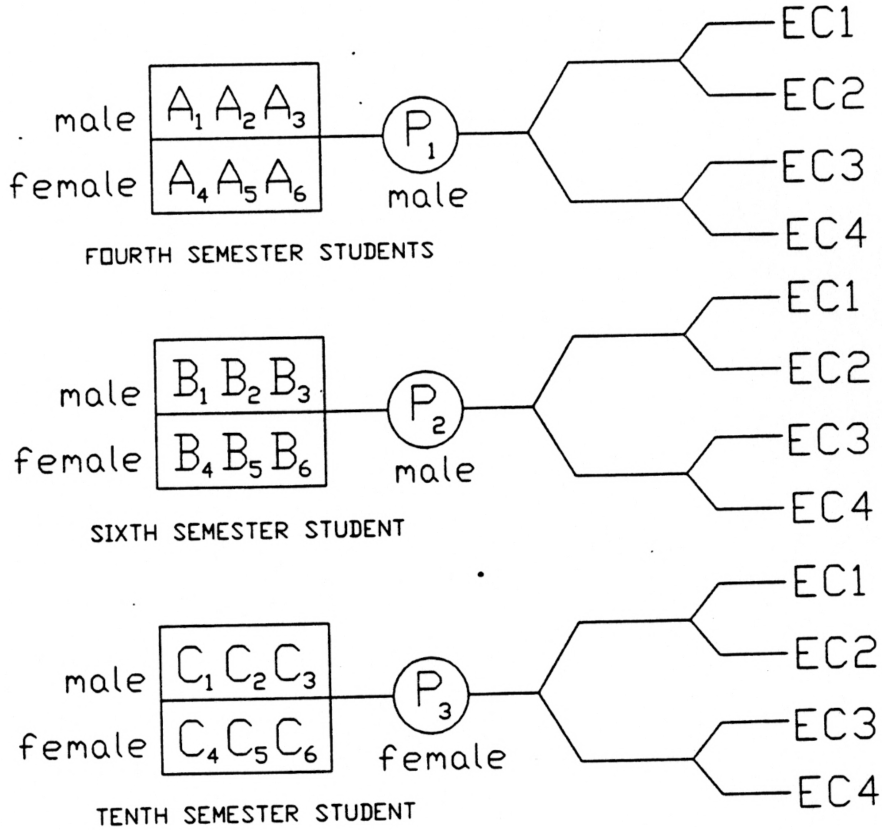
When each participant was given the problem statement, he or she was asked to complete the practice problem. After the practice problem was completed and the participant had had an opportunity to ask any questions about the method, the participant began to solve the problem. During the problem-solving procedure, if the participant lapsed into silence for more than fifteen seconds, the researcher reminded the participant to think-aloud. The recording was continued until the participant indicated that a solution had been reached.

Transcription and Segmentation of Protocols

One protocol was selected randomly from the pool of participants from fourth, sixth, and tenth semester respectively; yielding a total of three protocols to be encoded. (See Figure 17 for a graphic representation of the sampling process, and subsequent encoding). The three selected included a fourth and sixth semester male, and a tenth semester female student. The remaining fifteen protocols were reserved for future research. These three video-taped protocols were viewed by the researcher to gain familiarity with the content of the protocols, and the audio recordings were used to transcribe the verbal data into typewritten form. The researcher then segmented the three protocols into the units of study defined using Eckersley' s method. Each segment was separated by two blank lines in the typewritten form. Below is an excerpt from Participant 1's (fourth semester student) verbal protocol after segmenting.

P1: That's workspace two and then sandwich this space. Workspace - one, two, three - O.K.

Then in this area will be a deck type of thing.........



E C 1 - Encoder 1
E C 2 - Encoder 2
E C 3 - Encoder 3
E C 4 - Encoder 4

P_1 - Participant 1
P_2 - Participant 2
P_3 - Participant 3

Figure 17: Graphical representation of collection of protocols and subsequent encoding of protocols

I don't want to maintain this rigid geometry that I have I think.

We'll go a little bit more curvilinear form which would possibly hint at the shoreline and lake conditions here.

O.K. These are all studio spaces and just due to ....to the site I'm going to make this number one space lowest and the other two increasingly higher - at an interval of two feet - two feet higher. So actually we'll call this zero elevation, this is two, this is four.

Next I need to accommodate my display/reception area which I want tangent to all these spaces.
But, let's see - the office space which will be in the display area here, kitchenette should be accessed easily from the work areas as the restroom and storage should be.
O.K............
O.K. I'm trying to figure out how to put some storage in here and keep it adjacent from - not using my prime space for office and display/reception

Let me go to a different color pencil just so I can keep this clear - O.K.

The display/reception needs to be only 200 square feet, which is not even the size of one workspace - so this is kind of just conflicting with my original conception of this which will be a large open space where each of the workspaces could have access - visual access to the display area. I was thinking of a larger area.

Display/reception area - O.K. I'll go ahead and set that in.

Phase III

In the third phase, the verbalizations of the three chosen protocols were examined to explore the different ways in which each participant structured and solved the given design problem. The sequences in which the problem was solved, as well as the content of the verbalizations, were studied. The comparison was structured in three stages: (1) initial structuring of the scheme, (2) development of the initial scheme, and (3) solution to some specific sub-problems.

Phase IV

The fourth phase involved the training of encoders, followed by their coding of the three protocols. This phase also included the comparison of the inter-coder agreement achieved using Method I (Eckersley, 1988) and Method II (Goldschmidt, 1990) respectively.

Training of Encoders

The researcher trained four graduate students in architecture to code the protocols. Encoders 1 and 2 were trained to encode by Method I, Encoders 3 and 4 by Method II. The encoders were given the categorization principles, and operational definitions of the categories. The definitions used were those postulated by Eckersley and Goldschmidt. The researcher trained the encoders on an individual basis until they exhibited consistency using the pretest protocols. The researcher deliberately did not impose any interpretations of how a certain segment of a protocol should be encoded, since it was assumed that the operational definitions put forth by the different models should be sufficient to enable coding.

Comparison of the Encoded Protocols

Each of the three protocols was segmented by the researcher prior to coding. The coded protocols were compared using three criteria. First, the structural agreement across paired encoders was measured by the degree of agreement on the categories assigned to each segment. Agreement was determined by time units as well as by the number of segments. Second, the frequency of occurrence of the different categories in each protocol was compared. This measure was calculated using time units and the number of segments in each protocol. Third, the agreement and the disagreement in encoding by paired coders were examined. The different segments on which there was agreement on the categories were recorded. The categories on which there was disagreement, that is the disagreement pairs, also were recorded. The excerpt of Participant 1's protocol used earlier illustrates the three criteria employed to assess inter-coder agreement.

Segmented Verbalization of Participant 1	**Category**		**Time**
	E1	**E2**	**Units**
That's workspace two and then sandwich this space. Workspace - one, two, three - O.K.	MO	MO	5
Then in this area will be a deck type of thing.........	MO	IN	2
I don't want to maintain this rigid geometry that I have I think.	PL	PL	3
We'll go a little bit more curvilinear form which would possibly hint at the shoreline and lake conditions here.	PL	PL	4
O.K. These are all studio spaces and just due to ....to the site I'm going to make this number one space lowest and the other two increasingly higher - at an interval of two feet - two feet higher. So actually we'll call this zero elevation, this is two, this is four.	MO	PL/ MO	9
Next I need to accommodate my display/reception area which I want tangent to all these spaces.	PL	PL	3

Segmented Verbalization of Participant 1	Category E1	Category E2	Time Units
But, let's see - the office space which will be in the display area here, kitchenette should be accessed easily from the work areas as the restroom and storage should be. O.K............	PL	PC	10
O. K. I'm trying to figure out how to put some storage in here and keep it adjacent from - not using my prime space for office and display/reception	SA	SE	6
Let me go to a different color pencil just so I can keep this clear - O.K.	NA	MO	2
The display/reception needs to be only 200 square feet, which is not even the size of one workspace - so this is kind of just conflicting with my original conception of this which will be a large open space where each of the workspaces could have access - visual access to the display area. I was thinking of a larger area.	IN	IN	9
Display/reception area - O.K. I'll go ahead and set that in.	MO	PL	3

where:

LC - Literal copy

PC - Paraphrased copy

IN - Inference

PL - Plan/Intention

MO - Move

SE - Search

SA - Specific assessment

GA - General assessment

NA - None of the above

Total number of segments in this excerpt = 11

Structural agreement = 6 segments = 6/11 x 100 = 55%

Frequency of Different Categories

Category	Frequency of occurrence Encoder 1	Encoder 2
MO	4=4/11X100 = 36%	3=3/11X100 = 27%
PL	4=4/11X100 = 36%	4=4/11X100 = 36%
IN	1=1/11X100 = 9%	2=2/11X100 = 18%
SA	1=1/11X100 = 9%	----
SE	----	1=1/11X100= 9%
PC	----	1=1/11X100= 9%
NA	1=1/11X100= 9%	----

Agreement Pairs = MO (twice); PL (thrice); IN (once)

Disagreement Pairs = MO/IN; PL/PC; SA/SE; NA/MO; MO/PL

The calculations in this sample show the structural agreement, frequency of occurrence, and agreement and disagreement pairs when encoded by Encoders 1 & 2 using Method I. The same calculations also were completed using time units instead of the number of segments for analysis.

The ease of encoding the protocols was assessed by measuring the time required to code the protocols using the different methods. Since the same encoder did not use two different methods of encoding, it was assumed that there were no significant differences in speed that could be attributed to personal characteristics of the encoders. Problems reported on coding provided another indicator of ease. Discussions between the researcher and encoders (after the encoding process was completed) documented the following:

- Any problems noted with a particular category or categories.
- Any overlap perceived between categories, and if so the categories, and kinds of overlap involved.
- Whether the categories were comprehensive enough to encode the segmented data parsimoniously.
- Suggestions for refinement of categories.

Results from phases III and IV of the study are presented in chapters III and IV respectively.

Chapter IV: Comparative Study of Protocols

This chapter presents the comparison of the methods of structuring and solving the problem by students participating in this study, as illustrated by the three protocols that were chosen for encoding. All the three participants began by considering the basic requirements set by the problem statement. The general pattern of solution comprised the formulation of an initial scheme, followed by checking if the requirements set down by the problem statement were met. The evaluation of the initial scheme resulted in changes that were incorporated in the overall scheme until a satisfactory solution was achieved. The participants exhibited similarities and differences in structuring the problem, and in the specific methods used to reach the solution. For the purpose of illustrating the differences and similarities in solving the given problem, the discussion of the design process has been organized under three headings: structuring of the initial scheme, development of the scheme, and solution of some specific sub-problems. Diagrams of the final scheme designed by the three participants are presented in the following pages (Figures 18 to 22). The figures illustrate the designs produced by the three participants, as well as help the reader to follow the ensuing discussion. The variability of the final schemes generated by the participants is evident from the drawings.

Structuring of the initial scheme

Participant 1 began the problem by considering the given space requirements of the workspaces to be designed. He had a visual image of the workspaces and used this image to shape his initial scheme.

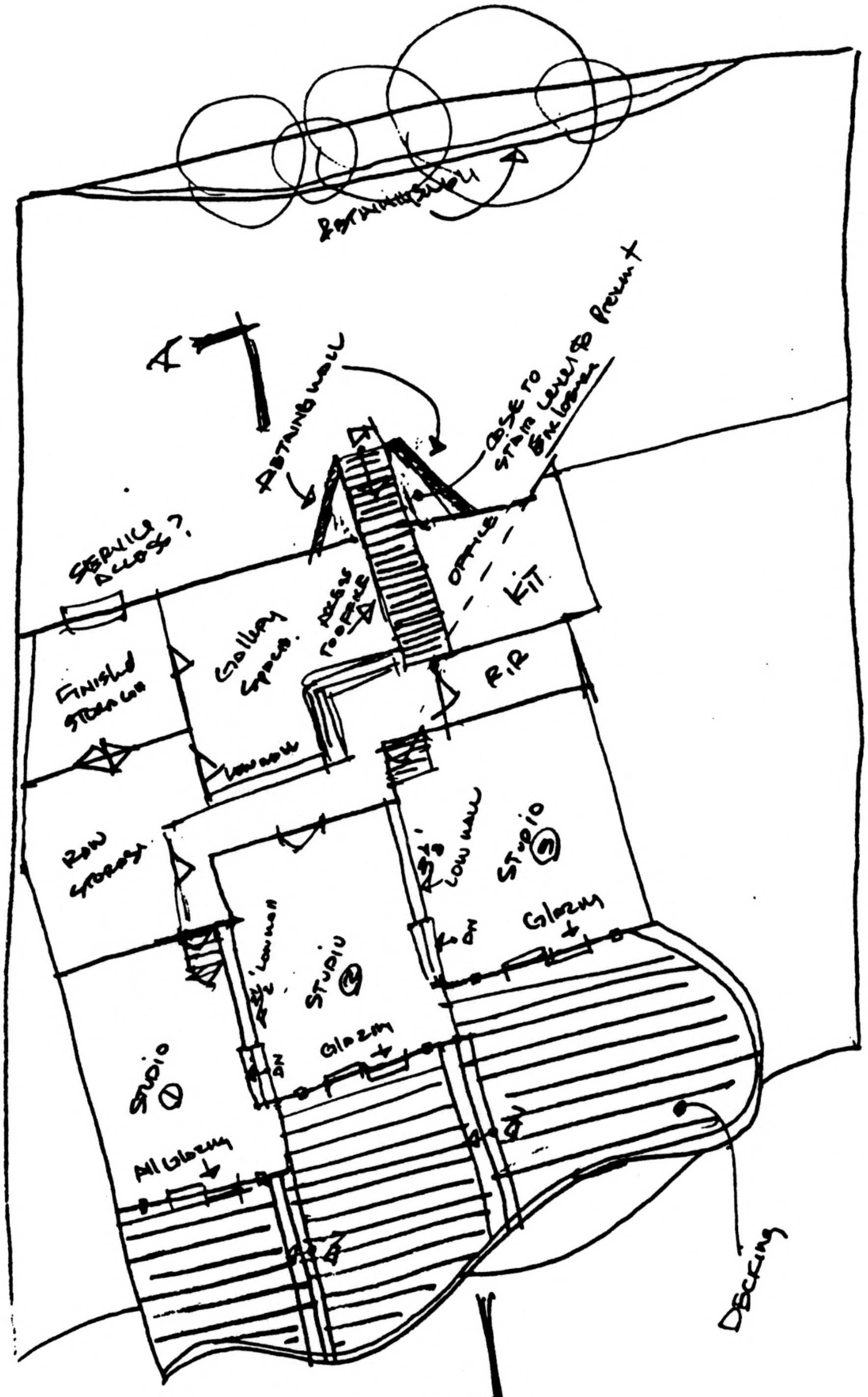


Figure 18: Plan of final scheme generated by Participant 1

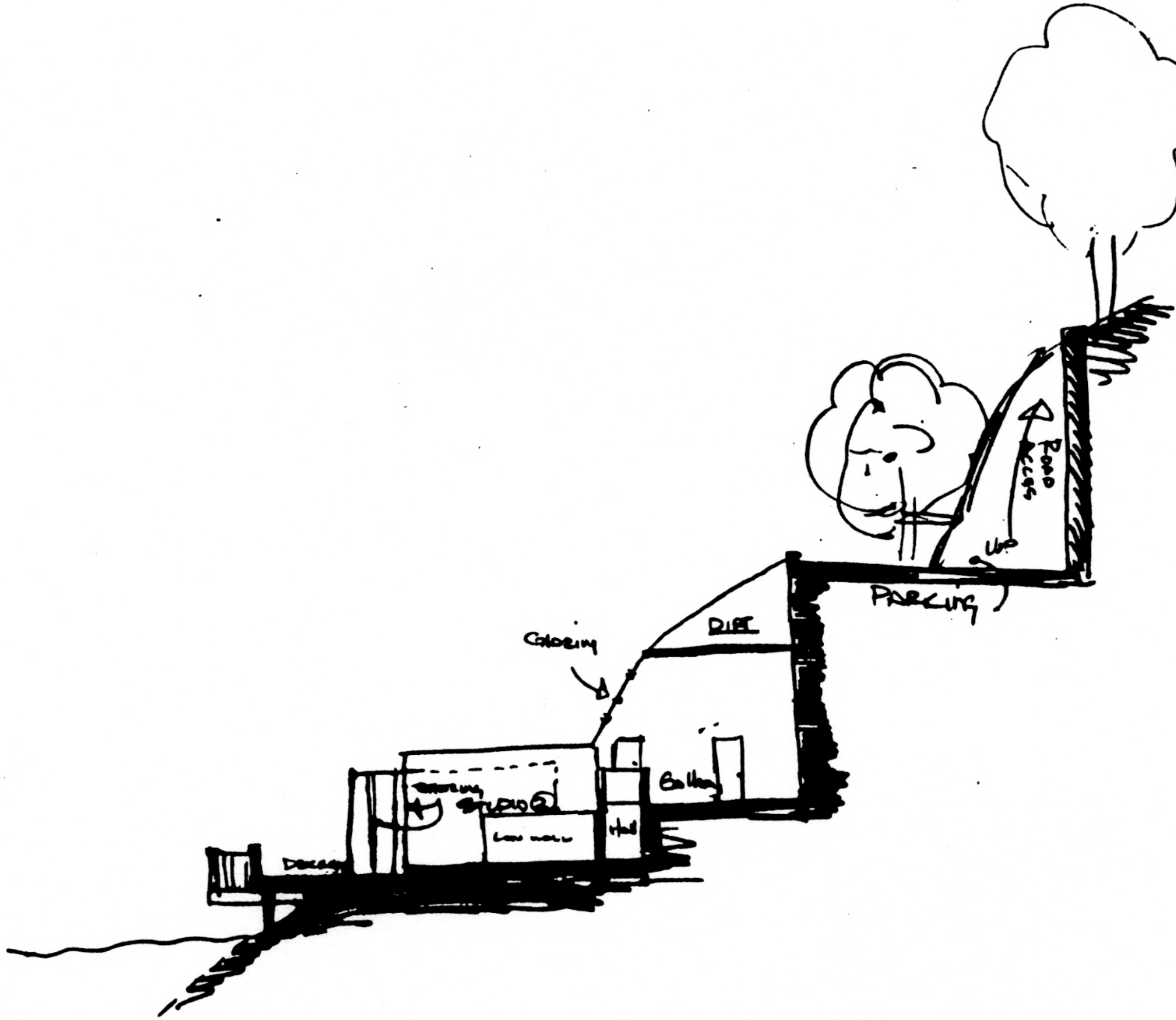


Figure 19: Section showing Participant 1' final scheme

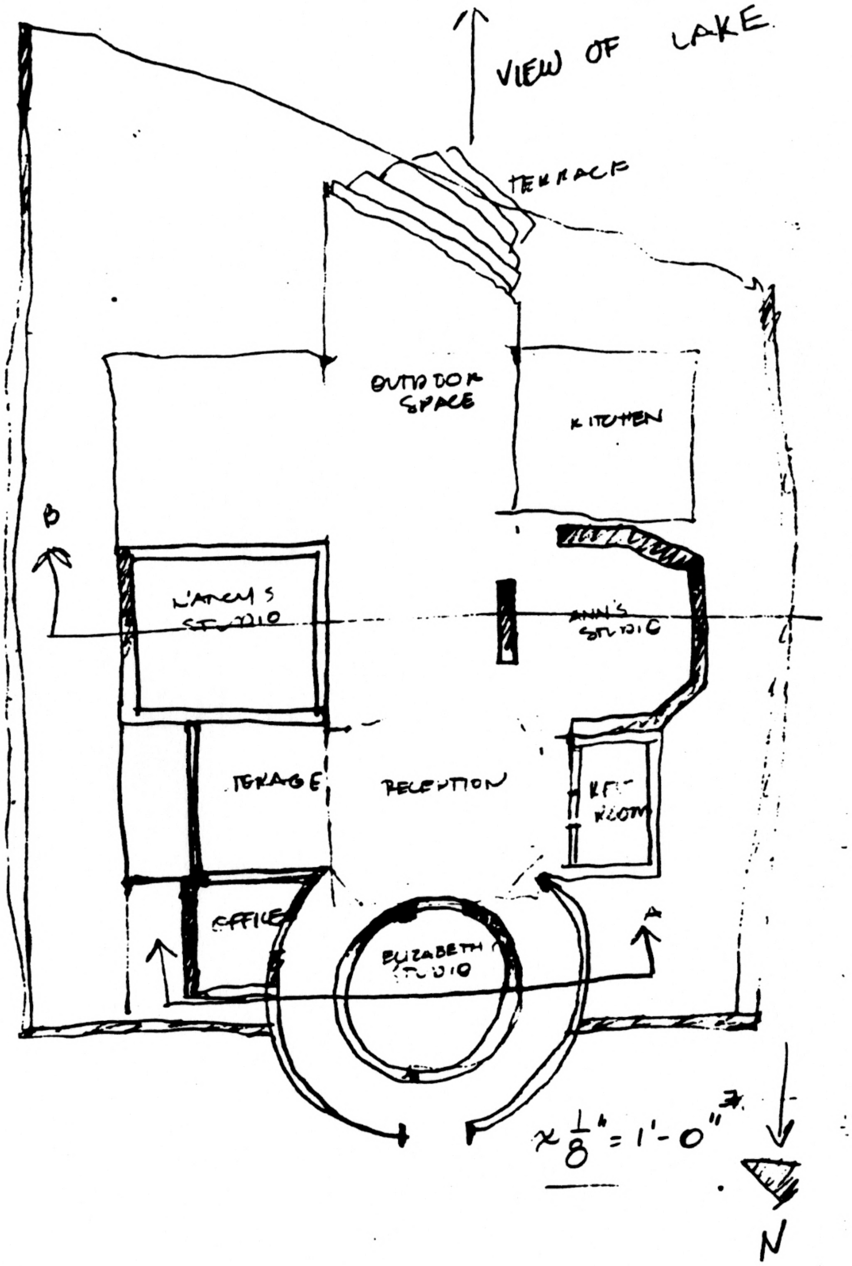


Figure 20: Plan of final scheme generated by Participant 2

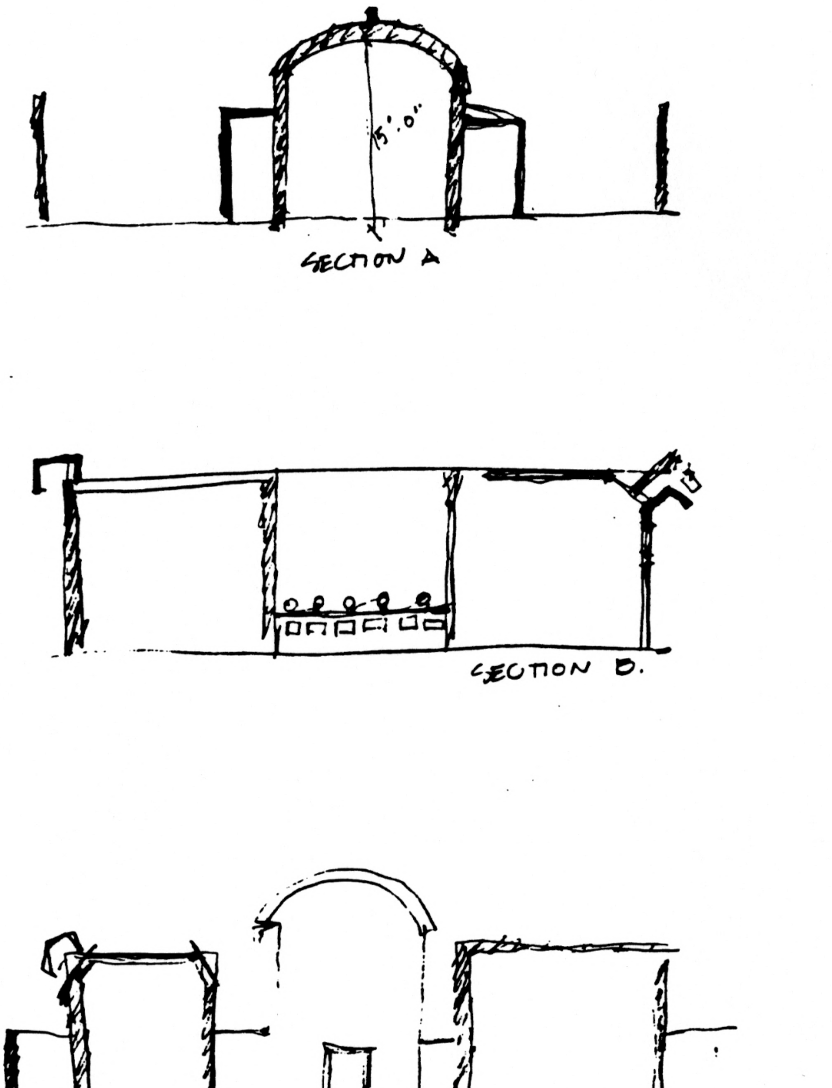


Figure 21: Section and elevation of scheme developed by Participant 2

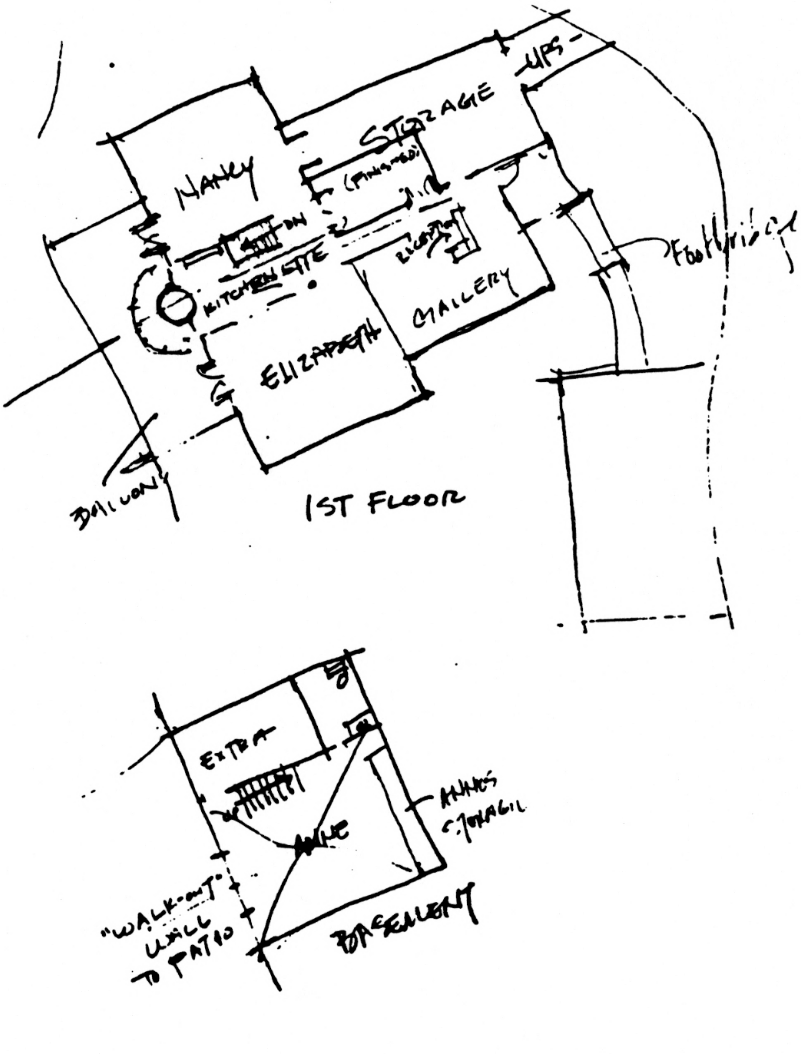


Figure 22: Basement & first floor plan generated by Participant 3

The work space - 250 square feet each. Just so that I have a dimension to work with - that's approximately 15 X 15. Although I'm not going to limit myself to a square space, it's helpful for me to know some dimensions.

I need three of these spaces

O.K., right now I'm starting to consider a large studio space with possibly different floor levels and ceiling planes for each workspace to identify that as a workspace.

I'm also going to - try to maintain a visual continuity with every space, except for storage and I think the kitchenette will be partially exposed.

Figure 23 illustrates the graphic output generated by Participant 1 at this point in time of the solution process. This figure illustrates how Participant 1 translated his idea into a graphic form.

Participant 2 and Participant 3 approached the problem in a different manner. Participant 2 reviewed the different requirements set by the problem statement and made connections between them in order to structure the problem and develop the preliminary design.

O.K., there's three people, each in a different ....each has a different craft which could indicate maybe a different space, a different form for each to work in.

which could indicate maybe a different space a different......form for each to work in......

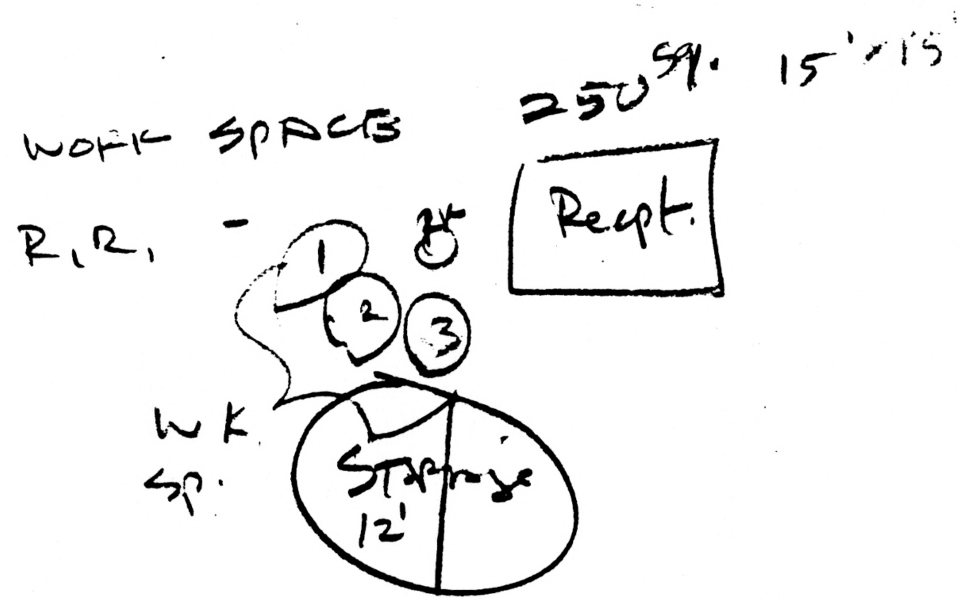


Figure 23: Bubble diagram illustrating initial scheme developed by Participant 1

And those three spaces could maybe be joined together somehow since they all work together........(reading the program)

Since they live in different locations, this could have some effect on where you place their space and.......

Since it says they have quiet place to work which could dictate what kind of lighting system, what kind of windows, thickness of walls etc.......

He continued his verbal protocol by discussing the equipment to be used in each of the workspaces, and the ventilation that would be required since Anne will be working with paints and chemicals. Participant 2 went on to talk about the duality he perceived between the fact that the clients wanted a simple building even though all three of them were involved in the arts. He assigned greatest importance to the workspaces and generated a scheme in which the workspaces were placed around a central common space. The office, kitchenette, storage, and rest rooms were located around the workspaces (refer to Figure 24).

Participant 3 began by developing an understanding of the site. She considered the major direction of travel along the access road and the nature of the adjacent sites before commencing the design. She then proceeded to draw the site section to understand the profile of the site and to consider where the building should be located on the site. Figure 25 illustrates the contours of the site plan and the site section drawn by Participant 3.

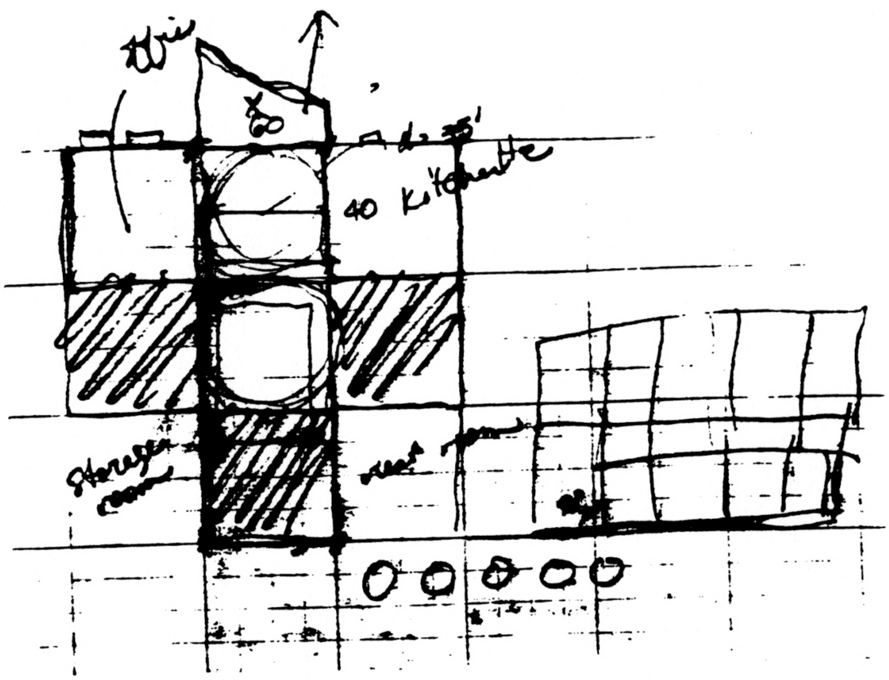
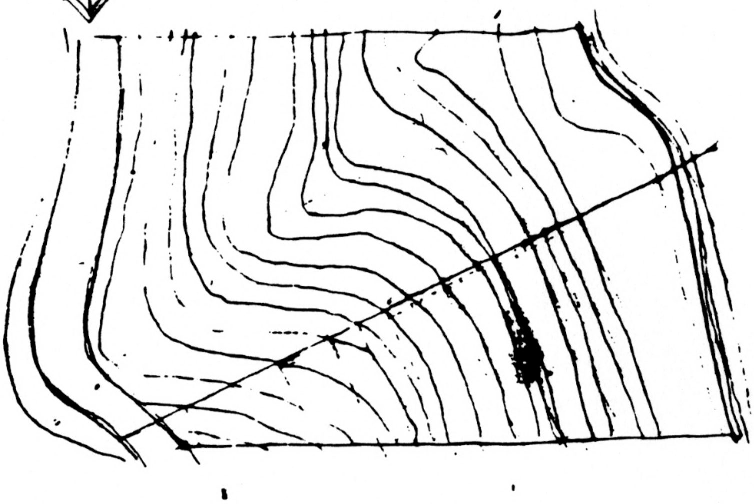
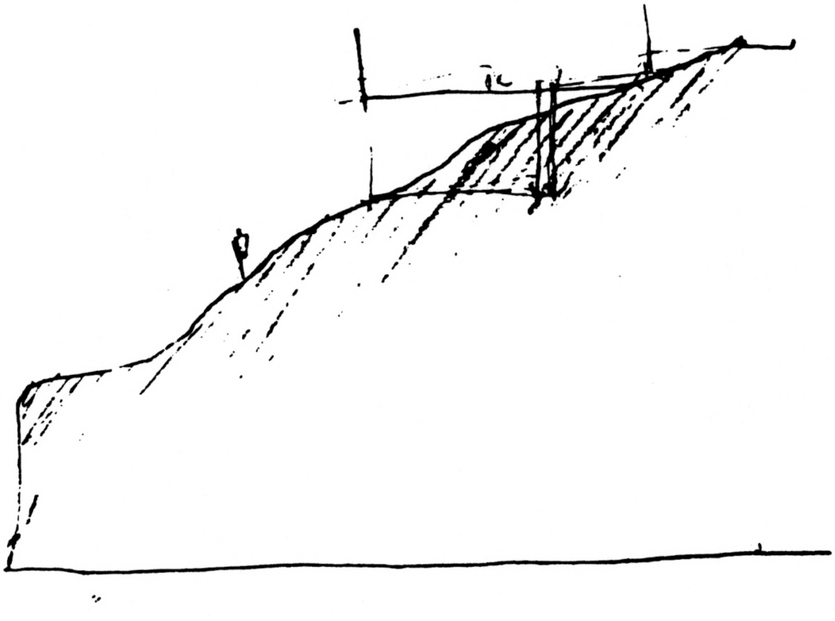


Figure 24: Sketch showing preliminary scheme developed by Participant 2



a) Site plan with contours



b) Site section

Figure 25: Site plan & section generated by Participant 3

First we need to do is site.......site plan.

I'm just drawing the contours so that I can.....trace and do a site section, so that I can get an idea of how large of a site we are actually dealing with, in scale and also an idea of how steep it is and where the most reasonable part is.

From these verbalizations, it is evident that Participant 2 and Participant 3 differed in their approaches to the problem from Participant 1. Participant 2 and 3 put forth logical reasons for proceeding along a certain direction; however, they differed in the reasons used to proceed with the problem. Participant 2 expressed logical reasons, which prompted him to structure the problem in a certain way. For example, he used the fact that the three artists Nancy, Anne, and Elizabeth pursued different crafts to justify a different form for each of the workspaces. Participant 3's protocol indicated a systematic sequence of tackling a design problem. She perceived that the slope of the site would play a decisive role in the design of any building on the given site. In contrast, Participant 1 was largely guided by his intuitive sense of the visual image of the space that he had conceived. Some of the differences in approach could be attributed to differential exposure to design training. Participant 2 and Participant 3 were students in the sixth and tenth semester respectively, and had been exposed to a wider variety of design problems. These experiences could have prompted the more methodological (logical) approach to the solution process. Participant 1 was a student in the fourth semester and relatively new to the process of design; thus he may have been more intuitive in his approach to the design solution.

Development of Initial Scheme

After drawing up his first scheme, Participant 1 thought of the placement of the building on the site. He tried to think of the grading that would be required for construction when placing the building on the site plan. He did not draw a site section, but developed a feel for the site by going over the contours on the site plan visually. Based on his assessment, he decided on the location of the building footprint.

> O.K.. Right here is the river's edge, O.K. and that is a fairly gentle slope. Two feet, well let's see. O.K. rise is four feet for every two feet; four feet for two feet so that is like a 26 degree slope. So that seems to be fairly common through out the entire site except for a small ridge right here - O.K..

Participant 1 proceeded with the parking problem and then continued with the location of the building on the site.

> Alright, I have a ridge area right here. Then a fairly gentle slope down to this area like this - O.K.. This area is relatively flat and I think that I would like to do something with the deck in that area.........

> O.K.. Then I'll go ahead and set it (the building plan) on grade there............

Participant 1 was largely motivated by his idea of the workspaces being visually accessible to each other and having a central display area. His verbalizations indicated that he was comfortable working with his tacit and intuitive knowledge.

> I'm going to go ahead and layout - some of my spaces that I want, and from them - that will generate the form of my building and from there I'll start pushing and pulling.........

He commented that he did not follow the dictum 'Form follows Function' and believed that function could be adapted to form. It seemed many of the design decisions that he made were spontaneously generated, without being the outcome of a series of expressed rational steps. The following excerpt illustrates this approach.

> O.K. I'm just gonna, actually I think I'd like to stagger these or pull that down a little bit.
>
> O.K. - 15 feet each approximately....O.K. right now move large(er) in scale - drop it down there............
>
> I don't want to maintain the rigid geometry that I have I think.
>
> We'll go a little bit more curvilinear form which would possibly hint at the lake conditions here.

When Participant 1 found out that the area requirement of the display space set down by the program did not match his concept of the display area as a connecting space between the three workspaces, he decided to disregard the given space requirement. According to his reasoning, the centrality of the display area was a higher priority need, and justified his concept. This decision-making process illustrates the way compromises often are made between conflicting requirements during architectural problem solving. Although Participant 1 did not explicitly mention considerations for the provision of natural light and ventilation, he provided clerestorey windows and sufficient openings in each space for purpose of natural light and ventilation. It appears that Participant 1 did take lighting and ventilation needs into consideration, but did not mention them in his verbalizations. This finding raises the question of whether think-aloud verbalization is truly representative of the actual cognitive process of design. Since this premise is a basic assumption of the encoding methods evaluated in this thesis, it suggests that caution should be exercised when interpreting such protocols as completely representative of cognitive design processes. Participant 1's verbalizations also indicated that he was more preoccupied by the shape and forms of the various spaces and their relation to one another in plan as well as in section, rather than the functional efficiency of the spaces. He thought of the spaces in three dimensions, as illustrated by his small sketches and his periodic references to the levels of the different spaces.

Participant 2 worked simultaneously with his ideas of form, adjacency requirements of the spaces, the area requirements, light quality, accessibility of the different areas, and heat gained during the summer months to develop his scheme.

> Let's see.......250 square feet.......so each space will be approximately 60 x 40 or circular with a radius of that's about 35, or diameter of 35, 35 feet ....uhm.........let's see

> So I have three different spaces - with a courtyard in the center for relaxing and whatever.

And that does fulfil the requirements of accessibility from the work space.

I'll probably have the space open.......and work this thing to have lighting come in through here at lot of the work places...........

My proposition is courtyard on the south .... to probably north to minimize heat gain.

Participant 2 used the strategy of dividing the problem into several sub-problems, which he tackled in order of the priority that he had assigned to them. Since the office space was not to be used as intensively as the workspaces, office space was given lower priority during location. Participant 2 used different requirements to structure his problem. He found it interesting that the program asked for a simple building even though all the three women were artists themselves. This apparent dichotomy was resolved in his goal that the building design should be "simple yet complex, maybe in detailing". He thought of using a cubical volume for his design to reflect the simplicity of the design.

Participant 2 worked in a cyclical pattern. He developed his initial scheme and then attended to the different levels of detail in an iterative process. He used the different activities to be housed in the workspaces to suggest the forms of the respective workspaces.

.....think I'll go up and base the shapes of the work places on what kind of activity is going to be done in each.

Quilting, the shape of the quilts may be square.

Weaving probably same thing.

Batiks and tie-due - I think I'll make Anne's workspace kind of octagonal, due to the kind of the twisting and contorting of the tie-dye.........

Elizabeth I think I'll make a......circle to show the unity between Nancy's square and Anne's octagon 'cause weaving is kind of like the in-between process between quilting maybe tie-dye.

After he had satisfied the other requirements of the workspaces (such as the relationship with other spaces and the circulation pattern), he attended to the next level of detail. He used the forms of the different workspaces to generate the roof forms and window patterns.

Also thinking of if the shape of the room should dictate (to) me maybe the window patterns and how you are going to light it, enter those rooms and how it effects how the work inside effects the lighting and what kind of light they need.

Participant 2 began with the idea of the cube, but in order to accommodate the other spaces and to introduce the entry, his design evolved into a cube with a cylindrical entrance. His verbalizations exhibited a willingness to work with different ideas and the ability to synthesize different ideas into one concept. Participant 2 worked on the elevations after satisfying the basic requirements in plan. The elevations induced some changes in the floor levels and the ceiling level of the different areas. He considered aspects of site planning, such as concealing the parking behind a line of vegetation, planning a small sculpture garden, using a water body as a barrier to separate the public domain from private domain on the site, and terracing the rear of the building to take advantage of the lake view. He also gave some consideration to the materials to be used, colors, roof forms and window patterns. Participant 2 's approach reflected a sequence of working from larger to micro-scale issues. He first worked on the location and adjacency requirements of the different areas. At the next step, he moved to the design of the individual spaces. He did not spend much time on site planning. Participant 2 was able to verbalize his reasons for most of his design decisions.

Participant 3 did some initial site planning before commencing on the design of the building. She considered where the entry to the site should be located, and then identified the most suitable portion of the site for the building and the parking. Participant 3 used the adjacency requirements of the different spaces; as well as access needs, to structure the preliminary building design.

> ....the idea of the gallery needs to be in the front part, including the office.
>
> Let's see - gallery and office, but we also need - direct access which is also going to have to be in the front from the road because (of access) to the storage and raw materials.
>
> So those are going to have to share the front space.

Since Anne's work (batik and tie-dye) involved paints, dyes, and water, Participant 3 decided to separate Anne's workspace from that of Nancy and Elizabeth. In order to accommodate all the different spaces as well as provide access to them, Participant 3 decided to develop a bi-level plan with Anne's workspace in the basement.

> O.K. - we have three people who are working in this place.
>
> Two of them are essentially dry work, - and the other is incredibly messy!
>
> And the first two - weaving and quilting - don't take - you can't spill or you can't mess things up by spilling on other things.
>
> So it would be reasonable to put those two together in a similar space, but dividable; and then the second to have their own (space)

The slope of the site was successfully used by Participant 3 to orient the building. The rear of Anne's workspace opened out to a walk-out deck giving Anne plenty of sunlight, fresh air and a lake view. Participant 3 decided to separate Anne's storage from that of Nancy and Elizabeth so that wet paint or paint fumes would not damage their finished products. This requirement was not mentioned in the problem statement, but it seemed to be a reasonable decision.

Participant 3 dealt with the schematic plan at a conceptual level and then transferred it into a scaled drawing. She was able to manipulate easily the different requirements until a satisfactory solution was reached. This facileness in design process is illustrated by her adeptness at solving the kitchen location problem, and the placement of the bathroom.

Kitchenette

You can have a small kitchenette....right there so that it's between the gallery and the front.

Although it would be nice to have a kitchenette on the front

Well, you know what (we) could do is to make these a little lot wider here at the sides and so expand the space out.

Put the kitchenette down the center and then you could put the stairs down...to the basement - here.

So you get a kind of symbolic meeting of the minds at this center nook - kitchenette.

Bathroom

O.K. first of all got the toilets

We have room to........have a problem - we don't want to put them in where the gallery storage is.

We also don't want to make that room............

We don't want to cut that room off the door, since there needs to be access from every direction.

So we need to put the toilet somewhere.

> Well, I guess it wouldn't hurt to have the toilet in the basement because that way you would have communication between Nancy, Anne and Elizabeth. They would go down and see Anne's work every once in a while and that way they would correlate some with her work.

> And I don't think it would be too much of an inconvenience to put the bathroom in the basement.

Participant 3 made a very strong case for putting the toilet on the lower level. She also verbalized that Anne was unmarried, so in all probability she would spend more time in the studio than either Nancy or Elizabeth. She believed it was good that the toilet was at Anne's level, so that she did not have to go up to the upper level when she was alone in the building.

Specific Examples

The different ways in which each of the participants approached and solved the problem can be understood by examining the manner in which specific problems were tackled. In order to illustrate a large variety of problem solving techniques in a concise way, the provision of parking for eight cars and the problem of the sloping site profile will be examined.

Parking Problem

Participant 1 began the problem with the design of the workspaces. After he had a basic idea of the size and approximate location of the different spaces, he moved to site planning. He tried to locate the building on the site, ascertain the entry point of the road into the site, and locate the parking lot on the site. Participant 1 went over the site contours before locating the parking area on the site plan. When he began to place the car modules on the parking area, he realized that he had under estimated the parking area. He tried to enlarge the original parking area, but still did not reach a satisfactory solution This prompted Participant 1 to abandon the first parking scheme and embark on a new parking layout. He was unable to resolve the second scheme satisfactorily, and decided to abandon the parking requirement for the moment.

> Actually I'm thinking that it may be more feasible to start a new scheme where we use the road tangency here and here as a more circular...........way to enter.
>
> So we'll go ahead and let the road come in. Drop parking in along here.
>
> Doing this to make the best use of my service access - because I was realizing in the other one that, that layout wouldn't have been very reasonable. O.K.. Need a room for my cars to back up and then turn around so make that a little further down there, -O.K..
>
> We'll just lay in eight stalls real quickly. One, two, three, four. So, O.K. I'm going to have to leave this last part open for service right here. Still ran out of room for my parking. I'm just going to do that later. I'm tired of messing with it.

Here we see how Participant 1 generated new ideas and then tested them (Generate-and-Test) against the requirements or goals. This excerpt also illustrates the importance of experience in design. If Participant 1 had been more experienced, he probably would have assessed the space required for parking eight cars correctly and would not have faced this problem. This excerpt is representative of architectural problem solving activity where sometimes troublesome sub-problems are abandoned for the time in the hope that the solution to other problems will give direction for the resolution of the abandoned issue.

In contrast to Participant 1, Participant 2 and Participant 3 did not spend much time or effort on the parking problem. This was indicative of the fact that they did not consider provision of parking space crucial to the solution of the given problem. Perhaps this could also indicate that Participant 2 and Participant 3 had greater experience with the design of parking lots and were confident of being able to provide the parking area without much problem.

Participant 2

It says parking for ten cars.

I don't think I want the parking to be very.........to have visual access to people like......for the approach of the building.

I think I'm going to hide it with some shrubs or vegetation............

I'm just going to put those parking spaces at 90 degree angles.

Participant 3

Ahm - sounds reasonable, the parking would be here but it could also be over here and walk - park here and walk across. So that's not a problem too.

Two options of parking here. Parking here, or parking in front.

And that will depend probably the more attractive would be.....well, I do not really want it that close to the road anyway.

The parking problem illustrates how the same issue is given differential emphasis by different designers. It could be argued that Participant 1 thought that the provision of parking was an important part of the design and accordingly spent considerable time and effort to solve the problem. On the other hand, Participant 2 and Participant 3 did not spend much time on the parking problem. Participant 2 concentrated on the design of the building and its integration with other aspects of the site, such as the entry, sculpture garden, and the backyard which overlooks Tuttle Creek. Participant 3 integrated the building design with the slope of the site and also designed the outdoor spaces that each of the artists could use. This strategy illustrates that the architectural solution to a problem is often a reflection of the architect's personal prioritization of the different sub-problems in a design.

Consideration of the Site Profile

Participant 1 worked out his building plan to a considerable degree before commencing to integrate the building plan with the site section. Earlier, he had considered the contours of the site conceptually, but only later did he realize that the site was much steeper than his assumptions. Consequently, he had difficulty in integrating his building plan and the parking area with the site profile. This inaccurate assumption forced him to make last minute changes to his design, and his response to the provision for parking was a poor compromise.

Due to the site slope at right here it's really steep that's all I see we can do. So we are going to doze it off, have it (the earth) hauled off and so now the section is starting to look like this then...............

O.K., this is now gone. And I've now provided my parking.

Participant 2 did not give much consideration to the site profile. He designed all the required spaces within the building, some of the outdoor spaces, and an elevation before even mentioning the site profile. Participant 2 decided on the location of the parking lot and the entry road into the site without taking into account the contours of the site. Even when he considered the site profile, he thought that it would not have any far reaching effects on his design.

Looking at the contours of the site plan, even the smaller site plan, - ahm ....let's see ......contours are going to have any effect on the building?

They (the contours) are fairly consistent, let's see rising up. Oh ....1, 2, 3 feet.

I don't have to worry about the contours too much.

More significant was the fact that at the later stage of his design, when he drew elevations and sections, the site was shown to be flat (refer to Figure 21), not taking into account the sloped site profile. This was a major flaw in Participant 2's design.

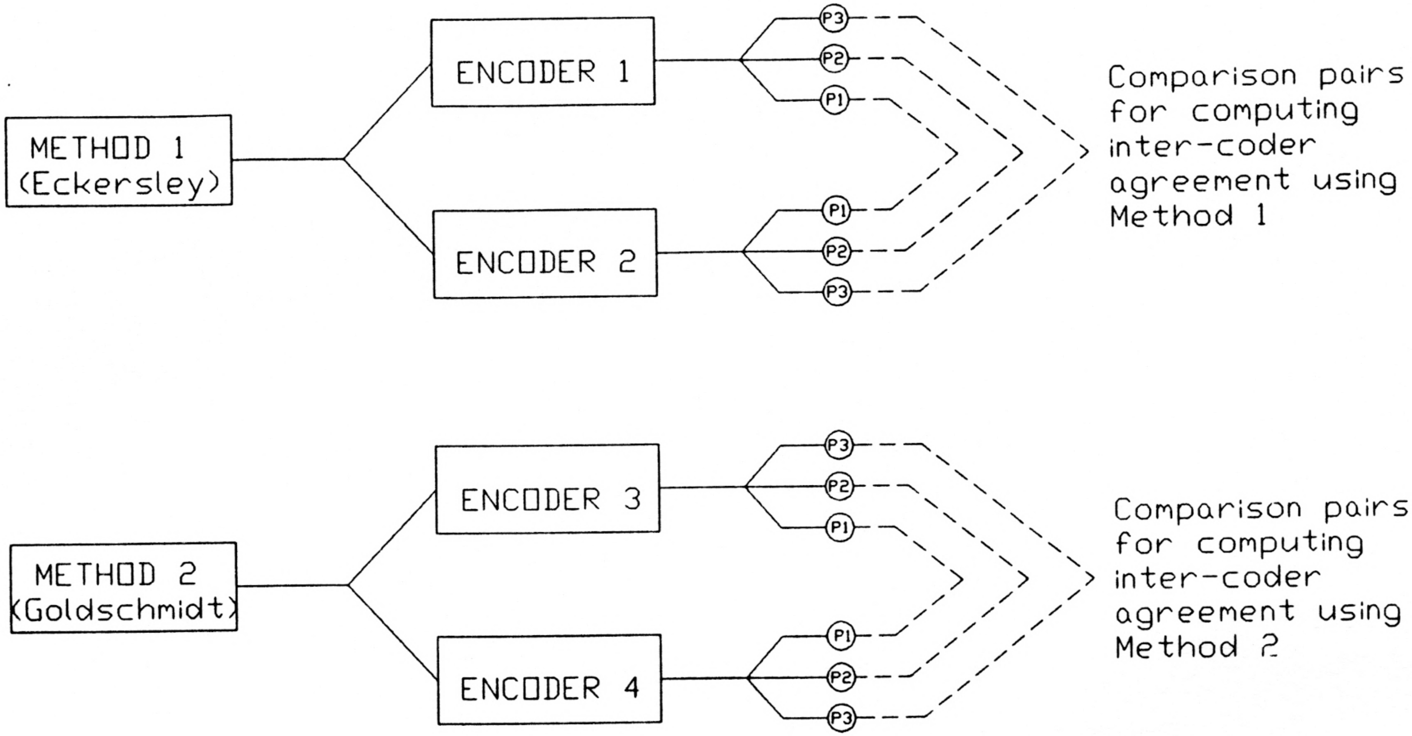
Participant 3 recognized the importance of the site profile. She located the area of the site where it would be reasonable to place the building, and then drew a site section through that portion of the site. She was successful in integrating her bi-level plan with the site profile. Participant 3 sited the building in such a manner that the lower floor had natural light, fresh air, a view of the lake, and a walk-out deck. She was also able to manipulate the design so that both cutting and filling would be necessary during construction. Though cost was not given as a constraint, this illustrates that Participant 3 gave some consideration to the economics of the project. Participant 3 showed competence in handling the different issues involved in the design. This competence could be a reflection of the fact that she was a senior-level student and more experienced with design. This greater experience could explain the logical manner in which she approached the problem: beginning with the site section and then moving from broader concepts to the details of the design.

A comparative study of the three protocols generated by the students indicates that there are generalities as well as differences in the approaches taken towards the structuring and subsequent solution to a design problem. All three participants solved the problem at different levels of detail, moving from broader issues (the location of the different spaces with due consideration to the adjacency requirements, and the area of each workspace) to more detailed design elements (the shape of windows and color of the walls). However, Participant 3 was the only one who began with the site section and determination of the approximate location of the building footprint on the site, before proceeding with the design of the building proper. Participant 1 realized that the slope of the site would influence the overall scheme. However, he intuitively conceptualized the slope of the site and proceeded with the building design. Only later did he realize that he had misjudged the slope of the site. By then, the building plan had been developed and Participant 1 had to make changes to fit the scheme onto the site section. Participant 2 did not take the site profile into account and sketched his building section and elevations as if the site was flat. Thus, Participant 3 was the only one who perceived that the site profile would play a decisive role in the design of any structure and responded to this perception by initially drawing a site section.

Participant 1 also under-estimated the area that would be required for the provision of parking for eight cars and had to compromise his initial plan for the parking. Participant 1's protocol indicates that he was often driven by his intuitive sense, he did not articulate many logical reasons for his design decisions. However, his design satisfied most of the requirements set down by the problem statement. This result could indicate that design experience helps to make explicit the otherwise tacit knowledge used by designers during problem solution. That reasoning would explain why Participant 2 and Participant 3 articulated a larger percentage of logical reasons for design decisions. Participant 1's protocol indicates that he had abandoned several sub-schemes as he progressed with the design. Participant 2 and 3 were more adept at transforming their schemes to take into account different requirements. They were more successful in manipulating different spaces and their respective requirements to arrive at a satisfactory answer. All these factors suggests that Participant 2 and 3, having been exposed to wider variety of design problems, had developed skills for arriving at design solutions efficiently. In spite of these differences in solving the problem, this comparative study illustrates there are similarities in the strategies used for designing.

Chapter V: Evaluation of Inter-coder Agreement

This chapter describes the analysis of inter-coder agreement using the selected protocols. Since only three protocols were coded by each of the encoders, statistical analyses were not possible. Temporal measures (measures of duration) as well as number of discrete instances of occurrences of different categories (as defined by the two methods of encoding) were used to compute the percentage agreement in encoding. The analyses of inter-coder agreement were done in three parts. The first section dealt with the structural agreement between identical protocols encoded by two different people. This analysis was followed by a comparison of measures derived from the coded protocols, such as the number of instances of occurrence (i.e. frequency) of each category in a protocol, and the time units in each category in the entire protocol. Last, the agreement and disagreement pairs in the coded protocols were analyzed. Encoder 1 and Encoder 2 assigned the segmented protocols to the nine categories of Method 1 (Eckersley, 1988); while Encoder 3 and Encoder 4 identified moves and then assigned the moves to the three categories of Method 2 (Goldschmidt, 1990). (For details of the two methods, refer to Chapter II). Since identical protocols were encoded, the agreement and disagreement pairs could be computed. Agreement was computed by identifying the segments across which different encoders assigned identical categories, while disagreement pairs were the segments across which the encoders disagreed. This pattern of analysis was followed for the protocols coded by Method 1 and then for the same protocols encoded by Method 2. Figure 26 illustrates graphically the comparison of the encoded protocols.



P1: Verbal protocol of Participant 1 (4th semester student)

P2: Verbal protocol of Participant 2 (6th semester student)

P3: Verbal protocol of Participant 3 (10th semester student)

Figure 26: Process of computing inter-coder agreement

Table 3 displays the general characteristics of the three protocols encoded. The protocols varied in duration from 52 to 57 minutes and consisted of between 174 and 195 segments. Table 4 summarizes the distribution of segments in the three protocols studied. Ninety percent of the segments in all three protocols varied in duration between 1 and 32 seconds. The protocol of Participant 3 had a slightly higher percentage of longer segments.

Method 1

In Method 1, the segmented protocols had to be assigned to nine operationalized categories: Literal Copy, Paraphrased Copy, Inference, Intention/Plan, Move, Search, Specific Assessment, General Assessment, and None of the Above/Not Applicable. (For details of this method, refer to Chapter II.) The inter-coder agreement in assigning the nine categories used in Method 1 was computed and expressed as percentages. In the first case, agreement was calculated by using the number of instances (i.e. segments) of agreement in the numerator, and the total number of segments in the protocol in the denominator. The second case calculated agreement using the time duration in agreement in every category as the numerator, and the total time in the protocol as the denominator.

The agreement across the paired protocols varied from 51.0% to 61.0% when calculated by the number of segments, and from 49.0% to 57.0% when computed by the time units. Table 5 indicates that the highest agreement occurred with the protocol of Participant 3. However, even the highest agreement of 61% falls far short of acceptable levels. This finding indicates that Method I in its present form does not have good reliability and needs to

Table 3: General characteristics of protocols encoded

NAME	No. of Segments	Duration of Protocol
Participant 1	174	52 min.
Participant 2	195	55 min.
Participant 3	178	57 min.

Table 4: Temporal characteristics of segments in protocols encoded

	Percentage of Segments		
NAME	< 32 sec.	32-64 sec.	> 64 sec.
Participant 1	89.7%	9.8%	0.5%
Participant 2	91.8%	7.7%	0.5%
Participant 3	90.4%	5.6%	4.0%

Table 5: Agreement on identification of categories (Method 1)

NAME	Percent agreement in identification of categories	
	by number of segments	by time units
Participant 1	55.00%	52.00%
Participant 2	51.00%	49.00%
Participant 3	61.00%	57.00%

be improved in order to be used as an effective instrument for assessing design processes.

The frequency of occurrence of each of the nine categories was computed and expressed as a percentage. This percentage was calculated by using the number of instances of occurrence of a specific category (as assigned by Encoder 1 or Encoder 2) as the numerator, and the total number of segments in the particular protocol as the denominator. The same computations were done using time units instead of the number of instances of occurrence of a category. These data are presented in Table 6 and Table 7 respectively. Table 6 and Table 7 indicate that Move and Plan categories occurred most frequently in the protocols. The frequency of the Move category ranged from 7% to 30%, and the Plan category from 15% to 53% when computed using the number of segments. This was followed by the Not Applicable and Specific Assessment categories. The high percentage of occurrences of the Not Applicable category suggests that this method needs to be refined to account for all types of verbalizations uttered during architectural problem-solving. The frequencies of the different categories across the encoders are quite consistent for the protocols of Participant 1 and Participant 3. However, the segments assigned to Move, Plan, and Specific Assessment categories differ appreciably between Encoder 1 and Encoder 2 (10% to 24%). This is a function of the fact that Encoder 1 assigned a large number of segments (53%) to the Plan category, which lowered the frequency of the other categories and led to a disagreement between protocols.

Next, the agreement pairs were analyzed. Category-wise agreement between Encoder 1 and Encoder 2 was calculated by using the number of instances of occurrence of a specific category (or the time units in the second

Table 6: Frequency of occurrence of categories
(computation by Method 1)

Category	Frequency of occurrence of categories by number of segments					
	Participant 1		Participant 2		Participant 3	
	Encoder 1	Encoder 2	Encoder 1	Encoder 2	Encoder 1	Encoder 2
Literal copy	0.00%	0.00%	2.00%	3.00%	1.00%	1.00%
Paraphrased copy	0.00%	4.00%	4.00%	1.00%	1.00%	2.00%
Move	30.00%	27.00%	7.00%	17.00%	23.00%	21.00%
Plan	27.00%	27.00%	53.00%	29.00%	20.00%	15.00%
Inference	4.00%	6.00%	9.00%	11.00%	12.00%	15.00%
General assessment	4.00%	2.00%	4.00%	4.00%	1.00%	1.00%
Specific assessment	12.00%	17.00%	7.00%	20.00%	18.00%	21.00%
Search	2.00%	5.00%	5.00%	5.00%	3.00%	3.00%
Not applicable	20.00%	12.00%	10.00%	10.00%	22.00%	21.00%

Table 7: Frequency of occurrence of categories by time units (Method 1)

Category	Frequency of occurrence of categories by time units					
	Participant 1		Participant 2		Participant 3	
	Encoder 1	Encoder 2	Encoder 1	Encoder 2	Encoder 1	Encoder 2
Literal copy	0.00%	0.00%	2.00%	3.00%	0.00%	1.00%
Paraphrased copy	0.00%	6.00%	5.00%	1.00%	0.00%	1.00%
Move	39.00%	36.00%	9.00%	20.00%	33.00%	38.00%
Plan	26.00%	25.00%	53.00%	29.00%	16.00%	14.00%
Inference	5.00%	7.00%	7.00%	11.00%	10.00%	12.00%
General assessment	4.00%	1.00%	4.00%	4.00%	0.00%	0.00%
Specific assessment	12.00%	16.00%	7.00%	20.00%	15.00%	19.00%
Search	1.00%	4.00%	3.00%	4.00%	3.00%	3.00%
Not applicable	13.00%	5.00%	12.00%	9.00%	23.00%	11.00%

case) in the numerator, and the total number of instances of correspondence of categories between the two protocols in the denominator. The disagreement pairs also were analyzed and expressed as a percentage in a similar manner. Only the number of occurrences was used to compute the percentage of disagreement pairs in the three protocols. The agreement by category is presented in Table 8 and Table 9, while the percentages of disagreement pairs are tabulated in Table 10.

Tables 8 and 9 indicate that Move and Plan categories have the highest agreements in the protocols encoded. The agreement across the Move category ranges between 12% to 30% when computed by the number of segments, and between 18% to 46% when calculated by time units. The agreement across the Plan category ranges from 17% to 52% for both analyses. The Specific Assessment category also has a relatively high rate of agreement. The high agreement in the Not Applicable category seems to indicate the necessity of other categories. It should be noted that the categories that have higher agreement, also have a higher frequency of occurrence (refer to Table 6 and Table 7 for frequency of occurrence). The Move and Plan categories have the highest frequency of occurrence as well as the highest rate of agreement across the protocols of the three participants. This suggests that the high frequency of occurrence of Move, Plan, and Specific Assessment categories may be partly responsible for the relatively high agreement along these categories. The high frequency of Plan/Specific Assessment, Plan/Move. and Specific Assessment/Move disagreement pairs indicates that the operational definitions of these three categories need further refinement to increase the precision of this method of protocol analysis. Since these three categories (Plan, Move & Specific Assessment) have the highest frequency of occurrence,

Table 8: Agreement in the identification of categories by Method 1

(using number of segments)

	Agreement in identification of categories (# segments)		
Category	Participant 1	Participant 2	Participant 3
Literal copy	0.00%	3.00%	1.00%
Paraphrased copy	0.00%	0.00%	1.00%
Move	30.00%	12.00%	20.00%
Plan	31.00%	52.00%	17.00%
Inference	3.00%	9.00%	13.00%
General assessment	2.00%	1.00%	0.00%
Specific assessment	10.00%	9.00%	17.00%
Search	4.00%	5.00%	2.00%
Not applicable	19.00%	9.00%	30.00%

Table 9: Agreement in the identification of categories by Method 1

(using time units)

Category	Agreement in identification of categories (# segments)		
	Participant 1	Participant 2	Participant 3
Literal copy	0.00%	3.00%	0.00%
Paraphrased copy	0.00%	0.00%	0.00%
Move	46.00%	18.00%	37.00%
Plan	29.00%	52.00%	17.00%
Inference	4.00%	5.00%	12.00%
General assessment	3.00%	1.00%	0.00%
Specific assessment	9.00%	7.00%	15.00%
Search	2.00%	3.00%	1.00%
Not applicable	8.00%	12.00%	17.00%

Table 10: Disagreement pairs computed by number of segments

CATEGORY	Percent disagreement pairs computed by # of segments		
	Participant 1	Participant 2	Participant 3
PL/SA	12.00%	20.00%	6.00%
PL/MO	14.00%	20.00%	16.00%
PL/NA	8.00%	6.00%	3.00%
SA/MO	21.00%	2.00%	23.00%
NA/MO	9.00%	1.00%	9.00%
SA/IN	.0.00%	6.00%	10.00%
IN/PL	0.00%	6.00%	7.00%
IN/NA	1.00%	5.00%	3.00%
PL/IN	4.00%	0.00%	0.00%
PL/PC	5.00%	2.00%	1.00%
PL/SE	1.00%	3.00%	2.00%
IN/MO	7.00%	1.00%	1.00%
IN/PC	1.00%	2.00%	1.00%
PC/GA	3.00%	0.00%	0.00%
SA/NA	5.00%	1.00%	4.00%
SA/SE	1.00%	0.00%	0.00%
SA/GA	1.00%	4.00%	3.00%
GA/IN	1.00%	1.00%	0.00%
GA/MO	1.00%	0.00%	0.00%
NA/SE	1.00%	3.00%	1.00%
SA/PC	0.00%	3.00%	0.00%

Table 10 (continued)

CATEGORY	Percent disagreement pairs computed by # of segments		
	Participant 1	Participant 2	Participant 3
LC/GA	0.00%	1.00%	0.00%
LC/NA	0.00%	1.00%	0.00%
LC/PC	0.00%	2.00%	0.00%
GA/MO	0.00%	1.00%	0.00%
GA/SE	0.00%	1.00%	0.00%
GA/NA	0.00%	1.00%	0.00%
IN/SE	0.00%	0.00%	4.00%
IN/LC	0.00%	0.00%	1.00%
NA/PC	0.00%	0.00%	1.00%

Legend

PL Plan

SA Specific assessment

GA General assessment

MO Move

NA Not applicable

IN Inference

PC Paraphrased copy

LC Literal copy

SE Search

improvement of the operational definition of these categories should increase the inter-coder agreement using Method I.

In order to understand the occurrence and distribution of the different categories across time, each protocol was divided into four equal quartiles. The frequency of the different categories in each quartile was recorded for each coded protocol, yielding six sets of data, two corresponding to each protocol. Each set of data consisted of the frequency of the nine categories in four quartiles of the respective protocols. The data were used to plot graphs of the frequency of occurrence of each category (on the abscissa) against the four quartiles (on the mantissa). The distributions of a specific category for all the three protocols were shown on one graph for ease of comparison and identification of general trends. Two complete sets of of nine graphs each were generated, one corresponding to Encoder 1 and another to Encoder 2. These graphs are presented in the following pages (Figure 27 to Figure 35).

Although the agreement for the protocols coded by Method 1 was below acceptable levels, the graphs illustrate a patterns of occurrences for the different categories. The Literal Copy/Paraphrased Copy/General Assessment/Search categories occur with low frequency across all the protocols encoded. The Literal and Paraphrased Copy categories are almost entirely confined to the first two quartiles of the protocol. This finding seems logical, since it would be reasonable to assume that the requirements set down by the program would be used by the designers to structure the problem. Since problem structuring is completed before problem solving, Paraphrased Copy and Literal Copy occur early in the design process.

The graphs indicated that Move and Plan categories occur regularly across the protocol, and there seems to be a reciprocal relation between them.

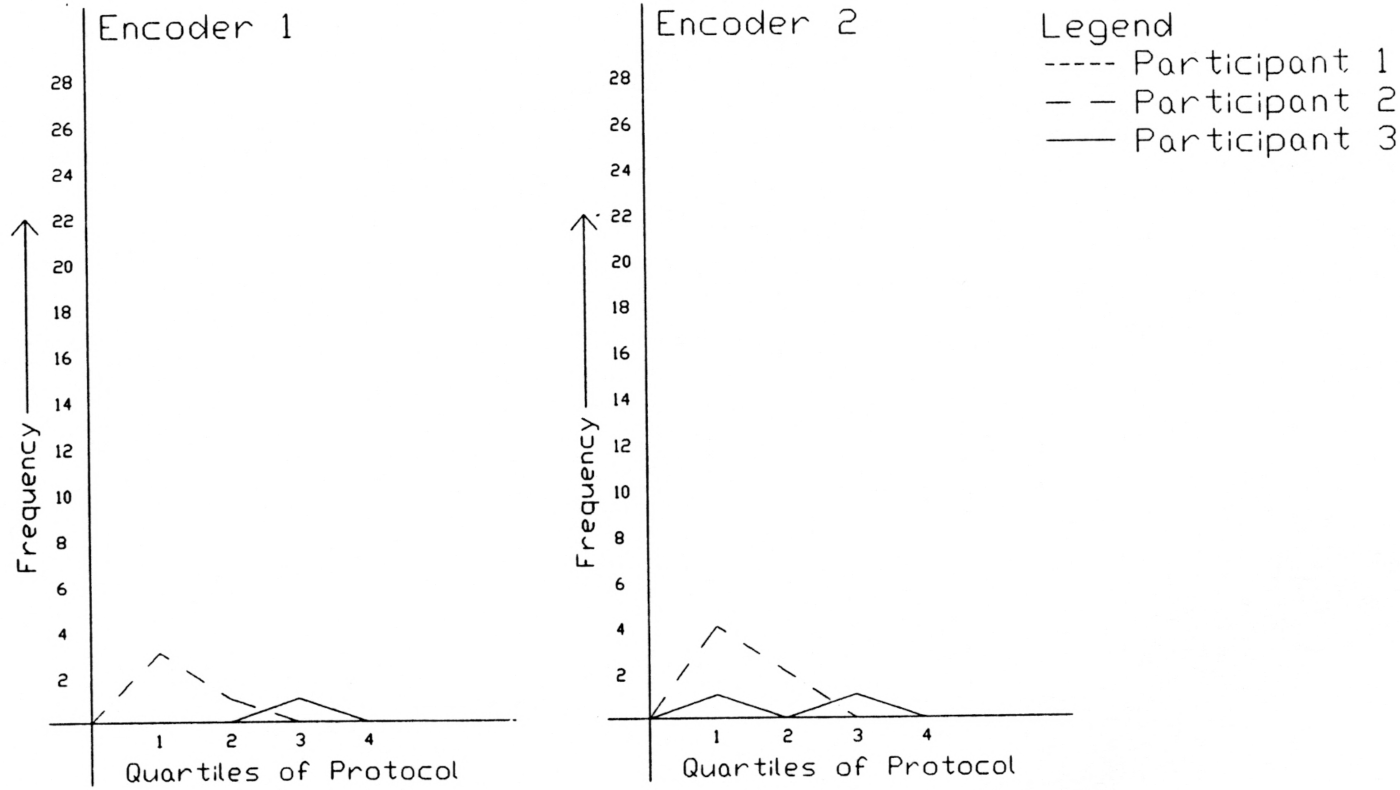


Figure 27: Graph illustrating the distribution of category - Literal Copy in protocols encoded by a) Encoder 1, b) Encoder 2

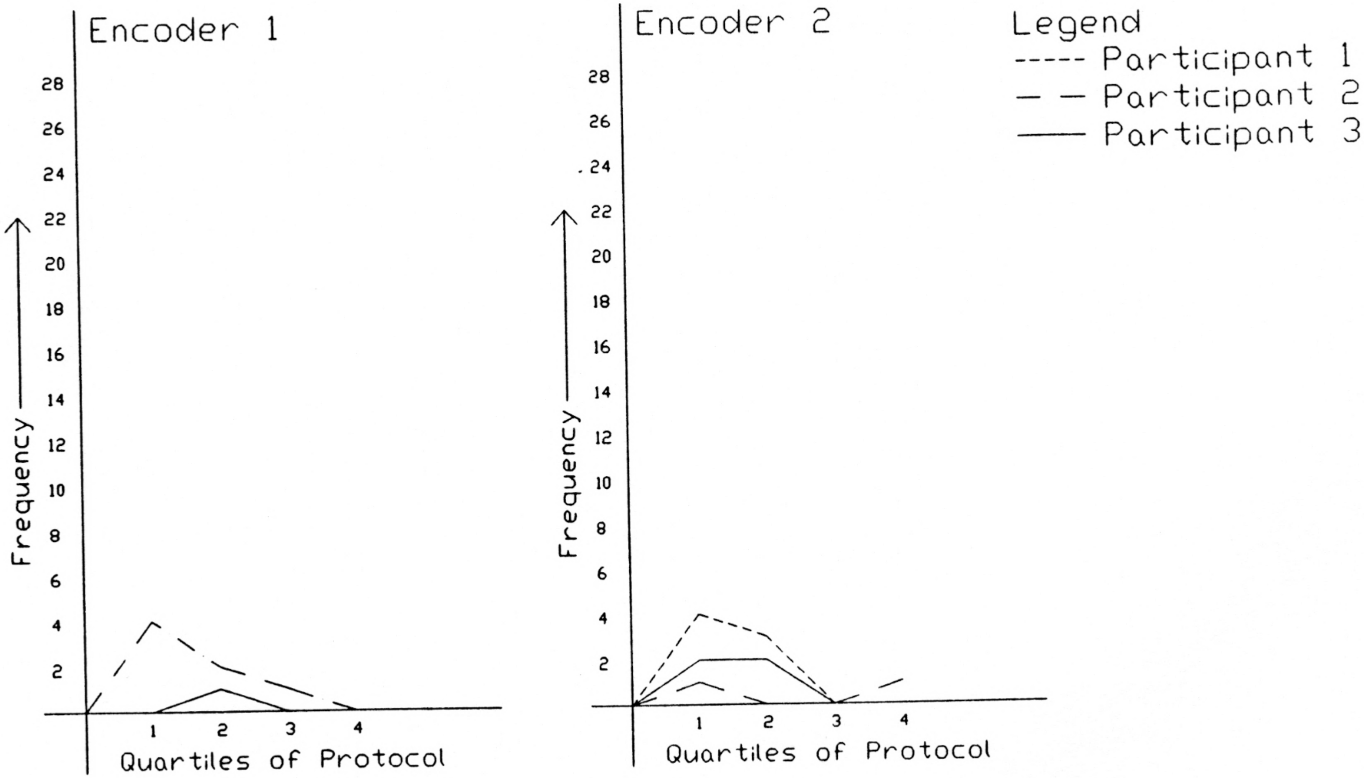


Figure 28: Graph illustrating the distribution of category - Paraphrased Copy in protocols encoded by a) Encoder 1, b) Encoder 2

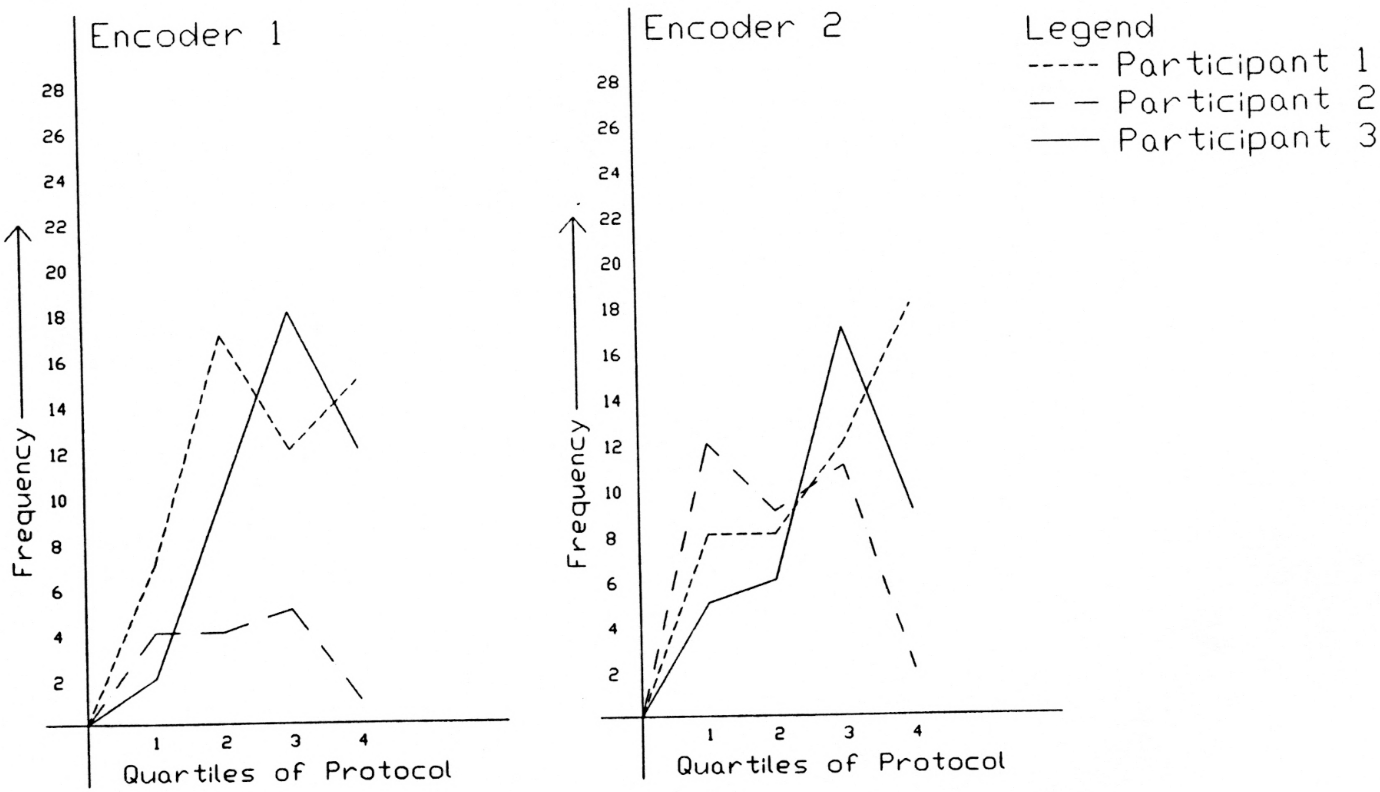


Figure 29: Graph illustrating the distribution of category - Move in protocols encoded by a) Encoder 1, b) Encoder 2

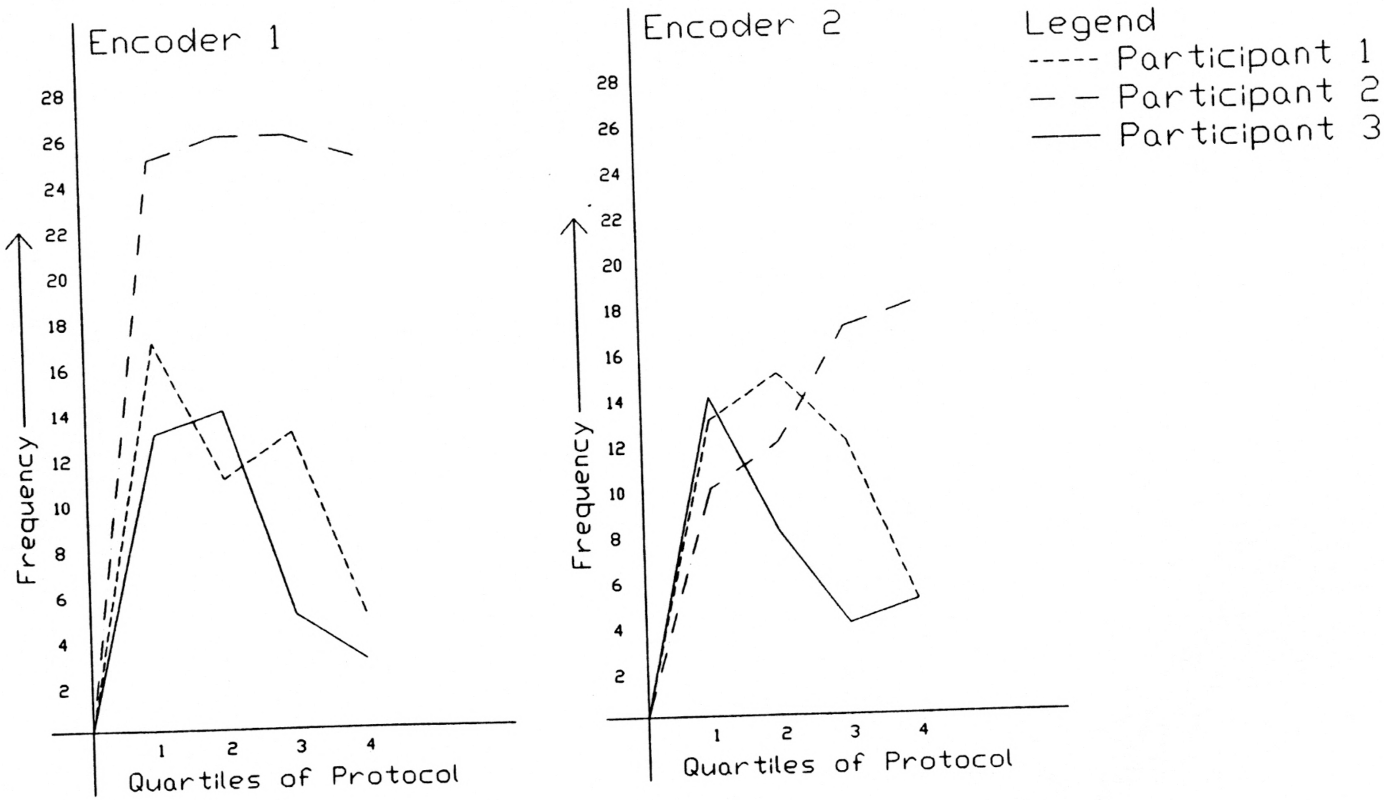


Figure 30: Graph illustrating the distribution of category - Plan in protocols encoded by a) Encoder 1, b) Encoder 2

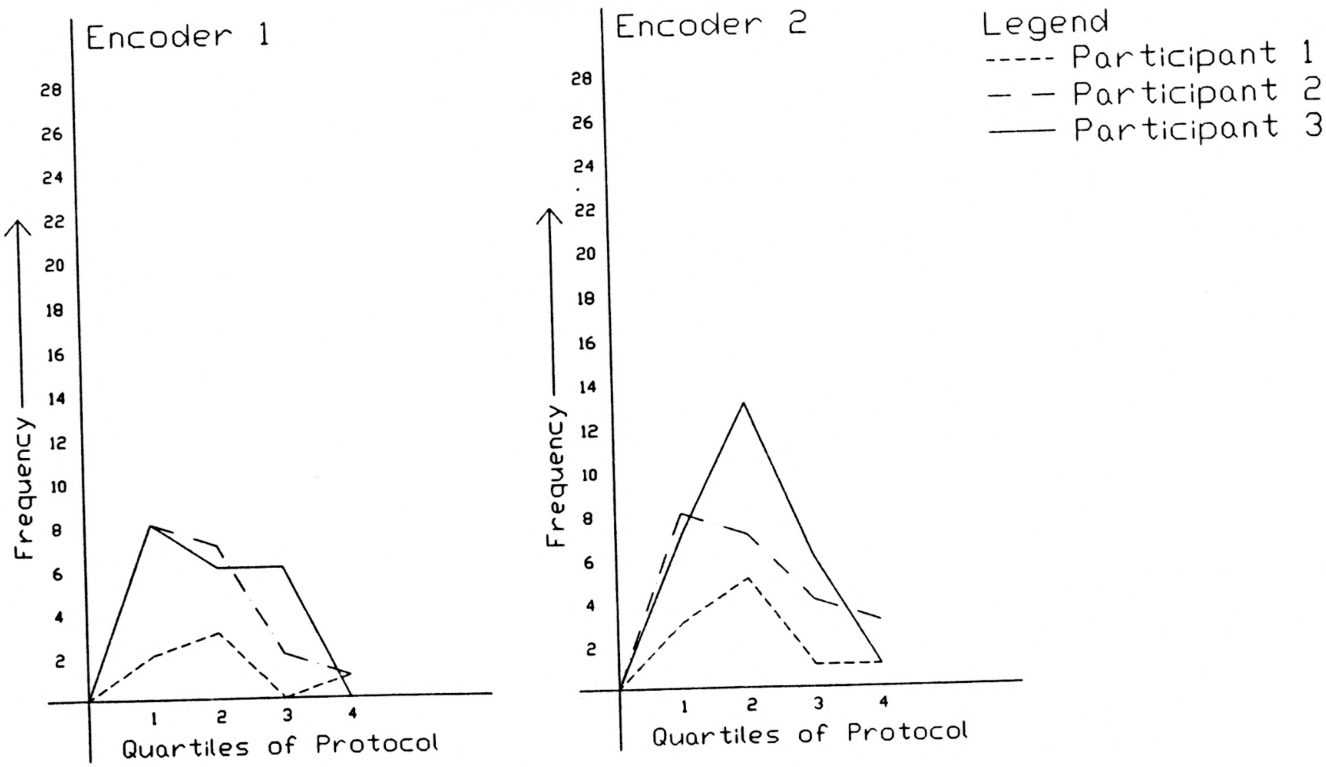


Figure 31: Graph illustrating the distribution of category - Inference in protocols encoded by a) Encoder 1, b) Encoder 2

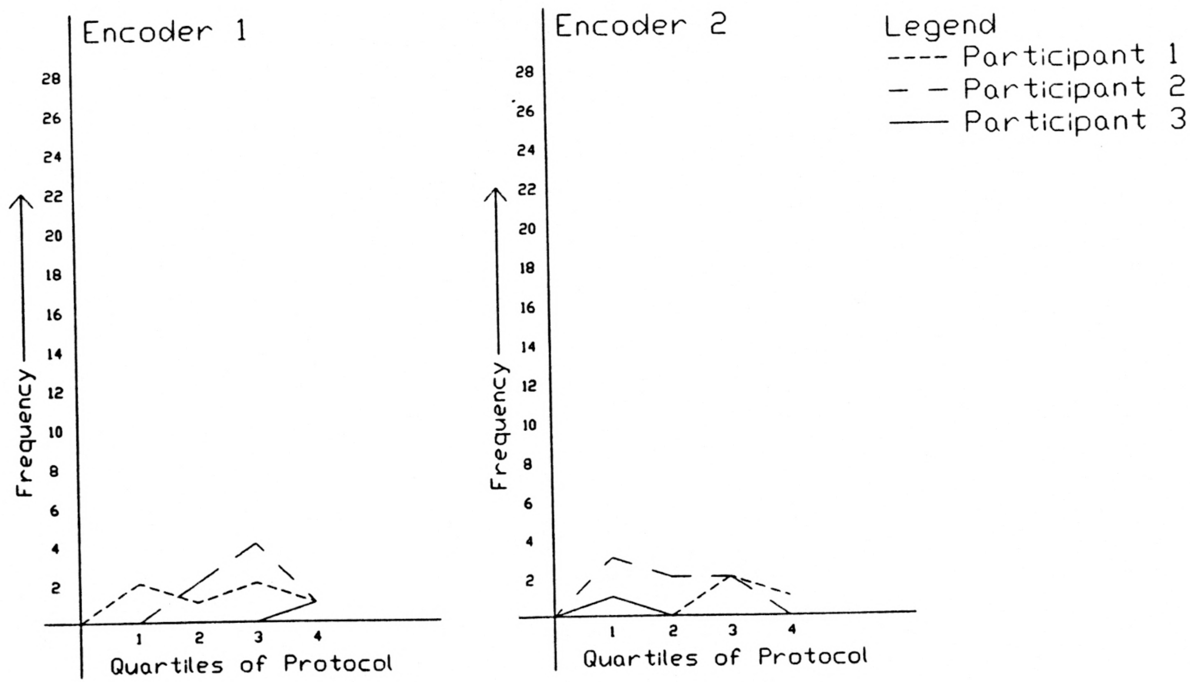


Figure 32: Graph illustrating the distribution of category - General Assessment in protocols encoded by a) Encoder 1, b) Encoder 2

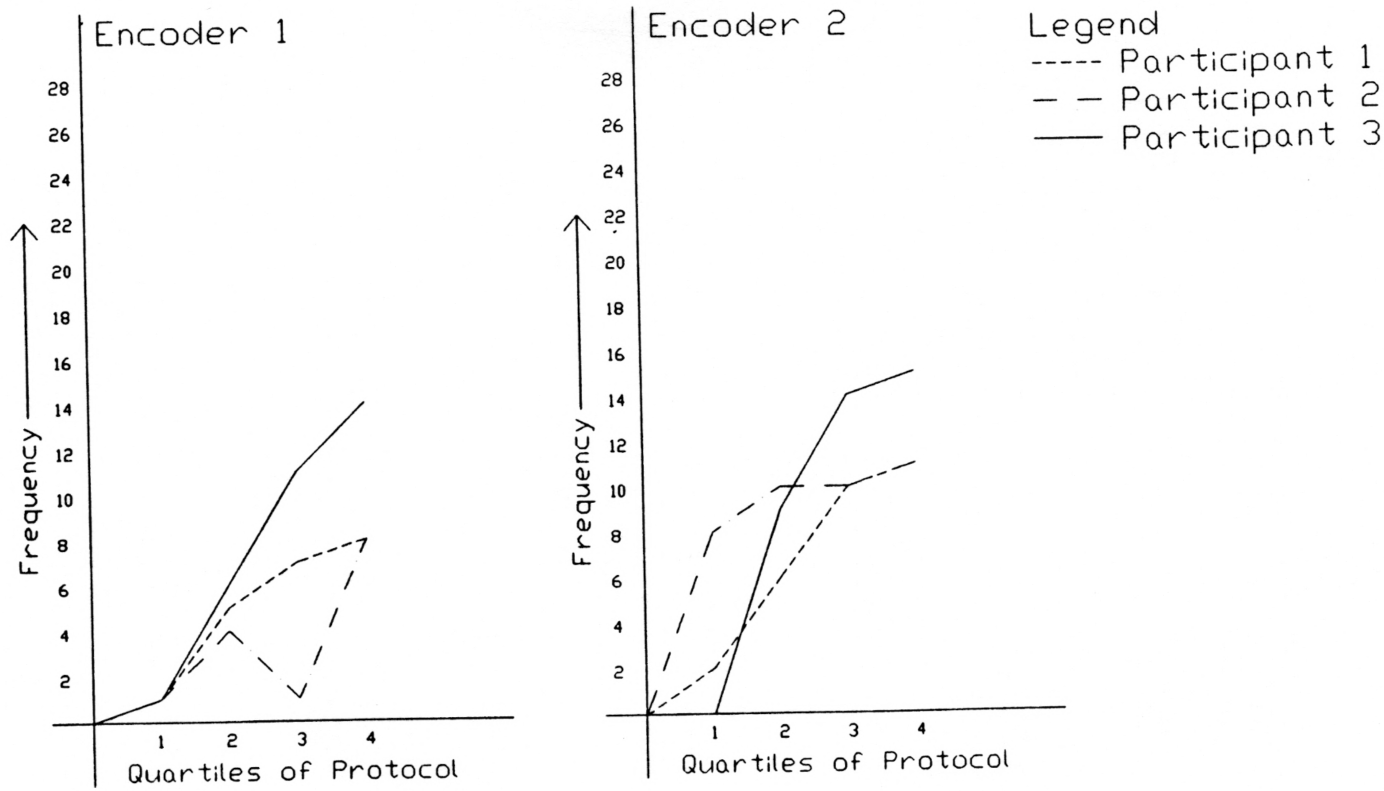


Figure 33: Graph illustrating the distribution of category - Specific Assessment in protocols encoded by a) Encoder 1, b) Encoder 2

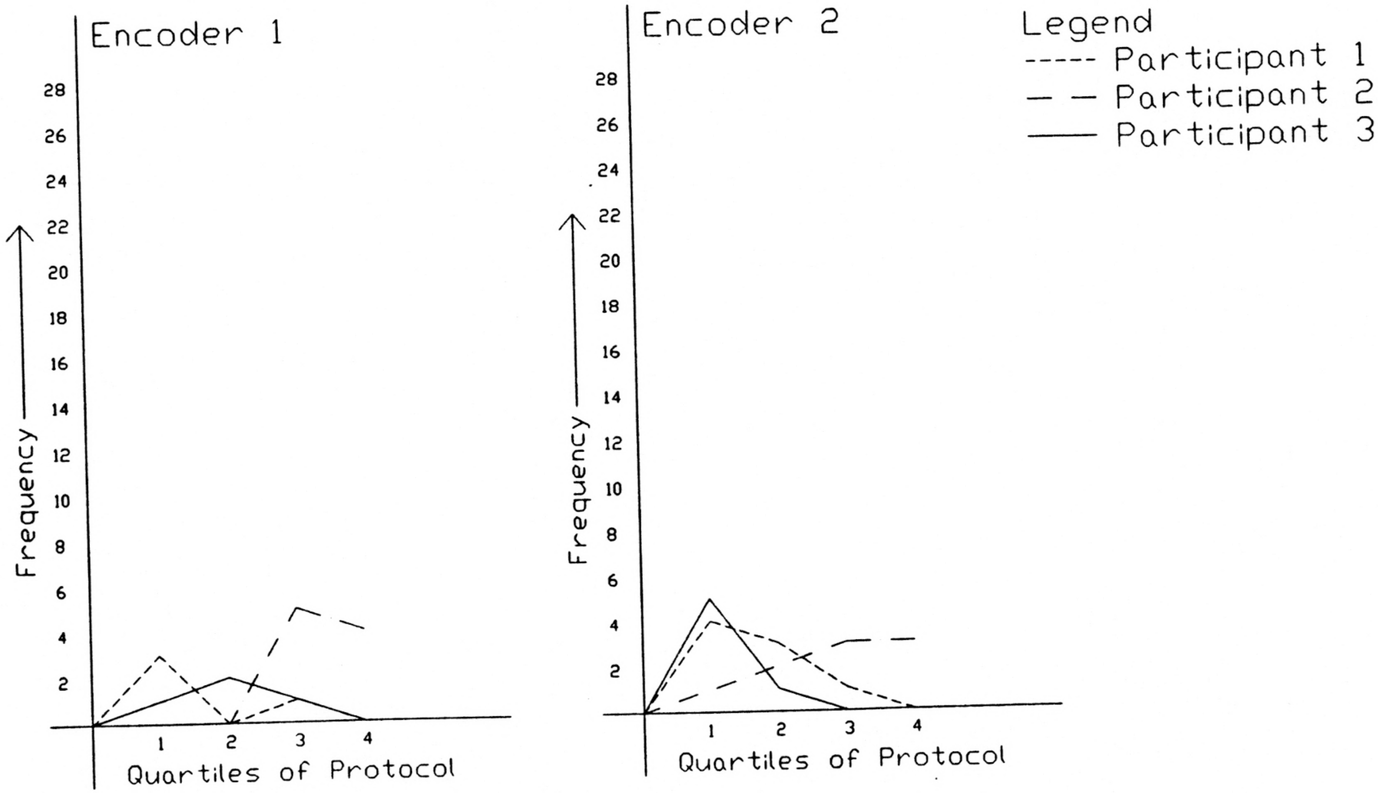


Figure 34: Graph illustrating the distribution of category - Search in protocols encoded by a) Encoder 1, b) Encoder 2

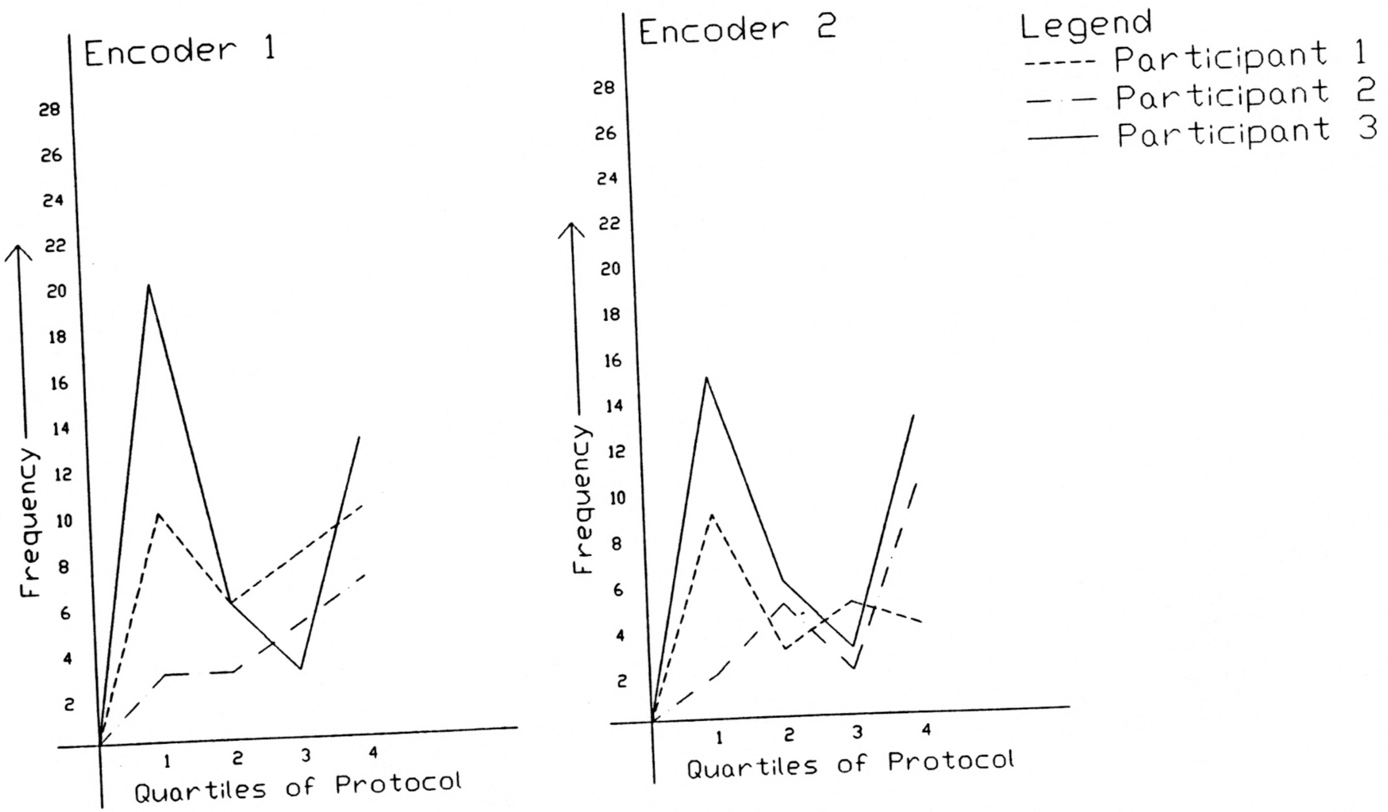


Figure 35: Graph illustrating the distribution of category - Not Applicable in protocols encoded by a) Encoder 1, b) Encoder 2

This pattern is illustrated by Figures 29, and 30. Coupled with the high frequency of Plan/Move disagreement pairs across all three protocols, this reciprocal relationship indicates the there may be some overlap between these two categories. In other words, the definition of Move and Plan categories may not be as distinct as desirable. Both of these categories involve decisions to proceed with a certain course of action. The only difference between them is that Move category deals with the actual movement of spaces, while the Plan category has a broader definition. It may be difficult for coders to distinguish clearly from verbal protocols when a designer is implying the actual movement of spaces, and when he or she is verbalizing an intended course of action.

The Inference category has a higher frequency of occurrence at the middle of the protocol (see Figure 31), while the Specific Assessment category begins with a low frequency of occurrence and gradually increases to a maximum at the last quartile of the protocol (Figure 33). This finding is consistent with the reasoning that inferences are made from initial planning schemes, which lead to alterations of plans, and assessments of the new plans until a satisfactory solution is reached. As more of the building is designed, more assessment is required to verify if the planned design fulfils the requirements; hence, the gradual build up and peaking of the Specific Assessment category at the end of the protocol.

The Not Applicable category occurs with greater frequency in the first and last quartile of the protocols. This finding suggests that some verbalizations typical of the beginning and end of the design process are not accounted for by the existing taxonomy of categories. At the beginning of the protocols, the participants often asked for some clarifications regarding the requirements, to which the researcher (R) replied. Such verbalizations constitute a large percent of the Not Applicable category in the first quartile of the protocols, and may be an artifact of the methodology. An excerpt from Participant 1's (P1) protocol illustrates this point.

P1: It's a quarter scale you said?

R: No - it's 3/32.

P1: Oh! - O.K. - 3/32

R: And if you need later on - this (graph) paper is also in 3/32 scale.

All three participants were involved in drawing activity during the last quartile of the protocols, which again may have involved queries of the researcher. An excerpt of Participant 3's (P3) protocol illustrates this finding.

R: Are you nearly done?

P3: Yes, I can be. I can do more. I don't have any kind of dimension as yet.

R: But they're pretty much to scale....

P3: Yeah - yeah.

R: That's fine then.

Method 2

Method 2 consists of the identification of moves across the segmented protocols of the three participants. The identified moves are then assigned to one of the three categories: move during no graphic input (NGI), move during contemplative sketching (CS), and move during active sketching (AS). For details of encoding by Method 2, refer to Chapter II.

In analyses similar to those used for Method 1, inter-coder agreement of moves was computed and expressed as a percentage. First, agreement was computed by using the number of instances of agreement on moves in the numerator, and the total number of moves in the entire protocol in the denominator. Since the number of moves identified in each protocol depended on each encoder, there was not complete correspondence between the encoders. For example, Encoder 3 identified 28 moves in Participant 1's protocol; while Encoder 4 identified 46 moves in the same protocol. Of these moves, only 17 were common to both the encoders. The average of the total number of moves (that is, 28 + 46 = 74, and 74/2 = 37 in this case) was used as the denominator during computation of inter-coder agreement in identification of moves. The percentage agreement between Encoder 3 and Encoder 4 in identification of moves ranged from 47.0% to 54.0% when calculated by the number of instances of occurrence. When time units were used to compute the inter-coder agreement, agreement ranged from 48.0% to 52.0% (see to Table 11). The highest agreement in identification of moves was 54%, well below acceptable standards. However, even when there was disagreement in the identification of moves by the two encoders, the moves were clustered together with brief slippages in between, as shown in Table 12. This finding suggests that with the refinement of the operational definition

Table 11: Percentage agreement on identification of moves

NAME	Percent agreement on identification of moves	
	by # segments	by time units
Participant 1	49.0%	52.0%
Participant 2	47.0%	48.0%
Participant 3	54.0%	51.0%

Table 12: Excerpt from Participant 2's protocol showing agreement and disagreement pairs using Method 2

Categories assigned by Encoder 3	Segment Number	Agreement/ Disagreement Pairs	Categories assigned by Encoder 4
AS	65	/	AS
NM	66	X	AS
	67	-	
	68	X	NGI
	69	X	CS
AS	70	/	AS
NGI	71	X	
	72	X	AS
AS	73	X	
	74	-	

Legend

AS - Moves during active sketching

CS - Moves during contemplative sketching

NGI - Moves during no graphic input

Agreement pairs: AS.

Disagreement pairs: NM/AS, NM/CS, NM/NGI.

of move, inter-coder agreement could be improved. Since there was a low percentage of agreement in identifying moves, the calculation of agreement for particular categories of moves would be even lower and not meaningful.

The analyses of inter-coder agreement were followed by analyses of the frequency of occurrence of specific move categories. Frequency was determined, first by using discrete instances of the occurrence of a specific category, and second by using temporal measures (i.e. actual time units of each category of moves). Since each protocol was encoded twice, two sets of frequency measures were obtained for each protocol. These frequency measures are expressed as percentages, and are shown in Table 13 and Table 14. The frequency table does not reveal any pattern of occurrence for the three specific kinds of moves.

The low percentage of agreement in identification of moves suggests that the operational definition of a move is ambiguous. This is not to say that an analysis using this method would not serve any purpose, but rather that this method is not suited to be used as an objective instrument to examine the design process across different participants. This method could probably be used by individual designers to study their own design process, in order to get a better understanding of the strategies used during design. It is important to recognize that research of this nature is in its infancy, and hence only exploratory in nature. Use of this method could result in applications to a wide range of design issues, leading to refinement and greater accuracy. Also, the three categories of moves are not distinct from one another. The distinction between Contemplative Sketching and Active Sketching is fuzzy. In the present study, the video camera did not focus on the drawings, but on the participant working on the design, which made it even more difficult for

Table 13: Frequency of occurrence of move categories by number of segments

NAME	Frequency of occurrence of move categories (segments)					
	by Encoder 3			by Encoder 4		
	NGI	AS	AS	NGI	AS	AS
Participant 1	36.0%	29.0%	36.0%	22.0%	20.0%	59.0%
Participant 2	59.0%	15.0%	26.0%	33.0%	49.0%	18.0%
Participant 3	44.0%	4.0%	52.0%	41.0%	50.0%	10.0%

Table 14: Frequency of occurrence of move categories by time units

NAME	Frequency of occurrence of move categories (time units)					
	by Encoder 3			by Encoder 4		
	NGI	AS	AS	NGI	AS	AS
Participant 1	35.0%	34.0%	31.0%	20.0%	20.0%	60.0%
Participant 2	53.0%	20.0%	27.0%	28.0%	50.0%	22.0%
Participant 3	38.0%	16.0%	46.0%	33.0%	55.0%	12.0%

Legend

NGI Move with no graphic input

CS Move during contemplative sketching

AS Move during active sketching

encoders to distinguish between the three move categories. Further refinement of the operational definition of moves would be required before the findings of different researchers using this system could be compared.

Ease of Encoding

All four encoders took about the same amount of time to encode the protocols, approximately equal to the time elapsed during the video recordings of the respective protocols. The time taken to encode the protocols varied from 55 to 65 minutes. Encoder 1 and Encoder 2 mentioned that they had trouble distinguishing between Plan, Move, and Specific Assessment categories. They indicated that in many instances they relied on their subjective assessment skills when assigning segments of the protocols to different categories by Eckersley's method. They also reported some difficulty in distinguishing between the Specific Assessment and General Assessment categories. A substantial portion of the verbalizations were difficult to assign to categories, which explains the high occurrence of the Not Applicable category.

Encoder 3 and Encoder 4 were of the opinion that the operational definition of move was subjective, and likely to vary across people. They had trouble in assigning moves to the three different sub-groups (moves during active sketching, moves during contemplative sketching, and moves during no graphic output). Both the encoders reported, that the video recordings did not allow them to decipher whether moves were made by the participants during contemplative sketching or active sketching. One of the encoders suggested that the participants might be told to draw their formal sketches on one kind of paper (that is, moves during active sketching); and the sketches generated during the thinking process (that is, moves during contemplative sketching) on another color paper - so that this would provide a cue to the encoders for assigning the moves to their respective categories. This suggestion has several drawbacks: (a) it assumes that active sketching involves drawing a worked out scheme, which may be a simplistic way of approaching the process of design, (b), it could alter the process of design by asking the participant to distinguish between active and contemplative sketching. Another suggestion was to use two video cameras: one focused on the drawing only, and the other on the participant with respect to the surrounding. However, this strategy would complicate the coding process, since the encoders would have to co-ordinate both the videos during their analysis.

The difficulties experienced by the encoders supported the trends exhibited by comparisons of the protocols. The difficulty that Encoder 1 and Encoder 2 had in assigning the segments to the Move, Plan, and Specific Assessment categories were reflected in the high proportion of disagreement pairs in these categories. The difficulties reported by Encoder 3 and Encoder 4 explain their low agreement in the identification of moves, and the even lower percentage of agreement between the specific types of moves. The problems that they faced echo the results of the analyses.

Chapter VI: Conclusions

The complex nature of the architectural design process has been a deterrent to its systematic study. In recent years, advances in cognitive science and information processing theory have paved the way for the development of models to examine the process of architectural design. This study explored the potential of four of these models (Akin, 1984; Chan, 1990; Eckersley, 1988; Goldschmidt, 1990) for providing insights into the process of architectural design. Students of architecture at Kansas State University were participants in this study. A design problem, consisting of a workplace for three artists, was given to participants, who verbalized their thought processes as they solved the problem. The design process was video recorded, and three protocols (that is, verbalizations) were chosen and transcribed for further study. The protocols were randomly chosen, one each from the pool of six protocols of second, third, and fifth year students respectively.

Summary of Findings

The synopsis of this study is organized around the objectives of this research as presented in Chapter I. Findings in response to each of the objectives is discussed in turn.

Structure of Solutions to Design Problems

The first objective of this study was to examine how participants structure solutions to design problems, and types of information used to structure and solve such problems. An analysis of the three protocols indicated that the participants exhibited similarities in structuring the solution at the macro-level. All three participants began with the requirements set down by the problem statement and developed schemes which were verified periodically against the goals that were to be achieved.

However, at the next level of specificity, the participants exhibited different approaches in solving the problem. Participants 2 and 3 relied primarily on functional requirements in designing the workspaces for the three artists. They were pragmatic in their approaches, and considered economics, adjacency requirements, provision of natural light and ventilation for their designs. Participant 1 also considered these issues, but gave priority to aesthetic issues, and the form of the building. The content of the verbalizations indicates the variety of issues used to structure the design problem. Many of the constraints imposed were not mentioned in the problem statement, but were generated by the participants. For example, Participant 3 concluded that since one artist was involved in batik, her workspace would be messy, involving paints, dyes, water. Consequently, Participant 3 placed that workspace in the basement, away from the other two on the first floor. In another instance, Participant 1 decided that the display/reception area would be a central space connecting the three workspaces; however, the space requirements given by the problem statement did not fit this idea. Participant 1 decided that it was important for the display area to be a central connecting space, so he disregarded the smaller space requirement given by the problem statement and designed a much larger display-reception area. This decision illustrates how architects assign priorities to different goals, and in case of conflict, certain requirements are disregarded to preserve higher priority design goals. In this study, the basis for assigning priorities to different functions seemed to be individual preference, underscoring the subjective nature of architectural design.

The protocols illustrate a relationship between the number of years of formal training in architecture and the design process. Participants 2 and 3, who had received more training, were more systematic in their approaches to the design problem. They were guided by pragmatic factors, and were able to articulate reasons for their design decisions. Participant 3 had the longest period of training, and she was the only participant who was able to use the site section to her advantage in her design. Participant 1, with less experience, depended on his intuitive sense and gave priority to aesthetic considerations when designing. Participant 1 also encountered more difficulties while designing - he had to leave the parking problem unresolved, and had to compromise his design due to an incorrect estimation of the slope of the site. The tendency to rely on intuitive feelings during the design process could be construed as an individual trait; however, the possibility that architectural training enables students to express their design process explicitly needs to be explored. Participant 2 and Participant 3 might have been able to articulate their thought processes due to longer periods of formal architectural training, rather than employing innately different processes of design from Participant 1. Further research is needed to examine this possibility.

Dependability of Models

The second goal of this study was to evaluate the inter-coder agreement between protocols using the methods developed by Eckersley (1988) and Goldschmidt (1990), and to assess the ease of encoding by the two methods. One pair of encoders coded three protocols using Eckersley's model (Method I), while a second pair used Goldschmidt's model (Method II) to assign categories to the segmented protocols. The highest inter-coder agreement using Method I was 61%. The categories with the highest agreement were: Plan, Move, Specific Assessment, and Not Applicable. These were also the categories used most frequently. Thus, the higher agreement along these four categories might be attributed at least partially to their high frequency of occurrence. However, the plan, specific assessment, and move categories were also the categories which constituted the bulk of the disagreement pairs. This finding indicates that there is ambiguity in the operational definitions of these three categories. Coupled with the fact that these categories occurred most frequently, these findings suggest that an improvement of the operational definitions of these categories could improve coding agreement considerably. Some patterns in the distribution of the different categories were identified. The Move and Plan categories exhibited a reciprocal relationship, supporting the premise that designers plan a certain line of action and then follow it up by a move implementing the planned line of action.

The maximum percentage agreement for the identification of moves was 54%. The percent agreement for specific types of moves was even lower. Although the moves identified by the two encoders did not exactly correspond, they were clustered together with small slippages. This finding indicates that both the encoders identified moves in comparable sections of the verbal protocol, but they did not correspond precisely. This level of agreement could have been partly influenced by the difficulty in deciphering the actual process of design through the video. In this study, the video camera was focused on the participant as well as the drafting table on which the participant was working. Thus, it was not easy to infer if the participant was engaged in making moves while involved in active sketching or contemplative sketching. It was comparatively easier to recognize whether the participant was involved in graphic activity or not. To distinguish between the type of graphic activity, a second video camera should be focussed on the drawing activity of the participant. This recording strategy would complicate the data collection process and make the task of assigning categories more tedious, since the coder would have to co-ordinate both the video recordings during the process.

The low inter-coder agreements for both the methods of Eckersley and Goldschmidt indicate that these models in their present form are not suitable for the objective study of architectural problem solving activity. The operational definitions of the categories used in Method I (Eckersley) are not distinct, and there is evidence to suggest significant overlaps in the definitions of some categories (Plan-Move; Specific Assessment-General Assessment). The high frequency of occurrence of the Not Applicable category indicates that there are types of verbalizations not accounted for by the existing set of categories. Most of the Not Applicable responses represent queries on the part of the participant (designer) that occurred during the beginning and end of the protocols, and may be artifacts of the methodology. Using only those parts of the verbal protocol which deal with the actual design problem might enhance the coding agreement. Second, the distinction between Specific Assessment and General Assessment categories used in this study is a subjective one, and it may suffice to have a single category - Assessment. It may be a better strategy to develop fewer number of well defined categories, rather than a large number of categories with substantial overlaps between them. Since these models represent the first level of development in this area of research, a sophisticated and refined method can be developed only with further research.

The inter-coder agreement using Method II (Goldschmidt, 1990) was even lower than that using Method I. The operational definition of the move category used by this model is subjective, and encoders had difficulty in assigning the moves to the three sub-categories: moves with no graphic input, moves during contemplative sketching, and moves during active sketching. Goldschmidt (1990) acknowledges that the definition of move is subjective and is dependent on the expertise of the encoder; thus, this model could have potential for studying the process of architectural design on an individual basis. However, the use of this model for systematic comparisons of architectural design activities would be inappropriate without further development.

The time taken to encode the protocols approximately equalled the viewing time of the recordings (55-65 minutes). Encoders 1 and 2 reported that they had difficulty in assigning segments to different categories. Often, they had to resort to personal judgement in doing so. According to Encoders 3 and 4, the operational definition of 'move' was ambiguous, and it was difficult to distinguish between moves made during contemplative sketching versus active sketching. Thus, the experience of the encoders reinforces the need to refine these models.

Although these models represent an area of much needed research in architecture, the findings of this study indicate that they need refinement before they can be used as instruments to objectively study the process of architectural design. As important as the process itself are the types of information used to structure it. In order to be valuable, any method of following architectural design should take into consideration the content as well as the structure of the verbalizations and actions.

Suggestions for the Refinement of the Models

The final objective of this thesis was to suggest ways in which the techniques studied could be modified, substantively or procedurally, to yield more relevant information for the study of architectural problem solving activity. This study indicates that one shortcoming of the models examined is the process orientation towards architectural problem solving activity. There is consensus that architectural designing involves problem setting as well as problem solving (Goldschmidt, 1989) ; it differs from other problem-solving activity in being ill-structured (Akin, 1984, Simon, 1984). Architectural problems do not have a specific 'correct' answer, and consequently there is no single path to the solution. Thus, during the process of architectural design, constraints are used to structure the problem, or to transform the ill-structured problem into a well-structured one. Different designers use different issues to structure problems, and the content of a designer's verbalizations are an indication of the different issues (constraints) used to structure the problem. The four methods studied do not deal with the content of the verbalizations, and do not present a holistic picture of the architectural design process. Thus, further developments of these models should incorporate the content of the verbalizations. Tzamir and Churchman (1989), in research on the type of knowledge used to structure design problems, identified nine facets used for architectural decision making: functionality and efficiency, technical and construction methods, economics and cost, energy and maintenance, environmental quality, aesthetics, user experiences, symbolic messages, and moral values. These facets could be used to analyze the content of the verbalizations involved in the architectural design process.

The nine categories of Eckersley's model exhibit significant overlaps in their operational definitions, probably contributing to the low inter-coder agreement. Using fewer well-defined categories could improve agreement. Within these categories, the type of information used (that is the domain from which the information is evoked) should be examined, so that both process and content issues are addressed. The repeated use and study of coding agreement for such a model would refine the categories, leading in turn to the development of a better instrument for the study of the cognitive processes involved in architectural design.

The move category used in Method II (Goldschmidt, 1990) is subjectively defined, and the three sub-categories are difficult to discern from video recordings. Creating video records of the design/drawing activity of participants, as well as the larger setting, could enhance agreement using this method, but would definitely complicate the encoding process. Another approach would be to redefine the move category to include moves made with and without graphic output. Further research is needed to refine different types of moves.

The models studied in this thesis represent a deductive approach to the development of categories to account for the different kinds of verbalizations articulated during the design process. The categories of both the methods developed by Eckersley, and Goldschmidt exhibited overlaps, and the operational definitions of several of the categories were not distinct from each other. Since this field of inquiry is a relatively new domain, an inductive approach to category development might prove useful. Analyzing protocols collected from a wide cross-section of students, professionals, and academicians engaged in the architecture profession should reveal the range of verbalizations, and suggest patterns among them. Such patterns could then be refined through a Delphic method to develop a set of categories that could be used to examine architectural design processes. With this approach, the categories would emerge from the data, spanning the full range of processes involved in architectural design activity.

Criticism of the Use of Models Based on the IPS

A basic criticism of these models is that the think-aloud procedure may not yield data representative of the cognitive processes involved in architectural design activity, since the design process may be altered by the verbalizations required. Think-aloud verbalizations have been used to develop problem solving computer programs in other fields (for example chess games developed by Newell, & Simon, 1972). The success of such programs is testimony to the utility of think-aloud verbalizations for examining the cognitive processes used during problem solving. Thus, given the present state of art in the field of cognitive science, think-aloud verbalizations seem to be an appropriate method of data collection for examining the process of architectural design with everyday contexts such as the studio.

Future Directions for Research

The process of architectural design is an area where there is much need for research. The development of refined, dependable techniques to study the process of architectural design should enable researchers to examine the cognitive process of design and to identify strategies used for solving architectural problems. In the next step, the strategies that have greater probability of producing successful options could be identified. The possibility that different types of strategies are effective for different types of design problems or different students could be examined. The content of verbalizations could reveal the different domains used to structure architectural problems. Once the techniques are refined, they could be used by researchers as objective methods to study the process of architectural design. In addition to the design process itself, research could focus on the ways in which teaching styles and methods relate to the development of design processes and capabilities among students. Furthermore, individuals could use such techniques to increase self-understanding of the design processes they use. Although this area of research is still in its infancy, it represents an important and much needed field of inquiry that should be pursued systematically using techniques that yield dependable data for study. This thesis represents a first step in that direction.

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APPENDIX A: PROBLEM STATEMENT PACKET

INSTRUCTIONS

In this experiment I will present you with an architectural design problem. I would like you to design the required building as you would do in your studio. The only difference is that I want you to 'THINK ALOUD' as you work on the design. Try to verbalize whatever comes to your mind. It does not matter if the verbalizations are not complete sentences, or do not connect directly to the previous statement. The key is not to plan out what you are going to say next.

I will focus the television camera on you. Just try not to bother about it. I will try to be as unobtrusive as possible so that I do not distract you. There will be times when you are thinking of something non verbal. In those cases, mention "I'm visualizing" or "I'm imagining how the space will look like". I will not interrupt you at all, except, when you have lapsed into silence to remind you to think aloud.

When you are solving the problem, please feel free to ask me questions. If you feel that some additional information would have been helpful, please mention it. The problem is very conceptual in nature. The idea is to generate some fairly conceptual level design options. You are expected to complete the problem within 45 minutes - so you can imagine that no details are expected.

In order to be comfortable with the method of 'think aloud', I will give a small problem for you to work on. This can be considered as a training process. Remember, please think aloud while working. Say everything that comes to your mind. Due to verbalization, you might take a little longer than under normal circumstances, to solve the problem. Don't let this bother you. I'm interested in how you go about solving the problem, not the speed or feasibility of your scheme. Work as normally as possible, and .....think aloud.

TEST PROBLEM

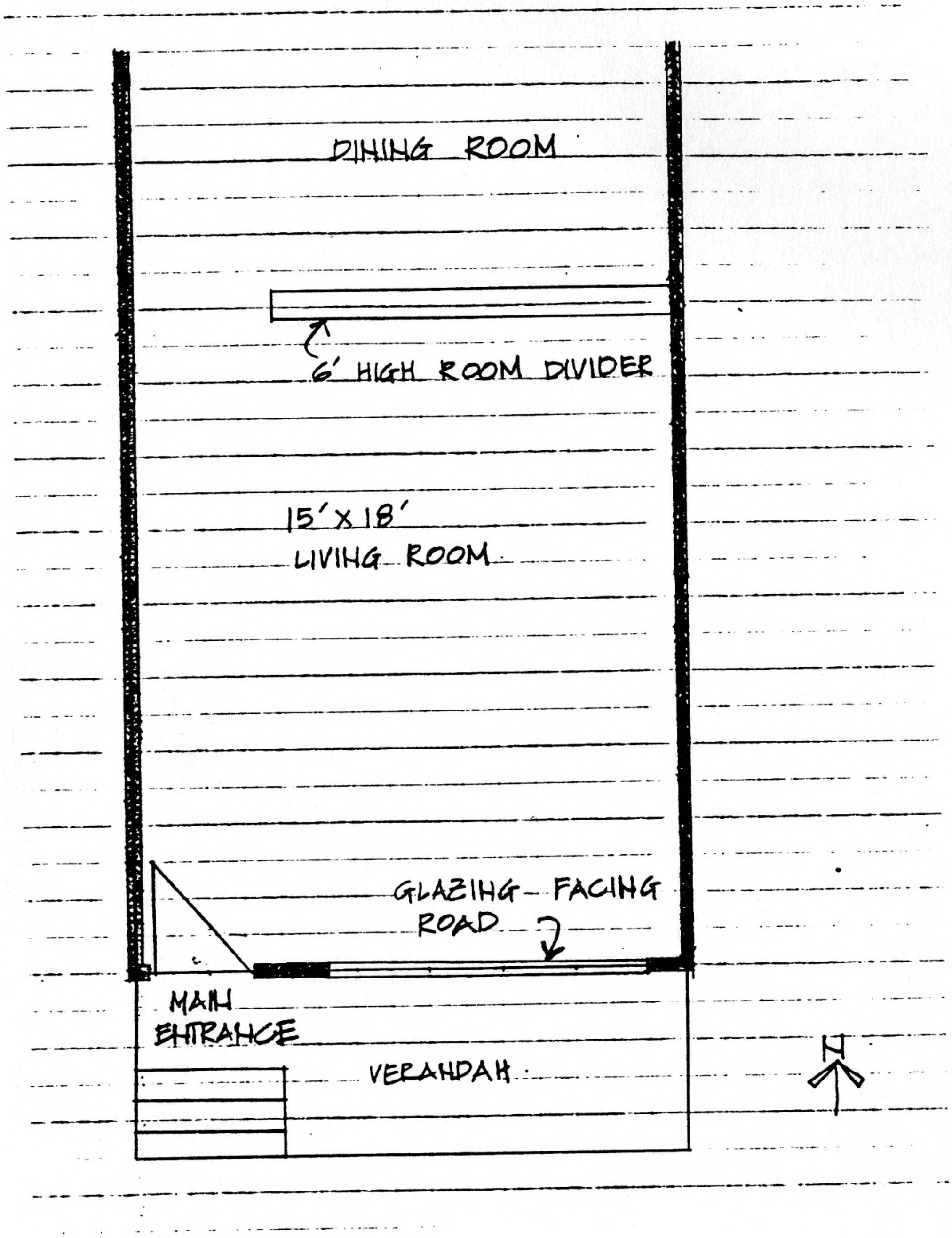
The problem consists of furniture arrangement in a hypothetical living room. The living room is 15' wide and 18' in length. The access to the dining space is through the living room. A room divider separates the living room from the dining space. The room divider is 6' high and forms a partially visual screen. The living room faces the road which provides access to the site. The front (south) wall of the living room is glazed, and provides natural light as well as view of the exterior.

The problem is to place furniture in the given living room. The restrictions are as follow:

- Seating for at least eight people should be provided.
- At least one three seat couch should be provided.
- The furniture layout should be able to accommodate television viewing by at least four persons.
- Provision should be made for a telephone, a bookshelf, and a rocker.

A plan of the living room is provided in the following page.

PLAN OF LIVING ROOM



PROBLEM STATEMENT

The task is to design a workspace cum display/showroom for three textile artists, - Nancy, Elizabeth, and Anne. Nancy specializes in quilting, Elizabeth in weaving, and Anne in batik and tie-dye. The three of them have formed a cooperative and work together. They have a small mail order business. At the moment they work in their respective homes and have a small office at Nancy's house, from where the mail order business is operated. Recently, the three of them purchased a plot overlooking Tuttle Creek, just outside Manhattan. They intend to build a structure that will function as their workspace and office.

Nancy and Elizabeth are married, while Anne is single. Nancy and Anne live in Manhattan, and Elizabeth lives in Junction City. They will come to the studio to work almost everyday, though they do not have fixed working hours. If they are in town, they meet on Mondays and Wednesdays from 2 - 4 p.m.. Other than that they maintain their individual schedules. All of them work in fits and starts. Long hours of intense work are contrasted by relatively relaxed periods. Often one, and sometimes all of them are away attending crafts fairs or exhibitions. All of them require a quiet place to work, with the minimum of disturbance. Light is an important feature in the work area.

The basic requirements are: work space for Nancy, Elizabeth, and Anne; a display area, which will also double up as the reception for customers; a kitchenette with provision for the three entrepreneurs to sit and talk about their plans over a cup of coffee; a rest room; storage space for raw materials and finished products. A space for packaging the mail order products is required. An UPS vehicle will be coming twice a week to pick up the mail order products as well as deliver raw materials. Thus the packaging area should have easy access by the pickup vehicle. There will be a part-time bookkeeper/secretary who will look after the mail order business and other miscellaneous jobs. The bookkeeper/secretary will come every Monday, Wednesday and Friday from 1 p.m. - 5 p.m.. Nancy requires two quilting frames, and a large work surface to cut her patterns, Elizabeth has three looms. Each loom requires an area of 6'x6' approximately. She also requires a work table. Anne requires a frame for her batik, and adequate space for dying fabric/t-shirts, etc.. Since she will be working with paint and dyes, there should be enough space between her workspace and the others so that the paint does not spill over and cause any damage. Fumes from paints and other chemicals used may also cause damage to other products. Since she will be using water to mix the colors/paints, provision for drainage should be provided. A space to dry the finished items will also be required.

They also need a small showroom/display area. It (showroom) will double up as the reception area. The bookkeeper will not have a separate office. A part of the display area will be used as the office. The main entry should be visible from the office area. Separate storage space for raw materials and finished products will be required. The workspace should be visible from the display area.

They would like the building to be unpretentious and simple. It should be clean with simple lines. The workspace is of greatest priority in the building. Light is an important element in the workspace. It should be a cheerful space, conducive to long hours of work. Display hours will be on Mondays, Wednesdays and Fridays from 1 p.m. to 4 p.m.. An outdoor court/patio is also desirable. The patio should be easily accessible from the workspace. Parking for ten cars should be located near the entry to the building. Additional parking for six cars should be conveniently located on the site.

You will be required to make sketch plans and elevations to explain you scheme. The plans should indicate the different spaces with approximate basic dimensions. Schematic sections should be provided if necessary to explain your scheme. All sketches can be annotated. Your sketches should explain the salient features of your design.

Approximate Space Requirements

Work Space:	250 sq. ft. (each)
Display/reception:	200 sq. ft.
Office space:	75 sq. ft.
Kitchenette:	50 sq. ft.
Rest room:	50 sq. ft.
Storage room:	150 sq. ft. (for both)
Total:	1275 sq. ft.

including circulation area, the builing area should be around 1500 sq. ft..

Climatic Data

The Tuttle Creek Reservoir Area has a typical continental climate. The summers are warm and the winters moderately cold. The Table below shows the normal temperature and precipitation at the United States Weather Bureau Station at Manhattan, Kansas.

TABLE: TEMPERATURE AND PRECIPITATION NORMALS AT MANHATTAN, KANSAS (ELEVATION, 1040 FEET)

Month	Temperature	Precipitation
January	29.6	0.89
February	33.8	0.96
March	42.5	1.71
April	55.3	2.60
May	65.0	4.37
June	75.4	5.11
July	80.7	4.00
August	79.7	4.18
September	70.6	3.71
October	59.1	2.32
November	43.3	1.24
December	33.6	0.94
Annual	55.7	32.03

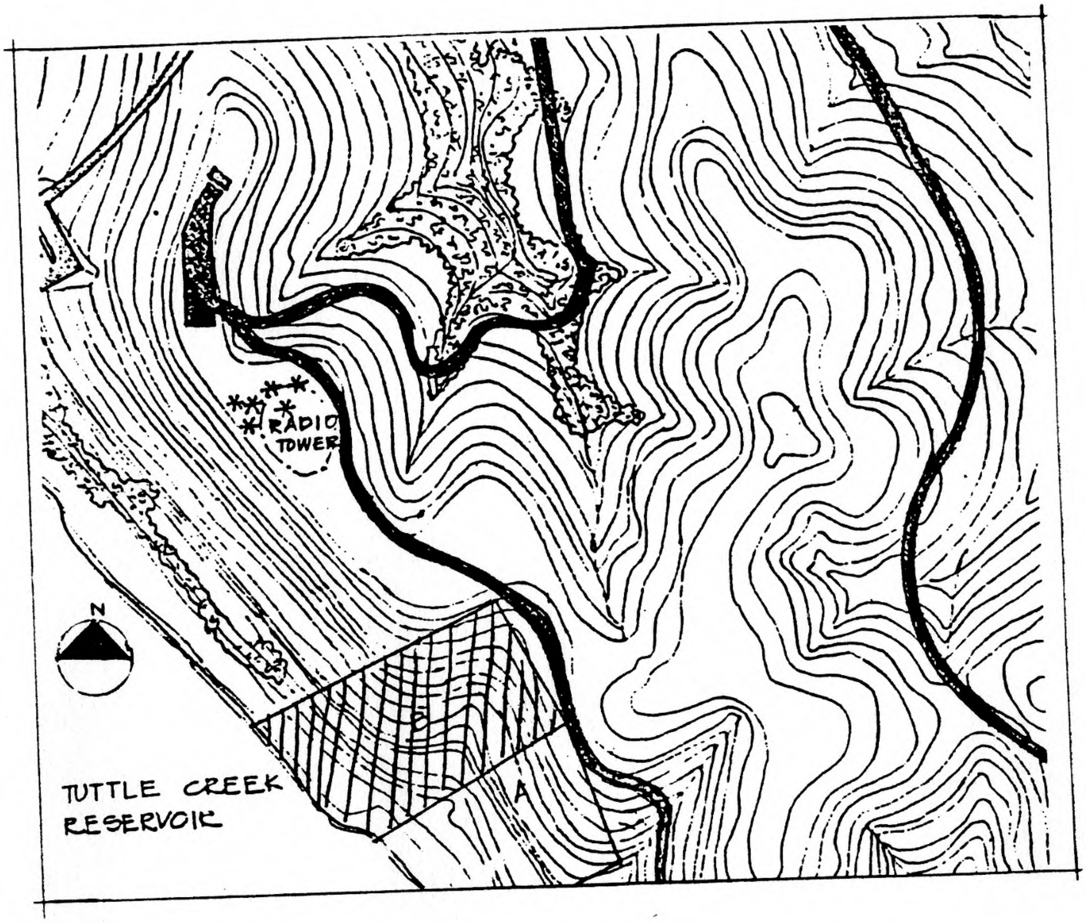
Precipitation is heaviest in late spring and early summer, occurring mostly during thunderstorms. Winters are generally open until December, when occasional blizzards may produce short periods of severe weather. Average rainfall is 32.03 inches. Normally, approximately, 70 percent of the total annual precipitation falls during the usual growing season. In summer, the rate of evapotranspiration is high.

The average frost free season is about 172 days, April 23 to October 15. Areas that lack good air drainage are especially subject to local frosts when low air stratification permits cold air to fill local depressions. Because of polar continental and gulf moisture of air masses, the weather changes frequently.

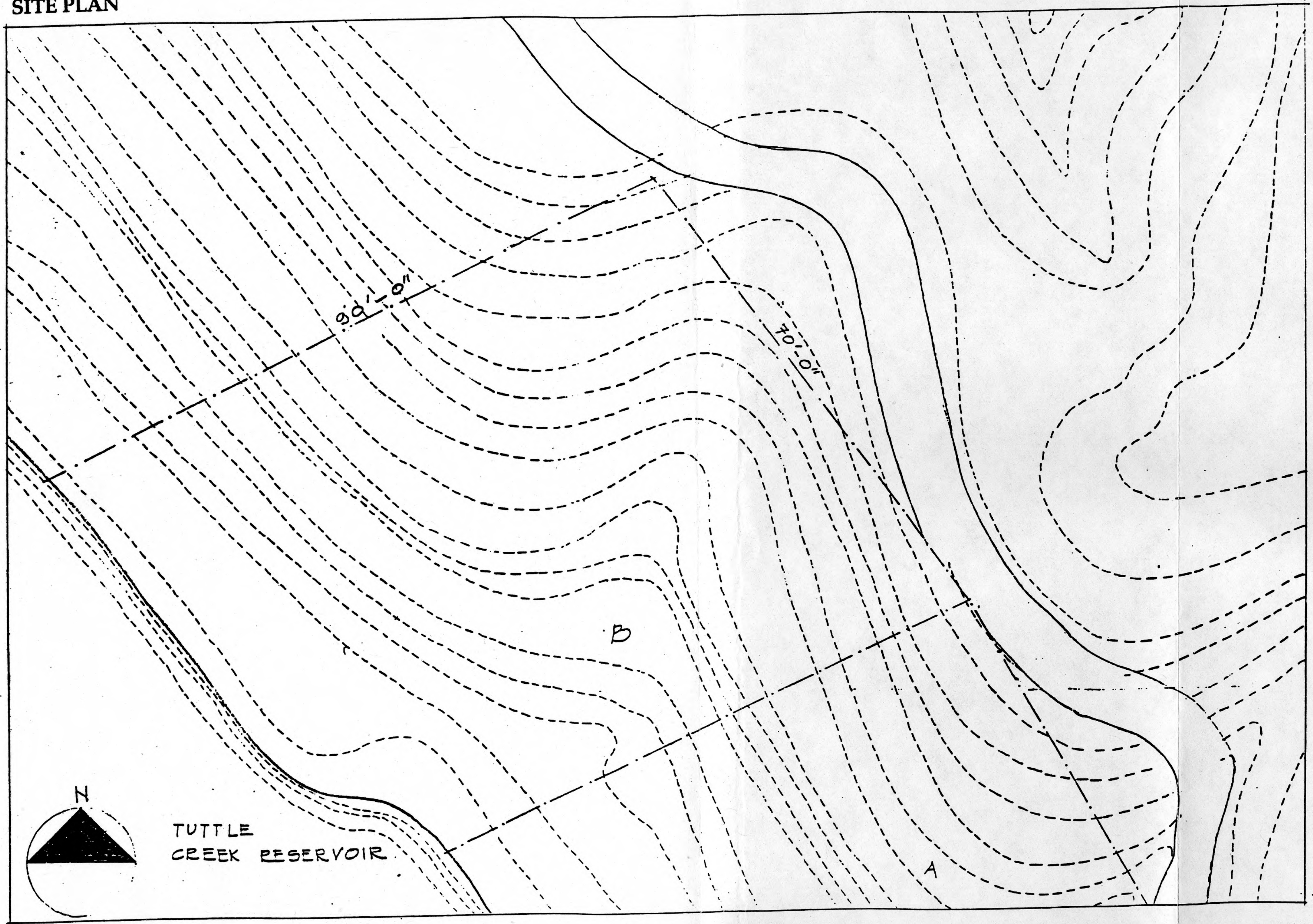
Prevailing summer winds are from the south. Periods of high winds can be expected in March, April, and May. Severe storms, with hail and damaging winds, vary widely from year to year. May and June are months of greatest severe storm frequency.

Site

The site is a plot overlooking Tuttle Creek Reservoir. The land slopes up to the north-east, and faces the lake on the south and west. There is a drop of about fifteen feet to the lake below.



SITE PLAN



The site plan had to be reduced and hence is not to any specific scale

MODELS OF EXAMINING ARCHITECTURAL PROBLEM SOLVING ACTIVITY: A DESCRIPTIVE STUDY

by

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B.Arch, Jadavpur University, India, 1986

AN ABSTRACT OF A THESIS

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MASTER OF ARCHITECTURE

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ABSTRACT

Architectural design occupies a central position in most programs of professional architectural education across the nation; hence better understanding of the process of design will further knowledge in the field of architectural design and education. Based on information processing theory, several models have been developed to study the cognitive processes involved in architectural design. Four such models developed by Akin (1984), Eckersley (1988), Chan (1990), and Goldschmidt (1990). The study compared the theoretical bases of the models that have been developed to describe the cognitive processes involved in architectural design. An architectural design problem was formulated and used to collect verbal protocols from first, third, and fourth year undergraduates in a professional degree program. The study evaluated the agreement between data obtained via two different models (Eckersley and Goldschmidt), and the usefulness of the inferences that could be made from the analyses of the data. Codings of three protocols were employed for these analyses. The maximum inter-coder agreement in encoding for the data using Eckersley's model was 61%, while agreement using Goldschmidt's model was even lower (54%). These findings indicated that the techniques need to be refined to be used as objective instruments for studying the process of architectural design, In spite of these low inter-coder agreements, some patterns existed in the data. A comparison of the verbal protocols indicated similarities and differences across participants. Refinements of categorization and coding strategies that might enhance the dependability of encoding were proposed and directions for future research suggested.