ABSTRACT

The "Design" Thing
A Study of Design in Practice and Theory

by
Magd Donia

The main purpose of this study was to present an overview of design practices and theories in different domains that would enrich the perspective of architectural design. To achieve this purpose, the study presented the initial purpose of architectural design which is providing an adequate shelter for different human activities. Positive and negative aspects of shelter were briefly discussed to trace the evolution of the concept of shelter. Change, as an essential aspect of design was presented in the context of problem formulation and problem resolution.

A presentation of design practices followed. It started by presenting design practices that are generally based on hierarchy. Two examples in architectural design illustrated two different styles of the design process in architecture were presented and discussed. They were followed by another two examples of computer–aided design systems in architecture; one is more concerned with the problem of knowledge representation while the other is an attempt to automate an existing design activity. Practices in engineering and organization design were then presented. Those practices were chosen because they do not follow the traditional functional hierarchical approach to design, but rather follow a system approach to the design process. Following the logic of the study the theoretical principles of the systems approach were presented with a hint to the importance of cybernetics as the control mechanism of large systems.

THE "DESIGN" THING

A STUDY OF DESIGN IN PRACTICE AND THEORY

by
Magd Donia

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The "Design" Thing

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This thesis is dedicated to
the memory of my grandmother

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TABLE OF CONTENTS

Chapter | Page

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

Design is thought to be the cornerstone of engineering and architecture. Yet, in both domains, it is a most debatable issue. Domain related definitions for design, or even design processes, do not exist. Design concepts are instead empirically developed. This is especially true for architects. Concepts are based on architects experience and are, in most cases, highly subjective. Each concept is valid for only a small group of architects. It is therefore highly debatable among other groups of architects.

One characteristic, common to design concepts in architecture, is that they approach design process from a narrow point of view negligent of many aspects of the building's environment and technology. An obvious example is the International Style. Reaching its peak during the fifties and sixties, buildings were considered as prototypes that can be built anywhere with little or no adaptation. This resulted in buildings that in many cases failed to be what they were meant to be, and manifested the failure of the design concepts behind the artifacts.

One might argue that these design concepts were made for a certain place and time, and therefore, should not be expected to perform equally well under different circumstances. This argument can be disputed with what C. West Churchman states as one of the characteristics of the design process:

> "There is a fourth characteristic of design behavior.... This is the goal of generality, or as many would put it , methodology; the designer strives to avoid the necessity of repeating the thought process when faced with the

same goal attainment problem by delineating the steps in the process of producing a design.

"In a sense, this design goal consists in communicating with another designing mind faced with similar problems. Once the designer has had some success in this effort, he can say that he can tell why a design is good,... The broader the class of problems that a design methodology can be used to solve, the deeper the explanation of the design." [Churchman 1971].

In the light of Churchman's articulation, most current design methodologies in architecture would be characterized by being shallow, which was noted by Buckminster Fuller:

"The International Style of *simplification* was then seen as only superficial. It was seen to only peel off yesterday's exterior embellishments, and instead put on formalized novelties of quasi-simplicity as permitted by the same hidden structural elements of modern alloys that had permitted the discarded Beaux-Arts ornamentation." [Banham 1980]

This apparent shallowness, besides the fact that architecture has been (and still is) slow to incorporate new technologies in design, has caused a decline in the architecture profession, as Renzo Piano points out:

"... architecture is on the decline, at least in terms of which its work has hitherto been conceived. It is no longer sufficient to update the catalogue of expressive tricks or renew the style code; it is the architect himself that needs to be redesigned. At the most delicate moment, on the brink of entering the microelectronics village, he finds the ground removed from beneath him. He is no longer able to build or invent.. Art, though mannered, becomes his refuge and often deteriorates into pure slight of hand, formal arabesques lacking substance...the architects role today is of no use to anyone or anything. He may just as well bow out." [Dini 1984]

Architecture, today, is in bad need to adapt to the change in its environment. New technologies are emerging and the demand on efficient building design is greater than ever. Global economics are providing new challenges for better building performance at a lesser cost. It is clear that the current design methodologies that are used in practice cannot meet those challenges. A broader, more general, concept has to be adopted. The design process needs to be perceived as a system design process, rather than an isolated case of designing a building or a group of buildings that does not need to be generalized or made aware of its environment.

This thesis shows the potential of a system–oriented design process in architecture through a study of design concepts in practice and theory. To achieve this purpose, chapter two starts with a brief discussion of design evolution that stresses how the concept of shelter, the initial purpose of architecture, has changed from a negative concept to shield and protect from nature uncertainties, to a positive one that inspires the creation of new human activities and interactions. This changing concept of shelter, creates a demand on architectural design to react to change as well as to produce change. Therefore change, as a necessary aspect of design is discussed in the context of problem formulation and problem resolution.

Chapter three presents some practices that are used in different domains. They are arranged in two logical groups. The first group contains examples of design concepts used in architecture and computer–aided design systems that are generally base on hierarchy. Each example is followed by a discussion that points out some of the problems associated with this approach. The second group contains examples of design practices in engineering and organization design that follow a systems–approach to design instead of the traditional hierarchical approach.

Arguing that a systems–approach to architectural design can be successful as it has proved to be in engineering and organization design, some theoretical principles of the systems approach are presented in chapter four. It is then followed by a conclusion that summarizes the context of this thesis and points out some of the inherit problem in architecture that stands in the way of a system–oriented design process in architecture.

CHAPTER 2
DESIGN EVOLUTION

2.1 Conceptualization of Shelter

Half a million years ago, when some of our ancestors took refuge in a cave, they established the concept of shelter from nature uncertainties. They gradually became familiar with two basic aspects of shelter; the negative and the positive aspects.

It is believed that the negative aspects were what necessitated the concept of shelter. According to Krissdottir and Simon: "The very word *shelter*, if we explore it gives us a clue to the stage at which people began to feel a house was necessary. The English word *shelter* comes from the old Anglo-Saxon word *scyldtrum*. This means, literally, "shield-troop"—a body of men protected by interlocking shields. In its most basic sense, then, shelter means shielding. The dictionary has two-part definition: a) something that covers, protects, or defends, as from the elements, danger, etc. a place of refuge; b) the state of being covered, protected or defended. The shielding is both physical and psychological. It is a material *something* that protects, but it is also a mental thing, a state of mind, a conviction that we *are* being covered and defended." [Krissdottir 1977, p.7].

Gradually people came to realize the positive aspects of shelter. Its contribution to the quality of life and to people's social habits and behavior. The shelter became a place where people can live, work, perform their activities in a better way, or even invent new activities. The concept of shelter was not confined anymore to shielding and protection and people became more demanding: "... the ideal shelter might be considered a built environment that promotes, or at least does not prevent, the full development of the whole person—the body, the mind, and the emotions." [Krissdottir 1977, p.3].

Architecture became the framework to create a shelter with its positive and negative aspects. The more the two aspect are integrated the more successful the shelter is. For example, HVAC systems can be considered as negative elements to protect from unsuitable weather. These systems can act as positive elements as well if they can be integrated within the shelter design to be esthetically pleasing. In other words the more the design process is integrated within a system, the more it is capable of providing a complete implementation.

2.2 Design and Change

2.2.1 Design as a Response for Change

Design is architecture's tool for creation. For that it is sometimes necessary to explore the origins of design and how we arrived to the present formulations of if in order not to lose track of what design is supposed to do.

There are numerous definitions and formulations for design, but they all share the property that a design should produce a change. In the "Design Argument"[1], Frederick Ferré traced the development of the design argument

1 Ferré 1974.

in theology. The two schools of thought[2] mentioned in his study disputed over the source of change—what produces change. There was no dispute, however, that a change is a necessary product of design.

Whether design is done by humans, computers or a combination of both, the common denominator is the necessasity of accounting for change and the ability to produce it as well. A change that could help improve the product being designed whether it is a building, a city or a car. This change can either be a contribution towards solving some of the inherit problems in the design process, or just preventing the decline of the current practice by keeping up with new demands and technology innovations. The authors of "Change" describe the latter type of change:

> "In other words, change becomes necessary to re-establish the norm, both for comfort and survival. The desired change is applied through applying the opposite of what produced the defiance ..." [Watzlawick et al 1974 p.31].

2.2.2 Types of Change

According to Watzlawick et al (1974), there are two different types of change that may happen in a system. First-order change which occurs in a given system which itself remains unchanged. This type of change is a change in the internal structure of the system but the overall system behavior remains the same, i.e. the system input and output remains unchanged. The other type of

2 According to Ferré, there are two main schools of though. Plato and Newton argued for the presence of an intelligent being who is the cosmic designer and produces the change necessary to maintain the stability of the universe (William Paley belongs to the same school of thought although there are some variations among the three concerning the nature of that being). The other school of thought was pioneered by Aristotle, then Darwin developed its argument in the 19th century. This school argues that design and creation is evolutionary—produced by the natural beings themselves in a random manner according to the need for survival and adaptation.

change is second-order change whose occurrence changes the system itself. In this case the system behavior will change and either its input or its output or both will be changed.

2.2.3 Problems of Change

In the attempt to make a change, however, design can contribute to the formation of the problem rather than to the solution. According to Watzlawick et al (1974) this contribution can happen in three ways:

1. Over-simplification of the problem which would result in neglecting important details. In this case, design will provide a solution to a simplified problem which, when applied to the real problem, can complicate the existing problem rather than solve it.

2. Setting unrealistic goals, described as "The Utopia Syndrome" [Watzlawick et. al. 1974, p.47]. This may occur by attempting to solve a problem that is practically unsolvable, by seeking an ideal solution that cannot be practically achieved or by attempting to solve nonexistent problems that results in the waste of time and effort and the possibility of creating new problems.

3. Seeking contradictory goals that would result in a paradox. This may happen when trying to find a solution to several problems within certain boundaries when the solution can only be found by changing the boundaries themselves. "A system which may run through all its possible internal changes (no matter how many there are without affecting a systemic change, i.e., second order change, is said to be caught in a *Game Without End*. It cannot generate from

within itself the conditions for its own change; it cannot produce the rules for the change of its own rules." [Watzlawick et. al. 1974, p. 22]. In other words the system will not be able to produce a solution on its own.

2.2.3 Managing Dilemmas in Change

In order to avoid a change that contributes to the problem, a four step procedure to create a purposeful change is articulated in Watzlawick et. al. (1974). Those steps are:

1. A clear definition of the problem in concrete terms. This step involves stating the problem in concrete terms that permits the separation of problems from pseudo-problems, i.e. problems that occur as a result of another problem. It also involves recognizing the complexity of problems, and whether or not they can be solved.

2. An investigation of the solution attempted so far, which would show the kinds of change that should not be attempted. At the same time it reveals the reasons that keep the situation unchanged. A small manageable problem can turn into a much complicated one by applying "more of the same" solution that does not contribute to the resolution of the problem.

3. A clear definition of the change to be achieved. Following the identification of the problems and the unfeasible solutions, the desired change can then be identified. The desired change however, has to defined in concrete and detailed terms that would make it

possible to apply. It should also be in the form of realistic and reachable goals in order not to fall into "The Utopia Syndrome".

4. The formulation and implementation of a plan to produce this change. This is the decision-making step where action is applied to produce a change. Although the previous three steps are research-oriented and can be accomplished rather quickly, they are of crucial importance to the success of the fourth step.

CHAPTER 3

DESIGN CONCEPTS USED IN PRACTICE

This chapter will present some design concepts used in practice in architecture, engineering, organization and CAD systems design. The ability of those design concepts to produce change will be discussed in the light of the principles presented in the previous chapter. The presentation of these design concepts serves three purposes. First, it illustrates the impact of using a systems approach to different design problems. This impact is shown in its ability to integrate design activities into one system that is more than the sum of these activities. Second, it provides a look into design problems addressed in multiple domains that can enrich the architectural design perspective. Finally, it offers an insight into disciplines characterized by a high degree of complexity, which is increasingly becoming an important aspect that needs to be addressed by architectural design.

It is important to note that the discussion of the design concepts presented in this section should by no means be interpreted as design criticism. The purpose of this discussion is to evaluate the design process in terms of its ability to fulfill the initial goals of the designer and contribute to the resolution of the design problem.

3.1 Architectural Design Concepts

Architecture lacks a formal definition of a design process that is in the form of a step–by–step technique. Instead the design process in architecture can be described as separate styles of decision making [Rowe 1991]. On some occasions the design process is strongly determined by the architects personal attitude and passion toward things like social concepts or a certain form of technology. On other occasions the process seem to be more influenced by problem constraints like the building context or "function". In most cases, however, the process is driven by a mixture of both orientations.

The design process is often a two–way process in which architects move back and forth between the problem and the design proposals in an early design stage. More often the two–way process continues to even the design implementation or construction stage which is due, in part, to the lack of an organizing principle to the design process.

This section presents two examples of the design process in architecture through the discussion of case studies of design work done by architects [Rowe 1991]. These examples illustrate different "styles" of the design process in architecture. The first is more concerned by the context of the design problem where one idea seems to dominate and the design process can be described as a serial one. In the second example, the conflict between two ideas portray the process as a parallel one. These examples do not represent all the "styles" by which architects conduct the design process. Instead they provide a sense of the variation of the design process among architects.

3.1.1 Example 1: Design as a Serial Process

The problem in this case is designing a commercial complex on a suburban site of an American city. The design process is described in terms of several stages with different goals associated with each stage[1]. Following is a presentation of these stages.

Stage 1: Providing a corporate image: In this stage the main intention was to provide a corporate image for the complex through the utilization of towers (figure 3.1).

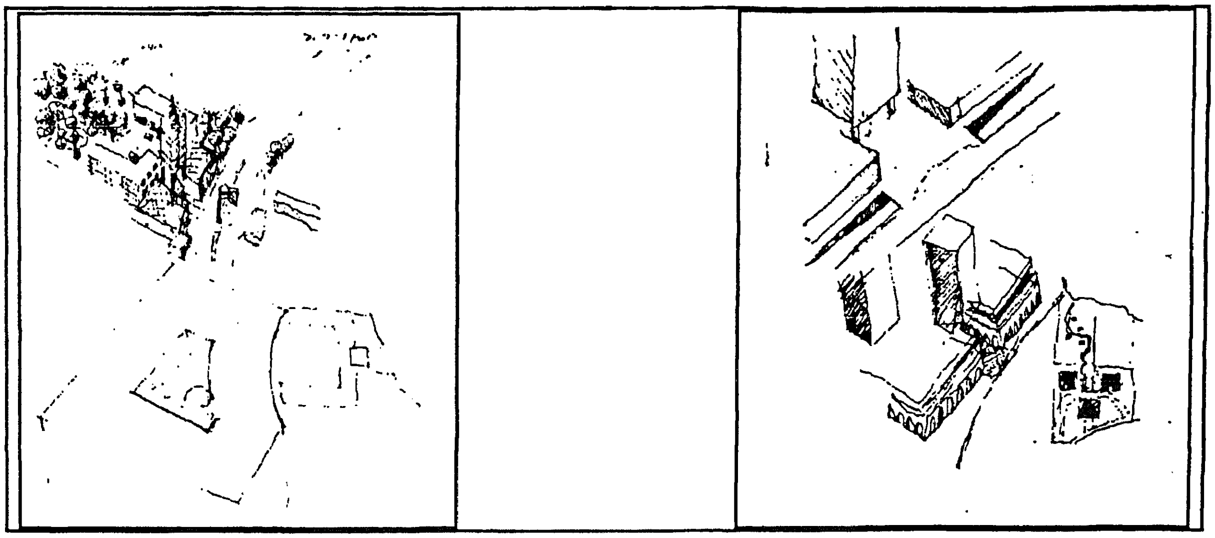

Figure 3.1 Stage 1.

Stage 2: Developing an urban form: The second goal was to develop an urban form that preserve the natural amenity of the site and acknowledges the public domain of the street, which resulted in creating a plaza along the street boundary (figure 3.2).

[1] The description listed in this thesis is different from Rowe's. Rowe articulates the design process as consisting of three stages. The first is early sketches, the second is exploration of design ideas and the third is development of design ideas. Although this articulation follows a format that is well known among architects, it implies that process is unidirectional moving from a preliminary stage to an intermediate stage and ending with a development stage which rarely happens.

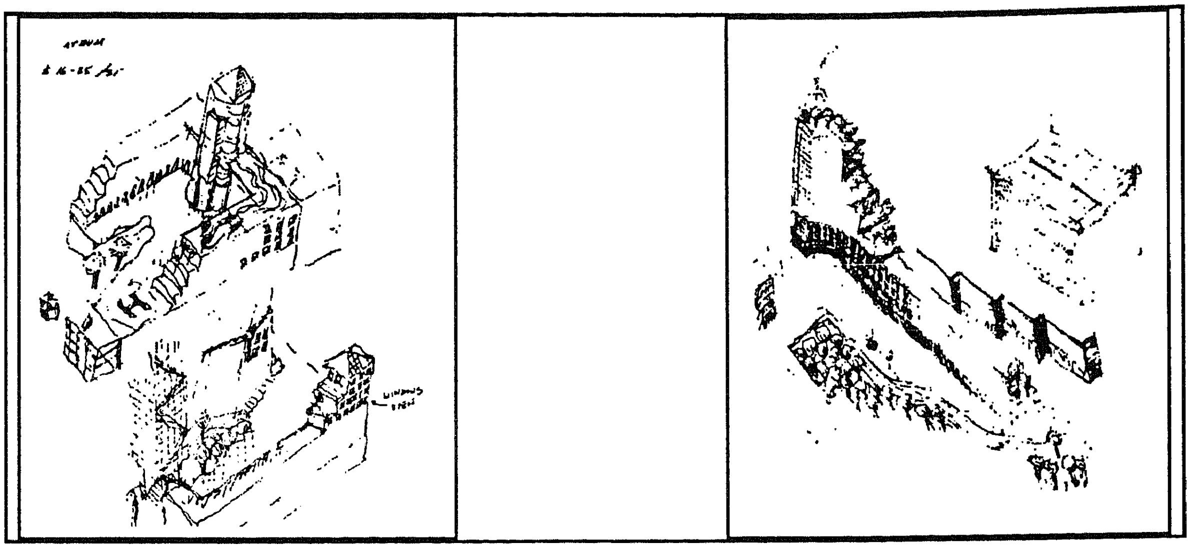

Figure 3.2 Stage 2.

Stage 3: Designing office space: The goal in this stage was to design office and commercial space for corporate tenants that would give each corporate some sort of identity. Complex entries and the overall appearance of the complex was addressed at that stage (figure 3.3).

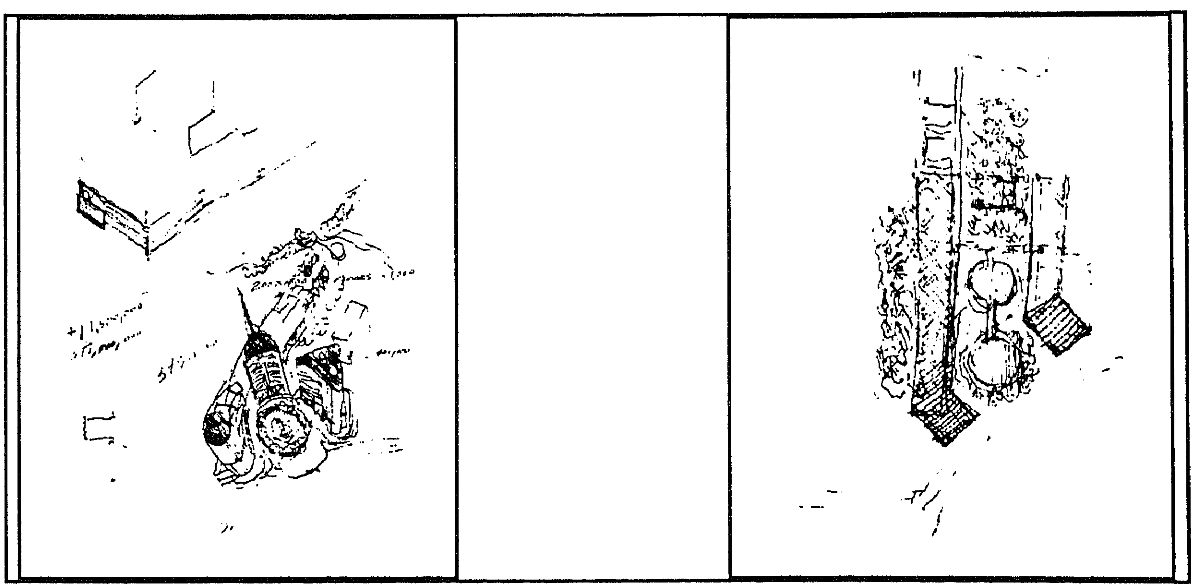

Figure 3.3 Stage 3.

Stage 4: Site arrangement: The first decision was a linear arrangement influenced by a desire to orchestrate public spaces starting from the major plaza on which each office building had an individual address and ending by the street on which the complex had a common address. However the linear arrangement was then seen to create some problems and rejected. Other arrangements were explored but they seemed to backtrack towards the linear arrangement (figure 3.4). The reason was that the problem was under constrained and lacking a specific direction [Rowe 1991].

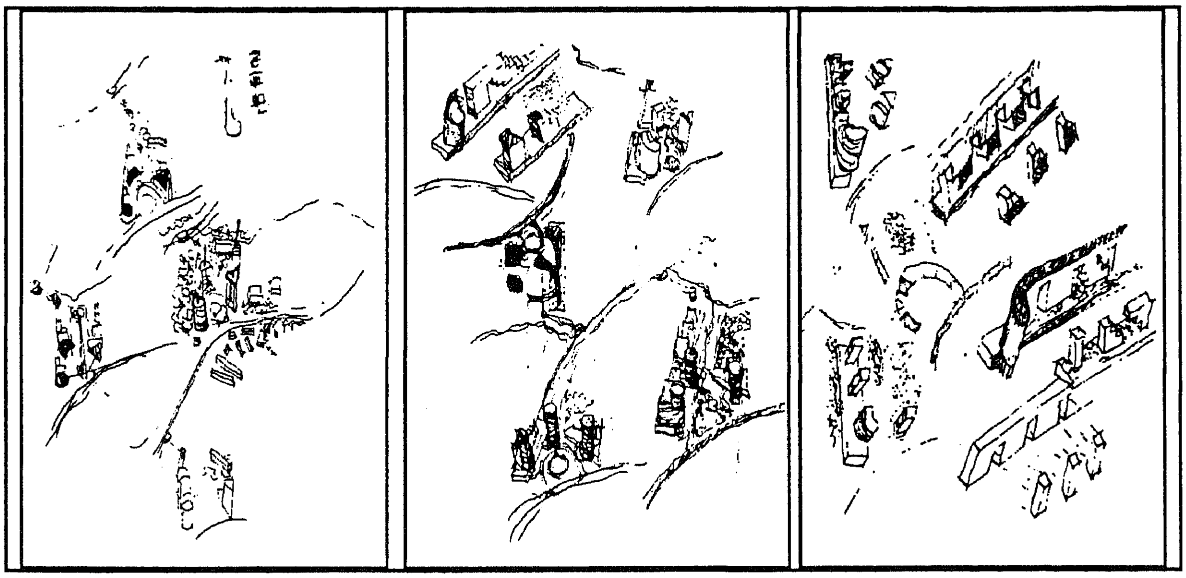

Figure 3.4 Development of site arrangement proposals

The designers then retreated to an early stage to evaluate the initial design ideas like the public plaza. Although most initial ideas were reasserted, the evaluation process provided a problem definition which Rowe noted to be lacking. A proposal rejected earlier prevailed which added an informal exterior space to the already established public plaza. With main guidelines established, the attention was turned to other aspects like the entrances, circulation elements and plaza design (figure 3.5).

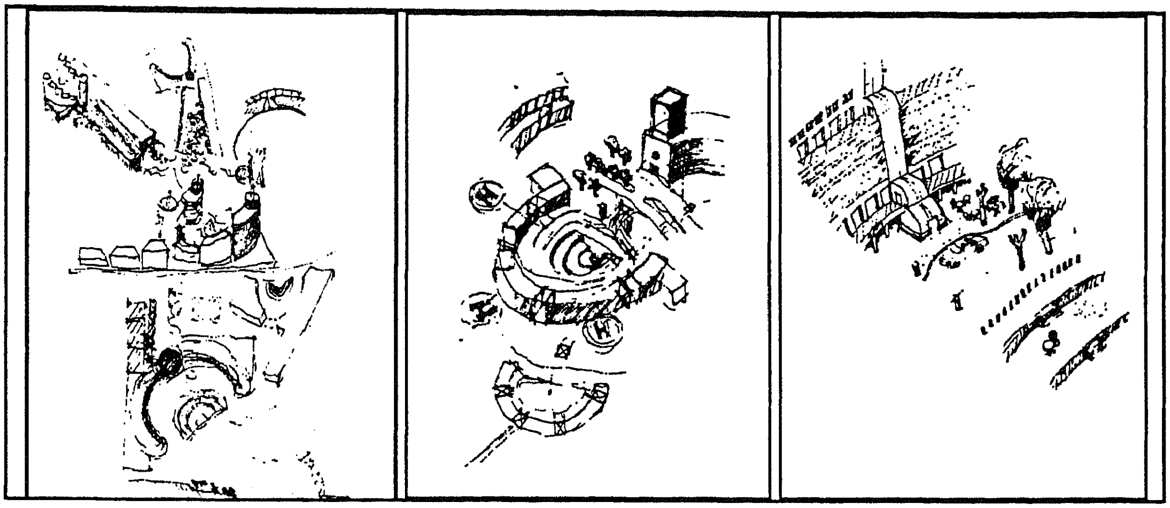

Figure 3.5 Selected proposal

Stage 5: Articulating the office towers: This was the first stage that a technological issue came into consideration; that is the structural design and building erection technology. The decision was made to use steel framing for the construction of the office towers because of the economic advantages of speedy construction. Following the same line of reasoning, the decision was made to use glazed fenestration and spandrel panels. This decision, however, hindered the earlier goal of providing an individual identity to each tenant. There was no attempt of discussing any other technological issues at this stage.

When the attention was turned to issues not pursued until that point, it was evident that some of the goals pursued earlier would not be achieved. One of these goals was to preserve the natural amenity of the site which could not be practically achieved because of the construction requirements of parking that required excavations over much of the site. Another earlier goal, the acknowledgment of the public domain, unable to be achieved because the extension of the building base across the site resulted in a perimeter of building mass that walled off the site along its boundaries.

Stage 6: Final adjustments: The final adjustments included studies of the vehicular and pedestrian circulation patterns and the scheme began to be finalized (figure 3.6).

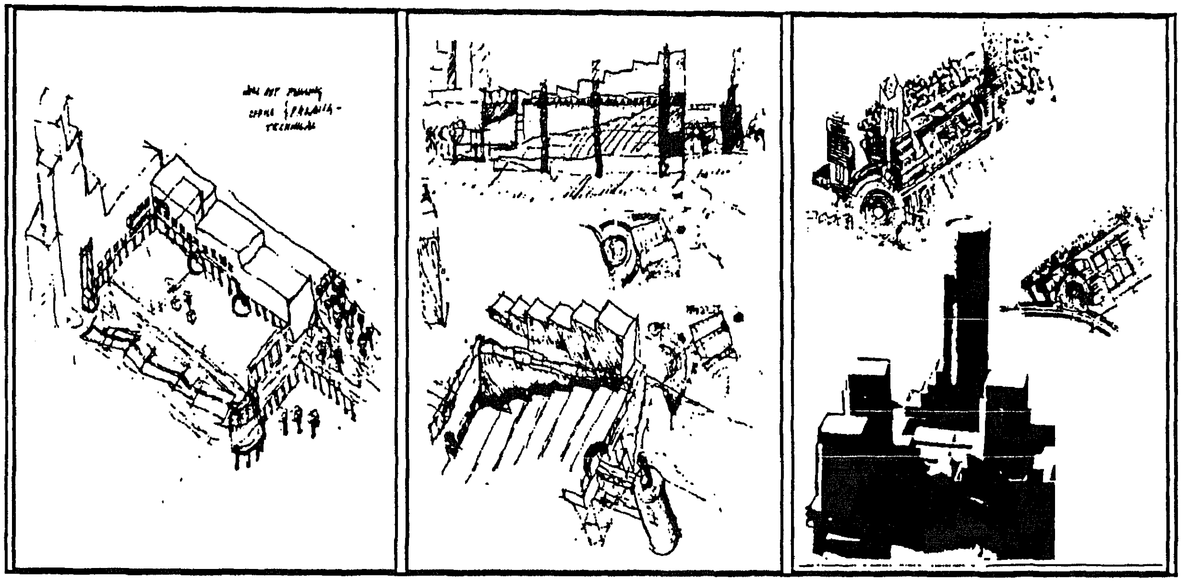

Figure 3.6 Final stage

3.1.2 Discussion

Problem definition: It is clear from the above description of the design process that there was no concrete definition of the design problem especially at early stages. This can be easily noted by the back and forth movement between stages and proposals which was noted by Rowe as "Periods in which the problem seemed under constrained to the designer were immedialty followed by systematic reevaluation if his position and an assessment of the potential outcome of various lines of reasoning" [Rowe 1991].

The lack of a concrete problem definition resulted in asserting several design ideas and goals in an early stage that proved to be impractical in a later stage when, for example, construction requirements were considered. It also caused a lack of direction during some design stages. The most important disadvantage, however, was the inability of the designers to accomplish all the initial design intentions. Instead, new goals and ideas were asserted and retracted throughout the design stages, and even some ideas rejected earlier were reasserted.

Response to the problem: The problem resolution method employed in this example, although inconsistent and ill defined, is considered the most popular among architects. The emphasis was mainly on following a certain procedure that will eventually produce a final design proposal whereas a little attention was paid to the purpose of the design itself. This can be easily noted by the changing goals in every stage and the failure of the final proposal to incorporate some of the ideas that was established as desired goals. Even Rowe's assessment that praised the process confirmed that "not all the initial intentions were completely satisfied, however, particularly with regard to the site's natural amenity" [Rowe 1991]. Although these initial intentions Rowe describes as "well-chosen urban concepts", the fact that they did not materialize in the final proposal was not seen as a major problem. It follows that if these urban concepts were "ill-chosen" instead of being "well-chosen", the outcome of the design process won't be much different because these concepts were not the real emphasis of the solution.

Another important feature of the solution that follows is the impracticality of the ideas that were established as goals. The main reason behind its impracticality is that very little attention was paid to its implementation with respect to the site constraints, the program and the construction requirements and technology. Rowe describes the final proposal as "a design scheme that developed from a few well-chosen urban concepts that were more an interpretation of what the project might be like than pragmatic responses to prevailing site conditions and program" [Rowe 1991]. However the final proposal shows that design decisions were more influenced by the site conditions and the program rather than by the urban concepts (figure 3.7).

The design process was regarded as a series of relatively independent stages rather than a system. The fragmentation of the design process resulted in wasting time moving back and forth between proposals. The process did not have a well defined start or a direction and its end is only marked by reaching an "acceptable" proposal.

It is clear that the design process described in "Example 1" has suffered from the three main problems of change described in the previous chapter: over–simplification of the problem, setting unrealistic goals and setting contradictory goals.

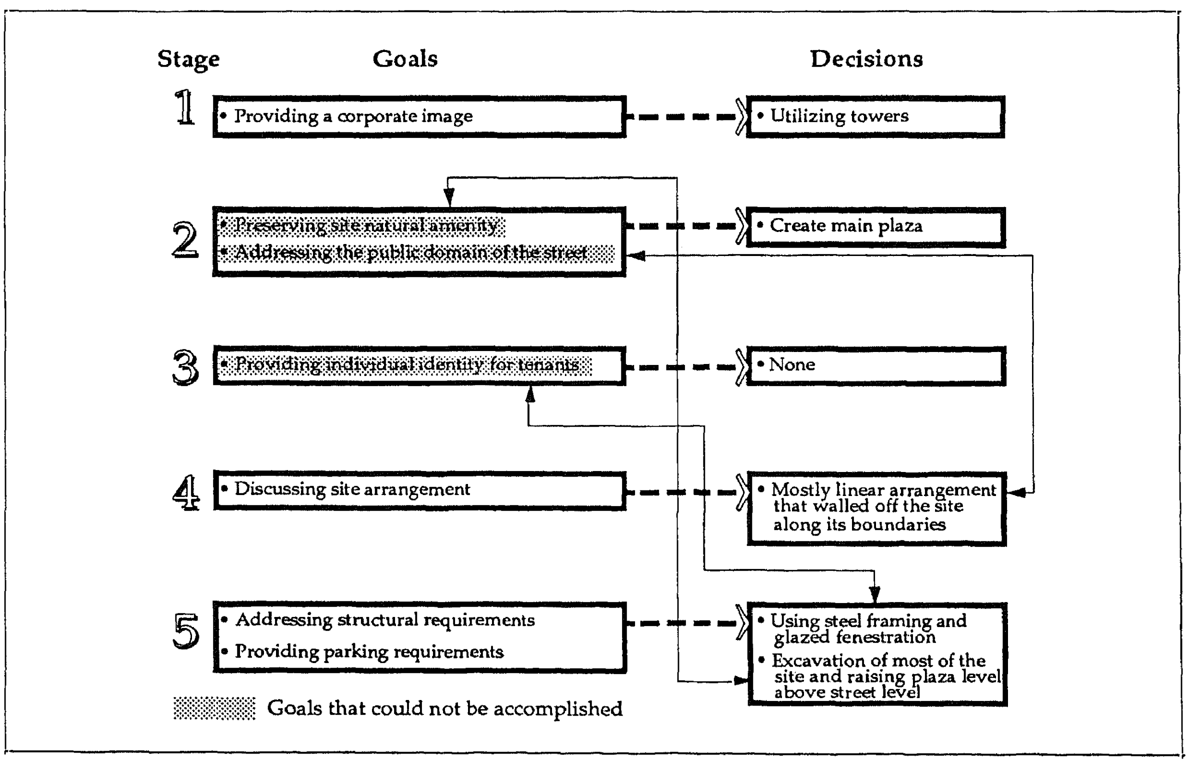

Figure 3.7 Conceptual ideas that could not be accomplished

3.1.3 Example 2: Design as a Parallel Process

This example present the process of designing a world bibliographic center on a waterfront site, adjacent to the downtown area of Chicago (figure 3.8, part 1). The program requirements included a library, a computer and data processing facility with telecommunication linkage with similar centers in other parts of the world, and several theaters. The site was a potential point of symmetry with Burnham's scheme for Chicago from the "City Beautiful Movement".

<u>Stage 1: The initial themes:</u> The process was characterized by a conflict between two themes. One was the creation of a landmark at the point of symmetry with Burnham's plan. The other was the development of a scheme of a linear system of buildings and interstitial spaces that would thematically extend the Chicago grid pattern out into the lake (figure 3.8, parts 2 & 3). The program itself, which is the main reason for the center to be built, was not discussed at all at that stage. Other experiments of building masses show some references to the buildings of the Chicago Exposition (figure 3.8, parts 4, 5 & 6).

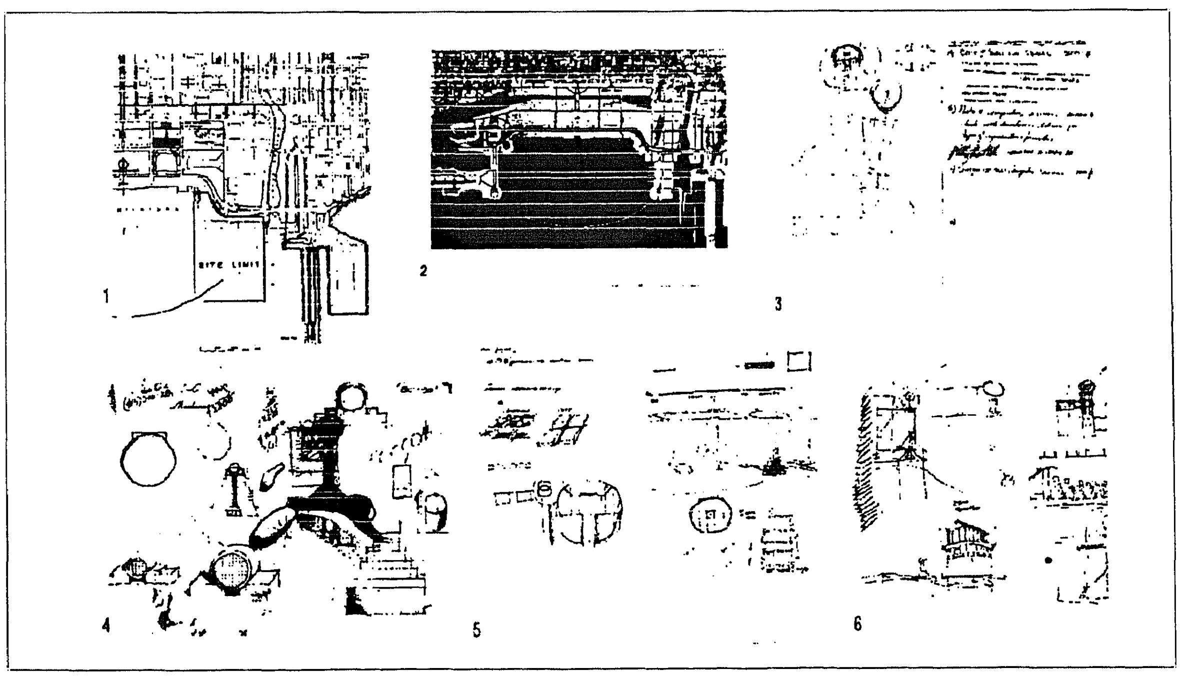

Figure 3.8 Stage 1 sketches.

Stage 2: The linear scheme prevails: At this stage the scheme became resolved as a linear form, protruding into the lake for the purpose of extending the Chicago grid (figure 3.9, parts 1 & 2). The grid terminated with a rotunda–like structure similar to the building masses that were tested in the previous stage (figure 3.9, part 3).

Stage 3: Linear scheme rejected: After a programmatic evaluation, it was discovered that the linear scheme would require more building facilities than were available and would prove to be an inefficient arrangement for library use. The decision then was to reject the linear structure and shift towards a single–building scheme (figure 3.9, parts 4 & 5).

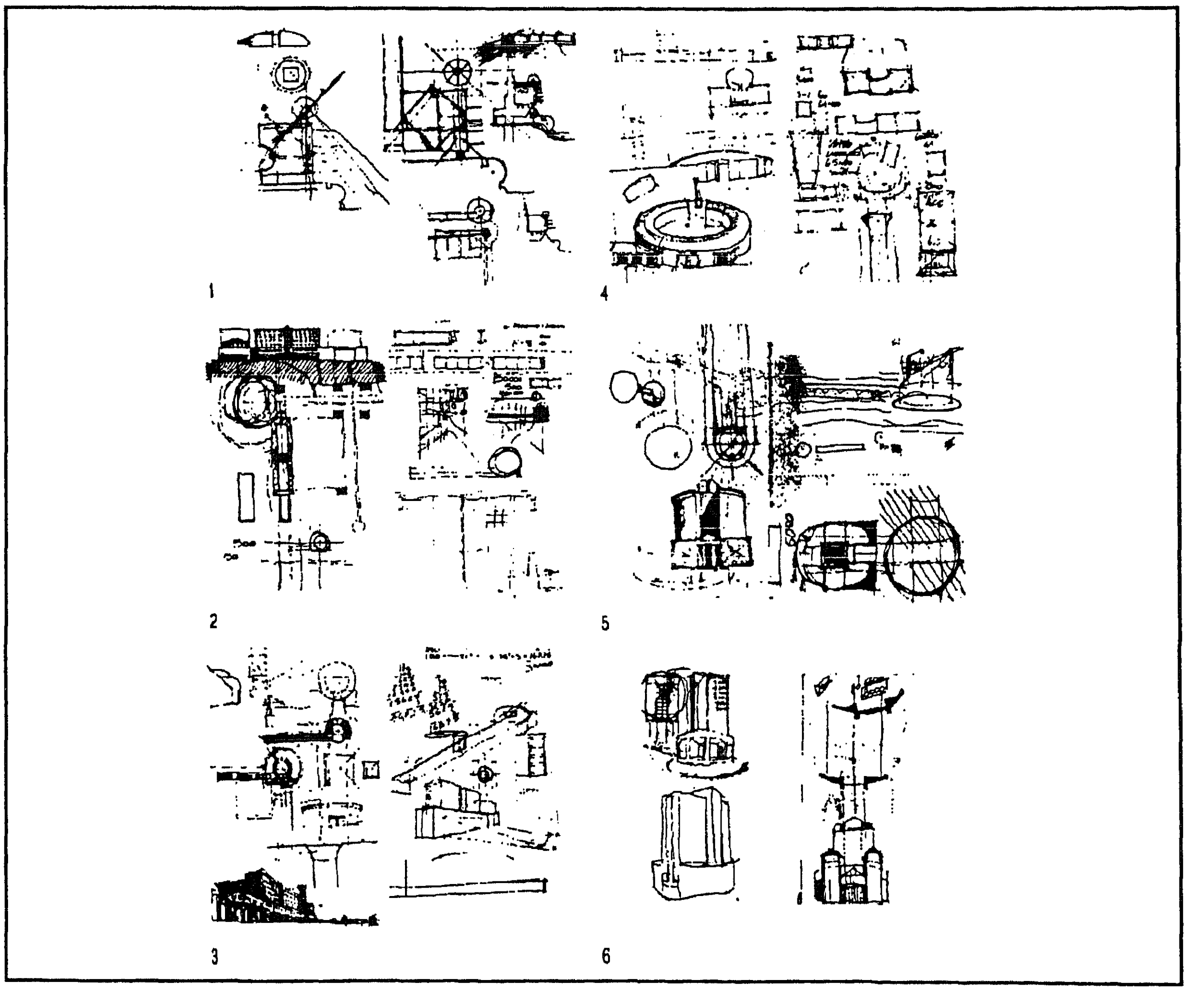

Figure 3.9 Stages 2 & 3 sketches.

Stage 4: A dual composition scheme: A large number of compositional possibilities were tested which resulted in the separation of the library from the electronic media and transmission devices (figure 3.10, part 2).

Stage 5: Dual composition rejected: Following another programmatic evaluation, the dual composition was rejected because the computing and technical facilities building would be much bigger than the library building and would hence be more dominant (figure 3.10, part 3).

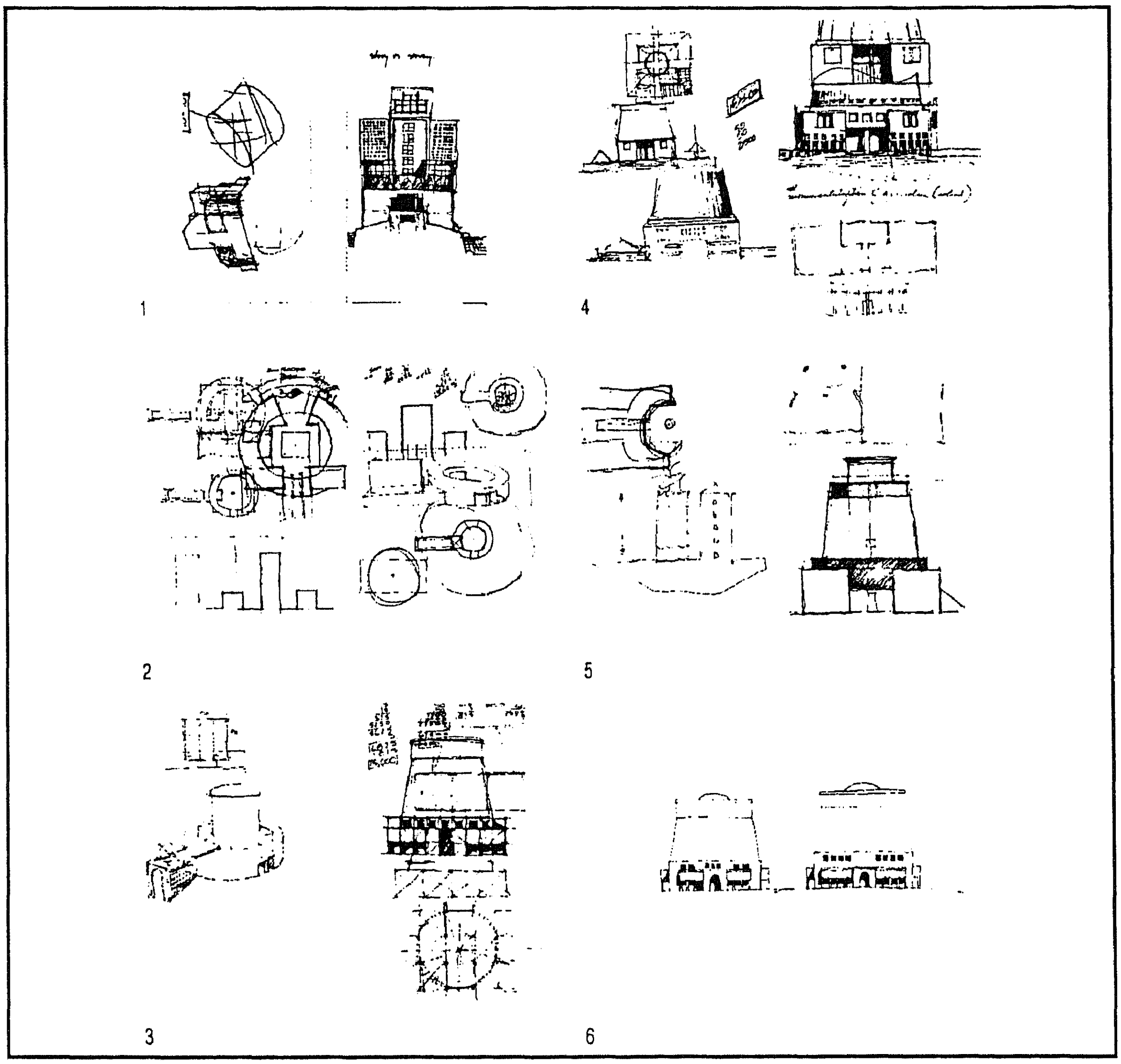

Figure 3.10 Stages 4 & 5 sketches.

Stage 6: Single–building scheme finalized: At this stage the attention shifted to the study of building proportions, entrances, circulation pattern and accommodating the design requirements and the scheme was finalized.

3.1.4 Discussion

Problem definition: The design problem in this example was defined in the context of the building form. The question was whether to have a single building that acts as a potential point of symmetry with Burnham's plan for Chicago, or to follow a linear arrangement of buildings that will extend the Chicago grid into the lake. Both schemes had nothing to do with program whether it was for a library, an office building or a commercial center. The first time the program was discussed was after developing the linear scheme.

Inspite that Rowe presents the linear and single–building schemes as the design schemes guiding the process, we find that, at a relatively late stage, a dual–building scheme was employed which was later rejected. This shows that the themes established at the early stages were not as influential as Rowe suggests.

Response to the problem: The designer's response was aimed towards the building form problem rather than the program. All the decisions taken were to support one of the building form schemes and very little attention was paid to ensure a high level of building performance. Even Rowe's analysis is not concerned whether the process contributed to a successful design in terms of the program requirements.

In the early stages, the design process was a parallel process in the sense that there was two conflicting themes regarding the building form (figure

3.11). In a later stage one of these themes finally prevailed because of program requirements. It follows that if the program requirements were discussed in early stages and were used as a design factor, the linear theme wouldn't have been discussed in the first place and a lot of time would have been saved.

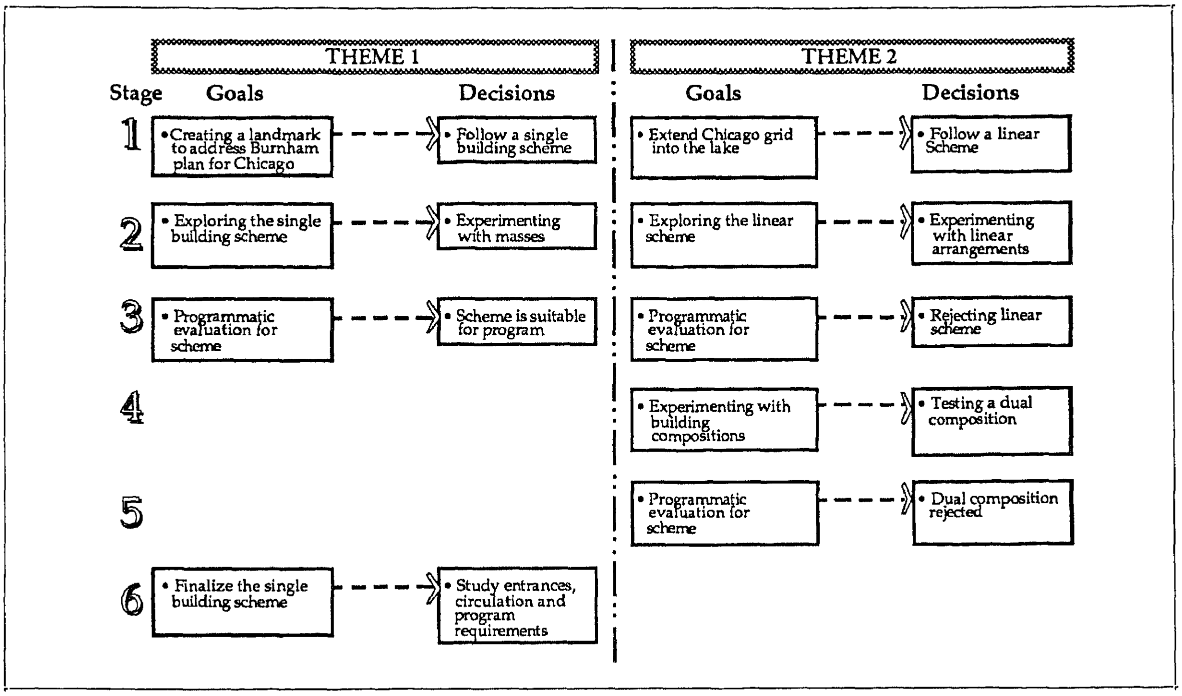

Figure 3.1 Conflicting themes in example 2.

3.1.5 Summary

- The problem definition was rather weak which caused the process to be a "generate–and–test" process rather than a one that is directed by an purpose or a goal.

- In both examples the emphasis was on the process rather then on the design objectives which caused these objectives to change from one stage to the other.

- The design process was not goal directed so that the solution reached is the best solution possible.

3.2 Computer Aided Architectural Design Systems Concepts

Several definitions exist for the term "computer aided architectural design". One definition that explains the term is the "technique in which man and machine are blended into a problem–solving team, intimately coupling the best characteristics of each, so that this team works better than either alone, and offering the possibility for integrated team–work using a multi–discipline approach" [Vlienstra et al 1973]. It follows, from that definition, that the purpose of building a computer–aided design system should not be restricted to automating existing practices. Instead, it should extend to offering new design methods that would lead to a better product quality and assure that design goals are established.

The following section contains a description of the design concept underlying two computer–aided design systems in architecture that are being developed. One of these systems is focused on the problem of the representation of design knowledge while the other is more concerned with automating an existing design task done by architects. These systems by no means represent the full scope of CAD systems in architecture that are being developed. However they touch on some important problems facing CAD systems in general. These problems are presented in the discussion that follows the presentation of each system.

3.2.1 EDM: The problem of Knowledge Representation

A computer–aided design (CAD) system consists of two main parts: the knowledge base (or database) and the problem solving technique. The knowledge base is that part of the system that contains the necessary knowledge to solve a design problem. The problem solving technique uses this knowledge to produce a feasible solution.

Knowledge representation techniques has been a major research topic in artificial intelligence (AI). The Engineering Data Model (EDM)[2] is an information modeling system dedicated to provide a representation of design knowledge in architecture and construction that can be manipulated by the problem solving strategies of CAD systems. This representation is in the form of conceptual modeling tools that can be used to build intelligent CAD systems, each dedicated for different aspects of architecture and construction. For example, systems for construction types (lightweight steel, concrete, wood frame), mechanical system design, exterior cladding, roofing and other aspects of design.

Structure: The developers of EDM represent design knowledge as a multi–dimensional matrix with many design alternatives existing in each dimension. Examples of these dimensions include building type, construction type and mechanical systems [Eastman et. al. 1992]. A building design is a combination of a number of those dimensions like a steel girder framed hospital, with cold air and hot water reheat, using concrete exterior panels. Following the moral of the Swiss Watchmaker allegory[3] presented in "Sciences of The Artificial" [Simon 1985], EDM is modularly structured. According to [Eastman et. al. 1992]: "the solution to building design is the

[2] EDM is being developed at the Graduate School of Architecture and Urban Planning at the University of California, Los Angeles, by Charles Eastman, Scott Chase and others.

[3] The Swiss watchmaker allegory is a story that compares the way two Swiss watchmakers build their watches. One of them assembles his watches by adding one piece at a time incrementally until the watch is complete, while the other assembles his watches using modules. Both watchmakers are frequently interrupted. The one putting the watch together by adding one piece at a time to the overall watch must put the watch down with the effect that many parts come apart, which he must redo after the interruption. The other watchmaker to who uses modules would only put a module down when interrupted so he has only to rebuild one module instead of rebuilding the whole watch.

definition of modular domains of design knowledge, for example, for different types of structural systems, different mechanical systems, external cladding systems and different building types, and to provide the means to integrate unique combinations of these packages into custom CAD configurations. The designer links together knowledge modules as the design proceeds, sometimes exploring alternative modules with different performances".

The essence of this modular structure is to provide a considerable degree of flexibility to accommodate changes in building technologies and design requirements in general by adding modules or modifying existing ones instead of changing the whole system[4]. For example, a definition of a wall does not include its construction method. The desired construction method module is connected later to the wall module (figure 3.12).

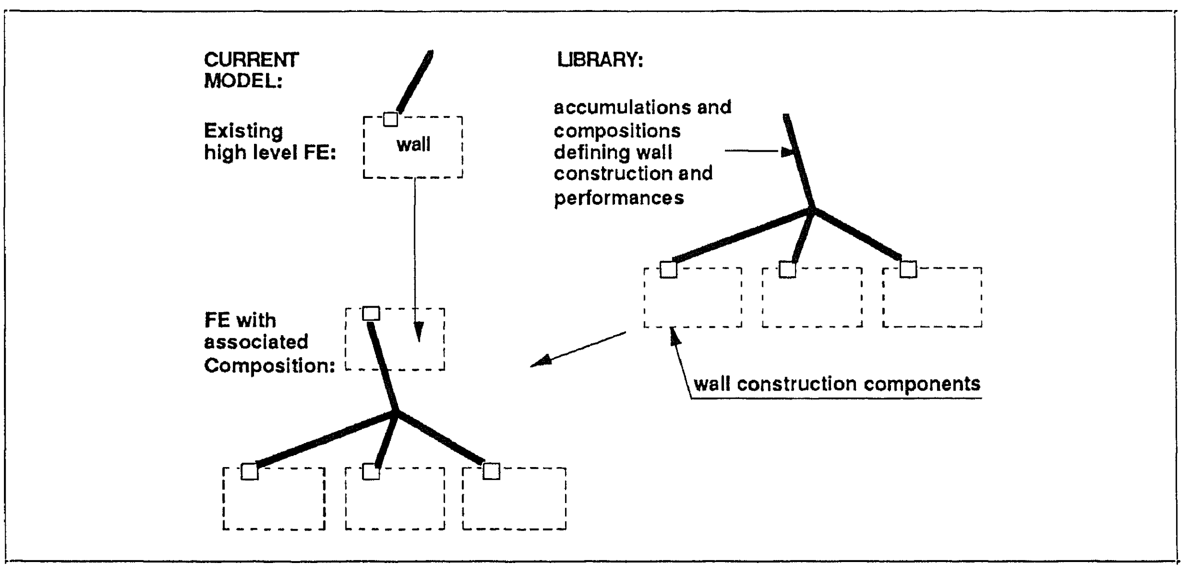

Figure 3.12 Adding a structural composition to a wall in EDM [Eastman et. al. 1992].

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4 The problem of modifiability is presented as a two–horn dilemma. One of the horns is to have an easy to modify system that is hierarchical, while the other is to have a non–hierarchical system that is difficult to modify. A third alternative would be a non–hierarchical system that is easy to modify.

The knowledge base is hierarchically structured with the building type modules at the core or "kernel" and the other modules attached to it as add–ons (figure 3.13). These modules are also hierarchically structured as shown in figure 3.12.

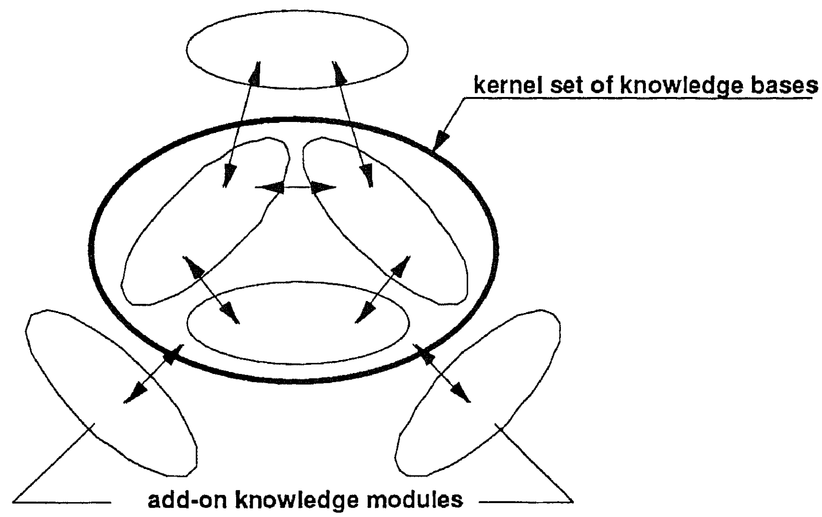


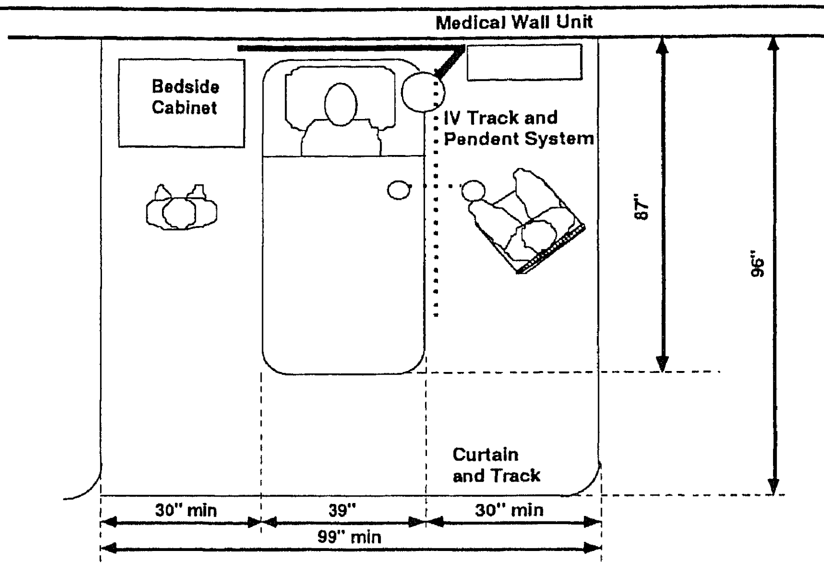
Figure 3.13 The EDM knowledge base structure [Eastman et. al. 1992].

Knowledge representation: EDM is based on a small number of knowledge structures to represent design information. These structures are defined using sets and first–order logic[5]. There are three types of primitives: domains (sets of values corresponding to a simple type), aggregations (sets of domains) and constraints which are general relations defined as logical predicates that may evaluate to true or false.

These predicates are composed into three high level pre–defined forms: functional entities (FE), accumulations and compositions. A functional entity is the primary data object within EDM, consisting of an aggregation and

5 First order logic as a knowledge representation technique which is presented in the discussion that follows.

constraints. It also contains a set of FEs whose values and constraints it inherits. FEs are grouped into sets representing design requirements like furniture or activities. An accumulation is a one–to–many relation between the properties of a composite object and the properties of its parts. It defines performance relations among properties as well as rules that the composition must satisfy to achieve that performance. A composition is a named structure between one FE and a set that composes it (figure 3.14).




```
FE(patient_room, {activity},{})

composition(activity_comp[n], patient_room,
   {hosp_bed,visitor_seating,medical_unit,bed_cab,bed_curtain},{to_activity})
accumulation(to_activity[1],hospital_room,{furniture,activity_area,environ_condit,fixed_equip},
   {C200,C201},C202,C203)
constraint(C200,'bed access space directly accessible from public access space')
constraint(C201,'all furniture inside of curtain area')
constraint(C202, 'bed adjacent to utility wall')
constraint(C203, 'medical unit attached to utility wall')

FE(hosp_bed,{activity},{},)
composition(hosp_bed_comp,hosp_bed,{bed,circul_activity,environ_conditions,IV_track})
accumulation(to_hosp_bed,hsop_bed,{bed,circul_activity,environ_conditions,IV_track},{},{C204,205})
FE(bed,{furniture},{},)
FE(circul_activity,{activity_area},{},)
FE(IV_track,{fixed_equip},{},)
constraint(C204,'IV_track attached to ceiling and aligned w/side edge of bed')
constraint(C205,'bed access space evenly distr. on 3 sides and >30"')

FE(vistor_seating,{furniture},{},)
FE(medical_unot,{furniture},{},)
FE(bed_cab,{furniture},{},)
FE(bed_curtain,{fixed_equip},{},)
```

Figure 3.14 A sample set of layout requirements and their EDM representation [Eastman & Siabiris 1992].

3.2.2 Discussion

Structure: EDM follows a modular hierarchical structure for reasons of providing flexibility and easier modifiability. However, as described in Simons's Watchmaker allegory [Simon 1985], hierarchy can be an acceptable approach for systems that produce a well-defined product which consists of parts that follow a logical hierarchical structure.

In the case of CAD system in architecture, the product is a building design which is usually characterized by a high degree of creativity, which means that the product, in many cases, is not well-defined. In addition, the modular structure does not allow for the integration of building systems. For example, consider an integrated structure that is the external envelop of a building. Some of its mullions are water supply elements, others are ducts for the electrical system while others are structural elements. Its LCD glass panels are windows, controlled lighting devices and climate control elements at the same time. To define the module for such a structure the system will be caught in a dilemma—whether to classify it as a wall, structural, electrical or a mechanical module. Moreover, the system will never be able to construct such a structure by combining its respective functional modules.

Knowledge representation: Knowledge is represented in EDM using "sets" and "first order logic". A set is a group of objects that share some common properties. Set representation is usually used to associate properties to a set rather than to explicitly associate it with every element of the set [Rich et. al. 1991].

First order logic is a monotonic[6] knowledge representation technique that can derive new knowledge from old using mathematical deduction [Rich 1991]. It is a relatively easy to use knowledge representation technique with a reasoning mechanism embedded within it. However first order logic has a serious limitation which is its inability to handle uncertainty, assumptions and qualitative reasoning which usually characterize design problems, especially in architecture.

Uncertainty and assumptions can be handled by Dempster–Shafer Theory which allows the use of probabilistic reasoning. This kind of reasoning, however, has some disadvantages: It is very difficult to use and modify and requires lots of very accurate statistics to produce reliable probabilities.

On the other hand, qualitative reasoning can be handled by another form of logic called "fuzzy logic" or reasoning. *Approximate* or fuzzy reasoning is "the process by which a possibly imprecise conclusion is deduced from a collection of imprecise premises. Such reasoning is, for the most part, qualitative rather than quantitative in nature, and almost all of it falls outside the domain of applicability of classical logic... Approximate reasoning underlies the remarkable human ability to understand natural language, decipher sloppy handwriting, play games requiring mental or physical skills and, more generally, make rational decisions in complex and/or uncertain environments" [Zadeh 1979].

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6 In monotonic logic, if a condition is proved to exist or to be true, it could not be proven otherwise in a later stage.

While formal logic defines set membership as a Boolean predicate—the value of which is either true or false, fuzzy logic allows us to present set membership as a possibility distribution [Rich et. al. 1991]. For example it is not possible to represent a quality such as "very" tall in formal logic because the definition of tall is a Boolean one (figure 3.14 b). While, as shown in figure 3.14 (a), fuzzy logic enables the representation of such quality—one's tallness increase with one's height until the value (1) is reached. "Once set membership has been redefined in this way, it is possible to define a reasoning system based on techniques for combining distributions. Such reasoners have been applied in control systems for devices as diverse as trains and washing machines" [Rich 1991].

Despite of all its advantages, fuzzy reasoning received very little attention within the branches of cognitive sciences "largely because it is not constant with the deeply entrenched tradition of precise reasoning in science and contravenes the widely held belief that precise, quantitative reasoning has the ability to solve the extremely complex and ill-defined problems which pervade the analysis of human systems" [Zadeh 1979]. Nevertheless, fuzzy logic is a very promising knowledge representation technique that deserves more attention, especially in architectural CAD systems.

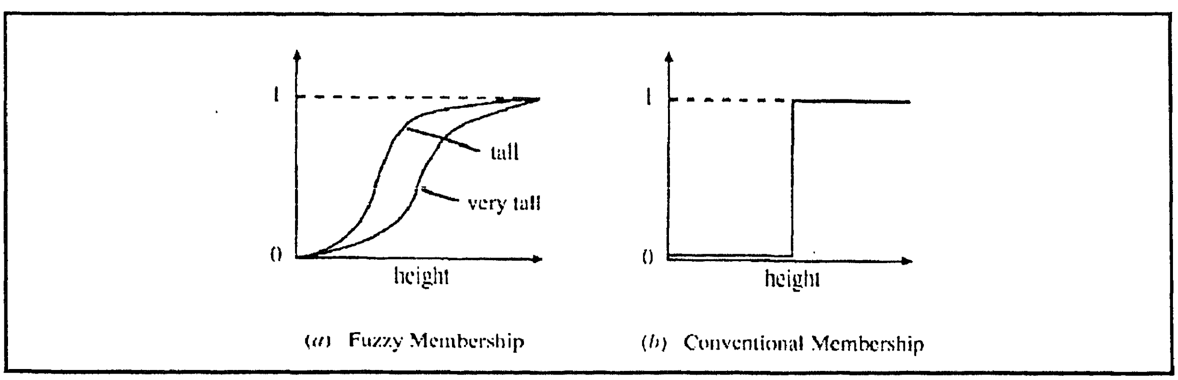

Figure 3.15 Fuzzy membership versus conventional membership [Rich et. al. 1991].

3.2.3 LOOS: Design Automation

LOOS[7] is an architectural CAD system specialized in "layout synthesis". Layout synthesis, or *generation,* systems are used to generate layouts or plans of buildings given a certain layout problem. They are supposed to be useful in the preliminary stages of the building design process where lots of design alternatives are developed. The architect would then select the more feasible alternatives and present them to the client to choose from.

The intent behind LOOS is to create a complement to human designers in the form of a system able to produce solutions to layout problems characterized by diverse and possibly conflicting criteria or constraints [Flemming 1992]. One of the goals is to generate alternatives with intelligent trade-offs in terms of these criteria. The architecture of LOOS reflects this goal by using a hierarchical generate–and–test (HGT) approach as a problem solving technique. HGT is a search technique described by (Stefik et al., 1983) that uses intermediate evaluations to guide the search for solutions into promising directions to avoid the inefficiencies associated with blind search.

LOOS constructs and evaluates layout configurations by using two types of rules that work on these configurations. The first type is called "Generation" rules which generate layouts from design elements by adding one element (rectangle) at time, starting with one element in the layout. Alternative layout structures are generated if more than one possibility of adding a design element exist. The incremental nature of the layout generation process allow for intermediate evaluations that can be used for stopping the search.

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[7] LOOS is being developed at the Department of Architecture and Engineering Design Research Center at Carnegie Mellon University, Pittsburgh, PA by U. Flemming and R. F. Coyne.

Intermediate evaluations are made by applying "test" rules to the layout configuration. Each of these rules checks if a certain constraint is satisfied. If a constraint is violated, the "test" rules denotes the failure in an evaluation record for the configuration. "Test" rules can also estimate how well the configuration performs with respect to a certain criteria like, for example, the minimum size of the overall area. Table 3.1 presents a layout problem that was used to test the performance of LOOS in [Flemming 1992]. It calls for a design of an efficiency apartment within an area that is accessed from the east and receives natural light from the west. Elements of this layout are arrangements of rectangles whose sides are parallel to the horizontal and vertical directions in a two dimensional space. A complete trace of how LOOS was able to solve the (Layout Problem) is presented in (figure 3.16). LOOS was able to find 24 feasible solutions and generated 40 states to find them.

Spaces	Living/sleeping area	Min. dimension	3.36 m
		Min. area	22.00 m^2
	Kitchenette	Min. dimension	1.80 m
		Min. area	4.20 m^2
	Vestibule or hall	Min. dimension	1.20 m
		Max. dimension	6.00 m
	Bathroom	Min. dimension	1.80 m
	max. extent of overall area from east to west:		7.00 m
Required adjacencies (min. length of shared boundary in brackets)			
	Living area/vestibule (.90m)	Living area/western border (3.60m)	
	Living area/kitchenette (1.20m)	Living area/southern border (3.60 m)	
	Vestibule/eastern border (1.2m)	Vestibule/bathroom (.70m)	

Table 3.1 Layout Problem Used for Testing the Preformance Of LOOS

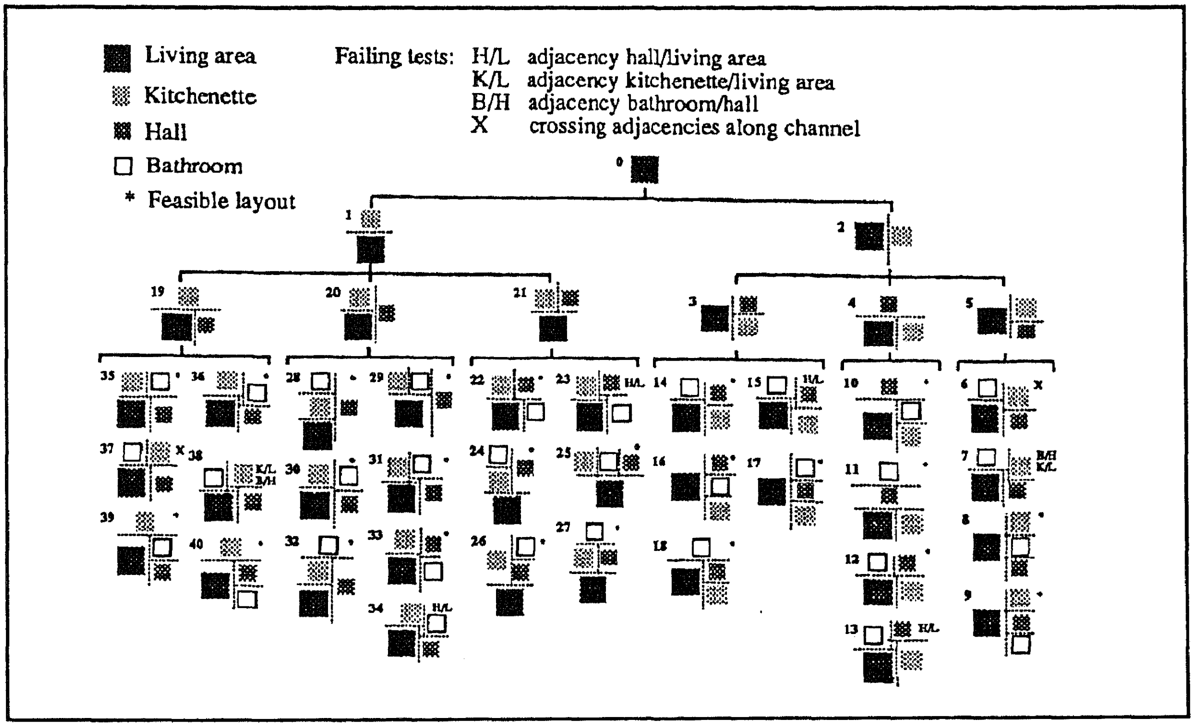

Figure 3.16 State space for Layout Problem generated by LOOS

3.2.4 Discussion

LOOS represents an area of CAD called design automation. Its goal is to build systems that are capable of producing a behavior similar to that of the human designer. It is not meant to introduce new design concepts but rather to automate the existing ones. The main purpose of LOOS is to automate the task of producing design alternatives at an early design stage. It works on very simple layouts as it fails to solve complicated ones due to the enormous amount of memory that the search requires.

There are two main drawbacks for design automation systems in general. The first is translating certain tasks from the human environment into that of the computer. In that attempt, design automation systems try to mimic human behavior and usually express very little success when they don't address the difference between the two environments. The human environment is characterized by a large amount of flexibility in making choices and selecting reasoning techniques compared to that of the computer. In addition, those design techniques were planned for the human mind and, in most cases, are not readily suitable for computer implementation. The result is usually CAD systems that are quite impractical due to their excessive computer requirements and their inability to tackle real–life complex design problems.

The second drawback is that the emphasis on automating existing practices deludes to believing that automation is in itself the solution. In many cases the result is either an automated chaos or an automated trivia. Automation, by itself, does not provide the solution and can even contribute to the problem by producing "more of the same" solution that doesn't work[8].

Another approach to design automation would be one that is more concerned with the purpose rather than by the process itself.

3.2.5 Summary

- Knowledge representation techniques, in architectural CAD systems, are generally based on formal logic which imposed limitations on representing qualitative aspects of design.
- Hierarchical structure of CAD systems limits the ability of these systems to accommodate integrated structures and generate new ones.
- Design automation cannot provide solutions if the automated process itself is not working.

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8 This point is manifested in the "Titeflex Company" example presented in a following section.

3.3 Engineering Design Concepts

This section as well as the following one comprises a logical transition in design concepts from the previous two sections. Whereas design concepts presented in the first two sections were generally based on hierarchy, the following two sections present non–hierarchical design concepts.

3.3.1 Ove Arup: Integrated Engineering Design

Ove Arup is one of the most successful architectural / engineering firms. Its is known for its ingenious structural and mechanical systems designs of some of the most famous buildings of this century. These buildings include Sydney Opera House, the Hong Kong and Shanghai Bank, headquarters for Lloyds Bank in London, and Centre Beaubourg—also known as Centre Pompidou. All those buildings were only made possible through the ingenious engineering design of Ove Arup (figure 3.17 describes the development of Sydney Opera House from Jørn Utzon's competition scheme to the final design).

Ove Arup who founded the firm in 1946 believed in "total design" which he explains as: "the integration of the design and construction process and the interdependence of all the professions involved; the creative nature of engineering design; the value of ingenuity and invention and the social purpose of design."

To achieve this goal the firm is organized laterally, rather than hierarchically, into multi–disciplinary teams each under the guidance of a project director. For example, "building engineering" comprises groups of structural, mechanical, electrical and public health engineers and architects.

The same thing applies for industrial, civil, geotechnical and transportation engineering. This approach was established to remedy the failings of the traditional approach to "service engineering", where services are linked to the building after the architectural and structural elements have been fixed. The method of team working employed by Ove Arup allows for considering the engineering implications of architectural concepts from the outset and thus identifying appropriate options at the earliest opportunity.

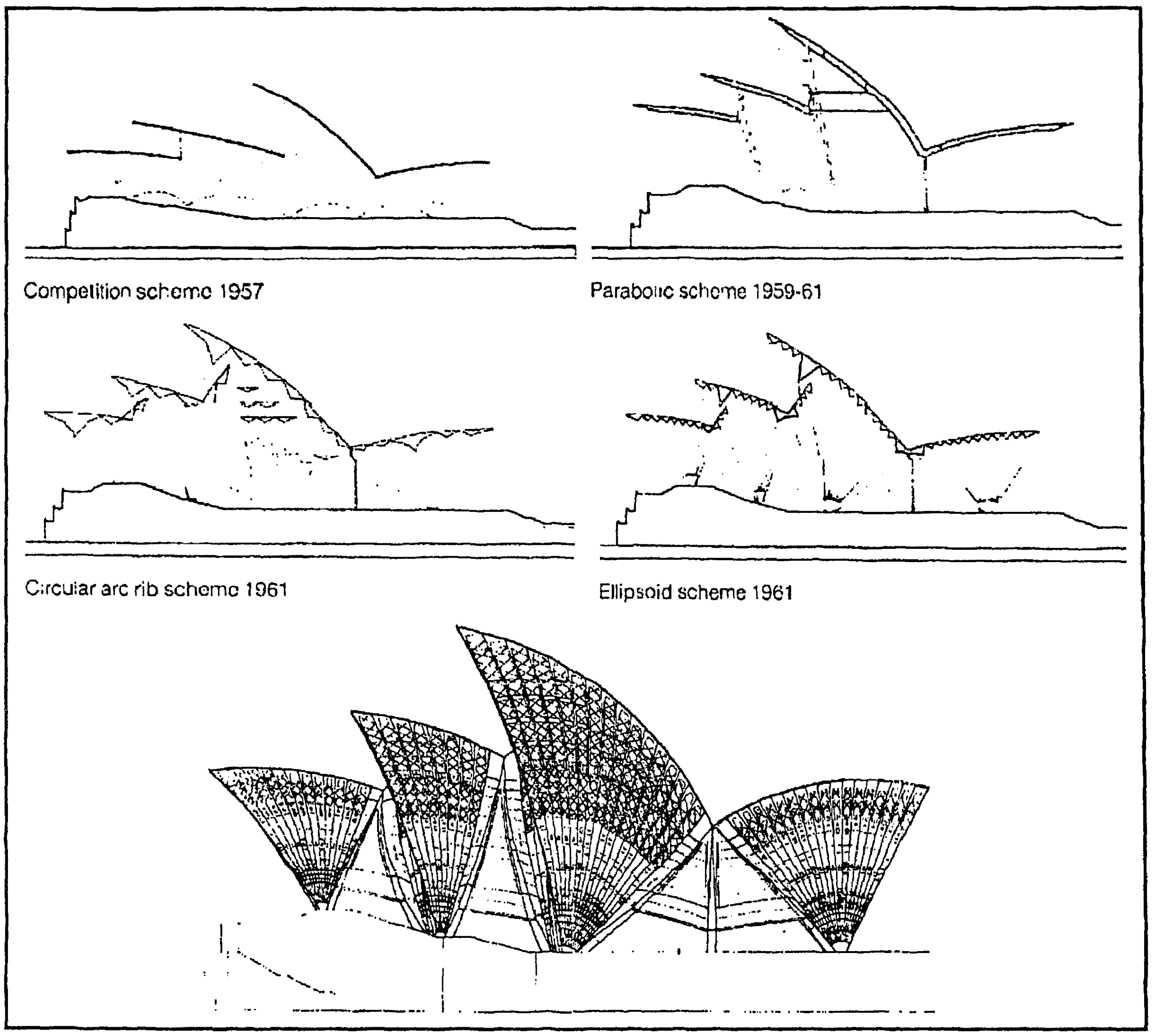

Figure 3.17 The development of Sydney Opera House scheme.

The emphasis of this approach is not on the "process", but on the "product". As Ove Arup puts it: "In building, the entity we want to perfect is not the structure or the air–conditioning as such –although that as well– it is the sum of all these parts... The search in this case is for a comprehensive quality which is the sum of particular qualities, each measured with its own particular yardstick, but modified to fit into a general pattern. The success of the whole undertaking depends on the right allocation of priorities and whether the resulting entity has this quality of wholeness and obvious rightness which is the mark of a work of art." The underlined statements show a strong implication to a systems approach to design problems.

3.3.2 Summary

- Successful engineering design can better be achieved through the integration of building systems from the start and throughout the design process.
- Successful design require an emphasis on design objectives and continuing the search process until no better solution can be achieved.

3.4 Organization Design Concepts

The business world of the nineties is characterized by being decentralized and "fickle" [Peters 1992]. The changes in global economics happens so fast that when one of Japan's best foreign–exchange dealers consider "long–term" factors in buying and selling, he is only referring to a period of ten minutes [Volcker 1992]. This exhilarating rate of change is largely contributed to innovations in information technologies and evolving marketing strategies. Fashion became a part of almost any industry and profession [Peters 1992]; it is no longer restricted to clothes and cosmetics.

In such a world, only a decentralized and responsive organization can survive. Big organizations with hierarchical structures are suffering, as shown by their record losses, due to lack of flexibility and adaptation to a rapid changing world. The most notable examples are IBM and GM. The big organizations that are still in good shape are the ones which have been divided into semi–autonomous independent units, like the Swedish industrial giant ABB (Asea Brown Bovery).

3.4.1 Going beyond Hierarchy

According to Harold Leavitt, an organization consists of task, structure, information, control, people and an outside environment [Leavitt 1978]. It is believed that 50% of the success of any business organization comes from its organizational structure [Peters 1992]. The 1970's hierarchical design model by no means accommodates the required flexibility and dynamics of the 1990's. The successful organizational design models of this decade will be the ones who go beneath hierarchy towards flat structures. In such organizations, strategy formulation and organization design are "more organic and bottom–up than structured and top–down" [Peters 1992]. As a result, functional barriers disappear. Instead of having specialized functional departments, like finance and engineering, the organizational structure is composed of work cells or units that contain people of different specializations. These work cells are in fact project teams with a lot of decision making power who simply work together to get the work done. In such cases the work becomes a series of projects that enrich team members experience and provide them with a wholistic perspective of how the overall organization operates. Every person becomes a business person in the true sense of the expression.

This form of organization can be perceived as a system. There are no multiple levels of management, and the concepts of "who is the boss" and "who reports to whom" only depends on the occasion and the task to be accomplished. This is a necessary characteristic to have because "working as equal partners is the only way that the talent of experts[9] can be correlated to create more than the sum of the parts[10]" [Peters 1992, p. 191].

The advent of using the system approach in design of organizations is that it makes the organization accountable to subtle changes in its environment. The introduction of "Chaos" theory [Gleick 1987] has shown that small changes in initial conditions can have enormous consequences, contrary to the scientific belief that big effects were generally the result of big causes. This kind of chain reaction is the one that happens in complicated systems like the weather system and the stock market. In such complicated systems, it has not been possible to arrive to good understandings of complex behavior. As modern organizations become more complicated, it is not feasible to pursue total understanding of them through centralized–control schemes. The control process must be decentralized and embedded in the building blocks of the organization.

The next section contains a case study that represents the effect of the organization design on its performance taken from [Peters 1992, pp. 62–71]. The study compares the performance of the firm before and after changing its organization design.

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9 Inspite that the previous statement refers to "experts", the case study that follows later in this section will show that this term is relative, and that "normal employees" can easily adapt to such structure.

10 From the definition of systems: The output of the system is more than the sum of its parts.

3.4.2 A Practical Example

Before redesign: Titeflex is a Springfield, Massachusetts based manufacturer of fluids and gas holding systems—high–tech industrial hoses. Until 1988, the company was functionally and hierarchically structured into departments and different levels of management. Operations were centrally controlled by the MPR I computer system which would create paperwork for purchasing, production schedules, the storeroom and the quality assurance department. Other paperwork would be initiated by other departments. The whole process generated a large number of meetings every day like engineering and quality review, make–buy and purchasing meetings (figure 3.18). The typical elapsed time for order entry was three to five weeks.

On the factory floor, part of the order went to the basic hose manufacturing line, along by the paperwork generated through the previous reviews. Another part of the order went to a factory group responsible for fittings for the basic hose—a job that involves five different departments.

"After the hoses and the associated components were built, they went to another department to be cleaned; then through at least three more departments for final assembly; then to the 50–person quality–assurance department; and, finally, to the shipping department.

Factory–floor "management" was overseen by a big production control planning unit.... A typical order–in–progress went through the stockroom no less than six times, as part of a three–quarter–mile voyage from initial order to shipping dock. Production controllers were also forced to invent six "expedite lists." They were necessary to override the formal systems. There was a Hot list (angry customers), a Luke–Hot list (moderately angry customers), and End–of–the–Month List (to assist in getting stuck orders out the door so that they could be recorded for accounting purposes), and so on." [Peters 1992, pp. 63–65].

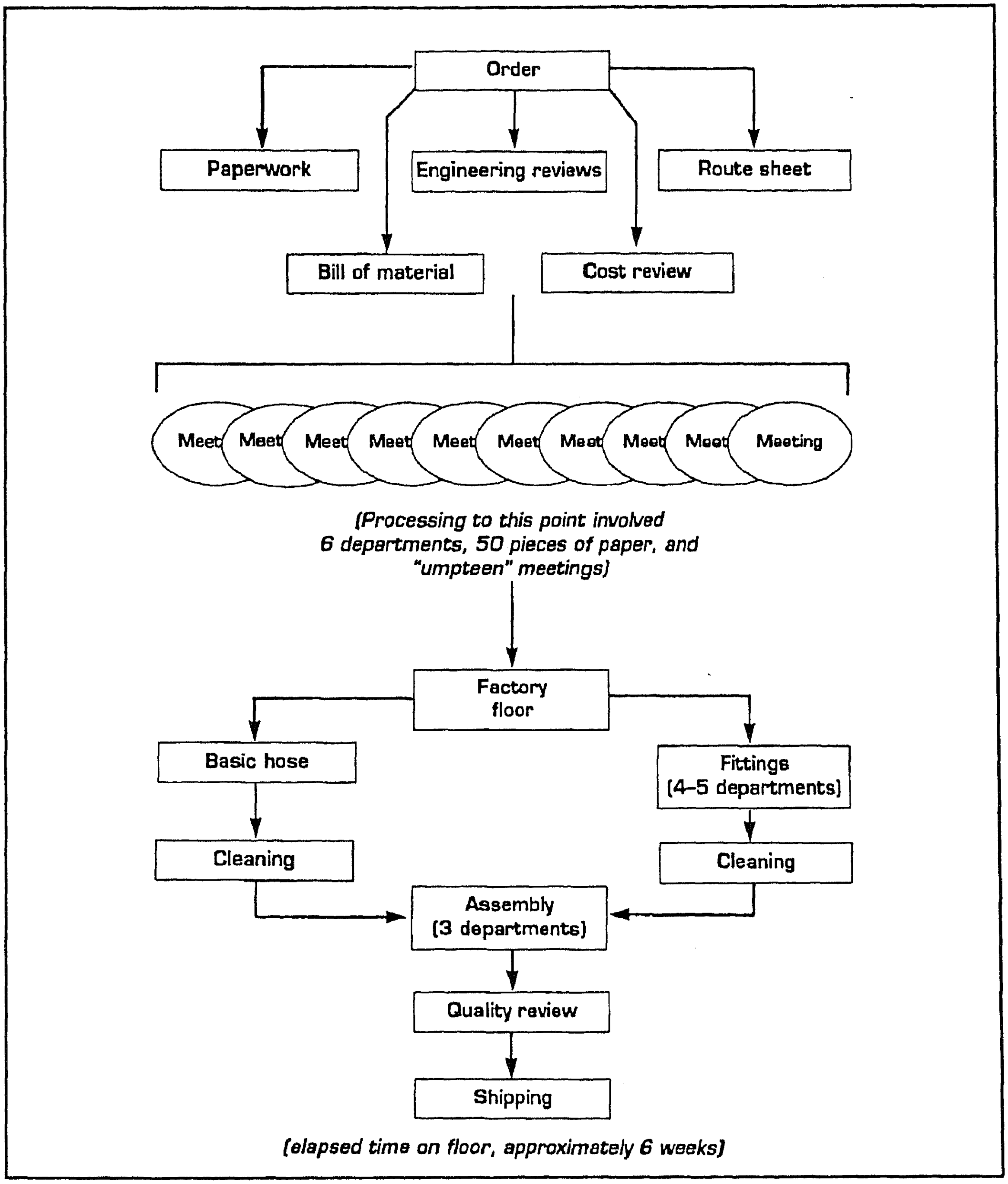

Figure 3.18 Titeflex system until 1988 [Peters 1992 p. 64]

In addition to the three to five weeks for order entry, manufacturing absorbed six weeks—for a total of nine to eleven weeks, if everything went smoothly.

After redesign: In 1988, Jon Simpson, who was appointed as president of Titeflex, conducted radical changes in the organization structure that was reflected in the way the company operates. The hierarchical functional structure of the company has been obliterated, layers of management removed, old processes abandoned, then completely reinvented and even the old computer system has been disconnected.

The hierarchical structure has been replaced by "cells" and "small businesses". The placement of new orders is handled by an "administrative cell" called a Genesis Team, "consisting of five people with their desks arranged in tight circle. Among the players are (1) a contracts administrator, the voice of Titeflex to the outside customer (discussing price, delivery dates and setting up "master contracts" with in–house "small businesses"); (2) applications engineers who immediately review each order from an engineer stand point; (3) a quality engineer, who checks that quality requirements are being met; (4) a draftsman, who draws up new designs if necessary; and (5) a clerical support person" [Peters 1992, p 65]. Instead of the numerous inter–departmental meetings that were imposed by the old functional structure, the Genesis Team handle all the details themselves through informal discussion—marginally supported by the MPR I system. The result has been minimal paperwork (no more than a page), and whole processing time of 10 minutes for routine orders or two to five days for a new or special request.

The factory has been organized into "small businesses" which are in fact self sufficient "manufacturing cells" consisting of 6 to 10 people each. For example, Business Development Teams (BDTs) are in–house small cells which "sell" complete hose–and–fitting sets to the Genesis Team; Final Assembly Teams are cells that handle ultimate construction. The communication between the Genesis Team and a BDT often starts before the order is released so that the BDTs begin manufacturing immediately once an order is released. When the manufacturing is done, the components goes to the stockroom, and from there to one of the Final Assembly Teams (figure 3.19). Total manufacturing time ranges from two days to one week. Crash orders are handled by a special Rapid Development Team which can process the orders from the order entry to the shipping dock in three or four hours.

To summarize the changes, the hierarchical structure of the organization has been demolished as well as the functional departments. Layers of management have been stripped out and some functional departments replaced by Business Development Teams, while others simply removed. The expedite lists vanished since virtually jobs are completed within a few days.

The results of the changes went beyond the improved organization efficiency. Relationships between functions were revolutionized. Engineers are now more seen on the shop floor than ever, checking out the feasibility of doing different tasks and occasionally seeking worker's advice. Workers routinely travel to visit customers like General Electric and suppliers like Du Pont. Inter–company relations with customers and suppliers, now established among a wide range of workers, has achieved a 50% reduction in the new–product development cycle. Workers from Titeflex are allowed intimate access into the Du Pont processes and operations and vice versa which was difficult to imagine a couple of years before.

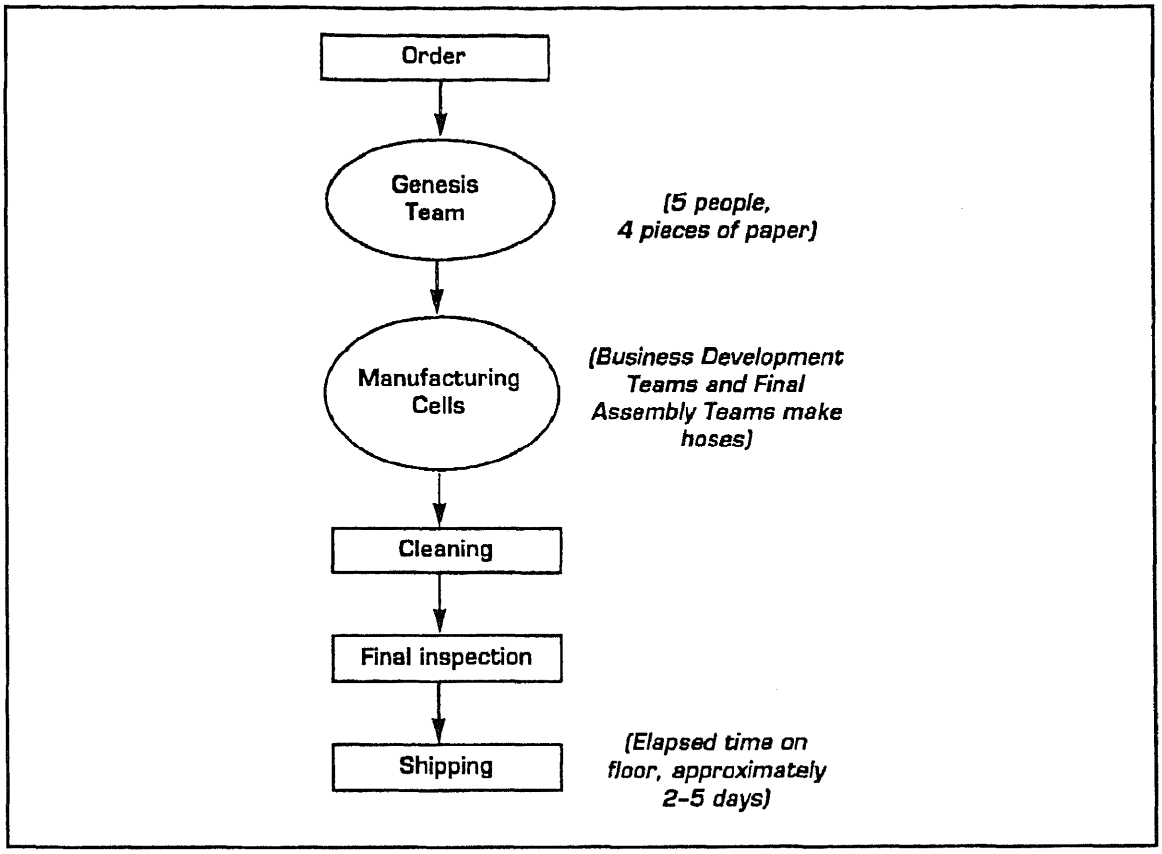

Figure 3.19 The Titeflex system after redesign [Peters 1992, p. 67]

3.4.3 Summary

- Functional integration is better achieved at a lower level.
- Lateral structure proved to be more successful than hierarchical structure.
- Automation can contribute to the problem formation rather than to its resolution, if the automated process itself is a failing one.

3.5 Conclusion

The case studies presented in this chapter illustrate some of the different design concepts used in practice in the fields of architectural, CAD, engineering and organization design. Design concepts presented in architecture and CAD are similar in being hierarchical-based and the emphasis on the process rather than design objectives. Case studies presented in these two fields suffer from the lack of a concrete problem definition and a process that leads to the best possible solution to the design problem in hand.

The cases presented in engineering and organization design present similar unconventional approaches to conventional problems. This approach can be described as a system approach that provides a wholistic perception of the problem at hand as well as a resolution that addresses all the aspects of the problem.

The following chapter contains the principles of system design to serve as a basis for regarding the design process in architecture as a whole system rather than as a series of separate stages.

CHAPTER 4

DESIGN IN THEORY

In the previous chapter, it was shown that design practices that used a wholistic approach to problem solving were more successful than those which used a narrow approach that was inspired by a single idea or belief. This wholistic approach has its roots in what Churchman describes as the "system approach" [Churchman 1968].

The system approach evolved as a result of the significant success of the teams of scientists that were assembled during World War II to help the British Admiralty solve some pressing problems. These scientist used a wide approach to problem solving that considered all possible aspects of the problem in hand. They pointed out the weaknesses in assumptions made by the military that were complicating problems rather than solving them. After the war, this kind of problem solving approach developed into a science called "operations research" that was used to solve military as well as nonmilitary problems.

Operations research continued to prosper through the fifties and early sixties when things started to change. By that time, it was discovered that operations research was more successful in solving problems that could be modeled mathematically or quantitatively and, as a result, the focus of operations research was turned to these problems. Gradually it became a "domain-oriented" rather than a "market-oriented" profession, its scope became narrower and it started to fade away. Today, operations research has very little impact compared to what it used to have during the fifties and early sixties.

The diminishing role of operations research, however, does not reduce the importance of the system approach to problem solving methods, including design. In fact the decline of operations research, as a profession, has been contributed to the shift from the wholistic approach that characterizes system thinking to a narrower, more specialized one. The decline of operations research sends a powerful message to architecture that professions which get too specialized and adopt a narrow approach to solving problems can easily become extinct. Instead of approaching architectural design from a narrow perspective, like *form follows function, less is more* or *less is bore,* the design process in architecture needs to be approached as a system capable of producing a high quality product—that is a successful design.

This chapter presents the theoretical principles of systems that can be used to articulate a system oriented design process in architecture.

4.1 Principles of Systems

There are many definitions of a system. Aristotle described a system as the whole that is "more than the sum of its parts". Other definitions for a system also exist. This chapter presents Churchman's definition because of its practical implications and because it represents the model that is becoming increasingly popular in today's organizations. According to Churchman, there are five basic aspects of any system [Churchman 1968]:

4.1.1 The Total System Objective and the Performance Measures of the Whole System

The objectives of the system represent the true purpose of the system and the specific tasks it is supposed to accomplish. It is useful at this point to investigate the objectives and not rely on any presumptions because "so many mistakes may be made in subsequent thinking about the system once one has ignored the true objectives of the whole" [Churchman 1968, p. 30].

To assure the achievement of the system objectives, there must exist performance measures of the whole system. They indicate how the activities that occur within the system contribute to the achievement of its objectives.

4.1.2 The System Environment: the Fixed Constraints

The environment is what lies outside the system and cannot be changed by any means of system activity—fixed in the sense that they cannot be changed by the system. Recognizing the environment is of significant importance. For example, a design system that works in a computer environment should not be expected to be the same as one that is operated by humans. These differences can show in the logic and structure of the system if needed.

4.1.3 The Resources of the System

These are elements inside the system which are the means the system uses to do its job. Contrary to the environment, the system can change its resources and use them to its own advantage. An example of these resources in a design system would be design knowledge and the system determines which kind of knowledge is suitable to which task. It follows that the resources are the general reservoir out of which the specific actions of the system can be shaped.

4.4.4 The Components of the System, their Activities, Goals and Measures of Performance

"The reason for the separation of the system into components is to provide the analyst with the kind of information he needs in order to tell whether the system is operating properly and what should be done next" [Churchman 1968, p. 42]. This means that systems do not have to be composed of modules arranged in a hierarchy according to their function. The way these components are classified should only be considered in association with the system objectives. This means that the arrangement of those components and the relationships between them is more important than the goal or activity of the individual component. For example, in a design system, some design elements can be classified as structural or mechanical elements depending on the design activity being performed by the system—whether it is structural or mechanical design.

The measure of the performance of the system components should only be done in terms of the performance of the overall system. As Churchman puts it: "One obvious desideratum is that as the measure of performance of a component increases (all other things being equal), so should the measure of performance of the total system. Otherwise the component is not truly contributing to the system performance" [Churchman 1968, p. 43].

The measure of performance of a system component can be affected by the introduction of a new member or the changes that occur in other components due, for example, to some technological improvements. In this case the nature of activities required by other components might also change and so does their measure of performance. For example, before mechanical systems in buildings became reliable, the measure of performance of windows and openings was affected by their ventilation abilities. Now that mechanical HVAC systems are more reliable the measure of performance of windows does not depend on ventilation as much.

4.1.5 The Management of the System

The management of the system deals with the generation of plans for the system that consider the overall goals, the environment, the utilization of resources and the components. The management also performs the "control" activity which makes sure that those plans are be carried out in accordance with the original ideas or objectives of the system. The most important aspect of control, however, is to evaluate the plans and consequently change them when necessary. This leads to one of the most critical aspects of management: Planning for change of plans, because it is not practically possible to account for all the objectives or changes that occur in the environment or any unexpected situation. The management performs this activity by collecting information that tell it when its concept of the system is erroneous and must include steps that will provide for a change [Churchman 1968].

The control aspect or *function* of management was studied by Norbert Wiener [Wiener 1965]. He compared this function of the management of a system to the steersman of a ship. The captain of the ship has the responsibility of making sure that the ship goes to its destination within the prescribed time limit of its schedule–"system objective". The "environment" of the ship is the set of external conditions the ship must face: the weather, the direction the wind blows, the pattern of the waves, etc. The ship's "resources" are its men and machinery, as these can be deployed in various ways. The components of the ship are the engine–room mission, the maintenance mission, the gallery mission, and so on. The captain of the ship as the "manager" generates plans for the ship's operations and makes sure of the implementation of his plans. He institutes various kinds of information systems throughout the ship that inform him where a deviation from plan has occurred, and his task is to determine why the deviation has occurred, to evaluate the performance of the ship. Finally, if necessary, he changes his plans if the information indicates the advisability of doing so. This may be called the "cybernetic loop[1]" of the management function, because it is what the steersman of a ship is supposed to accomplish.

To determine the transmission speed of the information within the cybernetic loop, an information feed–back loop is required to permit the management to react to the changes of the system environment in an optimal manner. The introduction of the "Chaos" theory [Gleick 1987] has shown the importance of feed–back to the system management. The feed–back process has to attain a very high degree of sensitivity to account for the subtle changes in the environment that can produce major effects on the system performance.

Wiener and Ashby developed a theory of cybernetics which has mainly been applied to the design of machinery. However it is a system oriented theory of control that is getting increasing attention in economics and other

1 Cybernetics is derived by Wiener from the Greek word for "steersman".

complex domains, and would certainly deserve some attention from architects, especially the developers of CAD systems in architecture.

CHAPTER 5
CONCLUSION

The main purpose of this study was to present an overview of design practices and theories in different domains that would enrich the perspective of architectural design. To achieve this purpose, the study presented the initial purpose of architectural design which is providing an adequate shelter for different human activities. Positive and negative aspects of shelter were briefly discussed to trace the evolution of the concept of shelter.

Change, as an essential aspect of design was presented in the context of problem formulation and problem resolution. First and second order change were presented as the types of change that can occur in systems. The ways change can contribute to the formulation of a problem were presented as the problems of change. These problems are:

- over-simplification of the problem,
- setting unrealistic goals (the "Utopia Syndrome), and
- seeking contradictory goals.

Another section followed that described how to manage these dilemmas of change that design processes are usually trapped in. The way to manage those dilemmas was presented in the following four step procedure:

- a clear definition of the problem in concrete terms,
- an investigation of the solution attempted so far,
- a clear definition of the change to be achieved, and
- the formulation and implementation of a plan to produce this change.

A presentation of design practices followed. It started by presenting design practices that are generally based on hierarchy. Two examples in architectural design that illustrate two different types of the design process in architecture were presented and discussed. They were followed by another two examples of computer–aided design systems in architecture; one is more concerned with the problem of knowledge representation while the other is an attempt to automate an existing design activity. Each system was followed by a discussion that pointed out some problems that existed in each system.

Practices in engineering and organization design were then presented. The practices that were chosen do not follow the traditional functional hierarchical approach to design, but rather follow a system approach to the design process that proved to be much more successful than the examples presented in architecture and CAD systems.

Following the logic of the study the theoretical principles of the systems approach were presented following Churchman's articulation. A hint to the importance of cybernetics as the control mechanism of large systems was also included.

This study did not intend to articulate a system approach to architectural design. Instead it just points out the possibility of using this approach in architecture, as it has proved to be successful in other domains. The process of articulating such an approach for architectural design is a monstrous one that could not be attepted in such a study. It is not a common sense approach and requires raising many questions especially about matters that are considered well known, because, in many cases, they might turn out to be not.

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