RICE UNIVERSITY

AN APPLICATION OF THE COMPUTER TO ARCHITECTURE
(A TOOL IN DESIGN DEVELOPMENT)

by

PETER GERALD DOYLE

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

MASTER IN ARCHITECTURE

W.T. CANNADY
THESIS DIRECTOR

Houston, Texas
May, 1967
"ABSTRACT"

AN APPLICATION OF THE COMPUTER TO ARCHITECTURE
(A TOOL IN DESIGN DEVELOPMENT)

BY
PETER GERALD DOYLE

The computer, since its development in the late 1940's, has created an era of unlimited potential and change. A transformation of the world about us and of the processes and methods with which we are accustomed is taking place at an accelerating pace.

Computer technology is making significant contributions to architecture and to the processes through which the architectural solution is produced. This is evidenced in its application to accounting procedures, critical path planning, specifications writing, cost estimating, and graphic data processing. Architects will see develop a new 'interprofessional and interdisciplinary dialogue' which will permit them to receive engineering data and evaluation of functional characteristics almost instantly, at any stage in the design process. Working drawings and specifications will be produced with great rapidity using computerized technology.

But the computer is more than just a tool for management or a more efficient means of producing construction documents. It can become a useful tool in determining criteria for the design process and through an analytic-synthesis and evaluation of such information can establish precise functional and environmental criteria, determine suitable engineering and architectural systems and solutions and make routine design decisions based on logical quantitative data.
The architect, today, cannot depend solely on traditional methods used in design development. In the search for form, we begin to uncover a very complex structure of elements of which it consists. It becomes evident that because of this underlying complexity that the sheer speed and accuracy of the computer can be an aid to the designer.

In the design development phase of the architectural process, the architect dissects his problem into its various component needs and by determining the relative importance of each aspect in his system of analysis creates a hierarchy of design criteria. Then, choosing from an information source a particular system or systems to fit the needs indicated or set forth in the criteria, he sets up a working model of combinations of these systems to approximate the correct three dimensional architectural solution to his specific problem. He then tests this model and its alternates until the best solution is found, that is, the combination of elements which best satisfies all the design criteria in its proper order of relative importance.

The computer, applied to such a task, would give man the opportunity to set up and investigate many more alternates to the architectural solution in a more sophisticated manner.

This in no way makes the architect less responsible for the final solution. In truth, it requires a deeper understanding of the architectural problem, a logical approach in solving it, and offers more opportunity for the architect to make use of his intuitive judgment on those problems which cannot be solved by computer technology.
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II.</td>
<td>Design Process, Scheduling</td>
<td>13</td>
</tr>
<tr>
<td>III.</td>
<td>Analysis of the Design Process for Computer Application</td>
<td>31</td>
</tr>
<tr>
<td>IV.</td>
<td>Component Decomposition in the Development of Form</td>
<td>53</td>
</tr>
<tr>
<td>V.</td>
<td>Conclusion</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>Appendix I. Analysis of Student Problem</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Footnotes</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Bibliography</td>
<td>85</td>
</tr>
</tbody>
</table>
I INTRODUCTION

The purpose of this thesis is to lay the groundwork for a comprehensive architectural service with the final design as the primary point of focus, making use of the computer in aiding the architect to cope with this major task.

We have come into a new age of technology and expansion in which our traditional methods are changing drastically. It is a change so great that it is effecting all areas of our daily lives. The computer is the key element in this technological revolution. No other inventions up to this time have made available the means to the tremendous extension of man's capabilities. We must remember that, "automation is no more than a tool; but, too, a tool of such immense possibilities that no one can yet see the full extent of what it might achieve for mankind". ¹

In this age of computers and computer technology, it has become increasingly evident that the key to successful application of the computer to any problem has been in the initial stages of the process when the problem was defined and systematically organized. Logic and clarity must prevail before the computer can be applied efficiently. This thesis proposes to set forth a clear
system with which to approach the problem of the design of a space and the processes involved in solving this problem. What are the limitations of its application to this problem? Where does man make his intuitive decisions and how do these decisions interrelate to those made by the computer? What is the degree of priority given to different components in the process and can these be changed to provide a flexible general program?

A computer is a machine that is able to calculate and perform sequences of arithmetical and logical operations in accordance with pre-programmed instructions. 2

They are electrically operated machines which are capable of performing many various functions of data processing with phenomenal speed and accuracy: receiving and converting information; storing, sorting, collating, computing, transmitting, and producing data in a usable form, as readable printed output.

We are establishing a set of intellectual techniques which, because of the computer, will allow man to handle an array of problems, the solutions to which people were only 'intuitively' aware in the past before the availability of this tool.

Although man must instruct or program the machine minutely, its chief present advantage is that it can manipulate symbols a million times faster than a man with a pencil and paper, and can make calculations in a few seconds or minutes that might take man alone a century. 3
The architectural profession must prepare to play a larger part in the evolution of environmental design. It must prepare itself to fulfill the physical, emotional, social, and intellectual needs of a complex society in a complex time. "Society and clients are demanding that the architect place himself at the center of the entire process of environmental design." 4 Society is presenting the demand and the architects must work quickly to come in control of the problem. He must become the creative coordinator of the total environmental design and the computer with its potential of super-human speed and vast memory banks will extend his capabilities to cope with the massive background of data which become part of the problem once we attempt to tie the fragmented parts together in some sort of total system.

The architect, if he is to accept the responsibility of the challenge, must expand his definition of the 'design process'. As the clients' needs become more complex so, too, do the problems of the architect. With the architect taking more responsibility for his client, the client can devote his time to his own immediate problems and the architect will no longer exist only as a minor consultant in simply the design and construction of the building, but because of his intimacy with the project from its very conception will be able to master the entire building process.

Programming of the building alone is hardly enough in a time when the operations that take place within and
around the building determine, to a large extent, the final architectural solution. It would seem patently impossible for an architect to solve the overall problems of a shopping center without having been deeply involved in the operational programming of its merchandising principles. Who are its customers? What income brackets? How do they get to the center? How do they buy? Such considerations are basic to the design of a shopping center. If he is simply presented with a ready-made program from which he must then somehow extract a building solution, the architect can scarcely expect to solve more than a piece of the total program. Nor can his client reasonably expect more than this.

The architect must provide more than just the limited services he provides today. This means that architects, individually and as a group, must equip themselves with the background and tools which will enable them to participate in the preparatory decisions which initiate all building projects; to relate buildings to the total environment, and control projects through all of their phases, and not merely through the last phases of the total design process, that phase which is the basic building design. He must proceed to relate all of the elements which go into creating a particular problem. This cannot be accomplished unless he has been in charge of all aspects of the problem and can make broad planning decisions in relation to all components for the good of the whole; not only those decisions dealing with the aesthetics or design of a particular space, but also those factors leading to or having any bearing on the design of the space—economics, site location, operational programming, etc. Too often there are others who are willing to perform these services before the architect becomes involved in the
project and the architect finds himself throttled by decisions over which he had little or no control. Such a situation often results in compromised design. If the architect can grasp the fundamentals of each of the disciplines involved, he will be able to direct and coordinate the other professionals with whom he will have to consult.

Designing and planning of buildings and their environment and of the operations to take place in buildings and the environment, together with analysis, programming and construction administration make up the basic framework of comprehensive architectural practice.

With the change of architecture must come a change in the tools and methods with which the architect works. We are in an era where the demands are greater than ever before and where there is developing a great need for greater inter-professional and inter-disciplinary dialogue. "If architects are to fulfill the great role being offered to them as creators of better human environment, the profession must make its choice now. Otherwise it inevitably will retreat to a lesser position." The computer can help man fill the gap. It is only logical that if the computer has given man closer control and greater efficiency in such operations as engineering and construction documents then this type of application might work as well in the design process itself.

The computer can be used as a research tool, as a compiler, as a sorter. It can synthesize, evaluate, control,
and accept variables into a pre-programmed system to facilitate the study of the total design problem. It can give architects quick and accurate answers and alternate solutions at early stages in the design process. The design process becomes a very complex man-machine collaboration.

The real benefit and result that will be produced in researching the application of the computer to the design process is through the understanding and clarity which will come from the investigation of the process. One of the most important characteristics of the computer is that it has forced men to think about what they are doing with clarity and precision. "A man cannot instruct the computer to perform usefully until he has arduously thought through what he is up to in the first place and where he wants to go from there." Wherever the computer finds application, there is a resulting improvement in the quantity and the quality of human cogitation.

"The development of such discipline is long overdue, and its absence accounts in a large measure for the mediocrity of the architecture of our time, and the ever-increasing complexity and pace of development makes clear and logical thought even more difficult, and yet even more essential. A systematic design method, universally understood, is vital to the exploitation of these techniques."

There are innumerable areas of the total design problem to which computer technology may be applied. The problem before us is to isolate and interrelate these components in a total system. To do this would entail the determination of measurable factors which are based on log-
ical actions and reactions. To develop an understanding of organizational relationships, and to create guides to planning and design by identifying measurable factors, intuition can be focused on those areas where objective measurements seem impossible or unrewarding.

The strength of the tool lies in its capability of substituting observed factual experience for suppositions. With this means of factual implementation, pure intuition and creativity can be focused more and more in the areas where it is most effective.

This new application of the computer to the planning process is in no way established to reduce the freedom of the planner, but more so to extend their capabilities and to reduce the burden of decisions which can be answered by a computer source which has been properly programmed and given the correct data to evaluate. We must remember that the computer does not become an effective tool until the full structure of the problem is understood. It gives the architect the ability to analyze complex structures and frees the designer from standard solutions.

We have now the tools to approach the total design process in a rational and functional manner. Thus applied, we will produce not fewer beautiful buildings, but many more precise and sophisticated planning results, produced with such efficiency as to allow the architect more time to exercise his design talents within a framework of optimum requirements and standards. "Our effort, therefore, must be to learn to see the actual complexities of design so clearly
that we can make use of the machine to help unravel them." The computer, then, is a tool which systematically handles vast quantities of information in ways which support and stimulate creative thinking. It is able to solve problems and give answers to questions which were sapping man's strength of intuition. We are not attempting to design buildings by computers, but to implement man's thought process by making use of the computer's great speed and memory, instructed and controlled by programs the architects initiate.

In what manner should one approach the design development process in order to create a flexible system which the architect can follow in order to better fulfill the demands of his work in the new and comprehensive sense? This thesis will present one method which will be oriented to the purpose of utilizing the computer to its greatest advantage— not to advocate or force its use in every area of the design process, but to indicate areas where it might be best applied to benefit both the designer and the client. We wish to find and define an orderly framework into which each of these single programs may work and interrelate, in order to help bring about an optimum architectural solution. In particular areas of the network, there will be a need to combine certain data and simulate particular alternatives to a problem in order to determine the optimum answers to certain combinations of data and criteria developed earlier in the program. These results would then, in turn, be fed
into other sub-programs to develop a new set of results. Simulation sets up and approximates a working model. Man will have to develop the program and will have to feed in the data, but he will be able to know pretty accurately what choices he has and the consequences of his choices in advance, because the computer allows him to test them. This is one of the areas of real potential of the computer which can be applied as an aid to the design process, above and beyond those applications which will aid in production and graphic presentation.

In considering the process in design: "If it is to become more than just a handmaiden to the symbols of good taste, we must be capable of developing the bold tools and more comprehensive knowledge which will keep us operational amidst the dynamics of the highly complex on-going cultural systems which now face unprecedented complexity in shaping the supporting environment". 12

We cannot apply the computer until we understand thoroughly the system to which it is being applied. In other fields of application, the act of defining the total system has been the key to the successful solution to many of the problems which had developed within the whole. In medicine it is the human body; with economics, their complex economic systems; with sociologists, their kinship systems, and so on. "We tend to think of things not relations, of items but not context, of dualities rather than a field." 13 We must learn to study interaction—a sense of the entire system—and the computer can become a great tool in this study if it is applied correctly.
The architect, today, is finding that problems on all levels are indeed more complex than he had previously assumed. "This phenomenon, together with the final breakdown of absolute ideas in this century, bares the possibility that we may have tacitly misunderstood the nature of the problem confronting us." Our whole approach to the problem of design development must change. We must bring about a new language of design which will consist of processes of gathering, evaluating, synthesizing, and then simulating. This new language will give us a clearer and more precise insight toward well formulated goals. Rather than basing our new solutions on the way things have succeeded to work in the past, we want to provide the means to evaluate accurately and test each solution before it is actually complete. This entails studying the behavior of simulated environments of buildings under certain manipulations, i.e. variations in arrangements of components. With the use of the computer we can manipulate the structure giving elements with great precision and economy. It becomes the testing ground for our ideas, rather than having to wait to see the results either succeed or fail in a real situation.

The problem exists with the increasing complexity of the design problem and the intrinsic inability of the cognitive apparatus of the designer to manipulate large numbers of variables, which leads to a general lack of clarity in the forms and the functions which they serve.
We must develop a systematic, but flexible, process of design which probes into the fundamental aspects of design phenomena. "Forms lack physical clarity because programmatic clarity is lacking in the designer's mind." The objective is to devise a method for analyzing design problems in which a clear pattern of activities and relationships is evident and workable. The design problem is essentially to find the correct combination between two entities: the form and its context. In order to facilitate our work as designers, we must find ways of investigating and symbolically demonstrating these entities in simulated working conditions in order to test a variety of solutions to the problem.

We must recognize, in our search for a computer-aided design system, that if this system is to have general application to all types of architectural design problems then it must truly be a flexible framework, a framework into which and for which a great number of highly complex computer programs will be constructed and executed. It is impossible to think of constructing a system which will satisfy all requirements immediately without modification. There will be a slow evolution of special packaged processes each designed to perform some special task in the design process. The assembly of a library of special purpose routines planned to work within and to contribute to a major system will be set forth in very general terms in the following chapters. This system
will be established so as to permit modifications to the general system by the individual designers.

This is a search for a unified approach which will be flexible enough to fit the needs and interests or philosophies of the individual users. The designer must feel that his normal thought processes are aided, stimulated, and augmented by the use of the system in such a way that he is able to think almost entirely at the concept level.
II DESIGN PROCESS SCHEDULING

It is clear that the major task of our analysis of the design process is to break down the total design process into the various activities which go into its composition and completion, beginning with the most general areas and working towards the more specific. We shall attempt to form them into some type of organized system, a hierarchy of order and priority which would be flexible enough to adapt to any design problem no matter what the limits or requirement of the specific problem.

The first phase of the method of approach being presented will involve organizing all the activities into a master schedule, a planning network which will be used as a guide in procedures and a means of efficiently scheduling time and manpower to a specific problem. Not only will this arrangement of elements serve to provide a scheduling framework; but, also, it will begin to evolve a framework into which the elements which bring about the final design decisions will clearly fit. Basically, then, our efforts in this task of analysis are twofold: first, the provision of an effective management tool in the design development process and the second dealing with the actual decision making process which will be discussed later in this chapter.
The first area to which this thesis will be oriented is a search for a systematic approach to the design process which will involve a new method of scheduling the activities which are a part of the process. In so doing, we shall evolve, in general terms, the decomposition of the design development stage. "Network planning develops the logic of a particular project work plan by showing the relationships of tasks, the time each requires, and the responsible persons and sources required. It also provides a system by which to check progress of project development." 16 We will not have time to discuss the process at great lengths, but will give a schematic explanation of its key elements and illustrations as to its application.

It is at this point in the thesis that the major areas of the design process will be defined and structured. This will be the general framework onto which will be superimposed the decomposition of the actual components of the process as they fit into a decision making hierarchy. Therefore, we must examine all the activities leading up to the design solution from that point in the process where the initial need is established. All activities, whether directly or indirectly involved, must be related in their proper order and sequence because all have bearing on the final solution and their improper handling will result in something less than the optimum solution to the problem. Each activity should be weighed and analyzed in terms of its position in the search for the best architectural solution.
In the past few years a new method of scheduling activities has been applied to every major field of work. This method called CPM (Critical Path Method) has become one of the most effective means of planning, scheduling, and controlling projects. Some architectural firms have adapted the process to the planning and production of working drawing documents with much success, but few firms have understood its value and application enough to see its benefit to the design process and attempted to systematize its development. This thesis will investigate the application of PDM (Precedence Diagramming Method) rather than CPM or PERT (Program Evaluation Review Techniques). The PDM method becomes more flexible and gives a clearer representation of task development. "PDM differs from CPM and PERT in method of networking in that it focuses its attention on the work item itself and its specific relationship to serial or parallel work items. PDM allows each work item to be considered independently and as one unit of work." 17

To initiate the PDM network schedule there are four elements of the process which must be fulfilled: (1) the task definition, which requires the designer to decide upon a list of activities on which the design development is based; (2) creation of a two-dimensional chart showing the sequence in which these tasks will be accomplished and indicating the relationship of the various tasks to one another within the system; (3) time estimates, this is the
assigning of time durations anticipated for the completion of each; and (4) computation and analysis of the network which in this case would entail the application of the computer for speed and accuracy. This is the calculation of all start and finish times in order to determine critical paths and slack periods. Before we begin to define the tasks for the design process, we shall give an explanation of the other factors involved in PDM network planning which are a vital part of the manner in which the system function.

In formulating a work flow diagram there are certain relationships between tasks which must be indicated. Work items can be either in parallel with one another or in series. Those tasks which are in parallel need not have any special notation to that fact, but those which are in series are identified to the preceding task. The name given to such identification is PWI (Preceding Work Item) and this relationship specifies the logic or flow of work through the diagram. "Each work item (except the first of the diagram) must have at least one PWI associated with it." In PDM, relationships other than those which are in a series can be described. This allows for simultaneous activity and feedback which are necessary to solve complex problems.

Another one of the key advantages of the PDM method over OPM and PERT is the application of the 'lag factor'. The 'lag factor' can be indicated in one of four different
code letters with each describing a different relationship between the PWI. Listed below is a guide to the code meanings:

1) S - This indicates that the work item following the symbol can begin at a certain interval after the start of the PWI. It also serves to indicate that the completion of the task is not dependent on the completion of the PWI.

2) C - A symbol indicating a delay is desired before the start of the next task. The completion of the PWI should not cause the next task which follows to begin immediately.

3) Z - This symbol expresses the same meaning as the 'S' symbol; but, it also indicates that the task may not be finished until the PWI has been completed for the same duration of time.

4) F - An indication that the beginning of the task is not dependent on the PWI, but that it cannot be completed more than a certain percentage before the PWI is completed.

An example of this application of the various 'lag factors' can be seen in Figure I.
In this diagram the S-25% indicates that the Location and Site Analysis task can begin after the Operational Programming task is 25% complete. The lag factor between Location and Site Analysis and Economics indicates that the Location and Site Analysis can begin at anytime in relation to Economics but that more than 50% of the total work required cannot be finished until the PWI is completed.

To develop a flow diagram we must create a two-dimensional sketch of the relationships of tasks within a particular process. The manner in which we will indicate each work item can be seen in Figure 2. The information it contains consists of the task name, the task number (which is required for computer application), the duration of the task, and start and finish dates.
The early start, early finish, late start and late finish are important factors in analyzing and scheduling the design process. These elements determine the critical paths and slack times which indicate the progress or delay of activities. There are three possible time relationships which can occur when the network is computed.

In the first possibility, if early start is before late start then early finish would come before late finish which would allow for some float time in the duration of that particular task.

In the second case, if early start were the same as late start then we would have no difference between early finish and late finish. This situation is referred to as the critical path and simply means that the duration of the task and the time allowed for completion within the network is the same.
The last possibility would be that where early start is after late start. This would indicate a negative 'slack' time which means that the overall network schedule cannot be met and that the network must be revised to increase the duration of this work item or rearrange the work flow. The computer allows us to analyze and re-analyze complex networks repeatedly and with great speed and accuracy until a workable schedule is formulated. It then serves as an easy method of updating the schedule periodically to give the architect the key to successful coordination of complex problems.

The four phases of work that the architect has traditionally accomplished are not enough for today's client and should not be for the conscientious architect since they do not include a number of services required in the overall development of certain types of projects. The total design development process is a much more complex organization of elements. The four activities to which we refer would come under the following headings: (1) schematic design phase, the formulation of design criteria and concepts from examination of prescribed program, budget, and site conditions; (2) design development phase, the further development of a chosen concept into a physical space; (3) construction document phase, the production of working drawings and specifications; and (4) construction and supervision phase. The situation in most cases is one where the owner has brought the architect the site and the program with which
he is to manipulate, in a limited time and in a limited capacity, to produce the most suitable architectural solution to the client's particular problems. A more logical system of approach would allow the architect to become involved in the project from its conception, for him to become the key man in the development of the project and the coordinator to all phases of its growth including aspects of operational programming, economics, site location, etc., all of which would be directed and controlled by the architect to provide the client with the optimum solution to his particular project. One purpose of this analysis is to prepare the architect with the knowledge and the tools which will make this type of situation possible.

As was stated earlier, one of the first requirements of preparing a particular activity for the application of a network schedule is to list and define its various components. The following is a breakdown of the design development phase and a partial list of information and activities which are an integral part of the latter:

A) **Feasibility Analysis:** In this phase of the design development process there is a requirement for the architect and consultants to run through, in a very general sort of way, all of the phases of the process up to the actual building design and planning stage. The architect will become familiar with all aspects of the project through a brief research and evaluation
period during which he will recommend the required consultants to the owner and then seek to retain them. Brief consultation meetings will be scheduled with each of these experts, individually or in groups, and general decisions will be made as to the feasibility of such a project. It would be a rule of thumb check to indicate the theoretical feasibility of the project. It would be decided at this time whether or not there is any value in beginning the project. Because of the involvement of this phase in almost all of the major divisions to follow, this phase must be formed into a similar schedule to the master schedule of which it is a part.

Activities which might be included in this phase are:

1) Need for a facility
2) Methods of accomplishment
3) Economic requirements
4) Location requirements and transportation
5) Personnel requirements
6) Legal considerations
7) Market analysis

B) Operational Programming: This activity involves the analysis of the function which is to take place within or around the planned space. It includes determining the types and numbers of personnel required to operate or serve the facility and the space requirements of the function. This is a research phase and should not involve concept decisions. This study will consider future, as well as, present
needs and will contain suggestions for organizational revisions or facility requirement changes. Activities which could be included in this phase are:

1) Functional requirements
2) Space relationships
3) Personnel requirements
4) Organizational requirements
5) Maintenance requirements
6) Operational procedure
7) Layout relationships
8) Systems and processes
9) Equipment and furnishings

0) Economic Survey: In this phase of the development of the project, all cost factors which will have either a direct or indirect bearing on the expenditure and return of the client's investment will be evaluated. Information to complete this study will come from almost every phase of the project's evolution and will affect all phases of the project; therefore, it will run simultaneously with the other activities and will feed in information, as well as, accept information until the end of the design development work. Activities which could be included in this phase are:

1) Operational financing—maintenance, etc.
2) Capitalization of project
3) Land values and availability—affect height, parking, etc.
4) Taxes and insurance rates
5) Interim financing
6) Long range financing
7) Project comparison
8) Income potential
9) Obtaining tentative commitment
10) Cost of obtaining financing
11) Interest rates and repayment plans
12) Degree of speculation—return and risk
13) Consultant fees
D) **Location and Site Analysis:** The selection of sites which best meet the needs of the planned facility. An analysis of the factors which affect its choice and development, as well as, its relation to the function of the facility. Again, we have an activity which may begin early in the development of the project, but which cannot be completed until after some sort of building program is developed. Activities which could be included in this phase are:

1) Survey of locations and sites available
2) Relationship to surroundings
3) Relationship to labor forces or facility occupants
4) Relationship to raw materials
5) Availability of markets
6) Population trends
7) Relationship to city plans and growth directions
8) Relationship to transportation and transportation patterns
9) Climatological considerations
10) Landscape and area relationships
11) Legal considerations (zoning)
12) Traffic and parking

E) **Building Programming:** This is the point in our network where the program is developed for the needed facility based on the previously gathered information. It is an evaluation of the data gathered and a synthesis of criteria with which to develop the optimum solution to the particular problem. Still, no basic concept has been developed. Activities which could be included in this phase are:

1) Space requirements and relationships
2) Occupancy requirements
3) Budgeting
4) Basic philosophy formulation
5) Establishment of criteria and levels of importance
F) **Building Design and Planning:** Working from the building program, the designer will develop one or several concepts which seem to provide a solution to the design problem. These are, in turn, evaluated and compared in order to pick the solution which best satisfies all elements of the building program. The solution chosen is then developed further in all its architectural details. Activities which could be included in this phase are:

1) Schematic designs
2) Preliminary estimates
3) Analysis of components
4) Evaluation of solutions
5) Design development
6) Major systems evaluations
7) Outline specifications
8) Architectural details
9) Cost estimating

Now that there exists a list of major activities, we may proceed with the second step which is to develop a work-flow diagram in which the dependency of certain tasks in relation to the accomplishment of others are illustrated. The diagram which follows in Figure III is to illustrate the method in which this entire process, in terms of its major divisions, will begin to take form.
In this schedule, the first group of work items is not involved in the actual planning of the work, but rather in phases in which the project is initiated and where responsibilities are assigned, and where all persons involved prepare themselves for a quick run through the project, by rule of thumb, to indicate the project's feasibility. It is during the feasibility study, which within itself becomes a very complex scheduling problem, that it is decided whether or not the project is worth further consideration. If so, the detailed research and analysis period begins; it being another complex arrangement of interacting forces. It is only after a thorough period of investigation takes place that the actual evaluation and design analysis begins to take form.

By being forced to create the flow diagram the architect begins to see the actual design process follow some orderly system. The designer's thought pattern is exposed and a new clarity enters into the process.

In each of the major phases listed there again would be a decomposition of elements which would, within the master schedule, form sub-schedules. Each of these divisions consists of numerous components which interact among themselves and which interact or are dependent on activities within another major task. In most cases simultaneous evaluation will have to take place with 'feed-back' information in order to complete all or part of any major division. Each of these interactions and activities must be located and defined in order to schedule them properly.
within the master schedule. In Figure IV can be seen the results of such a method applied to the Building Design and Planning task of the master schedule.

FIGURE IV
To take this schedule a step further, it would be advantageous to include in our task analysis some manner of indication of the various individuals responsible for or involved in each particular work item. This would mean a symbol for the consultant and the percentage of time allotted for each out of the total man hours allocated for the task. This would better prepare the architect for his manpower needs and those of his consultants before the actual beginning of the job. It would also be part of the up-date scheduling for the project. A list of some of the possible consultants and services required, other than architectural, could be as follows:

A) Engineering consultants
   1) Civil
   2) Electrical
   3) Mechanical
   4) Structural

B) Others
   1) Urban and regional planners
   2) Sanitary and utility planning
   3) Lighting
   4) Landscaping
   5) Acoustics
   6) Graphics
   7) Traffic and parking
   8) Interiors
   9) Economic advisors
  10) Market analysis
  11) Legal
  12) Special building types

Out of this general framework we can begin to see the underlying method of structuring the design process. The examples which have been presented in their most basic stages indicate in a small way the complexity which would be part of a total system. A comprehensive master schedule
would involve breaking down all of the major divisions in a similar manner as was illustrated in the decomposition of the Building Design and Planning task and its formation into a PDM sub-network. A master network, with all its related sub-systems, is a formidable task for the single designer to face before beginning any design problem; but, with the gradual application and development of this method of approach combined with the aid of the computer, it will become easier to apply and understand and will be a boon to the design development phase of the architectural problem.
This chapter is devoted to an analysis of the design process to determine guide lines for the application of the computer in the development of the final design solution. Efforts will be directed to the formation of a flexible system with which the architect can determine the position and relationship of computer programs with one another and with the cognitive process attributed to the individual designer. In the design process, the designer is confronted with a large set of variables which he must manipulate into some semblance of order to enable him to present a solution to a given design problem. Chapter II dealt with the decomposition of the tasks which make up the design process and indicated a method with which the architect could construct a master schedule for the same. Within this chapter there is also a decomposition of necessary components. The purpose of the analysis, however, is to define the relationships and interactions of the different components, not in relation to time, but with regards to levels of importance and value in relation to the ultimate goals of the designer.

On the surface, the requirements of simple problems seem clear and uncomplicated, but if one would take the time to understand and define the interaction between these requirements he would be aware of the underlying complexity of
the problem. The average designer simply scans whatever information he happens upon or that which is in his immediate reach. He must go beyond this point to find the problem's solution. An example of such a problem is found in Christopher Alexander's *Notes on the Synthesis of Form* which deals with the design of a vacuum cleaner. There existed four major requirements of this design problem:

1) Performance  
2) Simplicity  
3) Jointing  
4) Economy  

The designer's task was to determine the optimum combination of each of these requirements to produce the best end. Even within the bounds of these four requirements it was shown that there are a multitude of interactions to be considered to give a comprehensive solution. Compare these requirements, though, to those which would be necessary in the design of a major hospital. The requirements and their interactions become so numerous that they cannot all be counted. The computer will at least give a means to approach the problem's structure with some degree of success. The intuitive resolution of contemporary design problems simply lies beyond a single individual's integrative grasp. With the traditional methods of approach man is now using, most of these interactions of which we are speaking are not even uncovered. The time is not available under the existing circumstances to do so.

In order to gain accurate knowledge of the problem's
structure, we must investigate thoroughly the components into which the problem can be broken. The systems which are formed by the interaction of variables and tasks can become extremely complex in their relationships even in relatively simple design problems. The architect, alone, lacks the cognitive capacity to manipulate such complexity. The computer can aid the architect in this activity and can become the key tool needed to answer the demands of the complexities of today's architecture. We are looking for a system which would join man and machine into an intimate cooperative complex, a combination that would use the memory, computational capabilities, and accuracy of the machine, each with the greatest possible economy and efficiency. The different capabilities of man and the computer can complement one another in their operations together. They will reinforce each other if properly united in an outlined system. With the creative process defined it becomes easier to see the exact areas of applications of various aids to the cognitive process, not the least of which is the application of a system of computer programs. We are in search of a conceptual framework to describe and guide the planning process.

The concept of systems and the structural model of the planning process are arbitrary relationalizations of some things which exist. They do not lessen the problem. Indeed, they may increase the demands on architecture by demonstrating an increased array of problems to be solved; but, they make possible the introduction of techniques which other disciplines use for the solution of very complex problems. 19

Through this probe into the design process and the
means to study the relationships and levels of activity, and with the ability to simulate the architectural solution, the architect's work becomes more thorough and precise and his creative genius is funneled to the important points of decision making. "The possibilities for seeking, relating, measuring, and simulating the interaction of great numbers of planning considerations or variables, exists in modern computer technology." 20

The ultimate goal is the formation of an 'on line' computer system to use in the development of the design solution. To develop a system where the computer not only becomes an aid in the immediate tasks of the architect but, also, a tool with which the architect communicates directly with those of other disciplines with whom he is working. It will allow the immediate and complete exploration of ideas along with the results and effects these ideas have on the rest of the system. All the related disciplines involved in the evolution of a solution will be able to work in close and simultaneous contact.

In the planning of an on-line computer system there are many factors which must be investigated before it becomes an effective tool to the designer. We are working to arrange the elements and activities involved into a system which will allow the designer and the computer to work together. Figure V indicates the general allocation of responsibilities of man and machine within this system.
FIGURE V

ROLE ASSIGNMENT FOR COMPUTER-AIDED PLANNING

<table>
<thead>
<tr>
<th>Planning Phase</th>
<th>Man Provides</th>
<th>Computer Provides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation (development of requirements and programming)</td>
<td>Knowledge and experience</td>
<td>Storage, retrieval and processing</td>
</tr>
<tr>
<td>Synthesis of physical and organizational</td>
<td>Imagination and design sense</td>
<td>Manipulation, simulation, and short-time memory</td>
</tr>
<tr>
<td>Evaluation of arrangements and anticipated performance</td>
<td>Judgment and assessment of intangibles</td>
<td>Calculation and display. Selection based on programmed logic</td>
</tr>
</tbody>
</table>

We are looking in the future to have a library of inter-related programs under the control of a single grandiose executive routine within a master network schedule. The tasks which the computer will take on involve those aspects of the problem which require fast and accurate storage or retrieval of large quantities of data, rapid calculations, and repetitive manipulations of information. The computer is able to search through its vast memory and answer questions about the performance of existing facilities and display this information in graphic form, as well as, taking this stored information of existing facilities and evaluat-
ing new schemes in light of this information and establish-
ed criteria. An example of this process applied would be
the use of such a system in determining the factors dealing
with the circulation within a hospital plan. Figure VI
demonstrates the flow diagram of the computer in this type
of operation. In such work as this, where graphic data must
be presented, a display oscilloscope is used as output hard-
ware. This will give an indication of the potential of the
tool in architectural planning.

FIGURE VI
COMPUTER INPUT
& PROCESSING

COMMERCE CHARACTERISTICS

OUTPUT

EVALUATION
PLAN ARRANGEMENT

VERTICAL PATH
ARCH. REG. MARCH 64

COMMERCE MEASURES
LOCATION COORDINATES
PLAN SKETCHES
SPACE LOCATION

EVALUATION

COMMERCE FINDING
LOCATION COORDINATES

PATH USE PERI RESULTS

COMMERCE PERI RESULTS

ARCH. REG. MARCH 64
What we wish to do is set forth some notes on the methods of analysis which will allow the architect to begin to unite programs such as that discussed on the preceding page into a total system. What factors should govern the development of these programs; and how should the information they provide be incorporated into the total system with relation to the final solution and established criteria? The following work will touch briefly on the various requirements which programs must meet in order to work within this master network.

The decomposition of the design process is a reorganization of the way the designer thinks about a problem. It is a breakdown of the intuitive process into that which is truly intuitive and that which is purely quantitative and logical. It is a formidable task to think of breaking the problem or process into its simplest elements within a particular framework and toward a defined goal. It is a method of approach which will have to be built and tested, revised and retested, and always adapted to a new and a different problem.

We shall begin this analysis with the establishment of three major divisions of activities which will form the structural framework for the process. The planning and programming of the process would evolve around the following divisions:

1) Research and Analysis: This includes gathering all pertinent data which will affect the formulation of the design solution in an accurate and organized manner. It also includes the
creation of a data bank which will be drawn upon during the synthesis and formulation of various solutions.

2) **Synthesis and Formulation**: These activities are initiated in sequence or simultaneously with various amounts of interaction and dependency on data from other tasks. The information which goes to feed these programs comes from the data bank which stores all common data and previous decisions. When the individual program is completed it will, in turn, feed back information into the central data bank. The data bank begins with a collection of general information and is continuously sifted through during the entire design process, thus becoming more specific and precise as the development process evolves.

3) **Evaluation and Testing**: This is, again, a process which must develop simultaneously with the other phases of the program, working from the general to the more specific as the solution or solutions evolve. It includes testing through simulation at many levels in the framework and between many categories.

A graphic diagram of the general process which must be followed in this method of analysis can be seen in Figure VII.

**FIGURE VII**

```
START

INVESTIGATION

SYNTHESIS

EVALUATION

FEED BACK

COMPLETION
```
It is important to realize that the functioning of this system is a much more complex operation than is indicated here. In actuality, all of these three distinct phases will have activities working simultaneously and each division may be called upon by the other for information at any time during the development of the design solution. It would be established, in such a system, that at particular points in the process the architect could extract from the problem a complete solution based on information evaluated up to that time. This means that at many designated points throughout the master program, models of solutions, from general to precise, will be automatically formed from the available material so that programs and information which depend on a working model can be executed or determined. This requires, at times the intervention of the individual designer to introduce intuitive or assumed information until it can be further tested at a later time in the development. This requires that careful scheduling of tasks and their related programs and the application of the master network schedule which we discussed in Chapter II.

One real benefit in the break down of components into one of the three above mentioned divisions comes from being able to relate programs to be evolved within smaller related major groups. It is a decomposition process which begins to simplify the organization of the overall process. One of the components to an adequate system, which has tremendous importance to the effectiveness of the total system and its results, is the central data bank or memory of the process.
The means of retaining the answers we get in the computer's memory has now reached a point where we can do several things: accumulate information; extract whatever we require; integrate it with some other information; make calculations using both the existing and the new information; feed the answers back into storage where they can be kept until they are needed again; and, compare it with further information as the need arises. We can also revise previously recorded information as the project develops. All the programs that will be planned for the system will need data from the central memory for them to operate and will contribute new information at their completion. This memory will be established to contain data which is with reference to particular programs' requirements and the storage of information upon which the designer may wish to call during the process development. A list of some of the general data which might be recorded in a memory and kept current to assure the effectiveness of the system could be listed as follows: construction costs; climatological data; type information and statistical data on elevators, glass, wall systems, etc.; and others. After each new design problem, the computer memory will contain new bits of information which may or may not be applied to other programs. The cost and time involved in preparing this general information will decrease with each new application. This part of the master system will evolve a step further with each new application. An example of how this particular unit functions in the total process can be seen in Figure VIII.
The points to consider in developing individual programs for the system in relation to the system's memory are those of information required and data to be evolved. The program designer should list all required tables or schedules of information which must be read into the memory, as well as, its dependency on information developed through the functioning of sub-routines. This is important to know from a scheduling standpoint, but, also, to make use of as much common data in the memory by all the programs of the system. This prevents repeated processes and allows the program package to be as concise as possible. It eliminates, where possible, the need for sub-routines within a particular task, and therefore keeps the individual programs of the system as independent as possible.
In the design development phase of a comprehensive architectural problem, we are faced with a complex and dynamic task that requires the making of numerous judgments, all of which are related to a common purpose, in simultaneity. If the designer tries to make all his decisions based on intuitive or subjective judgment, he cannot serve the requirements of the problem adequately. Working with the computer will reduce some of the load, especially in those factors which deal with quantifiable data or objective reasoning. This will allow the designer to devote to his intuitive decisions the time, concentration, and research that they require. "Designers recognize, correctly, that calculations of magnitude only have strictly limited usefulness in the invention of form, and are therefore skeptical about the possibility of basing design on mathematical methods. What they do not realize, however, is that modern mathematics deals at least as much with questions of order and relation as with questions of magnitude." 21 Making use of the computer in this process should stimulate, not hamper, the creative process.

The architect must be able to see where and when he must make highly subjective judgments in critical stages in the process, not only in determining the criteria for the program, but in the research of information. He will have to make major functional decisions which are based upon more than just quantitative data and decisions on aesthetics for which he is trained. There will also be times in the process when the computer will be laboring fruitlessly
to satisfy incompatible constraints unknowingly imposed or where it might be investigating solutions which are unreasonable to the problem. When and if such situations occur, the individual designer must intervene. "Those tasks requiring a selection of goals, formulation of hypotheses, determination of consequences and handling of unlikely eventualities should be retained by humans." These would include intuitive decisions and subjective analysis. There would then be those tasks or activities which would be allocated to the computer which deal with measurable data and logical patterns of operation. This could be considered objective data. Those tasks which require the availability of large amounts of stored information, computational speed and accuracy or repeated trial and error applications are within this category.

We must look at the entire design process and decompose it into either one of these two categories. This will enable us to pinpoint those places in the master schedule where it will require human intervention.

It is of equal importance to consider the points in the individual programs which require the decision or introduction of intuitive assumptions by the individual designer. An example of a particular case in which this would happen would be in the selection of a wall type for a particular building. Factors of heat transmission, structural capabilities, acoustic transmission, scale and flexibility are factors which are objective in nature and require solutions
which could be determined through the manipulation of measurable data. But the color and texture of the wall depend on the abstract desires of the designer of the space to produce a certain unmeasurable quality. At this point in any program of this nature, human intervention would be required. It is important to indicate all points along the program where this becomes necessary for the completion of the program to prevent unnecessary lags or delays in the total process. There are other programs which require the introduction of data which must be based on assumptions until proven otherwise, such as the limits of a building shape. In these cases it is necessary for the designer to establish limits to the programs investigation in order to conserve time and to prevent wasteful experimentation. The assumption is usually based on the designer's own experience or general knowledge.

One important aspect in the development of a system for the design process is the determination of goals and values upon which the designer himself must decide. This is one of the major points where the architect must use his intuitive abilities in the development of the project towards the formulation of the final solution. It is at this point that many of the programs are given key criteria. This is one of the critical times when the architect asserts his individuality.

The architect today has often let the architectural solution be determined by the wrong goals. An example
might be the speculative building where the economic return becomes the key factor in the evolution of a solution and not the success of the architectural space or the operational functioning of the building itself. It is possible to serve all these requirements, though, if in the beginning and within an organized approach, the architect sets forth the requirements which the solution must meet and in their proper hierarchical position. The primary goal for any architect who wishes to call himself a professional will be the optimum design of building space, which includes the consideration of that building in relation to the surrounding environment. None of the other requirements of the problem should ever take precedence over this point in the evolution of an architectural solution. However, after this goal is established, the architect can place any number of requirements in their order of importance which he can set to order their influence on the final solution. These will change depending on the type of project being developed and on the individual architect. In the search for a solution to the design of a hospital, the function of the activities being provided for and/or the effectiveness of the mechanical system would follow the primary aesthetic goal, while economics might be at that position in the design of a speculative office building. To further demonstrate the point, refer to the following diagram. Figure IX indicates one arrangement of the major elements in the evolution of a design solution for a speculative office building.
The task relationship indicated in Figure IX is an arrangement of some of the components which are part of the planning solution necessary for the development of a speculative office building. They are placed in an order which would be used as a guide in determining the priority of programs. This is necessary within the overall system in order to prevent confusion between interacting programs. This relationship will be transferred into a coding system which would then be incorporated into the individual programs and would govern the interaction within the complete system in terms of criteria established by the designer. If this
were not done then it would be possible for the execution of an optimum situation in a less significant task to prevent a task of more importance to the total program from reaching its optimum solution. An example could be seen in the determination of a bay size for a building. One optimum bay size for the steel structuring and economy of the building might not allow for the efficient functioning of the building. In this case, it must be decided whether the economy of construction deserves more attention than whether the building functions efficiently. For individual programs to perform efficiently together with one another this criteria to govern interaction must be initiated. We must show the interaction of forces on different levels, always within the hierarchy, leading to the best building solution in accordance with the priority arrangement set up by the designer. This depends to a great degree on his choice of placement of activities in the design development framework. We must look at the whole and how each part contributes to the whole.

How should one begin to set out the components involved in the design process in order to describe in a clear manner their relationship to other components? The designer must have all the information which he is to deal with in as clear and concise a form as is possible. He must decompose everything into a group of tasks which can be related as groups and subgroups of activities. He will then break down the activity into the variables which go into its composition. Our first objective is to form a list of the components and
list them in such a way as to show the interrelations within the total system. A method in which this can be accomplished is shown in Figure X.

FIGURE X

In order to prepare the application of a task to this diagram, we must look at the individual elements and study their relation to the determination of the final design solution. Let us examine one of these components and its relation to those other components in the process which either affect or are affected by any development in this area of the total problem.
For an Office Building

**PARKING**

<table>
<thead>
<tr>
<th>Affects:</th>
<th>Affected by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>construction costs</td>
<td>construction costs</td>
</tr>
<tr>
<td>site development</td>
<td>site development</td>
</tr>
<tr>
<td>landscaping</td>
<td>landscaping</td>
</tr>
<tr>
<td>outdoor lighting</td>
<td>operational requirements</td>
</tr>
<tr>
<td>maintenance</td>
<td>code requirements</td>
</tr>
<tr>
<td>access</td>
<td>market analysis</td>
</tr>
</tbody>
</table>

In many cases as indicated in this example, there will be the duplication of elements in the two categories. The determination as to which of these will be governed by the other must be set forth by the designer as was discussed earlier in the chapter. We must try to find, if possible, some way in which in this same system of decomposition diagramming we could indicate the priority of programs over one another. The diagram of which we are speaking is not the key to the operation of the programs, but to the placement and control of these programs within a design process system. This list of interactions will help to indicate the arrangement of programs or tasks within a network schedule and will help to make evident the dependencies of programs on subroutines. We will now take a closer look at the analysis of the process of which we were just speaking in the development of a speculative office building. In Figure XI can be seen the diagram relating to this particular decomposition.
What must follow this arrangement of components is an establishment of the priority of components in relation to each point of interaction and the points of human intervention within the programs' developments. Examples of some of the computer programs already initiated which could immediately be adapted to a major network of programs are contained in the Appendices.
The notes in the preceding chapter will help to guide the architect in the analysis of the design process for the development of collaboration of computer and designer. We discussed a variety of points which should be considered in task analysis and program development. The major points which must be covered by those interested in the development of a master system are:

1) Analysis of the components and placement into one of three major divisions to aid in component analysis and network scheduling.

2) Indication of the purpose and the operation of the central bank or memory in relation to program development. A determination of general information demands on the memory and the interchange of data during the process evolution.

3) Points of human intervention within the system and in individual programs. In program intervention this would include the introduction of intuitive data or assumed limits to allow the program to go to completion. This might have to be done more often in the early stages of the process until enough programs are executed.

4) The determination of the hierarchy of components within the process. An establishment of degrees of importance to indicate which programs should ride over others in the search for the optimum design solution.

5) The determination and definition of the work components into which the design development process can be broken for scheduling.

6) The decomposition of the design process to determine where and what types of programs can be applied. The indication of the interaction of components and programs and the consideration of input and output relationships.

7) The establishment of requirements by which the success of the architectural solution will be judged. A method of presenting and organizing this material will be presented in Chapter IV.
The fourth chapter will present another method of decomposition of the design process. The placement of this particular decomposition method is found in the 'Building Development' stage of the total process; but, with some variation in the program the same principle could be applied to the decomposition of tasks within the design development process.

We have not developed a system, but have indicated an approach to its creation. The development of this master system which we have been discussing will be the results of the work of many and over a long period of time; but, the need for such a system is already upon us, and the tools with which it can be accomplished are available.
IV. COMPONENT DECOMPOSITION IN THE DEVELOPMENT OF FORM

Chapter IV deals with the elaboration on a method of approaching the design problem in which the computer is called upon as an aid in the formation of a design program. It is a different type of analysis from that found in Chapter III. In Chapter III, we are dealing with the analysis of the entire design development process and all its components. This chapter actually discusses a part of the major system discussed in the preceding work. Here, we are in search of the components of the actual building design and not the process leading up to that point. The components of which we are speaking in this case are statements of requirements or restrictions. They are variables, but only in the sense that they either exist or do not exist. They are criteria, established by the designer in the building development stage of the comprehensive process which must be resolved in order to produce the optimum solution to the design problem. If we take a good look at the architecture by which we are surrounded today, we will begin to see the confused application of form and the obvious lack of clarity in the structure and components of the forms. What has happened to these forms? What caused their illogical solution and by what means do we propose to correct such a problem? This chapter will not contain "the" answer, but will give the
fundamentals to an approach to a phase of the design development process which will aid in the development of form.

The form which is to be developed, ideally, should reflect the requirements and factors which relate to its existence. Today, though, the average architect cannot devote the time necessary to evaluate all the criteria which are pertinent to the design of the architectural space. Making use of the traditional methods of approach does not provide the order or clarity necessary for the architect to evaluate the problem thoroughly. The lists of variables with which the architect is confronted are too numerous to be handled in any sort of random analysis. Then, how is the designer to approach this highly complex problem of creating a design program?

There are limits to the ability of the designer to order and manipulate variables towards the optimum building solution, therefore, the architect needs a way in which he can decompose the problem into a clear program and then synthesize the components into a design solution. We must find some way to break down the problem into categories. The fewer and more concise the list of components, the easier to manipulate or satisfy them in a form. The architect must be given a total picture of the problem before the solution is initiated so that all requirements are given their due consideration.

There are two basic elements which we are considering in each design problem: 1) the form, which is the architectural solution as built, and 2) the context, which is the definition
of the problem in terms of a program. The optimum architectural solution is the harmonious relationship between these two elements. In the approach being presented, the context is described in terms of verbal concepts or statements of requirements which can either be fulfilled or not fulfilled in the evolution of the form. The form is the physical expression of the program.

The steps which will be followed in this process include: 1) The creation of a list of component statements; 2) the expression of their physical implication in a series of diagrams; and, 3) the evolution of the architectural form from the realization of these diagrams.

A man's thoughts about a problem begin in verbal terms as the mind creates statements to describe the form he is trying to produce. We are describing here, a method in which the designer may list these thoughts and place them into a clear and easily understood pattern. Presently the intuitive analysis which the architect today uses does not indicate a clear structuring to the problem. Neither does it provide a systematic manner in which the problem can be solved. "The complexity of the problem is never fully disentangled, and the forms produced not only fail to meet their specifications as fully as they should, but also lack the formal clarity which they would have if the organization of the problem, they are fitted to were better understood." 23

The method we are explaining consists of a period of
analysis followed by a process of synthesis. The establishing of a list of requirements becomes the point of departure for the analysis phase at the end of which we have a design program. The completion of a program begins the synthesis phase which is the diagramming of the program. Here, the end result is the developed form. The figure below indicates the manner in which the solution is achieved.

![Diagram showing decomposition and synthesis]

DECOMPOSITION —— SYNTHESIS

The program develops out of the decomposition of the requirements of the problem in sets and subsets of related data; while the 'realization' of the form is produced by the combining of diagrams from the smallest physical elements or implication to the larger, more general concepts. The diagrams mentioned here are abstracted from the sets of requirements and are not always easily found. The resolution of each set of requirements is translated into a diagram which presents an aspect of physical form such as the circulation diagram of the activity within a building. The final form of the architectural solution is found in a harmonious combination of these diagrams.
The designer, today, is not able to set forth the context of a given problem in full. He has not had, before this time, the proper tools or methods. He sees the context in a piecemeal fashion, but he cannot see the context as a 'single pattern' or in an ordered system. A good designer will have formed some sort of component analysis and criteria list, but they will not be as complete as possible. The complexity of the problem in its lower limits still prevents the designer from starting at the base of the problem. He must solve it from its major components down and hope that the majority of the simpler requirements will be taken care of in that satisfaction of the major requirements.

A program of the type of which we are speaking gives the designer a series of sub-problems to work with in a systematic progression towards a design solution. The program we create is a hierarchy of groups of variables or statements which relate to a common idea. Each set is as free from links with other requirements as is possible. It is a combination of systems and subsystems or requirements all interacting in some form or another, but each sufficiently free of interrelations with the others, to allow itself to be adjusted and solved independently of the other groups. The adaptation of a form will begin with the resolution of the smallest group of requirements within the system working up to the more difficult requirements of which there are fewer interactions with which to deal. Each of these groups of requirements is translated into some physical aspect of
the form in the form of a diagram. A collection of diagrams begins to develop from simple to compound in structure based on the solving of the various sets of requirements within the program hierarchy. The development begins with those patterns having the minimum amount of contact with other variables and leads to the units of which they are a part. The program analysis is a process of decomposition and division, while the program 'realization' is a process of integration and synthesis.

We are attempting to prevent the erratic development of forms by presenting a method of development which provides an approach that will keep the changes caused by certain forms, which satisfy one requirement and disturb the equilibrium of another, to a minimum, so that the designer can solve one part of the problem and proceed to the next set of requirements without having to worry about those he has previously solved. The architect now depends on his intuitive ability to guide him in this solving process, but the problems with which we are faced today are far too complicated for this method to be effective.

An example of the process of decomposition which we have been speaking of is illustrated in basic form in the Figure XII.

FIGURE XII

[Diagram showing the relationship between function, solution, and structure]
In this example there are two different sets of requirements into which the problem has been decomposed, each of which contains requirements relating to one another to form an independent group or set that will suggest in some way a physical aspect of the form under consideration. We will not try to construct a diagram for the total design solution until each of the subsystems is evaluated and brought to clarification. Then, we will approach the final solution in a simpler manner by bringing together the two sets of variables which have been solved within themselves. What we are looking for are groups of variables which have many interacting forces internally. These sets will give clearer indications of the form than those with a minimum of internal links. We try to evaluate the more complex groups of requirements with the larger number of intermediate links early in the program so that as the form develops and becomes less flexible, the requirements which it must satisfy towards the end of the problem consist of a smaller number of groups and fewer links.

"Variables which are linked, exercise mutual constraint over one another's state." 24 This is the situation we are trying to order. The determination of the order or structure of the requirements which make up the program is an extremely complex operation which is beyond the perception of the individual designer. We are able to provide a substitute, or at least an aid, to man's intuitive analysis of the program. The tool which we will make use of is the computer along with a series of mathematical formulas which have been developed. 25
The computer manipulates the requirements of a problem in relation to their stated interactions to one another, as decided by the architect, into levels or groups of interacting sub-sets. The different levels of decomposition are determined through limits indicated by the mathematical equations. In any problem, we could decompose it into as many different component levels as were needed. The final level of decomposition would be determined when all the sets on that level contained only one variable.

FIGURE XIII

This arrangement of sets and sub-sets of requirements gives us the order in which the synthesis process will follow in determining the solution. The hierarchial arrangement arrived at gives us a clear picture of the total structure of the problem in a program which contains the requirements necessary for the evolution of the best architectural solution.
The list of requirements upon which this program is developed comes from the architect's analysis of existing conditions and limitations and from the research data which was evaluated earlier in the design development process. An example of such a program statement would be as follows: Building 'set-back' on the south side of the property will be a minimum of fifty feet. Once a list of requirements is established, the architect will proceed to indicate the interaction of each component with the others in the list. The following would indicate a partial list of requirements pertaining to the development of a program for an office building:

6) Parking for one hundred cars to be provided to the rear of the property.
   1, 7, 8, 22, 64, 65, 93, 105.

7) Easy access from the parking space to the building must be provided.
   1, 6, 8, 23, 32, 34, 35, 62, 64, 73.

8) Employees should be provided a separate entrance.
   6, 7, 21, 24, 36, 41, 42, 43, 73, 74.

9) Ceilings in offices should be a minimum of 9"-0".
   12, 16, 17, 26, 38, 40, 53, 54, 83.

10) A minimum of 15% of the site should be landscaped.

The numbers following each statement requirement indicates its interaction with others in the program. The computer evaluates the complex arrangement of links or interactions between components and divides the requirements into related sets and sub-sets on different levels.
within a hierarchial form. All the requirements have a twofold nature. They are both units and patterns. "Its nature as a unit makes it an entity distinct from its surroundings. Its nature as a pattern specifies the arrangement of its own component units. As a unit it will fit into the hierarchy of larger components that fall above it; as a pattern it will specify the hierarchy of smaller components which it itself is made of." 26

The method being discussed provides a means to an isolation of the abstract components of the problem. If a designer follows this hierarchy of components in the process of the design, the major components of the physical form should become clearly evident. The evolution of the form is the reverse process of the determination of the program. One is the breaking down to clarify and order, while the other is the synthesis towards the creation of a whole. It is a synthesis of sub-programs into physical diagrams which develop wholeness as they are combined with other diagrams along the program structure. The object of the design process is to create a physical form which sets as many of the variables within the program into a state of non-conflict.

"The computer is not a tool to prescribe the physical nature of forms, but used to express the conceptual order and pattern which a problem presents to a designer." 27 The value of the computer to this method of approach to the
design of a building is in its manipulation of units of requirements into a system of interacting sets and sub-sets. It is a decomposition of the design problem into groups of related variables which will determine the form of the building or architectural space.

An example of how these subsets relate as requirements to one another and how aspects of physical form evolve out of the effort to satisfy these requirements can be readily seen in an example given by Christopher Alexander. He talks about the design of a highway and how two requirements; safety on curves and keeping land costs at a minimum, interact and conflict. If the curves are designed wider for the sake of providing optimum safety, then the amount of land used increases. Both are affected by the same physical aspect, i.e. the radius of the curve. An example which would apply in the development of an architectural form could be that which involved requirements leading to the evolution of a module for an office building. The computer would help us break out those specific requirements which affect its determination. Once these variables have been satisfied, the module, as a unit, will be part of an interacting group of aspects of form on a higher level; such as in the determination of the building's proportion.

What we are accomplishing with this program is a breaking down of these interactions which govern the complete physical form being considered into sets of independent requirements which have as few links with the other as is
possible. It will then be evaluated in terms of the sets which fall above it in the hierarchial arrangement of variables. As we progress towards the final solution, the completed form, these groups become less frequent in number and more general in nature. In other works, there are fewer interacting variables to satisfy at major concept levels. This process continues until all the sets of variables are brought to equilibrium. To place this process in the master schedule we would best locate it between the 'Building Programming' phase and the 'Building Design and Planning' phase. The programming is done in the first and the synthesis of diagrams develops in the last phase of the schedule.

It becomes evident that this decomposition process which is involved in this method of design analysis has some value to us in the breakdown and scheduling of individual programs within the total system. There, as here, we have a great deal of interaction between the programs in data requirements and supply which could be simplified and scheduled efficiently if groups of related programs could be combined into a structured hierarchy of sets and sub-sets, as was achieved in the decomposition of design requirements.

This chapter is just an analysis of one of the many ways in which the computer can aid in the development of the design process. It will take time to adapt to new methods and systems and tools to use within the development of architecture, but if we do not begin now, it will be more difficult later on. The architect's work is going to
continue to become more complex and involve more responsibilities; therefore, let him prepare himself now.
V CONCLUSION

The information set forth in the preceding chapters has contributed to the advancement of architecture and the development of the role of the computer in the design process in that it contains guide lines to follow in the search for the proper application of the computer to the design process. This has evolved from a thorough evaluation of the demands on the architect today and a clarification of his responsibilities to himself as a professional and to his client. Major effort has been devoted to an investigation into the design development phase of architecture to enable us to see more clearly where and how this application will take place. The purpose was to explain the place of the computer and its operation in the design process to assure that those individuals interested in developing particular programs, which deal in some way with the determination of the design solution, would have a guide to use in developing it in relation to the total design process.

We have indicated the importance of the development of programs within a major system and not just their value as a random program application. Its full potential must be made available to the whole or total system. The thesis explains why and how this system must be analyzed and built and how it must be developed to function in its most effi-
cient manner.

The preceding chapters lay the groundwork for this new approach to the design process, making use of the new tools and methods available to us in the best possible manner. We have indicated a direct application of the computer to the development of the design process, while discussing the process as a comprehensive system to which will be applied various computer programs. All of the chapters have overlapping relationships with one another, and from each we gain a slightly different approach to the breakdown of the design problem. The need is expressed for the ultimate combination of these methods to form a single unit with which the architect will work.

We began by describing the new responsibilities which the architect of today and the future must take on if they are to gain the leadership in creating the environment of man. The aid of the computer is presented as the answer to man's struggle for clarity and sophistication within the design process. We further show the need to reanalyze the methods of design which the architect has traditionally used so that he will see clearly the necessity of a new approach to the entire design process.

We have created a skeleton of a master schedule for the entire design development phase of the architectural process. If the architect accepts the responsibility of coordinating all the activities involved in the comprehensive design process, then he will find such a network a
must in properly and efficiently scheduling the multitude of tasks within the problem. It also contains a method with which he can determine the allocation of responsibility and the duration of particular tasks.

Chapter III is a further analysis of the design process in relation to the application of individual computer programs to create a man-machine collaboration in the development of the design solution. Within this chapter some of the basic guidelines for computer application are established along with the beginnings of a flexible framework into which these programs will fit. The creation of an on-line system is briefly discussed with some discussion on the limits and abilities of the computer.

Chapter IV deals with a component decomposition in the process of establishing form. In this chapter a method of decomposing the elements, which go into the solution of a design problem, is presented. The advantages of this method over the traditional method of approach is discussed. It is explained where this program fits in the master network of activities and how it contributes to the whole. The program discussed here is part of the 'Building Design' phase and becomes an aid in designing and evaluating architectural forms.

The conclusions drawn in this thesis are to act as a starting point to stimulate others to proceed with this study in hopes of developing a working system which will
bring clarity and precision to the increasingly complex situations with which we are and will be faced. It is an effort to establish an approach, not to find the solution. This will come only after frequent modifications and additions to the theory presented.

The architect must come to a new and deeper understanding of his responsibilities and develop a method or methods to apply order to these tasks. He must let his invaluable intuition be the key to the successful completion of any design problem. When functioning with the computer as an aid, he will discover that the machine does not change the definition of his abilities, but that it acts as an extension of his capabilities. "Surely, for the architect, the capability to see, then to comprehend, then to manipulate the great array of variables which planning deals with, and to deal with them at a pace and depth of his choice, must free much of his energy and intuition for the ultimate goal."

We must utilize this tool which gives us a new thoroughness in our investigations, and development of the architectural solution. It will instill in our clients a new confidence in what we do and a renewed respect for the art.

But, too, we must be careful that enthusiasm in the application of the computer to the design process does not develop prematurely. It must be a planned and careful evolution. We must first fully realize that the computer is a machine which must have every step in its operation programmed by man. It is to be complementary to man's ability and not to be thought of as replacing man's in-
"Man is able to invent relations between things, and to see things in a new framework, but in any very complex situation he is unable to explore relations very deeply without prohibitive expense and time. The computer, while unable to invent, can explore relations very quickly and very systematically, according to prescribed rules. It functions as a natural extension of man's ability." 29

We must make sure that the problem to which we apply the use of the computer's abilities is fully understood. In order to program a computer, the programmer must list step by step each task which must be initiated and completed in a long line of events in order for the computer to function properly. This can only be accomplished after the programmer has completed a thorough decomposition and analysis of the problem. Without this basic knowledge of the problem's structure there is no way in which a program could be written to aid in the problem's solution.

In looking at the design process, we are faced with the task of first defining and analyzing its development in detail before the computer can be applied. We must be careful not to let our desire for computer application to the design process prevent us from gaining an unbiased decomposition of the process. We must not force a system which has as its goal computer application. The goal for which we must be striving must be that of finding a system which will provide us with the optimum architectural solution.

Then, too, we should never force the use of the computer onto those problems or tasks which are not complex enough to
demand its application. We must use this tool intelligently and develop its abilities with the utmost care and scrutiny to prevent the tool from being used haphazardly and without need. We must learn not to over-extend the capabilities of the computer and to always provide as flexible a system as possible for the programs to fit within.

"There is little the computer can do if we do not first enlarge our conceptual understanding of form and function." 30 This thesis investigates a manner in which the practice of architecture might change that would expose some of its complexities and which would require the aid of the computer to help solve them. We are by no means saying that this manner of approach to architecture and the design process in relation to the application of the computer is the best or the only way; but, it is the beginning of the search for a systematic approach to architecture with this new tool. The architect must take charge and coordinate the activities involved in this approach. He must be careful, though, not to take on responsibilities for which he is not qualified and he must prepare himself to have a clear understanding of the work of those who contribute to the creation of the comprehensive solution.

With time, an effective man-machine collaboration in a systematic design approach will develop which will help the architect to produce better architectural results. What has been presented here has by no means been put down as either 'the problem' or 'the answer'. They are notes on the subject which we hope will stimulate further thought and study.
APPENDIX I / ANALYSIS OF STUDENT PROBLEM

The following is a brief review of a problem given to the fifth year architecture students at Rice University under the supervision of Mr. Charles B. Thomsen and Dr. Nat W. Krahl. The work will be reviewed in terms of the theories presented in this thesis.

The problem presented to them was to design a speculative office building, with the first phase of the problem devoted to creating computer programs which would aid in the determination of a design solution. There were six major divisions of the design analysis which were chosen to be studied. The investigations included the following aspects of the problem: the core, elevators, construction costs, economics, a planning module, and the structural system. The work was divided and assigned to teams consisting of two people. Each program was designed to work independently of the others. In most cases, to get the programs to function without extensive programming and subroutines, human intuitive intervention was required. As the programs evolved, it became clear that there was definite interaction and dependency of one program on another. Each program presented information which could be used in determining the best solution to the design problem, but how did all of this information fit into the total design process? When could information from one
program aid in another's completion and sophistication?

There were overlapping input data and subroutine requirements and the order in which the programs should be executed had not been determined. It was evident that what was needed was a system into which these programs might fit and a manner in which to analyze the individual program's requirements to work efficiently within this system.

If we are to look at the formulation of these individual programs into the system of which we are speaking, we must first look at their position in the master schedule of the design process. In what major division of work do these programs, which these students created, fit? Let us examine the programs' positions in light of the information in the second chapter of the thesis and as diagrammed in Figure XIII. Economics is the only program which comes early in the master schedule before the initiation of the 'Building Design'. It begins before, but works in feedback with the 'Building Program' phase until the general requirement for the building site and activity which these must accommodate are almost complete. This program establishes the scope of the work and forms a budget for the construction of the building which,
to a point, governs the choice of building systems.

The other programs which were written would be located in the 'Building Design' phase of the master schedule as seen in Figure IV. Five of these fall under 'Major Systems Investigation' and feed information into the 'Development of Schematics' phase.

These five programs involve the following areas of study: the sizing of the core, the simulation of elevator operation, the determination of a planning module, and two programs which evaluate the structural system proposed for the building. These programs are all an investigation into and an evaluation of the various possible systems which might go into the make-up of the building. Every building is a synthesis of component systems, each having some bearing or link with certain or all of the other components within the total architectural space. An example of this would be the weight of an interior partition wall on the structural system or the heat transmitted through the perimeter glass wall affecting the mechanical requirements of the space.

Within this major systems analysis, there will be a great number of programs created. We must examine each of
these individually to determine its dependency on other systems and to know how to relate it to the whole. Taking, for example, the programs with which the students worked; what are their inter-linking characteristics and in what order should they be begun and completed? If we look closely at the programs' relations with one another, a certain logic begins to follow.

\[\text{STRUCTURE}\]

\[\text{ELEVATORS}\]

We first see that the development of the core is dependent on information from the program dealing with elevators before it can be complete. The core can vary more in size than the elevator in size and number because the importance of the efficient handling of elevator traffic within a speculative office building is at a higher priority level than is the design and configuration of the core. Therefore, we have the elevator program feeding information into the core program. Some other data which is necessary for a precise analysis of the core would involve the study of the mechanical systems and code requirements.

Another clear relationship which comes to mind when examining these programs is the link between the determination of a planning module and the investigation of a struc-
tural system. In this case the functional division of spaces and the requirements for the proper mechanical and lighting system will probably have priority in determining the building module. We would then feed this module size into the structural system programs to evaluate them in terms of this module. Consideration should be given to making the module small enough to give some variance in space division and bay sizes. This module size could also be fed into the core program to allow its development to take place within the same related framework. In all of these cases the results would be subject to careful designer supervision to evaluate, in terms of intuitive reasoning and individual experience, the results presented by the computer programs along the way. In this way making sure that the data being presented is reasonable to the design solution and that the work is following the logical path programmed.

Information from both structural systems programs and the elevator program will go into the construction cost program so that the systems which make up the building can be priced and totaled according to updated data to indicate whether or not we are within the scheduled construction budget. The designer must decide, here, if the job is over the construction budget set by the economics program, in which areas he must cut back. This information would then be fed back into the individual programs affected and revised accordingly in terms of lower costs. The following figure
indicates the general relationship of the programs written by the Rice students.

Some other areas which could require review in terms of possible computer aid in their evaluation are:

1) exterior treatment
2) interior architectural treatment
3) air conditioning systems
4) electrical and lighting systems
5) space divisioning
6) influence of use and maintenance
7) furnishing inventory
8) site development

These programs give us a glimpse of what the organization and interaction of programs would be within a complex master system in which man and the computer would collaborate. The programs, here, indicate what might be done in terms of major systems investigation. This is but one area of the entire process which must be understood and programmed. At first there will seem to be many overlapping divisions of work and the system will bog down in the complexity of its organization; but, if we start now to work within this framework the transition will come easier.

Here, we should take the time to analyze one of these individual programs and its development in terms of the method
of analysis mentioned in Chapter III of the thesis. By
doing this we will gain a clearer understanding of the
program's relation to the total design process. We will
take as our subject the program written for analysis of the
elevator needs for an office building. The program is shown
in a step by step diagram in Figure XIV.

<table>
<thead>
<tr>
<th>INTERNAL STATEMENT NUMBER</th>
<th>Program UP-DOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Written by Tom Bean and Andrew Sheldon</td>
</tr>
</tbody>
</table>

2-3  Writes titles.

4-6  Reads data.

1-27 Runs through all combinations of number of elevators, number of floors, capacity, and elevator speed.

30-32 Compares elevator speeds and selects correct time for full speed run.

33  Calculates round trip time.

34  Calculates actual handling capacity.

35  Calculated minimum handling capacity.

36  Compares actual to minimum handling capacity.

37  Calculates actual waiting interval.

40  Compares actual interval with maximum interval (30 seconds).

41-167 Calculates cost for all speeds and capacities of elevators.

170  Calculates cost of system.

171-172 Writes data.
After we have positioned the program in general terms in the master schedule and studied its relationship to the overall scope of events, we are ready to examine the program in terms of the basic data upon which it depends for its evolution. A certain amount of basic material must be fed into the computer memory at the beginning of each program to provide it with the necessary background material for it to manipulate and examine. This particular program requires the designer to read in a certain amount of basic information on available elevators. This would include elevator speeds, capacities of the elevators, and the costs of the various types. We would also feed into the program, at this time, the occupancy requirements for the building which would have been established in the research and analysis phase of the design process. The computer then calculates and compares all combinations of numbers of elevators, number of stops, elevator speeds and capacity based on the total occupancy figures recorded in the memory bank. The calculations which follow are involved in comparing factors of various combinations of particular elevators and then printing out the results of the analysis. The designer then chooses which of these possibilities works best within the price range for that particular system and the requirements established for vertical circulation speeds. In reference to the time requirements, the designer sets forth a maximum waiting interval which is used as a limit to keep the computer from evaluating information which is beyond the practical range of possibilities for the project.
This information, which has been evaluated by the designer, is then available to be used in the determination of other parts of the total design. One such program which requires this data to reach a more precise answer is that of the core development. If this program on the analysis of elevators were linked to the construction cost program so that these two programs could work together in feedback, a more precise solution could be found. This elevator study program is one of the less involved of the programs, and its interrelation with the others in this phase of the design solution is at a minimum.

There are some programs which require interaction with a great number of others. One of these involves using the computer in making preliminary cost estimates of particular schemes based on costs of the various systems within the building. The computer memory is kept current on the various systems' costs and types and a percentage factor can be introduced for an adjustment in costs for different site locations. This program should be linked to each of the programs which bring about a decision on a building system component. Information may first be required by some of the individual component programs, as to what general cost range they are governed by, so that the solution which satisfies all requirements, including cost, might be evaluated properly. This is probably a rule of thumb figure, at first, which develops into more precise data as information from completed programs is fed back into the construction cost programs. Some of the
basic system components which the building can be broken down into are listed as the following:

1) Roof  
2) Floor  
3) Partitions  
4) Elevators  
5) Ceiling  
6) Exterior wall  
7) etc.

This program enables us to evaluate the architectural solution to a problem in terms of cost before schematics are too fully developed, and then gives us a more precise cost figure as the schematic development phase progresses.

This was just a brief look at two of the programs which were created by the Rice architectural students, but it gives us an idea of the potential of the computer in the area of major systems research. These programs cover only a few areas of possible application in this phase and this phase is a small part of the entire design process. We, as architects, have a long way to go to reach the ultimate goal of an efficient computer-designer combination. Let us accept the challenge of this age of technology and make the best use of the tools which it has placed in our hands.
FOOTNOTES


5. Ibid., December 1962, p. 59.

6. Ibid.


17. Ibid., p. 93.
18. Ibid., p. 94.
20. Ibid.
24. Ibid., p. 124.
25. Ibid., p. 125.
26. Ibid., p. 130.
Books


Articles

Computers


**Articles**

**General**


