CONTROL SYSTEMS
FOR THE
BUILDING DESIGN PROCESS

by

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ABSTRACT

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Submitted to the Departments of Civil Engineering and Architecture on May 9, 1975 in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering and Master of Architecture.

In response to the confusion, complexity and attendant lack of control apparent in the contemporary building design process, this thesis attempts to apply modern, scientific management control systems to the activities and participating professionals of this process. The problem is, in many ways, one of applying logical and quantitative methods to a process most often conceived of as creative and qualitative.

An information-flow based descriptive model of the design process has been evolved which graphically represents the process in terms of differentiated flows of specific information, its sources and destinations, and the activities and decision procedures which these information flows serve.

Using the descriptive information-flow model as a framework, five specific control subsystems have been designed, which together submit the various information flows to the quantitative control capabilities of appropriate management control methodologies. Applications of these control systems hopefully reduces the uncertainty of achieving design process goals.

Thesis Supervisor: Robert D. Logcher
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To R.D. Logcher and Ed Allen who sat
with me and on me to get this thing done.

To the women in my life, with and
without whom this thesis was written.

Nan
Stephannie
Vivian
Francis
Joey

and the one who started it all
June
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title page</td>
<td>1</td>
</tr>
<tr>
<td>Abstract</td>
<td>2</td>
</tr>
<tr>
<td>Acknowledgement</td>
<td>3</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>4</td>
</tr>
<tr>
<td>List of Figures</td>
<td>7</td>
</tr>
<tr>
<td>Chapter I - Introduction and Background</td>
<td>8</td>
</tr>
<tr>
<td>I.A Problem Statement</td>
<td>8</td>
</tr>
<tr>
<td>I.B The Building Design Process</td>
<td>10</td>
</tr>
<tr>
<td>I.B.1 Definitions</td>
<td>11</td>
</tr>
<tr>
<td>I.B.2 Descriptions</td>
<td>14</td>
</tr>
<tr>
<td>I.B.2.a Contemporary Models</td>
<td>14</td>
</tr>
<tr>
<td>I.B.2.b Information Flow Model</td>
<td>19</td>
</tr>
<tr>
<td>I.C Management Control Systems</td>
<td>21</td>
</tr>
<tr>
<td>I.C.1 Accounting Control Systems</td>
<td>21</td>
</tr>
<tr>
<td>I.C.2 Procedural (Activity) Control Systems</td>
<td>22</td>
</tr>
<tr>
<td>I.C.3 Psychological Control Systems</td>
<td>23</td>
</tr>
<tr>
<td>I.C.4 Design Methodology Control Systems</td>
<td>27</td>
</tr>
<tr>
<td>I.C.5 Integrated Control Systems</td>
<td>30</td>
</tr>
<tr>
<td>I.D Current Applications of Management Control Systems in the Building Design Process</td>
<td>33</td>
</tr>
<tr>
<td>Chapter II - Methodology</td>
<td>37</td>
</tr>
<tr>
<td>I.A Philosophy</td>
<td>37</td>
</tr>
<tr>
<td>I.B An Integrating Iterative Approach</td>
<td>39</td>
</tr>
</tbody>
</table>
Chapter III - A Control System For the Building Design Process

III.A System Overview

III.B The Six Control Subsystems

   III.B.1 CLIENT CONTROL
      III.B.1.a Choice of Manager
      III.B.1.b Goal Articulation
      III.B.1.c Set Process Objectives
      III.B.1.d Revise Objectives

   III.B.2 PROCESS CONTROL
      III.B.2.a Analyse Existing State/
                     Propose Objectives
      III.B.2.b Decide Procedures
      III.C.2.c Change Procedures
      III.B.2.d Correct Errors

   III.B.3 INPUT MANAGEMENT
      III.B.3.a Assemble Resource Summary
      III.B.3.b Decide Resource Allocations
      III.B.3.c Alter Allocations

   III.B.4 MONITOR
      III.B.4.a Establish Evaluation Parameters
      III.B.4.b Evaluate Progress/
                     Note Discrepancies
      III.B.4.c Analyze Discrepancies
      III.B.4.d Progress Report
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Design Process Responsibility Model</td>
<td>15</td>
</tr>
<tr>
<td>1.2</td>
<td>Design Process Responsibility Model B</td>
<td>15</td>
</tr>
<tr>
<td>1.3</td>
<td>Design Process Activity Model</td>
<td>16</td>
</tr>
<tr>
<td>1.4</td>
<td>The Iterative Spiral</td>
<td>18</td>
</tr>
<tr>
<td>1.5</td>
<td>Primitive Information Flow Model</td>
<td>19</td>
</tr>
<tr>
<td>1.6</td>
<td>Critical Path Method Network</td>
<td>24</td>
</tr>
<tr>
<td>1.7</td>
<td>Black Box Design Process Model</td>
<td>28</td>
</tr>
<tr>
<td>1.8</td>
<td>Self-organizing System Design Process Model</td>
<td>29</td>
</tr>
<tr>
<td>1.9</td>
<td>Information Flow Network</td>
<td>32</td>
</tr>
<tr>
<td>2.1</td>
<td>An Integrating Interactive Method</td>
<td>39</td>
</tr>
<tr>
<td>3.1</td>
<td>Comprehensive Control System Model</td>
<td>44</td>
</tr>
<tr>
<td>3.2</td>
<td>CLIENT CONTROL Subsystem</td>
<td>47</td>
</tr>
<tr>
<td>3.3</td>
<td>PROCESS CONTROL Subsystem</td>
<td>54</td>
</tr>
<tr>
<td>3.4</td>
<td>INPUT MANAGEMENT Subsystem</td>
<td>60</td>
</tr>
<tr>
<td>3.5.</td>
<td>MONITOR Subsystem</td>
<td>67</td>
</tr>
<tr>
<td>3.6</td>
<td>OUTPUT MANAGEMENT Subsystem</td>
<td>76</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION AND BACKGROUND

I.A Problem Statement

This thesis presents the foundations of a system, based on information flow, for the control of the process by which buildings are created, hopefully improving the process and making its products more responsive to human needs. This system permits conscious and explicit control over complex and changing processes usually controlled intuitively and implicitly. Underlying this system is a descriptive model of the building design process which characterizes all activities of the process in terms of their information input and output. Normative content comes from explicit description of previously undifferentiated information flows and from specific enumeration of control procedures. Such a system should increase the efficiency of the building design process, permit easier recognition and resolution of conflicts bound to arise, and help insure that the process's ultimate products, buildings, more directly and appropriately fulfill their desired purpose.

An explicit system of control for the building design process responds to the three greatest problems of building design: the complexity of the process, the difficulty of translating subjective human desires and goals into specific physical reality, and the uniqueness of each building created. Complexity arises from the necessity for hundreds of different goals and thousands of activities to come together and interact before a building can be successfully created. Translating subjective needs into
built reality is difficult because no algorithm, logical or heuristic, exists which can mechanically transform human goals into physical solutions (which achieve those goals). Mathematical models exist only for the most well defined components of this transformation. The uniqueness of each building situation denies the applicability of any single set of procedures with which all buildings may be designed. Any system of building design control must then simultaneously coordinate complex sets of activities and people, evaluate the validity of translations of subjective parameters, and adjust itself to a never before experienced sequence of events.

Four separate control system methodologies are required to regulate all information flows in the building design process. These four methodologies correspond to the four kinds of information which flow from person to person and from activity to activity in the process. Design methodology regulates the process by which general and qualitative human desires are transformed into specific and quantitative design solutions. Budgeting, scheduling and cost control methods regulate the amount of time and money expended in producing the design solutions. Network theory regulates the relations between and the interdependences of all the activities required to arrive at successful solutions. Group dynamics and other psychologically based methods regulate the relations between all the people whose labor and ideas are used in the creation of the product. Multiple control methodologies permit different information flows to be regulated in ways most appropriate to their content and use. They also explicitly focus on potential problem areas easily ignored by simpler methods. While
extensive research has explored each of these individual control systems, this thesis is apparently the first study which harnesses all four together in pursuit of building design process control.

The four information flows and their respective control methodologies will hereon be consistently described by four more or less appropriate labels. The information content of the design process's transformation of qualitative goals into quantitative solutions will be called "substantive information" - this is the "message" of the system. The activity relationships will be defined by "procedural information" - this is the "medium" on which the message is carried. "Accounting information" will describe the measures of cost which accompany design activities. "Psychological information" will identify the qualities of human interaction between client and professionals and between the professionals themselves.

The purpose of this thesis, control of the building design process for human ends, has now been established. The problems which accompany this goal have been outlined. The following chapters will describe in more detail the general concept of control as well as the workings of the four control systems required for successful regulation of the building design process.

I.B. The Building Design Process

This thesis attacks the specific problem of how a client can use control techniques to regulate the activities of the building design process, its contributing professionals, and its coordinating manager so that its
product, a building, best serves his interests. These five concepts: client, control techniques, building design process, professionals and manager, provides a simple and general conceptual framework for analysis which also allows specific normative prescriptions. Before analysis or prescription can continue, though, these concepts must be defined.

I.B.1 Definitions

The building design process is that set of people, activities, and information flows which come together to transform human goals and environmental needs into responsive physical built form (Building Performance Research Unit, 1972). The design process contains far more activities than mere physical "architectural design"; it also includes engineering design, legal negotiation, financial analysis and planning, political compromising and implementation (construction) coordination, as well as hundreds of other activities. The design process may be conceptualized as a highly interactive system whose boundaries are not precisely defined. As a human system the process may be further defined as a set of "consistant goal-directed activities" (Archer, 1970). The "goals" towards which the process hopefully strives come from the client.

The client is that person or group of people whose goals and needs are served by the design process, and who provides the resources necessary both for the design process and for the physical realization of the design process's informational product, the building design, as represented in drawings and specifications and, ultimately, the building. Though it is convenient to specify the client as simply one who orders, chooses and pays...
(Le Corbusier, 1946), modern commentators have felt a need to broaden the definition to include those affected by the building (specifically the "user" (Partlow, 1973) and those who directly influence the characteristics of the building (the government). These valid insights not withstanding, the client will be understood by the simpler definition; those affected by or affecting the process who don't meet the requirements of "order, choose, and pay" will be understood as constraining factors acting upon the actual client.

The professionals are that set of people who have the specialized skills, education and ability required to perform the tasks required for the successful goal accomplishment of the design process. They include architects, engineers, planners, bankers, estimators, functional specialists, market analysts, and others. The necessary set of professionals is defined by the scope, complexity and nature of the specific design problem, and thus is not constant from case to case. Professionals are assumed to have specialized tools unavailable to the client, tools which are required for successful design. Professionals interpret, create, and utilize information on the one hand, and require time and compensation for their services on the other. Professionals both deliver an information product to the client and help the client understand and communicate his needs and goals to the design system.

The manager is a special professional whose duty it is to coordinate the activities of all other professionals, solely in the interest of the client. The manager acts as liason between the client and the professional and coordinates activities and information flows of the design process.
As liason the manager must translate and communicate the client's goals to those able to achieve them and reciprocally must translate information created by the system into a language the client can understand. The manager is required because the client's ignorance of the specialized activities and information does not permit him to initiate, coordinate or control those activities. Thus the control of the process must pass from the client, through the manager, to the individual professionals and activities.

Traditionally, an architect has filled this managing role as agent and integrator, but other professionals such as engineers and project managers have filled it as well. The manager represents a centralization of responsibility: his existence permits the client to focus evaluation on one, pre-specified professional. When problems arise, the client need not search for the right profession to blame; the manager represents the focus of responsibility. In modern America the architect as manager acts as a legal responsibility center, assuming liability for the actions of his professional subordinates. The manager's three functions may then be thought of as: liason, coordination and responsibility centralization.

Control techniques are procedures by which one person or group of people can regulate the activities, products and resources consumed by another person or group of people. Control interfaces three entities: a person who controls, an activity or person who is controlled, and a mechanism by which that control is effected. Due to its interrelationships the tripartite client-manager-professional organizational structure requires two control relationships - one from the client to the manager, and one
from the manager to the various professionals. The client's relative naivete of the professional activities produces the need for the intermediate control link, the manager.

I.B.2a Contemporary Descriptive Models

Before a system for the control of the building design process can be discussed, the structure and workings of the design process itself must be examined, described and understood (to a lesser or greater degree). That is, the exercise of control requires both an understanding of the mechanism to be controlled (in this case, a complex set of activities and the professionals who perform them), and a breaking down of complex sets of interrelations so that control can focus on a more or less homogeneous set of problems. Although little consensus appears about how the design process proceeds, a positive statement can be made about what it produces. Somehow, the design process begins with a client, his needs and his resources, and through the use of various professionals and technical processes, transforms these needs and resources into a physical building.

There are several simple and widely accepted design process models which attempt to describe various facets of this transformation. These models describe the process in terms of responsibility relations, activity relations, and information relations.

The client/architect/contractor model (Figure 1.1) sketches, most primatively, the basic flow of responsibility in the building design process. This model does have some validity: it explains a certain kind
of agency. The architect is responsible to the client both for his own work and for representing the client in relations with the contractor. The contractor is not directly answerable to the client, but rather, receives orders through the client's agent, the architect.

Totally in keeping with the spirit of this model, additional responsibility relationships can be described as in Figure 1.2.

This more sophisticated model is instructive in describing who answers to whom. But it is obviously of little help in understanding what and how each of the various participants actually perform.

The activity relation model of the design process (Figure 1.3)
Jones, 1970, p.24 for a more complete list of activities) attempts to describe the design process in terms of process activities. Certainly, contemporary design professionals feel some sympathy with this model: they refer to various periods in the process by these activity names. Design fee payments are organized around the milestones which occur at the conclusions of these activities, and cost allocation and control is based upon these five categories.

The design process activity model has broader implications than simple activity relationships, though. Each of the five activities has a different kind of output: programs are written and general; schematic design drawings are imprecise, tentative and sketchy; and design development drawings are more precise and detailed than schematic drawings, but much less explicit and complete than the contract documents (working drawings and written specifications). The difference between these activity outputs is so pronounced and consistent as to give the model a gross informational content, as well as an activity relation content. Observably, the specificity of each successive information product increases as the process proceeds. The spectrum from program to contract documents is also a spectrum from general and tentative information to specific
and quantitative information.

Most students of the building design process (Markus, 1967, Maver, 1970, Broadbent, 1973 and others) agree that in terms of substantive (design) information, the design process transforms general and qualitative information (intentions and goals) into specific and quantitative information (drawings, specifications and contracts, which lead to buildings). The design process transforms "intention into achievement" (Building Performance Research Center, 1972). Unfortunately, there is no similar consensus about how this transformation occurs.

One insight into the mechanics of the design process information transformation is through the identification of the path the transformation takes. Most agree that the transformation is not linear, but rather, to some degree, circular: going backwards is part of the process. The circularity appears as observed "feedback" or evaluation procedures in which an information product is evaluated, and in the case of rejection, the activity which produced that product, or one with which it is in conflict, is repeated (Archer, 1963). Some (Mesarovic, 1964 and Watts, 1966) have modeled the circular path in the form of a spiral in which an interacting sequence of analytic, synthetic and evaluative activities lead the design process from the abstraction of intentions to the concreteness of physical solutions. Figure 1.4 shows one representation of this transformation spiral. Though helpful in elucidating what the design process does, the circular transformation model is weak in addressing the "hows" which affect various issues of control such as: who does the work?; how much is he paid?; how are joint efforts coordinated?; how does one participant know
what can be done next?; and a host of other questions. Knowledge of the structure of information transformation in the abstract is a far cry from understanding how that process is actually accomplished in real life.

In summary, it appears as if none of the above models of the building design process is essentially incorrect. Rather, their simplicity and lack of detailed analysis of information flows, activity content, professional responsibilities, or empirical realities (time, money and psychology) make them of limited use in devising specific methods of process control.
I.B.2.b Information Flow Model

It has proven useful to conceive of the building design process in terms of information flows (Yang & Fenves, 1974, Best, 1969, Archer, 1968 and others). An information flow is a message from one person, group or state of process to another. The specific information which describes how a wall is to be built flows from the designers to the contractor in working drawings, for instance.

The information flow model is, at its most gross level, an assembly of three elements: inputs, a transformation process, and outputs (see Figure 1.5).

![Figure 1.5: The Iterative Spiral (Becker, 1973 p.16)]
The transformation process, through logic, experience, synthesis, creativity and other methods, seeks to "raise" the input information content to a higher level (in the case of the design process "higher" would mean more precise, more specific or closer to desired intentions).

The content of information flows need not be only "substantive" (design) information. Accounting information, for instance, can be similarly transformed as less precise forecasts and more general budgets are raised to the level of quantified expenditures and specific activity budgets. Procedural (activity scheduling and regulating) and psychological information may be similarly represented by the information flow model.

The "input-output" nature of the information flow model does not require investigation of the transformation mechanism ("process") so much as it examines the various necessary inputs and desired outputs themselves. The model needn't be as simple and primitive as the one shown in Figure 1.5. Various circular flows running from "output" back to "input" describing how the process feeds itself with new, self-generated information can and should be a feature of the model. Additionally, the actual contents of various information flows can and should be both specified and differentiated.

With these suggested additions the information flow model will serve as a useful tool for establishing a framework for building design process control systems. For the moment though, this topic will be set aside and the various capabilities, uses and characteristics of individual management control systems will be investigated. Then, after an integrating
methodology is presented in Chapter II, the information flow model will be coupled with the control systems in Chapter III.

I.C. Management Control Systems

Management control systems are sets of consistent and explicit methods which minimize the uncertainties involved in achieving organizational goals. Because these systems are essentially analytic tools which deal with complex, stochastic and empirical processes, they never eliminate the uncertainties of goal achievement, but as the best rational tools available, they have proven strongly useful in eliminating unnecessary uncertainties.

The four management control systems of interest here deal with: the resources consumed by a process (cost control systems); the activities through which the process achieves its goals (network scheduling methods); the psychological characteristics of the professional personnel who accomplish the process activities (various psychological control methods); and the information transformation which is the purpose of the process and its activities (design methodology).

I.C.2 Accounting Control Systems

Cost accounting control systems seek to relate and balance the cost of resources consumed by processes with the value of the process's produce or output. For each definable product (which has an associated value, of some sort) cost accounting attributes all costs, direct and indirect, which go into producing that product. Cost accounting's strengths lie in
its ability to separate complex sets of costs and create one to one cost to product (benefit) relationships. In so doing items or activities whose costs exceed their values can be identified and dealt with in whatever appropriate manner.

The cost control systems most applicable to professionally based service industries like the building design process are generally somewhat loose and non-rigorous. Essentially, these systems require managers to budget for future expenditures, given an expected level of performance quality. Budgeting forces managers to exercise their experience and judgement, and provide their best estimate of the cost to do a certain job (a job which is most probably not specifically defined a priori). The manager is then expected to maintain the level of forecast expenditure in the course of actually delivering the product or service. If and when actual expenditures vary markedly from those budgeted, the manager is expected to explain how and why the variance came about and what he proposes to do to avoid similar variances in the future.

The looseness of this type of cost control system reflects the very justifiable fear that if a manager is forced to adhere too rigidly to budgets alone, the quality of the services which are being controlled will suffer. A professional cannot be evaluated simply on how cost effectively he performs his function, but rather on how effective his solution is.

I.C.2 Procedural (Activity) Control Systems

Procedural control regulates the relationships between the sequence and
timing of the various activities which must be successfully performed in order to complete a process. An entire process is a collection of activities, each requiring certain amounts of time to be completed. Procedural control systems attempt to regulate (usually minimize) the total time consumed by the entire process. This minimization is accomplished by planning and coordinating the sequences of activities scheduled according to dependences on other activities.

Network scheduling techniques (of which the popular Critical Path Method (CPM) is one) (see Moder & Phillips, 1970) attack the activity scheduling and control problem by explicitly recognizing that certain process activities are necessarily dependent on other activity "precedents". A complex process, made up of many activities, each of which is related to some other activity (ies) by these precedence relationships can be graphically represented as a "network" of such activities and their precedents. With the network the manager is able to locate those critical activities which most directly affect the successful completion of the entire process. Figure 1.6 is an example of one kind of activity "network". The network scheduling method forces a manager to explicitly identify, coordinate and schedule process activities. The network then tells him on which activities to focus his attention. Lastly, it gives the manager a rational method with which the macro-process implications of micro-activity decisions (and occurrences) can be explicitly expressed.

I.C.3 Psychological Control Systems

Non-rationally based human characteristics such as creativity, motivation
and temperament, as well as the complexities of human interaction, precipitate the need for dealing with and controlling psychologically based problems which might interfere with the successful achievement of a process's goals. Three general areas of psychological control are of interest: responsibility and reward structure; group dynamics; and conceptual language analysis.

By appropriately assigning responsibilities and rewards to the various participants in a process the manager attempts to create a congruence between the process's goals (organization goals) and the goals of the individuals. Relying on the concept of self-interest, this approach reasons that if participants are personally rewarded when their efforts
contribute to the organization goals they will be motivated to pursue those goals.

Through the understanding of group dynamics a manager attempts to devise strategies which encourage cooperation, interaction and sharing among the members of a group who strive towards a shared set of goals. By instilling in participants an allegiance to organization goals these methods attempt to eliminate or minimize narrowness, non-productive competition, insulation and other self-centered personal characteristics which tend to separate participants from each other, discourage effective communication and fragment the group effort. Although somewhat imprecise in application, these control techniques attempt to create an altruistic atmosphere in which the personal satisfaction of participation in a successful group effort is perceived by all participants.

With recognition of and attempt to control different conceptual languages the manager strives to minimize inefficiency and confusion created by communication in which the receiver does not understand the sender's "language". Dealing with very different levels of abstraction, for instance, an architectural designer and a structural engineer may "literally speak different organizational languages and, if they are to relate effectively, require a third party who speaks both languages to translate for them." (Bennigson, 1972 p.4). By serving as third party translator the manager strives to maximize the usefulness of valuable information by minimizing losses due to poor communication.
I.C.4  Design Methodology Control Systems

Control systems for design methodology can be described only as nebulous, weak and confused. Whereas control systems explicitly attempt to reduce the uncertainty of not achieving goals, design methodologists appear to focus on the much more amorphous end of making the design process "better". Some of this imprecision in control techniques evolves from a general uncertainty as to the nature of the descriptive model of the design process. Because of this uncertainty, this section will examine the three logical possibilities which cover the realm of possible design process descriptions. Those control systems which would be appropriate if a specific model were valid will be discussed as well.

The first model conceives of the design process as completely rational: the "designer as glass box" (all three models are as described in Jones, 1970, Chapter 4). All the activities in design processes are assumed to be rationally explicable and analytically based. For this model, control becomes exceedingly simple. Told what to do, the manager merely initiates the systematic method for achieving specified goals, checking to make sure that the analytically chosen activities are properly executed.

Four assumptions are necessary in order to make the glass box model valid (Jones, 1970 p.50): Goals and criteria must be fixed in advance; analysis is completed before solutions are generated; evaluation is logical (as opposed to empirical); and strategies are fixed in advance. The design process, as described in Sections I.B.2.a and I.B.2.b, meets none of these criteria. Therefore, the designer as glass box and its corresponding
simple control methodology are of doubtful use in dealing with actual building design process problems.

The second model conceives of the design process as totally inscrutable, creative and irrational: the designer as "black box" (Figure 1.7).

![Figure 1.7: "Black Box" Design Process Model](image)

Inputs can be observed going into the process and output can be observed coming out, but the transforming mechanism is opaque to rational analysis. The control implications of this model suggest that only choice of input can affect the output. Because this input is only one set of a priori chosen substantive information, the pure black box model is practically insulated from control.

The third model, the "designer as self-organizing system", conceives of the design process as some combination of rational pursuit coupled with a creative (and irrational) information transforming process (see Figure 1.8). Control appropriate to this model involves allowing the creative process to run its unbridled path in a context of rational evaluation and input planning. This approach admits that part of the design process is indeed an inscrutable black box, but that other design process activities can use rational and analytic tools to orient, evaluate and supply (with inputs) the inscrutable activities. Control occurs as the most appropriate
inputs, strategies and constraints are rationally chosen and supplied to the black box. Control continues as intermediate outputs of the black box are rationally evaluated (in light of analytically evolved parameters) and new input choices are made in the light of these evaluations of previous outputs.

Depending on how inputs are defined and chosen, there does not appear to be a great difference between the black box model and the self-organizing system model. Both descriptions recognize that some irrational activity is required to perform design process information transformations. The black box model merely (almost lazily) assumes that no intermediate evaluation and input re-selection activities exist. Because of this oversight by black box advocates it now appears that both black box and self-organizing system models require similar control methodologies. Further, if some existence of irrationality is the worst case (in terms of applying control), a control system which can permit some black box processes to continue, and still maintain control, should be a sufficient solution.
In the next two chapters the necessity of integrating the four management control systems into one comprehensive tool for coordinated building design process control will be discussed. This section describes three existing approaches which begin to interrelate the various control systems.

Moder and Phillips (1970 Chapter 10) illustrate the ease of integration of procedural control (activity planning) with accounting control (cost control). Using the CPM as a framework they suggest a method which attributes costs to the defined activities and uses the time-scaled network to budget expenditures over time. Resource allocation plans and decisions can then follow directly from the implied pattern of expenses over time. Control occurs as a specific level of expenditure is planned and budgeted for a specific date, and variances from this plan result in investigation, action and a new revision of future expense/time relationships.

Benningson (1972), with his "TREND" system, integrates the activity organization of the CPM network with various psychological considerations (as discussed in Section I.B.3). The TREND control system requires the manager to draw a "responsibility center map", derived from an analysis of the organization's structure, which describes the authority and responsibility flows and relationships within the organization. Using this map as a framework the implied dependencies defined by the CPM network precedents are superimposed and "important coordinating needs" (p.6) are highlighted. By pinpointing "relationships suggesting authority conflicts or communi-
tion (uncertainty) conflicts" the manager can then concentrate on interacting with the organization and its professionals in areas where psychologically based problems are most likely to occur. The TREND system does not tell a manager precisely how to correct such psychologically based problems so much as give the manager an analytic tool with which to identify potential problem areas.

Yang & Fenves (1974) have perceived the interdependence of design process activities and the flow of substantive (design) information in the design process. Drawing on the recognition that design process activities are information dependent since activities are essentially information receivers, transformers and generators, Yang & Fenves provide a method for mapping design information flow as a matrix overlapping the CPM activity network (Figure 1.9). Thus, the start of an activity depends not so much on the completion of its activity precedent as on the various information files which the preceding activity generates and provides. This method of representation focuses the manager's attention on the information requirements of activities, which are a more detailed and explicit set of requirements than the simple activity precedent requirements.

The Bennigson and Yang & Fenves research provides new insight into the problems of control of the design process. But both works are strongly tied to the CPM network as an organizing framework. If the design process is much less deterministric, less stable and less a priori definable than the network modelling techniques suggest, then it is not at all clear that the CPM network should be the central organizing framework upon which all
other control systems depend. If designing "activity strategies" is an integral part of the building design process, as it appears that it is, then the network activity representation itself must become dependent upon future generated information, and must be able to change, in recognition of this dependence.

In Chapter II a method for integrating all four control systems into one comprehensive and rational tool for design process control will be introduced. This method will permit the Bennigson and Yang & Fenves insights to be incorporated into a control system which does not rely upon the CPM network as its organizing framework.
I.D Current Applications Of Management Control Systems In The Building Design Process

Obviously some sort of control is always exercised during the building design process: buildings do get built, don't fall down, and satisfy some client goals to some degree. But, contemporary design processes are not, in general, controlled by explicit, conscious, rational or specific methods. Implicit standards, intuitively and inconsistently applied, appear to be the rule in contemporary practice. A great deal of improvement is possible.

1. Accounting control. Contemporary design process cost accounting methods are not extensive. In general the cost accounting systems allocate the total design fee to five gross design activity areas: programming; schematic design; design development; contract documents; and contract administration (inspection). The allocation breakdown is made by negotiation and experience; percentages of the total fee are routinely allocated to each of the activity areas rather independently of the particular project. Within each gross activity area cost control appears limited to allocations among professional disciplines and attempts to limit expenditures to allocated levels. Records of productivity, cost of discrete and identifiable activities, department budgeting and other common cost accounting procedures appear absent from most firms.

2. Procedural control. Although some firms experiment with network scheduling methods, process activity control in most firms is either intuitive or mechanical. Activity scheduling usually involves a manager's
experienced and intuitive activity assignments in the context of negotiated milestone deadlines. For a given schedule, manpower allocation is decided by various historical rules of thumb. Conscious scheduling strategies taking into account activity precedences occurs only at the macro level. The architectural "charette", in which all remaining work is jammed into a 24 or 36 hour continuous work session before deadlines, is good evidence of the lack of schedule planning inherent in the design process.

3. Substantive control. While the manager's control of design information is often competently regulated by intuition towards the manager's own expectations, the client is often at the manager's mercy in so far as pursuit of client goals is controlled. The process, regulated intuitively, becomes an inscrutable "black box" in the eyes of the client. His ignorance often limits his participation at scheduled design review sessions to simple approval or rejection of presented alternative schemes, which appear almost randomly (to his perception).

Because the client has no explicit methodology with which he can participate in design process activities his main tool of control is in the choice of manager (or architect). A fortunate client's manager will pursue the client's goals; an unfortunate client appears to have few tools with which he can regulate his manager and explicitly, consistently and effectively impress his concerns on the process.

4. Psychological control. Experimentation with the psychological
implications of different design process organizational structures has occurred over the past twenty years (Caudill, 1971 and Smithson, 1968). The general trend has been towards organizing professionals in project oriented "teams", instead of organizing offices in "functional" groups (which deal with many projects).

It appears as if communication problems due to disparate conceptual languages often goes unnoticed, much less controlled. Most often professionals speak in the language to which they are accustomed, regardless of to whom they are communicating. Only when gross misunderstandings occur do managers intervene and attempt to fulfill a translator's role. Such communication problems lead to clients not understanding what they are getting, managers not understanding what clients want and need, and various professionals not understanding the information input upon which they depend.

Given the general absence of rational management techniques evident in the contemporary design process, it is felt that there is a great deal of possible rationalization and improvement to be made in the area of "scientific" management techniques. One precautionary note, though: many design organizations are very small and tend to revise and adjust their organization (through hiring and firing) to meet immediate demands. The overhead costs implied in more rational management systems suggests that only larger and more stable organizations will fully benefit from some of the proposed control methods. Small firms, run by intelligent and sensitive managers, will probably remain better off depending on less expensive, intuitive methods. Still, even small organizations should be
able to improve performance by adopting the spirit, if not the letter, of rational management control techniques.
CHAPTER II
METHODOLOGY

II.A. Philosophy

Though the purpose of this thesis has been to provide rational and explicit techniques for the client's benefit in controlling the complex, indeterminate and usually intuitively regulated building design process, it cannot be said that the methodology used to arrive at the comprehensive control system detailed in the succeeding chapter was particularly logical or analytically based. The primary impetus behind this research was an intuitive recognition that the contemporary design process often runs, to a large degree, by itself. Decisions are made for unspecified reasons, designs evolve almost randomly, and the final solution representing undocumented compromises, "just happens to turn out the way it turns out", without conscious control or through a clearly definable sequence of events. It was felt that this obtuseness, confusion and opacity of the process tended to force decision makers into myopic choices that tended to "optimize subsystems" - choices that, while attempting to improve parts of the process, would, in the end, be deliterious to the process as a whole.

Several early perceptions were instrumental in this research. First, it was perceived that information was the prime commodity dealt with by the design process (and thus, the prime entity to be regulated). All process products take the form of either paper (written specifications, drawings, contracts, etc.) or talk (telephone communications, meetings, orders, etc.). Second, it was found that several very different kinds of information were
used by the process. The identification of the four information types (substantive, procedural, accounting and psychological) was an attempt to represent and categorize all possible different kinds of information used, transformed and created by the process. Third, though, it was subjectively posited that the client's successful goal achievement would be the end and reason for all activities of the process. Fourth, therefore, was a recognition that if four categories of information were to be used for control towards a single end, some sort of integrating method which would segregate all information for collection and communication, but tie it together for control had to be discovered.

The spirit of the methodology of "systems analysis" was found to provide many answers to the problems of integrating complex and disperate processes and activities towards a single end. Because systems analysis attacks "the fundamental issue of design and management: that of specifying how men, money and materials should be combined to achieve a higher purpose" (de Neufville & Strafford, 1971); because systems analysis is the "formal awareness of the interactions between parts of a system" (Forrester, 1961); and because systems analysis promotes "explicit, quantitative analysis ... designed to ... increase the value of (goals) achieved by an organization" (Hitch, 1969), it was felt that some use (albeit loose, non-quantitative, and analoguous) of the systems methodology could answer many of the problems of building design process control.

Specifically, the rigorous analytic methods of systems analysis (linear programming, marginal analysis, welfare maximization (cost-benefit
have not been applied to the problems attacked by this thesis. Rather, the consistant and logical approach of systems analysis in relating subjective values to technological problem solving has been applied to the building design process. Drawing a rough analogy to systems analysis, a process which forced all decision-making activities to regularly relate subjective and qualitative parameters to specific and quantitative activities and vice-versa, was designed, to act as a controlling and integrating framework for all design process decisions and control sub-systems.

II.B An Integrating Iterative Method

The integrating methodology viewed the design process information transformation as a process which started with subjective and qualitative client goals, translated those goals into tentative and quantitative objectives, chose activity strategies which would hopefully accomplish desired objectives, and initiated appropriate problem-solving activities whose information product would advance the process towards its goals. It was further assumed that such a method had to be iterative: a rationally developed evaluation process had to accompany the "specifying" process (goals-objectives-strategies-problem solving). By evaluating generated information in light of successively "higher" levels of generality it has been believed that all specific and quantitative information could then be related to the highest and most important goals of the process (the client's). Figure 2.1 graphically represents the steps necessary to accomplish the proposed general to specific to general process integration.
FIGURE 2.1: AN INTEGRATING ITERATIVE METHOD
The "up and down" movement of the iterative methodology which is superimposed on the activity-to-activity progression of the process, achieved two important ends: it insured that the individual activities were directly related to and responded to the larger issues represented by the goals; and it permitted process orienting objectives to change as generated information clarified the meanings and implications of goals. Day to day operating decisions would not then be made intuitively, by rote, or by accident, but rather, in the rationally established context of objectives. Additionally, though the quantified objectives which acted as planning and evaluation criteria were designed to be tentative and alterable themselves. Objectives had to be alterable because the goal to objectives transformation is not an analytic transformation: it can be tested empiracly only (through evaluation of information generated under its assumptions). Criteria cannot be fixed in advance if they can't be analytically derived.

By requiring each control system to periodically (once each iteration) relate its decisions to the overall goals of the process, the iterative method eliminated those decisions which (although having positive sub-system value) would have a negative impact on the system as a whole. I.e., the decision to completely re-design a building might marginally improve system performance in terms of substantive information and goals alone, but the resulting side effects in terms of design costs, schedule delays and professional frustrations, might well nullify the marginal gains and, in the aggregate, reduce the level of general process goal achievement.

Thus, under the guidance of the client's goals, a consistant, iterative
method can coordinate and integrate design process control systems into a complete and harmonious set of procedures which strive towards the common end of minimizing the uncertainties of goal achievement. In the succeeding chapter an outline of how such an integrated control system might deal with the needs and realities of the building design process will be presented.
III.A System Overview

In this chapter a comprehensive design process control system, based on an information flow model of the process, will be presented. In its descriptive content, the model attempts to differentiate and expose information flows (and their respective sources and destinations) which have been heretofore combined and implicit. Normatively, the control systems suggests methods with which the exposed information flows may be intercepted, evaluated and modified, to the end of achieving client goals with the greatest possible directness and efficiency.

As a description of the design process, this information flow model conceives of the process as containing an inscrutable "black box", which accomplishes the creative information transformation, surrounded by six rational (and "transparent") control subsystems, each of which act to regulate and chose inputs to the black box, evaluate intermediate outputs from the black box, make intermediate outputs available as new inputs and revise input selections. Figure 3.1 is a graphic representation of the model. The black box is represented by the square in the center of the diagram labeled, "DESIGN PROCESS BLACK BOX". The six control subsystems, CLIENT CONTROL, PROCESS CONTROL, INPUT MANAGEMENT, MONITOR, OUTPUT MANAGEMENT, and CLIENT EVALUATION, are labelled; their spheres of influence are delimited by the dashed lines.

-42-
FIGURE 3.1: COMPREHENSIVE CONTROL SYSTEM
The design process model superimposes differentiated information flows upon the activities of the goal directed iterative cycle, described in Section II.B. The seven activities of each iterative cycle (see Figure 2.1) are directly related to various control subsystems of the comprehensive design process model. **Goal articulation** is accomplished in the CLIENT CONTROL Subsystem. **Objective proposal** occurs in CLIENT CONTROL and PROCESS CONTROL Subsystems as the client and the manager negotiate and evolve the organizing (although temporary) set of objectives. The PROCESS CONTROL Subsystem, upon the guidance of the established objectives regulates **activity choice**. **Problem solving** is initiated as the INPUT MANAGEMENT Subsystem supplies the DESIGN PROCESS BLACK BOX with a set of rationally selected inputs (information, skills, money, organizational structure, etc.). **Performance evaluation** is accomplished by the MONITOR Subsystem which upon observance of unsatisfactory performance, notifies other subsystems, which can then revise or alter inputs. While reviewing performance the MONITOR Subsystem also compares performance with the parameters implied by the previously established set of objectives and decides whether **objectives** have been met. If intermediate output is both correct and meets objectives the CLIENT CONTROL Subsystem then evaluates the product in terms of **goal satisfaction**, revising objectives if and when objective satisfying output does not also satisfy goals. At this point the cycle begins again, with all newly generated information supplementing the various information matrices which supply all activities.

The "self-feeding" nature of the iterative cycle requires that intermediate information outputs of the process be reassembled into the set of information which serves as the basis for future process inputs. (See Figure 1.8)
The OUTPUT MANAGEMENT Subsystem serves to organize and summarize such intermediate output and communicate it back to the INPUT MANAGEMENT Subsystem, which can then use this new information as input for further process activity.

The following section will examine the comprehensive design process control system in terms of the inputs, activities, decisions and outputs of each of the six individual control Subsystems. Working together, the six Subsystems attempt to regulate those information flows susceptible to rational analysis (i.e. outside the DESIGN PROCESS BLACK BOX) by the management control systems. The addition of rational decision making to a process most often controlled intuitively and implicitly should then lead to a reduction of uncertainty.

III.B.I. CLIENT CONTROL Subsystem

It is possible to more directly and explicitly impose the client's needs and goals on the building design process; however, more effort, more questions and more time is the payment extracted for this increase in control. As the source of the process's qualitative and general goals, the client must understand the iterative nature of the qualitative to quantitative transformation; he must be flexible and open and permit quantitative preconceptions to change as the process provides him with new information. He must learn more about the process and demand that his manager tell him what is going to happen before it occurs.

The CLIENT CONTROL subsystem here proposed (see figure 3.2) provides four
FIGURE 3.2:
CLIENT CONTROL SUBSYSTEM
control activities with which the client can minimize the possibilities of unresponsive design. They require the client to demand specific kinds of informational input about what the design process is going to do its specifying function (see Section II.B.1), and symmetrically, demand progress reporting in order to participate in the evaluative function and to communicate evaluative output. Uncertainty about success is minimized by requiring explicit and differentiated forecasts and targets to regulate design process activities.

The four CLIENT CONTROL activities attempt to minimize confusion and uncertainty in areas of: 1. Choice of Manager (Control Activity I); 2. Goal Articulation (Activity II); 3. Objective Formulation (Activity III); and 4. Objective Alteration (Activity IV). Activities II-IV are labelled and represented in Figure 32. (Activity I has been omitted from the diagram in interests of graphic simplicity.) The various information flows needed to accomplish the control activities are represented by arrows labelled with letters A-E.

III.B.1.a Choice of Manager.

While all clients obviously assign responsibility to a manager (usually by hiring an architect), information flow control tools can make this choice less uncertain and haphazard. In reviewing previous work (of prospective managers), interviewing previous clients, and soliciting proposals, the client should realize that "good design solutions" are only one component of the building design process's information flows. Evaluation of design costs and psychological factors are important as well. This is to say that
information flow A - the client's environmental observation inputs - are a multiple-category set of inputs. Does the prospective manager understand the client's language (mode of communication) and vice versa? Does the prospective manager's personal value system permit him to pursue the client's needs without conflict? And, most importantly, does a prospective manager's methodology permit the flexibility necessary to evolve a responsive design? By evaluating each prospective manager in relation to these separate criteria, the client should be able to make a selection based upon a detailed set of information; the final choice then requires an aggregation of how each manager meets projected requirements in different areas.

III.B.1.b Goal Articulation (Activity II)

All clients articulate perceived needs to their manager. However, without a clear concept of the "goal directed" iterative character of the process (see section II.B.1) the relation between perceived needs and primal goals is not clearly defined. The client must step back from perceptions of needs to more basic goals. The source of these goals is internal to the client and is not represented by an information flow. The needs arise as the existing environment (received as information flow A) fails to allow full achievement of desired goals. In order to provide the design process with a positive foundation for activity, the client himself must go back to, identify, and communicate (via information flow B) these basic motivations.

Goals express the client's expectations for a better world; define his
subjective value structure. If, as is usual, investigation of these basic goals is omitted, future design decisions can become unacceptable for specified reasons. With goal articulation by the client at the outset, explicitly communicated to the manager via flow B, the subjective criteria which the design process outputs must meet are explicitly established, and further, stand as a basis for the quantified objectives (evolved in the succeeding Activity III, Set Process Objectives, below) whose accomplishment design process decision making pursues.

III.B.1.c Set Process Objectives (Activity III)

Mere articulation of goals is insufficient, though. A set of subjective goals conceals conflicts between goals. In order to represent relations between goals the goals must be represented as quantified objectives. The client's control Activity III, Set Process Objectives, draws upon the manager's interpretation of subjective goals for its input (flow C). (The evolution of the information contained in flow C is more fully discussed below in Section III.B.3.a Analyze Existing State/Propose Objectives). For example, window light and summer comfort may be two of the client's goals. The trade-off relation between window area and heat gain is a quantification of the conflicting relationship between these two goals which the manager would interpret for the client and communicate in flow C.

An enlightened client who wants to minimize confusion and activity predicated upon unnecessarily insufficient information must thus solicit the manager's aid in: 1. quantifying all identifiable goals; and 2. relating
all quantified objectives with each other. Once the manager has supplied the client all these quantified interpretations of qualitative goals, the client must then decide what objectives most appropriately represent his feelings. With the help of the manager's experiential judgement (supplied via flow D, Advice) the client and manager evolve a set of Process Objectives, the informational content of flow E. This client-manager decision activity is more fully described in the following Section II.B.3.a. With this set of Process Objectives the client has two new tools: 1. a prescriptive and specific list of targets the design process will be understood to pursue; and 2. a set of criteria upon which the client can, at a future time, evaluate the manager and the set of outputs for which he is responsible.

III.B.1.d Revise Objectives (Activity IV)

There is no logical reason why a set of a priori objectives is valid over time. The client must recognize that future design process information contains valuable implications about reordering the set of Process Objectives. He must understand that "feedback" not only serves to correct errors, but, more importantly, that it should be used to alter and adjust the objective criteria which regulate the design process's activities.

This revision of objectives is represented as control Activity IV, Revise Objectives. Here, the client is supplied with Progress Report Information (flow V, discussed below in Section III.B.4.d Progress Report), and upon decisions, revises the Process Objectives with the information he supplies as flow X. This adjustment of objectives is a tool by which the client's
general and subjective goals become clearer, become understood. The client must recognize the preconceived objectives are valid only as a means of specifically ordering future activities; when a future information set suggests that other objective formulations might be required to successfully achieve goals, the old set of objectives has become obsolete and need to be replaced.

In summary, no fanciful inventions are going to give the client more control over the uncertainties of the design process. The quality of the process's goal pursuit depends upon the quantity and quality of the effort expended by the client. His control system, presented here, is intended solely to help him organize this effort.

III.B.2 PROCESS CONTROL Subsystem

The mystery, confusion and resulting inefficiencies of the building design process's qualitative to quantitative information transformation can be greatly reduced if all the manager's decisions grow from quantified objectives, which represent the client's goals. The manager's decisions must reflect the information content implied by all four objective categories: substantive (design information); procedural (activity choice); accounting (design process costs); and psychological (responsibility and group relations). The manager must simultaneously pursue design objectives (substantive) with the initiation of appropriate activities (procedural) whose costs must meet budget constraints (accounting) and whose participating professionals must interact in a specified manner (psychological).
The four activities which comprise the PROCESS CONTROL subsystem are somewhat parallel in structure to the CLIENT CONTROL subsystem (Section III.B.1). Progress from objectives to activity choice to problem solving is coupled with an evaluative function which reinterprets specific information outputs in light of their higher organizing principles, the objectives.

Figure 3.3 displays the essential activities, information flows and information matrices involved in PROCESS CONTROL. The large center element represents the manager's duties, activities and decision processes. Each of the four interior boxes (denoted by roman numerals V-VIII) represent separate decision-making activities which use input information as supplied by arrows leading to them, and provide output information as represented by arrows leading away.

The partitioned rectangle in the upper right of the diagram, labelled Process Objectives, represents that information matrix which lists the client's quantified expectations as evolved by the client and manager (see Section III.B.1.c and Section III.B.2.a, below). The four partitions of the Process Objective matrix might be filled with information of the following form: substantive-building program and construction budget; procedural - tentative gross schedule of anticipated process activities; accounting - design expense budgets; and psychological - organizational structure (team approach, functional organization, or responsibility center specification). Psychological objectives may also specify communication formats reflecting the fact, for example, that the client understands models better than drawings.
FIGURE 3.3
PROCESS CONTROL SUBSYSTEM
The following four sections: Analyze Existing State/Propose Objectives (Activity V); Decide Procedures (Activity VI); Change Procedures (Activity VII); and Correct Errors (Activity VIII); examine a coherent system with which the manager can exercise explicit control over the building design process in the interests of the client.

III.B.2.a Analyze Existing State/Propose Objectives (Activity V)

As previously discussed, the only rational and unambiguous (although ephemeral) basis for design process decisions is the set of quantified objectives which the manager and the client evolve. The manager must receive information about the client's goals (via flow B), the physical environment in which these goals are to be realized (via flow A), and the resources available from the client with which to effect the realization. Implicit in the concept of the manager is the additional set of information (perhaps internal) which details the activities, professional qualities, and costs of those tools which will be needed to bring the client's goals, resources and environment together.

With these inputs (A and B) the manager interprets the client's qualitative goals and given environment in terms of quantitative objective suggestions. The proposed objectives evolved here in Activity V are communicated back to the client in flow C. The client's decisions about desired objective levels grow from both the proposed objectives (flow C) and the manager's advice as to reasonable objectives (flow D). Although the decisions as to what objectives will control design process activity are ultimately the client's, the manager's suggestions and advice
are crucial if the objectives are to relate reasonably to the existing set of available resources, processes and professionals.

The Process Objectives are thus the marriage of the manager's abilities to quantify the client's subjective goals and the client's decisions as to the relative weights which he desires to place on different goals. These weights set the level of objectives, which then act as prescriptive guides and evaluative measures for future work. Once the measures are set the manager has an explicit set of objectives for whose accomplishment he is responsible.

This proposed methodology improves the client's control of the design process by explicitly enumerating what the manager is expected to do. The Process Objectives matrix represents, at a specific point in time, decisions jointly evolved by client and manager about where to go, what to do, and how much to spend doing it. The Process Objectives act as an expectational benchmark for succeeding PROCESS CONTROL decisions.

III.B.2.b Decide Procedures (Activity VI)

Once the set of Process Objectives has been established, the manager can go to work and design an activity strategy which, in his judgement, will best accomplish the objectives. The Procedure Decisions are based upon the set of quantified objectives as supplied by information flow F. The output of the Procedure Decision activity (flow G) is communicated to the INPUT MANAGEMENT control activity (Section III.B.3 below), where the strategic "plan of action" is translated into a specific resource consumption plan.
The activity strategy might be represented as a sketch CPM diagram detailing the various activities required to accomplish the Process Objectives. The detail of the network sketch should vary with time and uncertainty. Next week's activities might be very specifically scheduled whereas the network of activities two months in the future would acknowledge the uncertainty of the future by having much less detail and specificity. Further, as the process's progress eliminates various alternative strategies and narrows its focus, it is probable that scheduling in periods of the process would be more precisely specifiable than that of earlier periods. The sketch CPM forces the manager to think logically about activities and their interrelations while giving him the flexibility to deal with different levels of uncertainty, not forcing him to spend excessive time, and not creating unrealistic (and detrimental) determinism in the activity choice decision.

As the Procedure Decision activity takes the general but quantified Process Objective matrix and transforms it into the activity strategy, the manager's judgement is most fully exercised. These decisions are, in a sense, creative, as the manager attempts to accommodate a new and unique set of objectives with a specifically responsive plan of action. It is these decisions by which the configuration of the specific design process is itself designed.

III.B.2.c Change Procedures (Activity VII.)

The manager must also be able to respond to the client's learning process. As discussed above in Section III.B.1.d, it is most likely that the client's
decisions about appropriate objective levels will change in light of newly available information output created by the design process. As the client learns more about what quantities fulfill his subjective goals, and this information is transmitted to the manager via flow H, the manager must have the flexibility to revise the activity plan of action decisions in order to pursue the new (or adjusted) objectives. Symetrically, he must issue new orders to INPUT MANAGEMENT which reflect the objective revisions' impact on procedures (and thus on inputs, as well) (flow K). Thus the looseness and tentativeness of the sketch CPM discussed above comes into play again. It offers a measure of logic to activity planning while not becoming so sacred or rigid as to stifle necessary adjustment and change in procedure choice and coordination.

III.B.2.d Correct Errors (Activity VIII)

Correction of activities gone awry should become a direct and straightforward problem for the manager when the basis for activity and decision has been explicitly outlined by the Procedure Decisions and their generating Process Objectives. When observation of errors due to poor performance are discovered and communicated to the manager (flow K) by the MONITOR subsystem (discussed below in Section III.B.4) the manager need merely transform the recognition of an error into a directive (sent via flow L) to those responsible, specifying the nature of the error, how the activity in question failed to meet the prespecified objectives, and reiterating the objectives under which the process activities are to be regulated.
In summary, the PROCESS CONTROL subsystem attempts to provide a rational basis upon which the client's expectations, as quantified and listed in the Process Objectives matrix, can be transformed into a specific plan of action to be used in resource allocation decisions by the INPUT MANAGEMENT subsystem. Such a transparent method should make activity choice consciously responsive to the case at hand. It should allow that the correction of errors is unarbitrary and logically based. And, while still maintaining control it should permit flexibility in the decision procedures so that changing client understanding of goals can be reflected in changing and responding design process orientation.

III.B.3 INPUT MANAGEMENT Subsystem

Once the controlling Process Objectives have been developed and stated (see Sections III.B.1.c and III.B.2.a), and the corresponding design process procedures have been chosen (see Section III.B.2.b), the manager must next match the available information transforming and creating resources with the specific plan of action and initiate the resources' entry into the design process. This matching and initiating activity will be called INPUT MANAGEMENT.

Figure 3.4 details the activities, information matrix and information flows comprising the INPUT MANAGEMENT subsystem. Central to this control activity is a Resource Matrix (see figure 3.4): it contains all the resources available to the manager with which he can carry out the chosen plan of action. This matrix contains seven elements: 1. External Information (information available (at a cost), but not yet in possession);
FIGURE 9.4: INPUT MANAGEMENT
2. Filed Information (information previously acquired or created and readily available); 3. Other Activities Information (information being created simultaneously with the process at hand); 4. Professional Skills (lists of available professionals and their capabilities to perform specific tasks); 5. Costs (cost of creating or transforming information); 6. Durations (length of time usually required to perform specific tasks); and 7. Personalities/Language (descriptions of how the available professionals work together, how they communicate, and other psychological factors).

The mere existence of the Resource Matrix does not automatically explain how the available resources might be used by the design process. The matrix is only a jumble of potential. The traditional design process enters these human and informational resources into activity intuitively and rotely; the active and more transparent method here proposed orders specific inputs in relation to a conscious comparison of needs (as defined by Decide Procedures' information output flow G) on the one hand and availability and costs of resources on the other. Increased efficiency hopefully results as all possible available resources are examined and: 1. the most appropriate are used; and 2. available and valuable information is not forgotten or ignored. Rational organization of available information should eliminate repeating work already done but forgotten.

The INPUT MANAGEMENT control activities have been divided into three areas: Assemble Resource Summary (Activity IX); Decide Resource Allocation (Activity X); and Alter Allocations (Activity XI). An additional book-
keeping activity, Confirm Input, which confirms and records inputs' entries into the design process completes this control subsystem.

III.B.3.a Assemble Resource Summary (Activity IX)

Before the manager can initiate people and existing information into the design process he must know of their existence, location and attributes. An Index (left hand side of figure 3.4) of resources listing the kinds of information readily available to the manager (and the design process) coupled with location descriptions (file drawer number, drawing number, computer address, library reference, etc.) serves as a starting point for rational input management. Routinely compiled, the Index's information is received by the manager as information flow N. The Index (or a companion one) would also include a "catalogue" listing where and how presently available (External) information might be obtained or created. Completing the Index would be lists of presently available professionals who, with their special skills, abilities, and knowledge, have potential to accomplish necessary design process tasks.

A Price List, either appended to Index entries, or as a separate guide (routinely compiled and updated and sent to the manager as information flow M) completes the set of inputs necessary for the manager to assemble the Resource Summary (Activity IX). The Price List attaches dollar cost attributes to all available resources. This list describes the costs of retrieving information, transforming it, developing new information, etc.

With the Index (flow N) and the Price List (flow M) the Resource Summary
can be assembled. This compiled and integrated information set is then forwarded, via flow 0, to the Resource Allocation Decision Activity X. Ideally, before any new input management allocation decisions are made the Resource Summary should be revised to show the latest resource status. Continual Index updates must be supplied to Activity IX to keep the Resource Summary current and maximally useful.

III.B.3b Decide Resource Allocations (Activity X)

The critical decision activity within the INPUT MANAGEMENT subsystem relates the Resource Summary matrix (supplied via flow 0) with the strategic plan of action decisions made by the manager in the Decide Procedures Activity (VI) component of the PROGRESS CONTROL subsystem (Section II.B.2). The procedural choice information is supplied to Activity X by flow G.

Given the demands on the design process, as specified by the procedural plan of action, and the capabilities of the resource matrix to meet demands, as specified by the Resource Summary, the Resource Allocation decision (Activity X) attempts to specifically commit explicitly available resources to specific activities, given various cost, time and psychological constraints. This commitment might take the character of a explicit list: such and such people are to pursue certain tasks, using certain external information, transforming information to a specified output format, all within specified time and dollar constraints. This list is then communicated back to the Resource Matrix as information flow P, Order Input.
This method forces the manager to explicitly plan and allocate resources to the specific problem at hand, while at the same time forbidding him from taking for granted the tools at his disposal. Further, it establishes an explicit basis of expectation for future results before any design process activity has commenced. The professionals who are ordered to begin work know, at the outset, both what is expected of them and how much time and money has been allocated for their tasks. No work is begun without an explicit explanation of how, why and with what resources that work is to be accomplished.

III.B.3.c Alter Allocations (Activity XI)

A priori knowledge of all inputs required by the design process is most probably not complete. As the process's objective oriented information transformation continues, realizations about new and unplanned input needs will arise from within the design process itself (as well as from the client (as previously discussed in Section III.B.1.d). This is not so much a matter of poor planning as a recognition of the essentially creative and self-organizing (Jones p.55) nature of the design process. The proposed control system does not forbid such spontaneously generated new input requirements, but it does require that they be explicitly voiced and represented.

Unplanned inputs can enter the design process only through a roundabout path: insufficient inputs are perceived by the MONITOR subsystem (see Section III.B.4 below); the manager is notified of such insufficiencies via flow K; the INPUT MANAGEMENT Activity XI, Alter Allocations, is then
ordered, via flow J, to enter new inputs. Though apparently tortuous, this complicated input revision procedure has several virtues. First, it maintains control: new inputs add new and unplanned costs to the design process. By having the manager intercept the call for new input (at Activity VIII) he can check irresponsible (or simply questionably productive) new expenditures. Secondly, the "long" input revision information route encourages learning: if new (and unplanned) inputs are indeed required, the manager's participation in such adjustment gives him a better idea of how to plan and order inputs in the future. That is, previous short-sights in Activities VI and X, Decide Procedures and Decide Resource Allocation, can improve the quality of future decisions and choices in these areas if the shortsightedness is explicitly corrected as here suggested.

The "Confirm" information flow (R) represents the bookkeeping entry made as ordered resources are actually observed entering into the design process. With such a record (communicated back to Resource Allocation Activity X) the input manager can, at a future time, relate evaluation information (received as flows L and J) with specifically recorded past inputs.

In summary, the INPUT MANAGEMENT control subsystem does not attempt to radically alter the flow of resources into the building design process. Rather, it attempts to make the decisions about appropriate input choice explicit and based upon the best and most complete information available. Further, the INPUT MANAGEMENT concept attempts to provide decision makers with learning tools by which past experience can be translated into useful
information which can influence (and hopefully improve) future decisions about resource allocation.

III.B.4. MONITOR Subsystem

When the intuitively controlled design process goes awry, most managers can readily perceive that something is wrong. Pinpointing the location and cause of the problem is not so easily achieved. The MONITOR subsystem aims at identifying problems more quickly, isolating problem areas more precisely, and maintaining the relation between specific activities and their generating goals and objectives more consciously and explicitly.

For comparative evaluation a monitoring system requires: standards, or parameters, specific progress output information relating to those parameters, and a process to analyze any discrepancy between parametric expectations and actual output. Additionally, the monitoring system must be able to aggregate and translate the "raw" information output supplied by the design process into a format which the client can readily grasp and evaluate.

Figure 3.5 details the activities and information flows involved in the MONITOR control subsystem. No information matrix is associated exclusively with MONITOR. Rather, it uses the Process Objectives information matrix (described in Sections III.B.1.c and III.B.2a) as a basis for establishing evaluation parameters. The MONITOR subsystem has been conceived of as four separate activities: Establish Evaluation Parameters (Activity XII); Evaluate Progress/Note Discrepancies (Activity XIII); Analyze Discrepancy
FIGURE 3.5: MONITOR SUBSYSTEM
III.B.4.a Establish Evaluation Parameters (Activity XII)

Just as the PROGRESS CONTROL activity, Decide Procedures, translated Process Objectives into strategic plans of action for use in resource allocation decisions, so must the MONITOR subsystem activity, Establish Evaluation Parameters, translate Process Objectives into specific and quantified performance parameters for use in evaluation activities. These performance targets, the parameters, act as explicit and specific measures towards which design process professionals are expected to strive and against which their output, and hence, their performance, will be evaluated. Improved design process performance hopefully results as professionals are told specifically what is expected of them, and as evaluation proceeds from concrete and quantified standards instead of from intuitive feelings about quality.

Control Activity XII, Establish Evaluation Parameters, uses Process Objectives (represented as information inputs F1-F4) as a basis to create expected performance level criteria. These performance parameters in turn serve as the basis for evaluation in the succeeding activity, Evaluate Progress/Note Discrepancy. Activity XII also establishes a Reporting Format to which future design output will be expected to conform. Transmitted to design process professionals as flow T, the Reporting Format informs the professionals both of expected performance levels and of the desired format of design process output communication.
Prespecified progress Reporting Format is suggested in interests of ease and comparibility in output evaluation. The units and measures with which various kinds of output will be reported and evaluated must be agreed upon by both evaluator and those being evaluated (the design process professionals). Standardization of reporting format establishes explicitly those specific quantities which the manager deems as appropriate measures of successful objective accomplishment. Complete standardization of output reporting formats seems undesirable: it is difficult to imagine quantifiable evaluation comparison between physical design and market analysis, for instance.

III.B.4.b Evaluate Progress/Note Discrepancies (Activity XIII)

Once the Evaluation Parameters have been established and the Reporting Format specified, actual Progress Evaluation (Activity XIII) becomes a matter of receiving quantified design process output information (received as flows U1-U4) and comparing it with the expected quantities as represented by the several Evaluation Criteria. When actual reported output quantities do not correspond with the prescribed progress targets a discrepancy is noted and reported to the succeeding MONITOR activity, Analyze Discrepancies, Activity XIV. Such a discrepancy would arise if a set of mechanical progress drawings were due on a specific date, but were not ready until a week later.

By evaluating performance in terms of the four separate information types (substantive, procedural, accounting and psychological), the source of problems can be more easily isolated than in the case of general examination of all information, as is more usually done in less transparent and
explicit control methods. Additionally, when the problem identification part of the evaluation process becomes as simple and mechanical as the above methodology suggests (problem identification reducing to mere quantity comparison), more frequent and complete monitoring should be possible.

III.B.4.c Analyze Discrepancies (Activity XIV)

Mere existence of discrepancies as identified by Activity XIII does not automatically and mechanically dictate proper corrective measures: the reasons behind the discrepancies' appearances must be analyzed. There are three basic causes for discrepancies between actual performance output and expected parameter values. Each case requires a different solution.

The most obvious cause for discrepancy between expectation and performance is improper execution - simple error. The engineer who was supposed design on a 24 foot bay spacing designed on a 25 foot bay spacing. But external conditions, uncontrollable by anyone within the design process can also cause actual performance to fall short of expectation. A rapid change in the relative price of construction materials can force redesign of structural systems, for instance, thus extending the period of design beyond the targeted completion date. Lastly, improper forecasts can cause monitored output to display discrepancy. In establishing objectives and performance parameters, the manager may have created unrealistic performance targets. A market analysis which supplies the kind of information required by the design process may simply take more time and money than was originally expected and forecast.
Information flow K represents the communication between the MONITOR subsystems, Analyse Discrepancy activity and the PROCESS CONTROL activity, Correct Errors in which the manager is notified of observed problems and their causes. It is then up to him to issue a directive to the INPUT MANAGEMENT subsystem (via flow J) indicating both that a problem exists and specifying which input or inputs are apparently responsible for the problem. The INPUT MANAGEMENT Activity XI, Alter Allocations, then interacts with and/or disciplines the offenders.

III.B.4.d  Progress Report (Activity XV)

The raw information output communicated by the design process (flows U1-U4) to Activity XIII, Evaluate Progress/Note discrepancies, is most probably too arcane and detailed to be understood and used by the client. This raw information must be reduced and translated into some pre-determined format for client use and analysis. A Progress Report (whose assembly is accomplished in Activity XV, is a tool by which the raw information and the analysed discrepancies (from Activity XIV) can be presented to the client in a concise and understandable package.

The Progress Report is used by the client in two ways. First, it tells him whether or not the manager has been doing the job he agreed to do when the Process Objective matrix was established (see Section III.B.2.a). Should the manager's performance (or the performance of all those under the manager, for whose performance he is also responsible) fall short of the expectations specified and quantified in the Process Objectives, the client can communicate his displeasure via flow K. In most cases, the
client's observation of poor performance should merely duplicate the manager's observation. In the case that the manager himself was responsible for errors (as in the case of poor forecasting (see Section III.B.4.c) the client's call for improved performance is probably not redundant, though. The second use of the Progress Report by the client involves the information it provides him with which he can re-examine the assumptions and decisions he made when the Process Objectives were previously evolved. The progress report's information represents the transformative of the client's general and qualitative goals into something more specific and quantified. It is these specific realizations of the objectives' generalities which give the client a rational basis upon which to modify his decisions about desired objective weights (see Section III.B.1.d). Should the information included in the Progress Report make the client want to change the Progress Objective matrix, these desires are communicated via flow W.

In summary, the MONITOR subsystem is the basic continuous evaluation mechanism of the building design control system. Whereas CLIENT CONTROL, PROCESS CONTROL and INPUT MANAGEMENT subsystems basically generate decisions about Process Objectives, plans of action, and resource commitments, the MONITOR subsystem observes the consequences of these decisions and provides evaluation thereof. The more often monitoring occurs the less likely it is that errors and fruitless activity will continue. Obviously, the more monitoring is done the higher the costs of this control will be. Additionally, it appears as if excessive monitoring can stifle creative activity necessary for successful design by "looking over the shoulder" of professionals as they work. Especially
in architectural design, there appears to be a need to permit designers a wide range of freedom to pursue, without interference, what may appear to be illogical paths. Some sort of balance between the requirements of creative processes and the requirements of acceptable control obviously must be struck.
III.B.5. OUTPUT MANAGEMENT Subsystem

One of the saddest observable inefficiencies of intuitive and implicit information control is its great ability to lose, misplace and otherwise destroy useful information. Redundant activities, decisions made with unnecessarily incomplete information, failure to learn from mistakes and general waste of valuable resources is inevitable if generated information is not explicitly managed. All information produced by the building design process is intermediary: its value exists only in how it can be used in future processes and by future activities. The design process's generated information output represents, at a point in time, one level of specification and quantification of the client's transformed goals, brought about by the expenditure of the client's resources.

Because the proposed design process model is conceived of as continually cycling, provision must be made for the reception, sorting and assimilation of newly generated intermediate process output information. Received by OUTPUT MANAGEMENT as flows XI-X4 from the DESIGN PROCESS activities, the new information must be prepared and communicated back to the Resource Matrix via flows Y1-Y4.

As suggested by Yang & Fenves (1974), this newly generated information cannot be simply poured into the Matrix, but rather must be labelled and catalogued, according to its level of specificity or "status". The addition of this information has important procedural implications also. A fuller and more complete Resource Matrix implies that certain activities with previously unsatisfied information precedent requirements can begin
when the Matrix is supplied with those necessary information precedents (inputs). As new output communicated by OUTPUT MANAGEMENT becomes assimilated into the Resource Matrix, the Resource Summary, Activity IX, revises its catalogue and Resource Allocation, Activity X can initiate new inputs to start new process activities. Of course, all these decisions are still regulated by the strategic plan of action, which has been communicated to Decide Resource Allocation by Decide Procedures, Activity VI, of the PROCESS CONTROL Subsystem via flow G.

Figure 3.6. details the activities, information flows and destinations with which the OUTPUT MANAGEMENT control subsystem concerns itself. Various information output products of the design process are received via flows XI-X4. These outputs are first processed by being sorted into appropriate categories, translated into compatible (or standard) languages, and labelled as to content, level of specificity, etc. in Activity XVI, Sort/Label. Translate.

Once the format of newly available information has been established by Activity XVI, the second OUTPUT MANAGEMENT activity, Address/Send/Confirm, Activity XVII, can communicate various pieces of the information set to specific destinations. There are two general destinations: the Resource Matrix; the Existing Environment matrix. The character and format of communicated information depends upon its general destination: the information placed in the Resource Matrix is most probably more detailed and specific than that communicated to the client.
FIGURE 9.6:
OUTPUT MANAGEMENT
SUBSYSTEM
In managing information output several considerations should be recognized:

1. Because of its intermediate nature, process output is useful only if it reaches its appropriate destination. Specific addresses must be appended to all output. Hourly wage sheets go to one place, structural calculations go somewhere else. Given a specific address, though, another consideration must be examined. 2. Creating information for someone else to use involves getting it to him, but it also involves the recipient being able to understand and use the information received. Often this requires a translation step. The structural engineers' conclusions may be needed by the architectural designer, but the designer may have no way of understanding pages of computer printout. Obviously intuitively controlled processes are conscious of this fact in such obvious cases: OUTPUT MANAGEMENT attempts to explicitly recognize the output recipient as a definer of communication format in all cases. Enormous inefficiency results when potentially useful information is received by someone who can't understand it. 3. Information not immediately required by other processes or activities must be filed or stored. Information storage is meaningful only if stored material can be located at a later time. Just as a library becomes a confused and useless jumble without a cataloging system, so does the value of design information decrease as it becomes more inaccessible. Like books in a library, design information must be labelled and catalogued, then rationally and consistently stored. The more carefully output is stored the more easily it can be used in the future, and thus, the more valuable it becomes.

In summary, OUTPUT MANAGEMENT is a set of control activities which attempt to minimize information loss and information access inefficiency by
explicitly accounting for all information produced by the design process. By recognizing that information is useful only as it serves to further processes, OUTPUT MANAGEMENT strives to maximize the usefulness and value of the design process's informational product.
The ideas, approaches and suggestions presented in this thesis hopefully open the field of design process control to new and greater levels of performance and accomplishment. Admittedly, the present presentation is sketchy, tentative and rough, not to say primitive. A great deal more work in terms of specifying, clarifying and implementing the information flow based comprehensive control system needs to be done before its practical implications for the design process can be realized. However, it is felt that an adequate foundation upon which future research can proceed has been presented here.

It now appears that certain parts of the comprehensive control system would lend themselves perfectly to implementation by computerized management information processing systems. Yang & Fenves (1974) have already indicated that electronic data processing can be an invaluable tool in organizing, categorizing and accessing the voluminous intermediate information products generated by process activities and used by subsequent process activities. The sheer amount of this information and the requirements that it be accessible as possible suggest that a computerized information system might be the only tool which could permit full and conscious recall, comparison and analysis of all necessary information flows. But though there are certainly many areas in the comprehensive design process control system in which computers can improve control performance and aid the manager in making good decisions, based upon the
most complete and current set of information available, it must be remembered that design process control cannot be accommodated entirely by logical operations. The creative, tentative, qualitative and subjective nature of some design process information (most notably, the client's goals) must be processed with judgement, experience and sensitivity - all qualities which describe human managers, not machines.

It is hoped that the framework here presented will lead to new and more rational methods of design process control. Such methods should not only reduce waste, but should also give humanity a little more control over its own fate. Consciously, intelligently and sensitively applied, such increased control should lead man a little closer to achieving his goals, desires and hopes.
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