

THE SYSTEMS APPROACH TO BUILDING:
A STUDY OF SYSTEMS BUILDING DEVELOPMENT

by

PREECHAYA SITTIPUNT

Bachelor in Architecture(July-1982)
Chulalongkorn University
Bangkok-Thailand

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

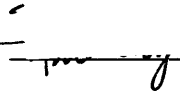
MASTER OF SCIENCE IN ARCHITECTURE STUDIES
at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June-1984

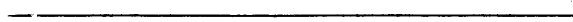
© Preechaya Sittipunt -1984

The author hereby grants to M.I.T. permission to reproduce
and distribute publicly copies of this thesis document in
whole or in part.


Signature of Author


Preechaya Sittipunt
Department of Architecture
May 11, 1984

Certified by


Eric Dluhosch
Associate Professor of Building Technology
Thesis Supervisor

Accepted by


N. John Habraken, Chairman
Departmental Committee on Graduate Students

Rotch

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

JUN 19 1984

LIBRARIES

THE SYSTEMS APPROACH TO BUILDING:
A STUDY OF SYSTEMS BUILDING DEVELOPMENT

by

PREECHAYA SITTIPUNT

Submitted to the Department of Architecture on May 11, 1984
in partial fulfillment of the requirements for the degree of
Master of Science in Architecture Studies.

ABSTRACT

The new demand for building and the problems generated by this demand confronting the building industry have become more complex as a result of increasing social change, evolution of industrialization and inadequacy of traditional methods to cope with new needs and problems. Accordingly, the building industry has conscientiously directed itself towards a more efficient and economical use of limited resources and available technology on the basis of science-based procedures.

In this thesis, the so-called "Systems Approach" is perceived as an effective methodology to solve problems in the building industry, leading to its improved performance, if the process using the systems approach is properly developed and appropriately used. Its application requires the application and the requisites of disciplined and scientific methods, management and orderly operation of planning, design, procurement and construction, including change in many traditional procedures.

This study aims at the development of an approach to systems building embracing its theoretical, conceptual and practical framework, and looking at the various facets which must be approached with caution in its development. The process is developed as an integral aspect of the systems approach based on performance requirements as a strong tool to procure a specified building system, in compliance with user requirements as a primary concern.

Throughout the study, the focus is on the differences between system procedures and traditional procedures. Examples from the real systems programs are included.

Thesis Supervisor: Eric Dluhosch, Ph.D.

Title : Associate Professor of Building Technology

"My worthiness as a human being doesn't have to be tied into my achievements or how productive i am....."

"It's natural for me to feel terribly disappointed in the experience, but it's not necessary for me to feel disappointed in who i "am". i'm essentially the same person i was before this failure; and i'll be essentially the same person after i have a success...."

ACKNOWLEDGEMENTS

I hereby express my deepest gratitude to my advisor, Prof. Eric Dluhosch, to whom I am greatly indebted for his unequivocal support, understanding, and fatherly guidance throughout the years of my study. Particularly, his patience, painstaking reading and tedious corrections of this thesis. Without his concern, neither my study nor my thesis would have been accomplished.

Thanks Emorn and Dr. Pibul for looking after me during my thesis work and also Chartsiri for his help and contribution during my study.

To Nadia, Tope, Demola and Garrett, for your help in various stages of my study and your loves that will remain in my memory.

Lastly, to the ones that are most dear to me, my father and mother who inspire me to have unlimited tolerance to overcome all difficulties throughout my study abroad.

TABLE OF CONTENTS

Abstract..... 2

Acknowledgements..... 4

Introduction..... 8

CHAPTER 1 - THE SYSTEMS APPROACH

1.1 Introduction to "System"..... 11

1.1.1 Basic Considerations of a System..... 12

1.1.2 System Characteristics..... 16

1.2 The Systems Approach..... 18

1.2.1 Its Application..... 19

1.2.2 Steps in System Approach..... 20

1.3 The Systems Approach to Building..... 22

1.3.1 Prerequisite Conditions for the Application of the Systems Approach to Building..... 24

1.3.2 Systems Building and Building Systems..... 25

1.3.3 The Building as a System..... 27

1.4 The Evolution of Building Towards "System"..... 28

1.4.1 The Problem: Drawbacks of the Traditional Building Process.... 28

1.4.2 Changing Context in Design..... 33

1.4.3 New Demand..... 34

CHAPTER 2 - THE SYSTEMS BUILDING -ITS PROCESS AND VARIOUS FACETS-

2.1 Introduction..... 36

2.2 The Building Process of the Systems Building..... 37

2.2.1 Organization of the Program and the Program's Owner..... 37

2.2.2 The Program Objectives..... 39

2.2.3 Performance Requirements..... 44

2.2.4 The Implementation..... 49

2.3 The promises of a Systems Building Program..... 50

2.3.1 Quality..... 51

2.3.2 Time Benefit..... 55

2.3.3 Cost Savings..... 58

2.3.4 Flexibility and Change: The Systems Design Procedure..... 59

2.4 Industrialized Building VS. Systems Building..... 66

2.5	Roles and Responsibilities.....	68
2.5.1	The Owner.....	69
2.5.2	The Manufacturer.....	71
2.5.3	The Architect.....	72
2.5.4	The General Contractor.....	73

CHAPTER 3 - THE PERFORMANCE CONCEPT IN BUILDING
PROCUREMENT PROCESS

3.1	The Performance Concept.....	75
3.1.1	Performance Requirements and Performance Criteria.....	75
3.1.2	People Participation.....	81
3.1.3	The Performance and the Systems Concept.....	84
3.1.4	Performance Specification.....	90
3.1.5	Process Implications.....	95
3.1.6	Prescriptive Specifications....	97
3.1.7	The Advantages of Performance Statements.....	99
3.1.8	Performance Evaluation.....	103
3.1.9	Two Approaches of the Performance Concept in Building Systems Procurement.....	104
3.1.10	Subsystems Performance Specification.....	112
3.2	User Requirements.....	115
3.2.1	The Importance of User Require- ments.....	115
3.2.2	Users' Activities.....	117
3.2.3	Users' Characteristics.....	120
3.2.4	The Formulation of User Requirements.....	120

CHAPTER 4 - BUILDING SYSTEMS DEVELOPMENT
-SYSTEM DESIGN AND PROCUREMENT-

4.1	Introduction to Building System.....	124
4.2	"Open" VS. "Closed" System.....	129
4.2.1	Closed System -Its Advantages and Dis- advantages-.....	133
4.2.2	Open System -Its Advantages and Dis- advantages-.....	135
4.3	Bidding Procedures.....	138
4.4	Subsystems Compatibility and System Integration.....	145
4.5	Management Coordination in System Design.....	151

4.6 System Design - Guidelines for Development of Building System Hardware.....	155
4.7 Testing the Subsystem Integration and Feedback.....	157
4.8 Building System Generation.....	161
CONCLUSION.....	166
Appendix A.....	172
Appendix B.....	182
Appendix C.....	185
Appendix D.....	189
References.....	190
Selected Bibliography.....	195

INTRODUCTION

At present, the building industry is becoming increasingly important as part of any national economy, as seen from the 9 billion dollars increase in total construction expenditure between 1977-1978 in the United States and from the situation in many other countries.[1] The proliferation of demand for buildings resulted from increasing social complexity, for instance, housing which is paralleled by diminishing supplies of skilled labor and limited resources. Thus, the building industry and building processes are conscientiously driving at increasing their capability to meet demands economically and efficiently by accelerating development and speeding up productivity. Ultimately, the goal is for a more efficient use of the limited available resources and technologies within the constraints imposed in the provision of built environments.

This ever-increasing complexity of building needs, the vast amount of resources required to fulfill these needs and the available scientific and technological potential have produced an unprecedented interest in the methodologies in dealing with the problems at hand in the building industry. There is an emerging interest in "the systems approach" to the entire building process which has led to research in design methods-decisions, building products and user needs. Such an approach should provide both the building industry and building process with higher capabilities and better

interrelation and coordination of all activities involved.

The systems concept was developed first by scientists involved in basic research and later has become recognized in its usefulness to solve industrial, managerial and technological problems from small industry to large organizations, such as aerospace industry. Like others, the building industry, has recognized over the last two decades the importance of the systems approach as a distinct and contemporary way to deal with complex building programs. The techniques of the "systems approach" in building and "building system" have been utilized more and more in building industry as an effective means to solve the complex problems confronting it.

It is important, however, that the participants in building, who wish to apply the systems approach, understand the new rules of the game conscientiously and make sure that they are developed and applied properly in order to yield the best results. The systems approach, if correctly understood and properly used, provides a means of utilizing techniques of scientific engineering methods in the service of humanistic needs. Nevertheless, if the systems approach is not properly assimilated, its application offers less promise than expected and may even lead to failure. Hence, a comprehensive understanding of its procedures, disciplines, principles and various other facets of its development is essential.

The objective of this thesis is to study the application of the systems approach concept to the building process, i.e., study systems building development and building system design and procurement for generic building programs. As a consequence of this study, rules of the systems approach are made explicit and accessible, which then, can be properly used to fulfill the promise of a more efficient and rational use of resources and effort.

CHAPTER 1

THE SYSTEMS APPROACH

Before proceeding to the main issue of the systems approach to building, some basic concepts should be introduced. First, it is necessary to discuss briefly the concept of "system". This introduction embraces what a system is and its characteristics.

1.1. INTRODUCTION TO "SYSTEM"

As mentioned before, that the systems concept was first developed by scientists. A problem confronting scientists in many fields early in this century was that traditional analytical techniques relied on the elaborate isolation of the smallest possible component of the subject under study, which in many cases failed to provide a suitable description of the behavior of the subject as a whole. This is particularly true when there are strong and complex interactions between the various components in their natural state of combination. Thus, subjects, which had to be examined as organized wholes to allow further scientific progress, were given the general name of "systems".[17]

There exists a variety of definitions for "system" postulated by specialists in different fields, such as management, systems analysis, operations research. To mention

some:

"A kit of parts with a set of rules to yield some desired behavior."[6]

"The assemblage of subsystems or components united by some regular interaction or interdependence aims at the understanding of system as a functional whole."[4]

"An array of components designed to accomplish a particular objective"[12]

"A set of parts to accomplish a set of goals"[8]

Although the word "system" has been defined in many ways, it can be seen that there are some inherent similarities, which are:

- Any system must consist of parts, or components, or subsystems.
- These parts interact with each other and they are assembled into a system, have an effect on the system's performance as a whole.
- The system, as a functional whole, is to achieve a particular goal.

1.1.1. Basic Considerations of a System

The meaning of "system" presented here is not well-defined, therefore, some additional information about "system" is required to provide a broader definitional basis for subsequent discussion.

When studying a "system", five considerations, as outlined by Churchman, should be regarded:[8]

1.1.1.1 The Total System Objectives and the Performance Measures
of the Whole System

The objectives of the overall system are a logical place to begin with, as many mistakes will be made in the subsequent study of a system, if one has ignored its true objectives. Thus, the objectives must be stated explicitly as a first step in system analysis, bearing in mind that these are quite independent of the system performance. Vague objectives are misleading and will yield results which are irrelevant to the system's desired activities. Moreover, some precise and specific measures of overall system performance are desirable so that we are informed how well the system is doing. To measure performance, one can look at the consequences of the system activities.

1.1.1.2 The System's Environment: The Fixed Constraints

After the determination of system objectives, the next aspect of the system to be considered is its environment. The environment of the system is what lies "outside" of the system, remembering that systems are never independent or isolated. They are surrounded by other systems. Thus, a system is defined by boundaries, separating it from its environment and other systems.

When we say that something lies "outside" the system, we mean that the system can do relatively little about its characteristics or its behavior. Environment, in effect,

makes up the things and people that are "fixed" or "given", from the system point of view. For example, budgetary constraints are the environment of a system, if it cannot be changed by any activities of the system. But if a system is able to influence the budget by some organizational change, then, the budgetary process would belong inside the system.

Even though the environment is outside the system's control, it influences and determines, to some extent, how the system performs. For instance, if a system has to operate in a very cold climate, the system equipment must be designed to withstand such climate as a result of its environmental effect.

1.1.1.3 The Resources of the System

System resources, as opposed to its environment, are the factors that lie "inside" the system. Therefore, the system can change and use such resources to its own advantage and for its own functions. It should, therefore, use resources as efficiently as possible.

1.1.1.4 The Components of the System, their Activities, Goals and Measure of performance

A system is composed of subsystems or components which correspond to the rational breakdown of the tasks the system must perform. The division of a system into subsystems minimizes the system into a manageable size and provides a better understanding towards the whole system and its func-

tion. Within a defined system, i.e. within its boundaries, a hierarchy of its subsystems must be made, including the specific action for each to take. Thus, the critical subsystems which have the greatest effect on total system performance must be identified for proper operation. The determination of the subsystem hierarchy is a function of their contribution to the overall system performance.

System analysis leads to knowledge about the interaction and interdependence of the subsystems and how they effect the system as a whole.

1.1.1.5 The management of the System

Designing a system requires controlling operations and interactions within the system so that the system will work as expected. This implies the management of a system.

The management of the system has to deal with the generation and the development of plans for a system, which involves considering its overall goals, the environment in which it is operated, its utilization of resources and how these are supported by the activities of its components. In other words, it controls the system operation to assure that the plans are being carried out in accordance with the original objectives. Not only does "control" mean the examination of whether plans are being carried out correctly or not, it also implies the evaluation of feedback, to improve system performance.

While there exists a whole universe of ways of thinking about systems, the above considerations offer a principal approach to system study which is relatively concise, minimal and informative. These basic principles are typical attributes of any system, including systems building.

It is noteworthy that, in order to develop system thinking, a series of mental steps must be laid out and followed in sequence. Proceeding along this mental check list is essentially a process of checking and rechecking the thoughts one has already had in previous steps.

1.1.2 System Characteristics

Systems analysis means attacking problems of planning in a rational, straightforward and systematic way, characterized by a number of attitudes which a systems analyst and designer should acquire as follows:[15]

- 1) Every attitude should be somewhat detached from the problems at hand: the approach should be rational, as objective as possible and scientific, in attacking the problems.
- 2) Because the whole system has many facets and the problems of planning are not the responsibility of any single discipline, the system should be characterized and perceived as a whole and not in terms of piecemeal improvement, i.e. sub-optimization.
- 3) The approach of the systems analyst and designer must be "interdisciplinary".

- 4) The main principle is to optimize, i.e. to incorporate all relevant and important aspects of the planning problem at hand into one measure of effectiveness which is desired to be a maximum. This is to maximize productivity in the sense of optimizing resource allocation.
- 5) The systems researcher is supposed to be innovative, i.e. to develop novel solutions from the formulation of the problem, or in other words, from the mission of the project.

The aim is to derive a better understanding of a system's characteristics: the significance of its problems, a perception of the system as a whole, the roles of the members of its interdisciplinary team, its goal towards maximum efficiency, effectiveness of resources aiming toward optimization and innovation.

This efficiency approach to systems is seemingly based on the idea of the "one best way". Nevertheless, concentration on efficiency per se may be an ineffective way to manage a system from an over-all point of view.[7] Thus, the objective would be ideally achieved by rationalization on all system levels and by optimization of the total. Here, rationalization aims at the elimination of parts which do not contribute effectively to the whole system, if necessary, with the replacement of better parts. Optimization is the balancing of all forces and constraints with regard to their impact on the system for best over-all results.[5]

1.2 THE SYSTEMS APPROACH

The "systems approach" is an orderly procedure followed by an interdisciplinary team to analyze and remedy problems within their defined context. The results obtained are optimized in that this approach avoids traditional methods of independence or ad hoc treatment of the elements involved. The systems approach does this by conceptualizing a process which utilizes many scientific and management techniques such as project management, system analysis and operations research.

Herbert C. Auerbach outlined the "systems approach" in the following manner:[1]

- 1) Pragmatic - since it is action oriented, its products must respond to real world needs. All activities within the "system", therefore, are oriented to meet such needs.
- 2) Organized - information and resources, inputs into the system, are generally large. These inputs are required to be implemented and controlled by interdisciplinary teams, comprising of specialists, skilled professionals, system scientists, management scientists and others, while the interaction of this team must also be controlled. The "system approach" method is, therefore, primarily reliant upon organized managerial inputs and coordination of all components and process in the system.

- 3) Empirical - lessons are to be learned from the evaluation and feedback of previously implemented systems. This will result in an empirically better approach towards creating the system.
- 4) Theoretical - to find solutions, theoretical models can be built and extended with respect to the problems.

1.2.1 Its Applications

The distinguishing characteristic of strong interactions between components gives a special meaning to the work "system". Thus, the proper technological and managerial applications of the "systems approach" are, strictly speaking, only those situations requiring serious consideration of the effects of interaction. Systems analysis and systems engineering, are the related disciplines of operations research and management science, include techniques developed specifically to identify, measure, describe and control various kinds of interaction.[17]

Applications of the systems approach range from scheduling of toll bridges, layout of a production-mix for a company to missions of the aerospace industry. More proposals have been made to use this approach in other fields, for example, in urban renewal, improving the environment, in tackling the nutrition problem of mankind, health systems, and many other problems.[15] Apparently, this approach is more useful on large scale projects. Its application to building was adopted 20 years ago, first to housing and

school programs, then to other building type, e.g. hotels, shopping malls, office building, etc.

1.2.2 Steps in System Approach

The systems approach is characterized by certain procedures and by a certain sequence of steps or phases for attacking a problem. That is to say, it is based on a set of ordering principles and procedural rules as follows:[18]

PROBLEM DEFINITION--isolate conceptually the system to be studied. Determine and define the problems which are generally associated with needs. Specify system boundaries, i.e. the environment it will work in, and its resources. In other words, understand the system context and its constraints from the viewpoint of a given problem. The result is the quantitative and qualitative statement of the disparities between the actual state of affairs and what is desired or ideal.

GOALS--establish the system objectives in relation to those problems. The subsystems within the system studied must be defined in terms of their components, activities, and how they interrelate and interact. The systems approach recognizes the importance of every aspect and act which involves the whole system. These set of components will function to accomplish the system objectives and contribute to the whole system performance.

ANALYSIS--generate the greatest possible amount of

information about the problem, goals, evaluation criteria and modeling, and the quantitative and qualitative aspects of their components and relationships.

SYNTHESIS--generate alternative ways of achieving system objectives. For each alternative, measure its performance and feasibility under the system's context and constraints. In this step, various methods can be employed, such as the development of a model which can be tested through simulation to generate alternatives. Evaluation criteria is established for both the quantification and qualification of the goal statements in detail and priority for the purpose of measuring the effectiveness of a solution in the models. The result is a set of possible alternatives of solutions (at least one).

SELECTION--the selected alternatives, with their supporting evidence, are presented to the decision-makers. They will evaluate these alternatives in detail and choose one which best accomplishes the system objectives. This should result in the determination of the solution which in the models most nearly meets the evaluation criteria.

IMPLEMENTATION--the execution of the selected solution in the real-world.

FEEDBACK--test and evaluate the results, i.e. the whole system performance. Thus, how well the system has been developed and how well it is doing can be monitored. This is

for the purpose of validation and feedback to the system. As a consequence, procedures can be modified and better decisions can be made in each stages. This, in turn, will modify the solution and improve the subsequent results.

In summary, the systems approach simply means that any problem posed will be solved in an orderly manner. It is noteworthy that, the systems approach demands, to a great extent, the coordination by management of all element and process involved on the scientific basis, such as information system, analysis, synthesis, modeling, (see fig.1).

1.3 THE SYSTEMS APPROACH TO BUILDING

The systems approach to building is the management of an integrated approach to building. This means that the whole building process, as well as its management and operation are subjected to disciplined (and scientific) methods of planning, design, product procurement, and construction, by cooperation among the various professionals involved in the building process. This brings into play the main characteristics of systems building, i.e. coordination and the utilization of a scientific management system, in order to define, analyze and realize the development of buildings and building projects.

Thus, the systems approach to building is concerned with the integration of both process and product of building by the use of scientific management techniques involving

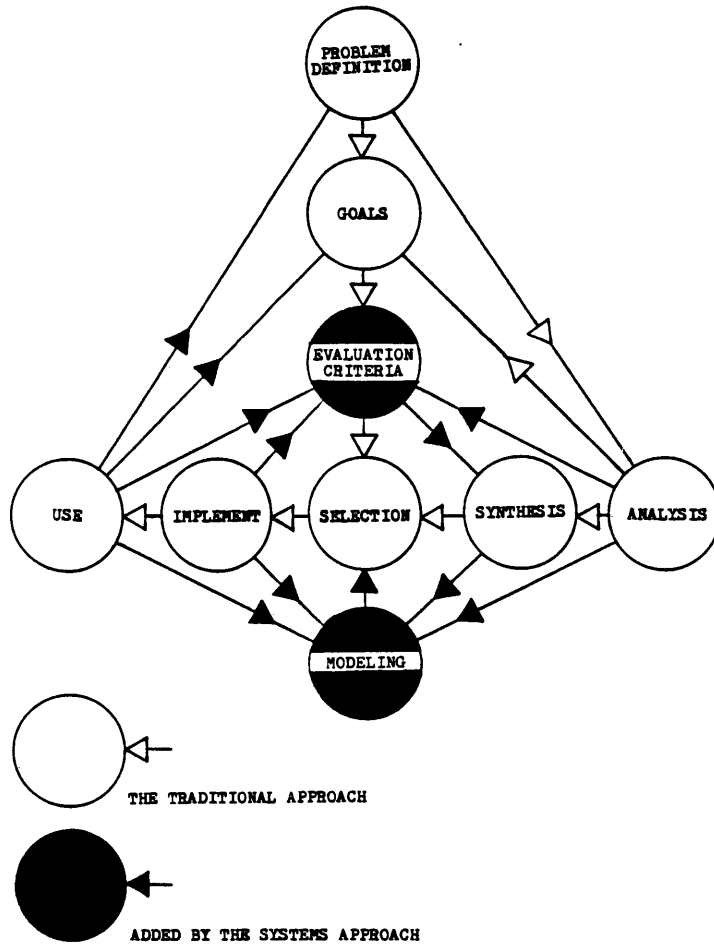


Figure 1 : The Systems Approach
Source : Ware, "Performance Specifications for Office Space Interiors", 1972.

organized research and development to result in a rational model for guided invention. It converts scientific knowledge into applied technology by means of goal-oriented processes within clearly defined contexts and constraints of function, cost and time.[10]

1.3.1 Prerequisite Conditions for the Application of

The Systems Approach to Building [2]

There are certain prerequisite conditions to the application of the systems approach to building. Firstly, the concept of the "building industry" and "professionals" must be broadened so that it takes into account all activities involved in the entire building process, as well as provides feedback to the process for improvement and modification. Secondly, the construction industry, confronting growing demands and new needs should support the development of a management system as a disciplined approach towards solving its problems. This will enable the industry to perform in three important areas essential to its productive growth:

- 1) To handle large volume construction according to growing market demands.
- 2) To manage, evaluate and coordinate a broad interdisciplinary team, required to deal with multi-faceted and multi-level problems inherent in the entire process.
- 3) To measure and evaluate its own performance, resulting in modification and improvement of its methodology. The development of a variety of management tools to serve

the application of the management system is important. Various tools, such as the use of computerized reporting, data manipulation, communication system networks, information collection, storage, retrieval and dissemination, must be developed within the building industry by those who understand the context in which they will be used.

Principally, the application and development of a management system is, therefore, a prerequisite to be able to use the system approach in the industry at all levels. Once all the above requisites have been achieved, the condition is set for the application of the systems approach to building of so-called "systems building" which results in

- 1) Higher degree of rationalization.
- 2) Better application of applied technology and resource utilization which could possibly result in the a of innovation and the development of specific "Building Systems", this is not always.

1.3.2 Systems Building and Building Systems

The term "system" may be understood in two ways; as a verb or as a noun. As a verb it refers to a way of doing something. As a noun it describes a collection or set of objects and their dependent relationships. In other words, a system may be a process (software) or a product (hardware); a "set of rules" as well as a "kit of parts". coincidentally, the term "building" has exactly the same ambiguity.

It may refer either to the construction process or to an artifact that results from that process.[16]

When applied to building, a system may refer to an organization of activities, as in a prefabricating system or to an organization of physical elements, as in a structural system, i.e. "Systems Building" and "Building Systems".

The terms "Systems Building" and "Building Systems" need to be differentiated, and are defined as follows:

"Systems Building" is a process of project development dealing with its planning, design, procurement, production and erection in explicit steps and procedures. By means of systems building, the building process is organized, analyzed and realized as a whole.

A "Building System" is the organization of tasks, resources and parts which, when integrated in a pre-engineered manner, results in methods for the construction of buildings and the creation of environment.

While the systems approach to building (or systems building) relates to the way of achieving and of applying systems, a system for building (or building systems) relates to a particular technical procedure or physical procurement and assembly.

"Systems Building" viewed as a building "process" should be able to respond to various context variables, as

for instance, varied physical, economic, political, social and technical conditions that may exist in a country or a specific situation. Conversely, "Building System" viewed as building "product" or "hardware", are designed solely to work in a given context. The development of a specific prototypical "Building System" is the result of the application of "Systems Building" techniques which are principally "software". Systems building, if properly developed, is supposedly applicable universally, although the specific hardware which results from its use may not be so.

The evolution of systems building as well as building systems has tended towards increasing rationalization of the building process and products, with the goal of more efficient organization of tasks, resources and integrated building components, all combined in a pre-planned, pre-coordinated and pre-engineered manner.

Herbert C. Auerbach, stated the advantage of "Systems Building" vividly as the following:[3]

"The realization of the 'Management System' and the 'Systems Approach to Building' will made it possible for the industry to take full advantage of the diversified products and talent available on a competitive basis in a free market economy. It provides the vehicle through which the best manufacturing capabilities, professional services and new technology could be integrated to produce the optimum solution."

1.3.3 The Building as a System

A building is a collection of systems: a structural system, a mechanical system, an electrical system and so on.

Apparently, there is nothing new about the notion of building as a system. Nevertheless, what has evolved more recently is the conceptualization of the whole building as a system and, moreover, the total process of building production and utilization as a system demands a much higher degree of internal coordination than has been achieved conventionally. This internal coordination commences with an analysis of the building into its components and a study of how well each meets its intended function in accordance with needs under real conditions. Of particular interest is how the characteristics of each component directly or indirectly affect the performance of all the other components and that of the total building. The objective of the analysis is to identify those components which have the most important functions.

1.4 THE EVOLUTION OF BUILDING TOWARDS "SYSTEM"

There are, essentially three main reasons that direct the building towards "system":

1.4.1 The Problem:

Drawbacks of the Traditional Building Process

The comprehensive process of building is traditionally understood as a sequence of steps namely, programming, design, bidding, contracting and execution. Most of today's building progresses as follow [11]:

- | | |
|---------------------------|------------------------|
| 1) Inception | 7) Bills of quantities |
| 2) Feasibility | 8) Tender action |
| 3) Outline proposal | 9) Project planning |
| 4) Scheme design | 10) Operation on site |
| 5) Detail design | 11) Completion |
| 6) Production information | 12) Feedback |

Traditional procedures and sequences have several drawbacks as a result of the processing heuristic, i.e. the repetition of procedures over long periods of time allows gradual changes for achieving improved results. The predictability of building performance is, therefore, relatively low. Heuristic techniques are used, where an acceptable goal is to obtain a reasonable, rather than an optimal solution. An obvious risk of using heuristic methods is the possibility that the best alternative may be eliminated accidentally.[13]

Good cooperation within the comprehensive process of buildings are practically non-existing. The lack of discipline and coordination among various participants involved prevails. In other words, private authorship is still dominant and all members of the building process work independently. Furthermore, traditional procedures have tended to underemphasize many of the interrelationships among building components and subsystems, which significantly affect the overall cost, time and performance and adaptability of buildings over their lifetime. As a consequence traditional approaches to building design and management have produced

inefficiencies at several levels;[9]

- 1) Manufacturers develop specialized products without reference to specific ways in which they will be combined with the products of other manufacturers. The architect and engineer, therefore, design in effect, a different building "system" each time he deals with a new building under new circumstance. Conventional design schedules and budgets do not permit serious systems analysis. Thus, the result is usually a composite of performance compromises, unintentional experiments, and vast numbers of special condition details.

- 2) Building and plan configurations tend to be over-designed, as if they were to remain unaltered forever. The organization of building services (mechanical, electrical, etc.) on the other hand, is usually under-designed, on the apparent assumption that, as concealed elements, their configuration is of no consequence. Each subcontractor is more or less free to use his own judgement in finding the shortest route between two points, and much of the detailed coordination between subcontractors is worked out in the field on an ad-hoc basis. The result is a building which is awkward and costly in routine maintenance and repair, let alone in growth and change.

- 3) The lack of pre-coordination between manufactured products, and the lack of discipline in the layout of service subsystems, are serious deterrents to the development of prefabricated assemblies. Manufacturers are unwilling to commit themselves to mass production of large complex units as long as interface conditions within buildings are essentially unpredictable from their point of view.

- 4) The conventional design approach has emphasized excessively the original design configuration of a building or building subsystem developed in response to its original program. Many detailed architectural decisions are made prior to serious consideration of structural and service distribution requirements. The result has been very complex structures and service networks, tailor-made for the original design configuration of a building, but severely restricted to alteration. Feedback usually only occurs when the project is finished.

- 5) Buildings are often evaluated during construction and occupation. But evaluation procedures are usually not specifically structured for maximum return of useful information, either to the original designer or to architect/engineer's work on current, similar building projects. Thus, many design deficiencies are repeated, even though they may have been actually identified at

one point in the past. Without specific feedback procedures for introducing improvements in design and construction, innovation is painfully slow, depending largely on the limited personal experience of individual designers.

- 6) Conventional design procedures are highly linear, requiring a complete program before design can begin, as well as a complete preliminary design before working drawings can begin. Furthermore, architectural design is developed to a considerable level of detail before engineering design is started. The people responsible for each phase do most of their work independently, rather than as a team. This type of process is time-consuming and makes coordination difficult. Interrelated decisions, which should be made on the basis of trade-offs are often made in different phases, so that the later decisions are unduly constrained by earlier ones.

- 7) Change with respect to new needs over a building's life-time are likely to occur. Traditional design and construction is rigid and not very sympathetic toward change. Hence, it often results in a building's obsolescence before the end of its estimated life span, or alterations are extremely difficult and costly.

This fragmented organization in traditional process hampers technological innovations, including the complete utilization of the building industries' potential, as well as frustrating rationalization of available resources and technology.

1.4.2 Changing Context in Design

The design of a building is the optimization of resources in the creation of a functioning human environment. Traditionally, the designer determines the best design solutions empirically through his experience of the direct correlation between alternative solutions and human needs as addressed previously. There are two revolutionary forces which are changing the context of the building design.[14]

Firstly, changing technology in relation to industrialized evolution results in new methods, new materials and new skills available in the marketplace. The context changed from a time when building being built by widely used methods, i.e. traditional methods to a time when most buildings are produced by manufacturing products, each of which has its own performance and technology. This proliferation of building methods severely threatens the designer's ability to know alternative building methods, varying product performance and their costs.

Secondly, while industrialized countries have arrived the industrialized period in which goods, including build-

ing, are mass-produced for a faceless marketplace, There is a growing consciousness of individual difference. People want to participate in the decisions which shape their environment. Mass education, mass housing, mass consumption do not meet the need for individuality. Not only does the consciousness of the differences between individuals directly affect the design of buildings, but accelerating changes in human's needs and technology should be reflected in building design. For instance, the design of schools has recently reflected not only new methods in education but the anticipation of future changes. Schools must be capable to respond to these new methods.

Accordingly, only industrial knowledge of new methods and products does not suffice to serve the designer about the user needs of buildings. Each new design effort should involve substantial analysis of user needs and requirements.

As a consequence, traditional knowledge and skills of the designer are severely threatened. What could be traditionally be accepted as a "good" design solution may now be invalidated right upon completion of a building or project by new technological development or by changing in needs of the building's users.

1.4.3 New Demand

Apparently, society has increased its complexity in urbanization and structure considerably. The radical changes

brought about by the industrial revolution, rapid growth of population, technological innovation and other related factors place many diverse and new demands on building, increasing its complexity both in terms of new products and processes.

Since building projects are growing both in size and complexity, problems related to the drawbacks of the traditional process increase, and therefore many building projects have reached a level of complexity that is beyond the capability or capacity of traditional practice. Thus, the traditional approach to building process cannot be "one best solution", but optimization, and by balancing all constraints to diminish the chances of error that may have occurred as a result of traditional procedures.

In conclusion, the complex problems of planning and execution which have evolved as a result of the aforementioned factors in existing building processes are beyond the capability of traditional practice and, thus, more scientific and highly organized procedures are required. In the light of the above, the systems approach to building is a promising candidate for solving a number of the above mentioned difficulties, and has been tested in actual practice.

CHAPTER 2

THE SYSTEMS BUILDING

-ITS PROCESS AND VARIOUS FACETS-

2.1 INTRODUCTION

The systems approach, when applied to building problems, results in a process whereby resources and needs can be related effectively to performance, cost and time. Note here that resources which one deals with in buildings are land, financing, management, technology and labor, while needs refer to user requirements, e.g. different types of space, service, environment.[3]

Systems building aims at combining both system elements and related processes into a multitude of possible design solutions which are defined by a given program. The mutual compatibility of these elements and its processes are controlled by a set of abstract ordering principles and the system rules. It is a methodology which is concerned with the process of building which refers to every stage from the establishment of objectives, a program and its development to the construction of building including its effective life.[1]

The intent of this chapter is to bring the theoretical framework presented in the chapter 1 into a realistic setting by discussing the systems building program in its process and various facets, in particular concerning certain

rules which are different from those of the traditional process.

2.2 THE BUILDING PROCESS OF THE SYSTEMS BUILDING

The building process using the systems approach commences with

2.2.1 Organization of the Program and the Program's Owner

This embraces the questions:

Who establishes the program (Who is the owner)?

Where is the program implemented?

What are the needs and the problems?

A problem exists where there is an undesirable imbalance of elements in a given context. Also it exists when there are needs or desires to improve any elements from what they currently are towards a quality that is perceived as better. For instance, cost reduction, speed in time of construction, and increasing flexibility are such factors. It is essential for any system, including systems building, that the problems are precisely stated and explicitly defined. Otherwise, they would lead the process to carry out system's activities with irrelevant solutions.

For understanding the problems and solving them, the context and constraints must be defined and analyzed. Context means parameters and of the program such as the social, political and economic environments, ranges of geographic

and climatic conditions, available resources and technology, level of manufacturer capability, ranges of project subject to the program, e.g., SCSD provided the capability of school buildings ranging from a 12-classroom elementary to a 3,000 student high school, demand-supply and market condition. Program organization is considered as context as well. All relevant bureaucratic procedures and authorization involved in the development of the program as well as its administrative aspects are to be analyzed. For instance, these procedures are financial aid allocation, ability to aggregate demands and assemble markets, if there is a development of new building products for the program, and the ability to undertake long term research. The strength of the organization influences the possibilities of solutions considerably, aside from the context and constraints of the program e.g. the possibility of whether or not to develop a building system to meet the required performance.

Constraints mean factors that impact unfavorably on the program such as limited budget, and time elapsed from the inception to the completion of the program. As an example, the SEF organization is presented to exemplify the organization of such a program:[7]

-WHO- The Metropolitan Toronto School Board which is in
 charge of
 400,000 students

20,000 teachers

2,500 officials

544 schools

-WHERE- Metropolitan Toronto with 5 Boroughs.

-NEEDS- Each year the Board must build 20-30 schools plus many additions and alteration.

-PROBLEM- How to grapple with the problems of explosive growth, capital shortage, while maintaining and advancing educational standards and meeting the intense pressures of fundamental social change in a cosmopolitan population. Note that the analysis of the problem is the first move towards its solutions.)

-SEF- The Metropolitan Toronto School Board established a multi-disciplinary team with various professionals to carry out the study of Educational Facilities. (See fig. 2,3)

2.2.2 The Program Objectives

Once the problems are analyzed, context and constraints defined, and a study team has been assigned, the terms of reference, i.e. the program objectives can be established according to the problems posed. (See fig.4) To give an idea of the objective statements, an example of program objectives of the SEF program is presented as follows:[8]

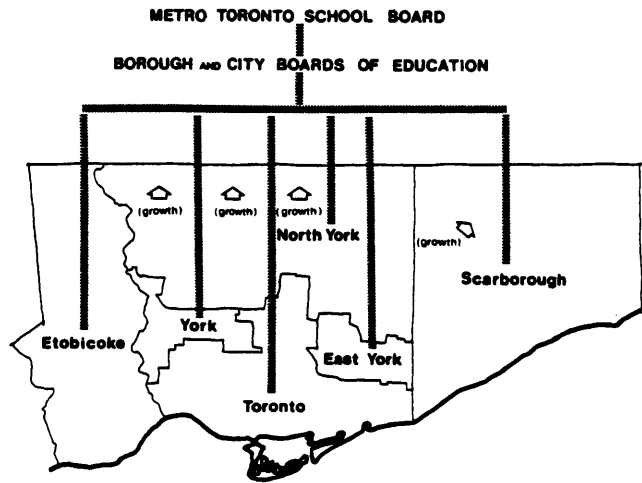


Figure 2 : Organization of Metro & Borough Boards of Education.

Source : Robbie, 1969.

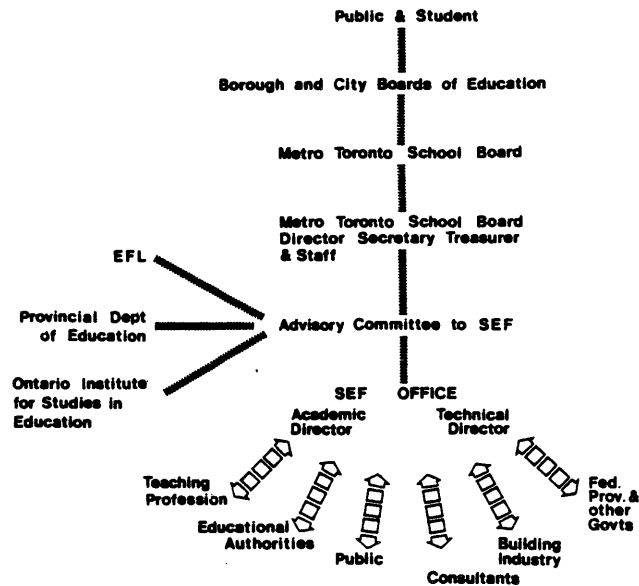


Figure 2 : Metro Toronto School Board & SEF Office.

Source : Robbie, 1969.

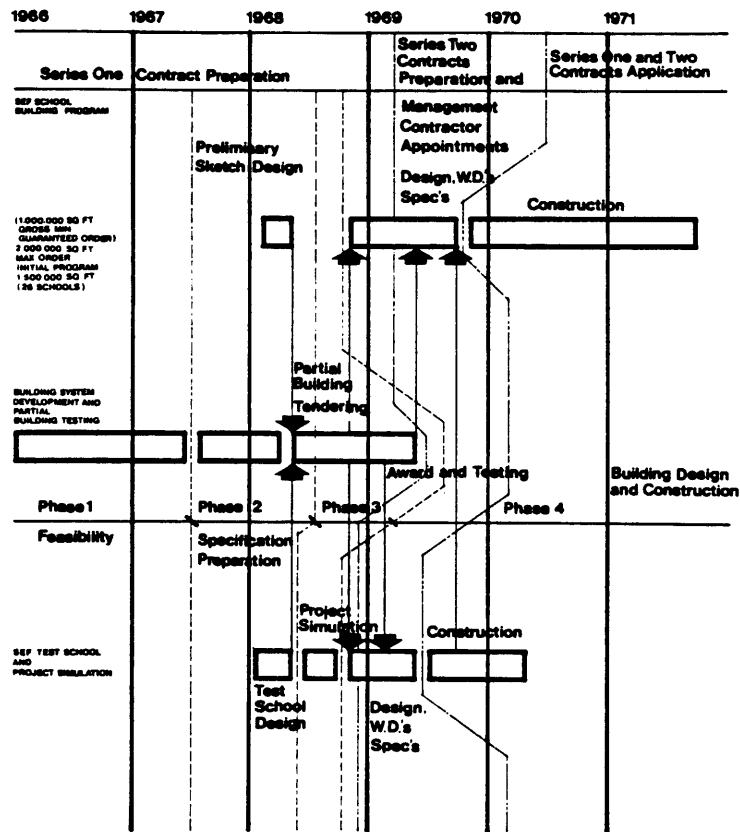
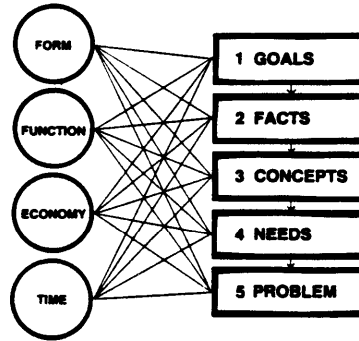


Figure 3 : Organization of the SEF Building System Program.
 Source : Robbie, "The application of the Systems Approach to School Building in Toronto", 1969.

CONSIDERATIONS	
FORM	SITE ENVIRONMENT QUALITY
FUNCTION	PEOPLE ACTIVITIES RELATIONSHIPS
ECONOMY	INITIAL BUDGET OPERATING BUDGET LONG TERM BUDGET
TIME	PAST PRESENT FUTURE

1 The information index lists information under four considerations.

2 All considerations interact at each step.



	FORM	FUNCTION	ECONOMY	TIME
GOALS	•	•	•	•
FACTS	●	●	●	●
CONCEPTS	•	●	•	•
NEEDS	•	●	●	•
PROBLEM	●	●	●	●

3 The matrix dots indicate a value judgement of the emphasis of information.

4 The cost estimate analysis must account for all budget items.

COST ESTIMATE ANALYSIS

A. BUILDING COST	315,500 S.F. @ \$20.00 S.F.	\$6,310,000
B. FIXED EQUIPMENT	(8% of A)	504,800
C. SITE DEVELOPMENT	(20% of A)	\$1,262,000
D. TOTAL CONSTRUCTION	(A B C)	\$8,076,800
E. SITE ACQUISITION		300,000
F. MOVEABLE EQUIPMENT	(20% of A)	\$1,262,000
G. PROFESSIONAL FEES	(8% of D)	484,600
H. CONTINGENCIES	(10% of D)	807,500
J. ADMINISTRATIVE COSTS	(1% of A)	89,700
I. TOTAL BUDGET REQUIRED (D & E thru J)		\$11,011,700

Figure 4 : Systems Building Program Development
 Source : Pena and Focke, "Performance Requirements of Buildings and the Whole Problem", 1972

- 1) Develop systems and components specifically for school use.
- 2) Apply more effectively the principles of modular construction for the achievement of greater flexibility in interior design.
- 3) Reduce the cost of school construction, to provide better value for expenditures in terms of function, initial cost, environment and maintenance.
- 4) Analyze means of reducing the cost of site acquisition and school construction through the building of a joint occupancy structure.
- 5) Analyze the problem of short-term accommodation, including an evaluation of the present use of portable classrooms and a consideration of alternatives to meet short term needs.

The program's organization has general objectives and immediate goals. The achievement of these is the basic driving force behind the behaviour and activity of organization or individual for that matter.

The diversity of the objectives of each program depends on its needs, and on problems which need to be faced within its context and constraints. Although every program has different objectives, there are some similarities that exist in the basic objectives, i.e. the advantages of systems building, which are quality, cost and time reduction, design capable of providing for flexibility, and a suitable

environment for the users. Indeed, every systems building program, if its process is properly developed and the result implemented, should perform its promises.

2.2.3 Performance Requirements.

When the objectives are clearly stated, then the team proceeds to conduct a study of the general criteria for the required solution performance. Note that the systems approach needs not to include the performance concept, this will be discussed later in Chapter 4.

However, this thesis is focused on the systems building which employs the performance concept as a mediation between the hardware solution and its procurement. To establish the performance requirements, the requisite studies need to embrace all aspects of the various problems posed, including the program objectives. In addition, two other aspects which are essential to be studied are the user requirements definition and the technical study.

2.2.3.1 The User Requirements

User requirements -define who are the users and arrive at an understanding of their activities and characteristics, the equipment used, the spatial configuration and space requirements to be accommodated, desired ambience, satisfactory environmental conditions, and so on. Most of these can be expressed in measurable terms of quantity.[6]

From a comprehensive study of user requirements,

(including the elaboration of program objectives), main guidelines are obtained for the required system's performance, i.e. the performance criteria. Examples of performance criteria from SEF are as follows;[9]

- Flexibility-- It must be possible to rearrange the space dividers and all services and casework easily and economically without extensive on-site work.
- Open ended services--It must be possible to rearrange the services to match the servicing characteristics of specific areas, to add to or subtract from existing services, and to replace services without damaging other work.
- Extension-- It must be possible to make additions both horizontally and vertically within a consistent framework of service techniques.
- Building Design-- It must be possible to design any required school building, within the program range with the system, giving maximum design freedom to the project architect.

2.2.3.2 The Technical Study

To meet the physical aspects of performance criteria in accordance with the requirements and to compromise technically between the ideal and the practical, detailed technical studies must be undertaken, as for instance; establishment of a dimensional system, planning grid, appropriate coordinated subsystems, along with a detailed review of the technical aspects of the built environment; lighting, acoustic climate, tactile considerations, flexibility of space, and so on.

By integrating performance criteria as derived from user requirements with their respective technical solutions, the result takes the form of technical specifications for

each subsystems and its physical performance capabilities.

Thus, one of the main features of the systems approach has been obtained, i.e., goals are stated in performance terms which are not prescriptive, but descriptive. The descriptions will state how solutions must perform and not what it must be.

In order for the performance specifications to match a wide range of procurement strategies, alternative solutions need be explored and generated. In other words, variability of design is matched by equally "open" procurement alternatives.

2.2.3.3 Alternative Solutions

Before proceeding to the issue of alternative hardware solutions and detailed design, the study team should approach a given problem in a broad sense first, with the following check-list in mind;

- 1) Consideration of complete building system development. This thesis will take this approach towards hardware solutions.
- 2) Use of building systems or building sub-systems already available in the market, if and when the context and constraints do not allow the first approach.
- 3) Decisions made at this stage need not necessarily result in hardware solutions. In fact, a program may end up with recommendations for a new institutional organiza-

tion, or a plan for improved organization procedures, such as financing and/or planning. The aim is to arrive at an improved process, resulting in a better rationalization of current design and construction method, even in cases where a program is carried out by traditional construction methods.

Thus, one or many approaches are possibly. These approaches imply that the results of systems building are not necessarily a building system. It can also be an acceptable range of building systems, to be tested in compliance with performance specifications, or it can be a process to be implemented.

Once relevant information has been assembled and analyzed, alternative hardware solutions can be generated. This is the stage of analysis and ultimately synthesis, using techniques such as cost analysis, calculations, modeling, sophisticated management practices and computer programming to simulate the performance of alternative solutions.

As far as methods to find alternative solutions are concerned, the methodologies for variety generation (as well as variety reduction) become very useful.[1] The need for variety is implicit in any particular set of ordered principles and procedural rules applied to systems building. These principles and rules also provide the means for reducing

excessive variety by including only those alternatives which are compatible with the performance specifications, and the conceptual, technical and economic constraints of the program. Thus, the process of variety generation and variety reduction is a significant factor in any systematic design procedure for planning, design, procurement and realization.

In the light of the above, as many reasonable and feasible as practical options need to be examined. It is also important to maintain as much as possible an attitude of impartiality towards alternative options, which may emerge during program development. Technical, economic and other constraints are factored in as parts of the development process and therefore help to prevent the proliferation of unlimited numbers of unrealistic options. In other words, in systems building, which includes the design of a given building systems, there is a mandatory requirement which demands that no option is excluded from consideration, unless it has been scrutinized and found unfit for realization in terms of legitimate program constraints.

To examine alternatives, each individual option can be assigned its proper place in a larger hierarchy of more or less feasible design solutions and can be assessed in terms of their advantages or disadvantages with regard to each other, and the requirements of the program. In addition, proper evaluation criteria must be established. At each stage of the design/development process, only those criteria

considered must be the ones which are judged relevant and/or absolutely necessary to satisfy functional, structural, economic and other constraints at each particular level of evolution imposed by the program, e.g., the structural system is required to be as "open" as possible to accommodate the greatest possible range of plan options.

Accordingly, the aim of generating alternatives is that within the range of alternatives that meet user needs, those are eliminated which cannot be developed within the established constraints. Once a range of possible solution is found, all the promising alternatives are evaluated to select those (or one) which, within the constraints, holds the greatest promise for implementation and user satisfaction.

The whole process must be regarded as iterative, in the sense that each solution at each stage of resolution has to be rendered compatible with the constraints imposed by the conditions of both the preceding as well as the subsequent stages.

2.2.4 The Implementation

The next stage is that of implementation. It concerns the design and construction of individual building projects subsumed by the program, which are expected to utilize newly developed building system, acceptable building systems, including its sub-systems and the process to be implemented.

The solution is subsequently evaluated against the goals, and corrective feedback into the process is facilitated, including the improvement of subsequent predictive conceptual models or plans.

2.3 THE PROMISES OF A SYSTEMS BUILDING PROGRAM

The promises of systems building can be viewed differently and in many aspects. However, the most significant problems facing building process, design, construction are the main reasons for using systems building, to wit:

- 1) Buildings as part of a system of alternative designs can be extremely flexible. Also, compatible building production provides the performance ability to accommodate change in a pre-determined and technically coordinated manner.
- 2) There are significant savings in construction time and material costs as result of the efficient assembly of subsystems and the use of new prebidding procedures. (See 4.3)
- 3) There are savings in design time through the use of performance specifications, instead of conventional prescriptive specification documents.
- 4) Total costs are usually expected to be less than those of conventional construction, owing to the use of standardized products and due to scheduled time savings in procurement and assembly.

Principally, systems building should result in greater flexibility, higher production quality and efficiency, rapid scheduling, and economy in design and construction.

2.3.1 Quality

The most basic gain offered by systems building is production quality, since the systems approach stimulates improvements in building technology, if the opportunity for innovation is provided. It enhances cooperation between owner, building production manufacturers and design professions to systematically work in finding and developing the best end products. Confronted with new performance requirements, manufacturers are stimulated to seek for and produce economical innovations, instead of continuing traditional industry practice which tends to be conservative. Consequently, this provides the possibility for drastically improved hardware by means of particular system components, designed in accordance with clearly established performance specifications.

2.3.1.1 Fragmented Organization in the Building Industry

There are many reasons for the building industry's failure to respond spontaneously to new demand. Some of the obstacles to technological progress arise from restrictive and outdated building codes that discourage innovation and standardization, labor union rules that bar factory fabrication or mechanized field assembly, and finally a general lack of clearly stated performance standards and tests for

evaluating and approving new building products.

Basically, however, this failure to respond spontaneously to new demand springs from the industry's fragmented organization. For decades, the building industry has operated within a warped organizational structure of vaguely defined responsibilities. Furthermore, it is comprised of numerous professionals with responsibility conflicts and communication gaps, such as, between owner and architect, between architect and manufacturer, between manufacturer and subcontractor, and so on. The manufacturers of different components generally work in isolation, unconcerned with the overall integration of their products into a total building system. Each segment of the industry pursues its own specialty, though this has advantages on the basis of competition, often oblivious and always powerless to control the entire process. Consequently, the fragmentation of the building industry is slow in generating technological innovation.

Systems building is capable of transforming the cumbersome and fragmented building process into a coordinated and rational organization, free of the building industry built-in frictions and obstruction towards technical innovation.

2.3.1.2 Justification of Building Systems Development

Creating the right condition for building product manufacturers to produce improved hardware instead of con-

tinuing traditional industry practice as aforementioned is the major problem. Small and fragmented tiny markets cannot sustain the research and development effort needed to produce new building components e.g. to build an automated production plant designed especially to turn out the new developed system components. The development of a building system would not succeed unless a market has been aggregated large enough to justify the investment for developing the new products.

Accordingly, the first and more indispensable step for a systems approach program, aiming at developing a building system, is to integrate a market in terms of building volume, i.e., to aggregate several projects into a single program, large enough to call for bids on the various coordinated building subsystems developed. Such a large market gives manufacturers the expectation of reasonable profit to offset research and development costs that could not conceivably be justified for a single building, custom built in accordance with conventional practice. For conventionally built buildings, with no guaranteed mass market, there is no provision for research and development, and usually no incentive to introduce automated production plant and no incentive for innovation.

Yet the chief significance of the systems building program lies less in its technical results than in its organizational achievement. The systems building program owners

play an important role in assembling and aggregating the required market, convince the building project which is subject to the systems building program to make a commitment to use building components they are not fully developed and award bids by a new method. The realization of a building system program is essentially to have enthusiastic support from various participants.

It may be stated that the right condition for building system development requires the careful considerations of available technology and incentive for manufacturers to work towards new products justified by sufficient demands for their profit expectation. In other words, a building system is conceived in the context of "market place" supply and demand. As a result of these new products developed by manufacturers, we expect in their quality and efficiency.

The system hardware developed will contribute considerably to cost savings both in construction and during a building life cycle, and time savings in addition to the direct benefit from its high performance. Thus, the systems building eases construction and shortens erection time, thus, leading to earlier occupancy of a building. It facilitates alterations while maintaining its overall performance. Moreover, integrated system hardware offers flexibility to user's wishes and provides many possible options for individual designs, which can be considered as facilities that users would like to enjoy but seldom get from their

buildings.

2.3.2 Time Benefit

There may be significant time savings gained in the application of the systems building approach, such as the following:

- 1) Hardware produced for a building system leads an innovative approach towards efficiency in its assembly and erection, thus, results in earlier completion than with conventional construction. Time savings may also be gained due to ease of building alterations throughout the life-cycle of a building or project.
- 2) Pre-bidding of subsystems, discussed in chapter 4, before general contract awards produces major time savings. This is so because pre-bidding of basic subsystem contracts prevents material delivery delays and facilitates the use of known components in architects' design work, i.e., architects design with pre-coordinated systems.
- 3) Dramatic time saving can be achieved by a combination of systems building with "fast-track" scheduling*, see fig.(5). The added fast-track schedule compression enhances other time savings already gained through the systems approach.

2.3.2.1 Systems Building and Fast-track Scheduling [5]

Because both design and construction contribute to overall building process, the key to accelerate the overall building process is to telescope design and construction as much as possible, i.e. to start construction as soon as possible, after completion of the minimum required design work.

Systems building and fast-track scheduling achieve this goal for the following reasons;

- 1) Possibility of postponement of final design decisions on precise room layouts and sizes is permitted by the flexibility of system design in terms of plan option and as a consequence of system production, e.g., flexibility of the partitions, multizone air-conditioning which can be adjusted for final location late in the over-all construction process.
- 2) Prebidding of subsystems allows early commitment to construction.

Time savings attainable on a project with a large number of coordinated subsystems and full fast-track programming ranging up to 45%. With fast-track scheduling applied to conventional construction, time savings are limited to about 25%.

* Note: "Fast-track" scheduling is the construction management technique telescoping the traditional serial or linear sequence of programming-design-construction i.e. on stage starts only after the preceding stage ends, into a shorter sequence of overlapping stages.

The price of such dramatic time savings gained by the potential benefits of fast-track scheduling is considerable. Programming and design must proceed in a more rigorous, controlled way. Decisions at each stage become irrevocable. Project stages must be broken into a more logical order. Design decisions must parallel the manufacturers' and contractors' works. Communication between owner, architect, manufacturers and contractors are extremely important. Basically, the construction manager becomes indispensable for the complex work of coordinating the many simultaneous activities of a large building project. The true fast-track technique is most applicable for large-scale projects, since the resulting increased management effort is better justified.

Even though systems building and fast-track technique combined together result in considerable savings in building delivery time, nonetheless if the project is not well-coordinated the result can be lose than gain.

2.3.3 Cost Savings

Cost savings obtained through systems approach provide for later change and benefit for not only the first cost but also the building life-cycle cost. These savings stems mainly from time savings and production efficiency. Time savings not only deliver buildings at an earlier date, they also contribute to large cost savings during periods of rapid building-cost escalation. For example, an additional

cost saving of 10% comes from the accelerated construction schedule which compensates 10 months of cost escalation at 1% per month. Also, economy may be achieved by subsystem rationalization, since subsystems make up around 30-70 % of the total construction cost. Principally, system-built building cost should be lower than conventional building both during construction and throughout a building's life-cycle.

2.3.4 Flexibility and Change: The Systems Design Procedure

The methods used in the design and development of building systems are considerably different from those governing the conventional design procedure, i.e., the design of single edition solutions. This means, if a school board wants ten schools, architects hired may work on ten designs, one for each school, with ten sets of drawings, ten specifications and ten tenders may be called for. By means of conventional methods, each design must be worked out individually and specifically for each building, each with its own fixed plan. Beside, conventional design practice rather adheres to fashionable formalistic notions of style, appearance, uniqueness etc. On the contrary, the planning/design processes of systems building aims at open-ended solutions that is both conceptually and physically capable to embrace three performances required by the systems building procedures as the follows:

- 1) Performance and ability to accommodate individual projects' diversity.

Since a systems building program usually integrates several projects into the program. These individual projects vary in ranges of use, site condition, etc. Accordingly, the system design must take into account all range of conditions of individual projects and allow possible design freedom for individual architects for each individual project. Thus, the system design is to be accommodate diversity, various design and planning options of each individual project.

- 2) Performance and ability to accommodate flexibility-variability-adaptability

It is reasonable supposition that, within the parameters of first use, most generic building types call for flexibility, i.e. the feasibility of modifications for required change, different functions or modified used patterns. System design accommodates plan changes in first use e.g. relocate partitions, change functions, etc.

- 3) Performance and ability to accommodate life-cycle change

Aside from minor plan change in first use, radical changes might occur during the building's life-cycle, and result in major alterations, such as conversion, expansion, upgrading, etc. The building systems approach is supposed to accommodate such changes as well.

In the light of the above, the terms "flexibility", "variability" and "adaptability" are defined as the following.[2]

- 1) FLEXIBILITY- defined as the ability to adapt to the various wishes and needs of the end users. Provision for flexibility must be made an integral part of the initial design phases. It should be possible to accommodate flexibility without necessarily having to change the basic system or its elements as such.
- 2) VARIABILITY- defined as the possibility to make subsequent change in plan by means of changing the position of the elements within the rules determining the system, or by a pre-designed modification of the system or its constituent elements.
- 3) ADAPTABILITY- the ability to respond to, or be readily adjusted to, changing condition.

The resultant degree of flexibility-variability-adaptability determines the capability of system design to accept changes in function, use, execution and form.

2.3.3.1 The Need to Accommodate Changes in a System

Changes, ranging from minor ones e.g. relocate partitions to major ones e.g. full conversion occur as a result of changing in user requirements, (see fig.7) changing in needs, technology, equipment, policy, program requirements, the impact of energy consideration, etc. Numerous studies, particularly those related to various systems building

program, e.g., SEF, SCSD, RAS, VA, have been done, regarding the effect of change on building life-cycle, life-cycle cost, and the need to accommodate changes in most generic types such as, office buildings, health facilities, educational facilities, laboratory, dormitories, and so forth. The results of these studies confirm that within a fixed plan of conventionally designed buildings, any change is costly and time-consuming, radical changes in particular. A rigid pattern of interior space divisions or structural elements can pose a tremendous obstacle to any alteration, and thus, result in a shorter building life time than that of the full designed life time, or incur expensive alteration costs.

Accordingly, rather than confronting change in an ad-hoc manner, resulting from lack of anticipation of probable required changes, potential functional or spatial alterations can be anticipated in advance and provisions can be made for the system to compromise with the demands of alterations, upgrading, expansion etc. throughout the anticipated full life cycle of the building and as incorporated in the design/planning stages. (See fig.6)

Economically, this makes sense since the first cost does not necessarily mean that a building is economical if its full life-cycle cost is not taken into account. High life-cycle cost resulting, from the failure to cope with periodic or imposed change can shorten a building's life

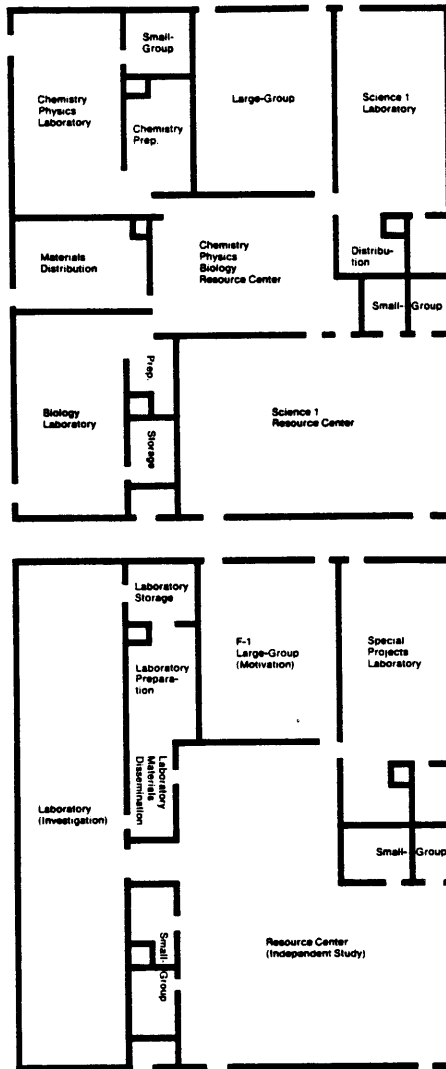


Figure 6 : Relocatable partitions enabled original plan, above, of science department to be transformed into open instructional areas, below, at minimum cost.
 Source: Griffin, "Systems", Educational Facilities Laboratories, 1971.

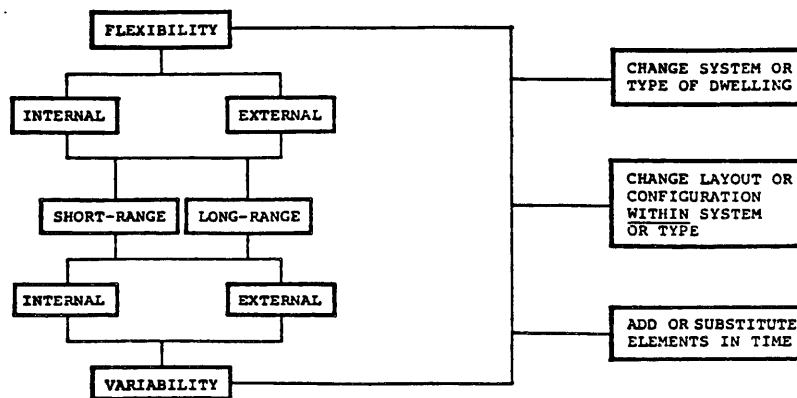


Figure 7 : User Requirements and Change
 Source : Dluhosch, "Flexibility/Variability and Programming", IF, Vol.5, No.5, 1974.

time considerably and may lead to obsolescence before expected life time. Therefore, and with regard "first use" - flexibility / variability / adaptability and life-cycle change, a fixed plan is unacceptable for many generic building types.

With this in mind, system design aims toward open-ended solutions (see fig.8), which endeavour to anticipate change and provide explicit means to accommodate changes by exploring the spatial potential of a given structural system or dimensional order in terms of testing their capability to accommodate a specified range of solutions, without major changes of the primary and/or secondary elements of the original system. Theoretically, no system built building should cause the costly, harassing delays or exorbitant renovation expenses when changes are required or if the plan has to adapt to changed or new needs. This implies not only a purely conceptual manipulation of layouts and plans which contain the feasibility of subsequent modifications, but also includes the calculation and assessment of the technical means to accommodate such changes.

Thus, both in principle and in practice, the basic structural frame of a system should be capable to be extended both horizontally and vertically. Theoretical extensibility in all directions at each floor level enables the system to have the capability to accommodate many varied plan options beyond those fixed by the first use and beyond

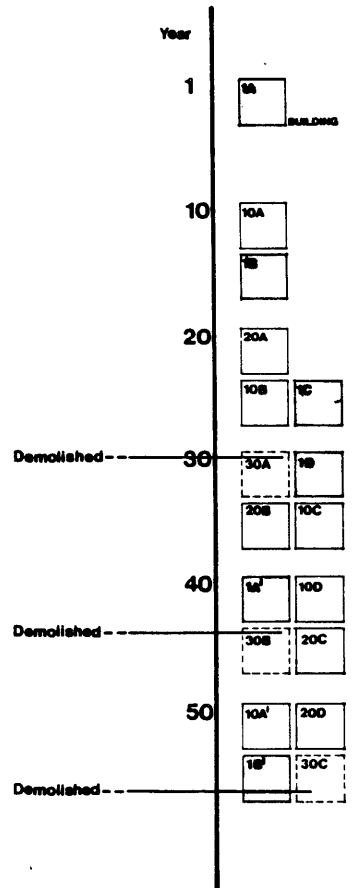


Figure 8 : Open-Ended Building Evolution
Source : Robbie, "The Application of
the Systems Approach to School
Building in Toronto", 1969.

those specified by the original program. Moreover, to think in terms of open-ended planning/design, it is necessary to develop a planning and design strategy about how to generate a flexible plan, i.e., images of certain prefigurations, including a consideration of aesthetic considerations in terms of the development of process, and the systematic coordination of all subsystems with structural layout and service.[1]

The skillful manipulation of all generic design elements to satisfy a range of specific solutions, including the nurturing of an aesthetic attitude is based on the mastery of system's instrumentalities.

Clearly, in the planning/design of systems building, prime concern is to anticipate all possible exigencies which may emerge in the future. In addition, system design has to accommodate variety of building projects which are subject to the program. A system, therefore, could be designed within the range of such a framework, to offer the architect design freedom for each project and to provide the possibility (and feasibility) to accommodate change. This can be taken into consideration as a long term economic benefit of system design.

2.4 INDUSTRIALIZED BUILDING VS. SYSTEMS BUILDING

The first stage of systems building appeared in the form of industrialized building and started in Europe after

World War II as a result of the urgent needs to rebuild devastated buildings in those war ravaged countries, housing in particular. A continuing program of government subsidies generated the required housing volume to justify mass production. Industrialized construction of schools was first used in Great Britain. It reached a high by successful level of development with the Consortium of Local Authorities Schools Program (CLASP).[4]

Early building systems lacked one of the two requisites of systems building, one of which is the analysis of user needs or defined functions of the various subsystems on the basis of open-ended design. No new performance criteria or mandatory interfacing requirements with other subsystems were set. Neither was there a possibility of later change, nor for user flexibility, and did not give architects' freedom in their original design because all building components are fixed in their combination, e.g., a rigid set of room sized and arrangements, floor and roof spans, partition locations, utilities etc. until CLASP began to offer some minor options. It also standardized a set of modular dimensions and offered some competition among various manufacturers furnishing standard building components.

Here, it becomes possible to distinguish between industrialized building and systems building. If early industrialized buildings do not qualified as true building system, then, they must be regarded as industrialized building of

the traditional building process by perfecting production techniques for casting and curing precast panels, creating sophisticated jointing details and solving other strictly technical problems. They did cut construction costs by greatly reducing the uncertainties and expense of field labors i.e. by maximizing factory production. Nonetheless, these systems still offered the industrialized version of a conventional dwelling to users.

It is fairly obvious that a building system is possibly regarded as industrialized building in many aspects, e.g. manufacturing standard building components, efficient production techniques, but not necessarily vice versa. Even though both building system and industrialized building achieve improved performance with regard to "cost, time and quality", the systems approach, to a great degree, offers better performance physically and conceptually in design and planning beyond the traditional building process as discussed in the previous paragraph.

2.5 ROLES AND RESPONSIBILITIES

During process development, the same as in conventional process, systems building program is supported by numerous professionals and consultants to carry out complex studies aforementioned. These groups include

- Architect
- Mechanical engineer
- Structural engineer
- Electrical engineer
- Specification writer
- Construction manager
- project manager
- Quantity surveyor
- Programmer
- Industrial designer
- Technician
- Economist
- Consultant for testing techniques etc.
- Building component manufacturer

The systems approach brings about a considerable change in these groups' activities from the traditional practice (see fig.9). It necessitates the groups to mobilized their capabilities and work simultaneously towards the development of a required numbers of subsystems to meet both cost and performance specifications of a given program.

Among the groups, the roles of the owner, manufacturer, architect and general contractor are changed more than those of any others, and noteworthy to mention here as follows:

2.5.1 The Owner

Active owners are vital to successful systems building. They should not rely passively on professionals and industrial experts. On the contrary, they must play an active role, mainly in organizing the program efficiently, establishing the system study team, aggregating individual projects in the program, and creating an atmosphere to induce

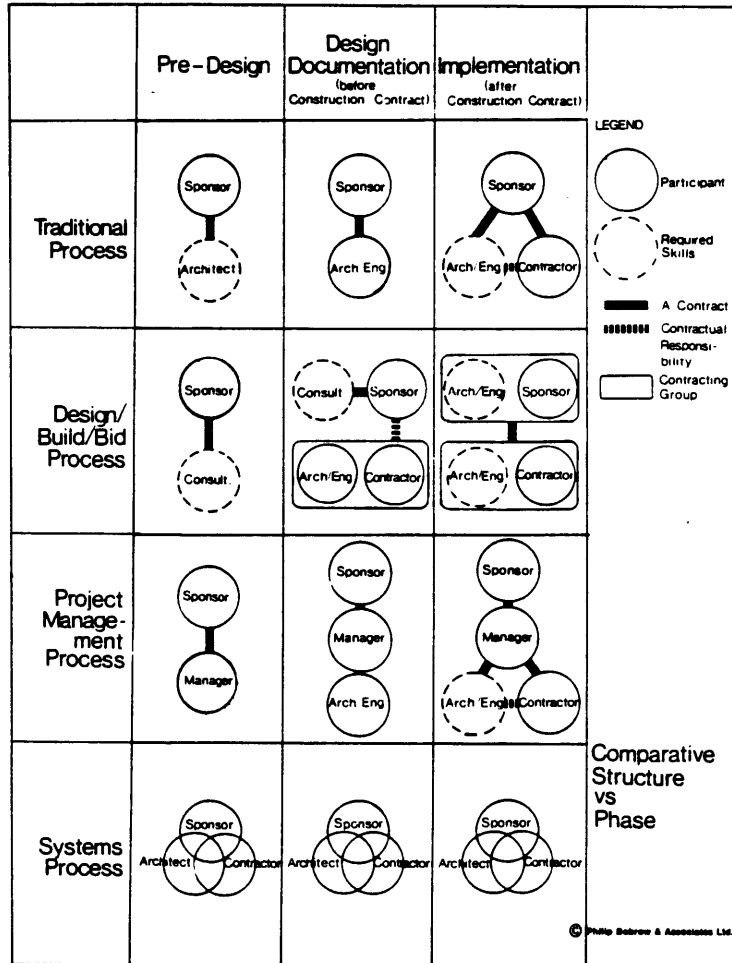


Figure 9 :Four processes for the acquisition of building, showing the participants at each stage.

Source: Bobrow, "Experimental changes to the Architecture Process", IF, Vol.5, No. 5, 1974.

manufacturers' participation in product development.

2.5.2 The Manufacturer

The major change in roles is the expanded role of the manufacturer. His previously untapped potential is fully exploited in a systems building program. Conventionally, the architect and engineer are responsible for designing details for components' assembly and construction which contractors and manufacturers have perennially criticized as being expensive or impractical, and which are either difficult to produce or to install, or perhaps both. In the building systems process, it is the manufacturer's obligation to solve such problems.

To illustrate why this is so, the problem of accommodating structural frame deflection above a partition fixed to the structure will be given. Formerly, this was a problem for the architect-engineer, who had to design a detail for it. Under the building systems rules it is the manufacturers' problem to solve a "mandatory interface" on which the structural manufacturer and the partition manufacturer have to work cooperatively to prevent buckling of a partition under of loading. Such problems logically should be the concern of manufacturers, since they have both the practical expertise and the production experience to solve them.

Consequently, the role of the manufacturer is expanded to the full scope of his capability in the systems building

program. He is not restrained by inhibiting specifications of the conventional construction project. He is required to consult and cooperate with other manufacturers, and even to concern himself with aesthetics.

2.5.3 The Architect

Though the manufacturer takes over some of the architect's traditional functions, the architect's role, nonetheless, remains crucial in building design and planning. Relieved of the troublesome technical details of connecting and fitting components which are now more efficiently coordinated by manufacturers, architects should be able to do a better job in their design. They can forget about window caulking, roof flashing, and other troublesome details that have traditionally deflected them from their larger concerns. The architect of a systems building can focus more on design, function and on creating an aesthetically pleasing environment for users.

Systems building program, utilizing industrialized building systems, is usually accused of producing monotonous environment. One can argue, however, that instead of limiting the architect, standard system components enhance the architect's imagination in allowing him to arrange them in limitless combinations. Thus, the architect has the freedom to manipulate building elements which offer great freedom of choice and lead to a great range of end results. The standard kits of subsystems are, indeed, no more confining than

the piano composer's keyboard. Any single system-built building should be capable to display a great range of architectural concepts as well.

However, in order to be able to manipulate the system components and potential wisely, the architect has to understand and be acquainted with the system-catalog of construction materials and techniques which he is given to work with. In the final stages of design and construction of individual projects, architects, engineers, and contractors carry out their works with final subsystem manufacturers' catalogs, management handbooks and full details of the application of the system. For instance, the architect may be retained to design a building, using coordination of the system-catalog in his individual project. This procedure, if properly used, does not restrict intuition which is to some extent involved in every design process.

2.5.4 General Contractor

The general contractor plays a truly different role in a system-built program. In contrast with the normal general contractor's role in conventional practice, he does none of the actual construction work and he has no financial dealing with subcontractors and no longer does he select subcontractors and take bids. His role changes to that of a professional construction manager, scheduling and coordinating the work of the subsystem contractors.

Such a restricted, specialized function removes some intrinsic conflicts of interest that exist in the general contractor's role. The notorious "bid-shopping" practice, in which general contractors first submit bids for subcontracted items and then "shop" for the cheapest rather than the highest quality subcontract they can negotiate, is eliminated. Instead, subsystems are bid in parts or aggregated package.

It should be understood that this is so because in a systems building program subsystems represent a very large portion of the construction cost, e.g., 70%, while only a small portion is made up of non-system elements managed by the sub-contractors.

Aside from coordinating the subsystems contractors' work in each construction project, a construction manager's responsibility also includes coordination of the subcontractors' work in non-system elements done in the conventional way, e.g. foundations, circulation core, staircases, and so on.

CHAPTER 3

THE PERFORMANCE CONCEPT IN BUILDING PROCUREMENT PROCESS

3.1 THE PERFORMANCE CONCEPT

Generally, the building design process starts with user needs and ends up with the physical solutions. The "performance concept" is an intermediary between user needs and physical solutions.

The performance concept, as defined by the National Bureau of Standards, is an organized procedure or framework within which it is possible to state the desired attributes of a material, component or system in order to fulfill the requirements of the intended use without regard to the specific means to be employed in achieving the result.[10] The goal of the performance concept is the assurance of desired performance delivered to building users.

The performance concept, as applied to the systems building, is to procure various system hardware items in correlation with their performance and user needs. The term performance, e.g. sound reduction in walls is a measure of physical attributes of building.

3.1.1 Performance Requirements and Performance Criteria

A key aspect of the systems approach to building which integrates the performance concept is the establishment of performance requirements, i.e. a description of exactly what

a building is supposed to do, in whole and in part, in terms of given functional context and constraints. The performance requirements are qualitative statements based on extensive user requirement studies. (see fig 10)

Robbie commented on the establishment of performance requirements as the following; [16]

"Ideally, the performance requirements for generic building types and the sub-systems components of buildings should be established in absolute terms, where a user activity is evaluated within its ideal philosophical climate together with the quantifiable physical descriptions of what a built environment must do to meet the needs of the user's activity in that ideal climate. Performance requirements established in this manner are of little practical value, as they tend to overlook "local factors". They do have an academic use as a research tool for the development of the techniques of user requirement analysis and performance requirement definition. As such, they belong in the university research ."

Implicit in this statement, on performance requirements, as being practical in use, is the need for re-interpretation and adjustment by the building profession into the context/constraints of an actual program, (i.e the "local factor" mentioned by Robbie). Accordingly, the procurement of such requirements can be met by reality. That is to say, in systems jargon that the system software can be met by the system hardware. (see fig 11)

The performance requirements, then, are developed to be performance criteria which is a quantified statement for building quality. This statement ties evaluation of building

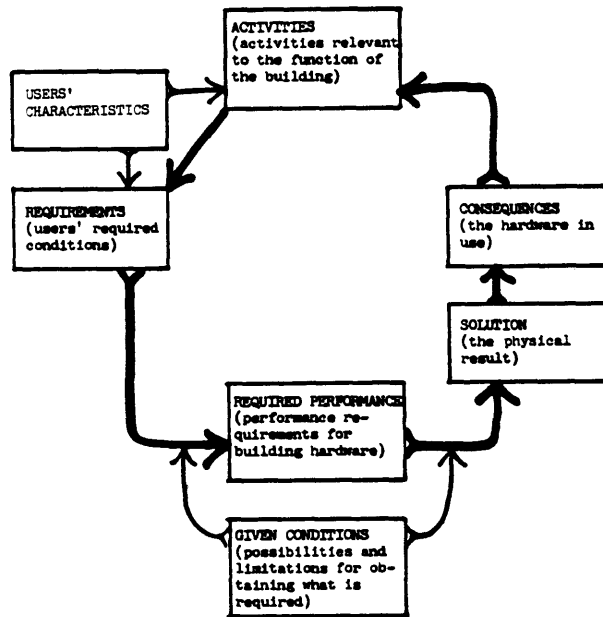


Figure 10 : Conceptual Framework of Performance.
Source : Cronberg, "Human Requirements for Buildings:", 1972.

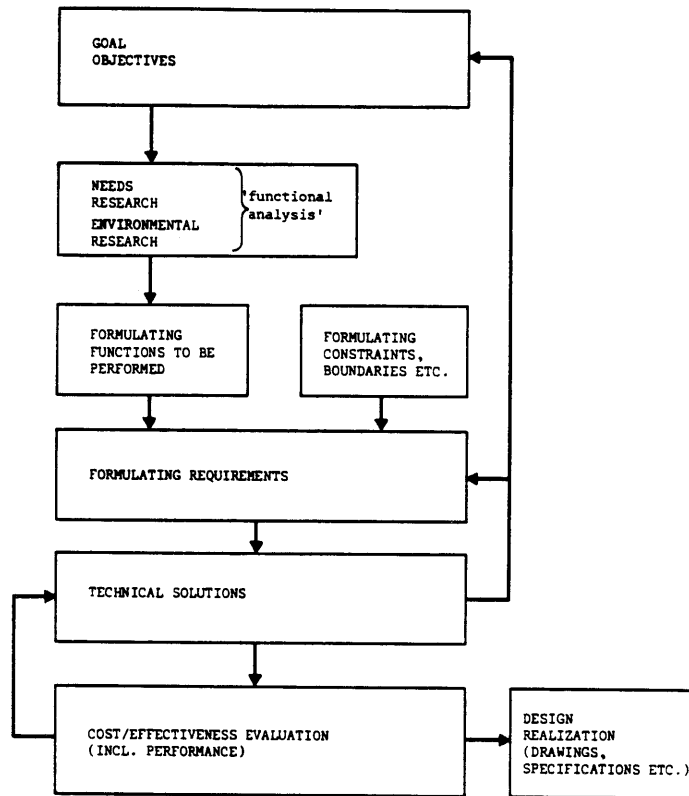


Figure 11 : Model for Formulation of Requirements and Evaluation of Technical Solution.

Source : Karlen, "Performance Concept and the Systems Approach-Some Comments", 1972.

quality, which had been a question of subjective judgement to measurable objectives. Accordingly, performance criteria are applied as measures for guiding hardware solutions in compliance with the performance requirements.

Performance criteria can be generative or regulative, i.e. they state ranges within which alternatives may be developed or definitive value which must be achieved. This could be stated in many aspects, e.g. spatial, constructional, financial. However, they can be categorized into four groups with regard to [1]

- 1) Performance in creating functional and environmental conditions
- 2) Performance during the process of building
- 3) Performance of the physical structure and the equipment under working condition
- 4) Performance in considering life-cycle behavior of the building as a whole (see fig.12)

Regarding to changes in user needs, advances in technology, design condition, administrative policy, etc., performance criteria must be modified or new ones developed.

Examples abound of cases where the performance concept has been put to use. Among pioneering systems building programs utilizing performance criteria for both buildings and building components were the various North American educational systems building programs, established and financed

DRAFT.

INTERACTION MATRIX OF PERFORMANCE REQUIREMENTS: TYPICAL FLOOR-SLAB (WITH FLOORING AND POSSIBLE SUSPENDED CEILING).

- INDEPENDENT REQUIREMENTS
- COMPATIBLE DEPENDANT REQUIREMENTS
- INCOMPATIBLE DEPENDANT REQUIREMENTS
- ▣ COMPATIBLE/INCOMPATIBLE DEPENDANT REQUIREMENTS

	moment resistance	shear strength	stiffness	shock resistance	hardness	abrasion resistance	wear resistance (flooring)	resist. insert. extr. nails etc.	fire resistance	effect fire on load bearing cap.	emission fumes and gases	inflammability	permeability to vapor	air-tightness	water solubility	humidity content	capillarity/absorptivity	dryness/evaporation	susceptibility to frost	hygrometric movement	thermal resistance	thermal inertia	coldness to the touch	uniformity surface temperature	thermal movement	resist. temp. extremes	effect thermal shock	permeability to air	sound absorption/reflection	transmiss. air-borne sounds	transmiss. impact noises	electrical conductivity	dielectric characteristics	physico-chem. stability	corrosion resistance	resist. insects/micro org.	ease maintenance/cleaning	flexibility, ease inspection		
moment resistance	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
shear strength	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
stiffness	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
shock resistance	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
hardness	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
abrasion resistance	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
wear resistance (flooring)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
resist. insert. extr. nails etc.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
fire resistance	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
effect fire on load bearing cap.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
emission fumes and gases	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
inflammability	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
permeability to vapor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
air-tightness	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
water solubility	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
humidity content	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
capillarity/absorptivity	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
dryness/evaporation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
susceptibility to frost	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
hygrometric movement	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
thermal resistance	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
thermal inertia	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
coldness to the touch	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
uniformity surface temperature	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
thermal movement	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
resist. temp. extremes	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
effect thermal shock	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
permeability to air	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
sound absorption/reflection	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
transmiss. air-borne sounds	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
transmiss. impact noises	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
electrical conductivity	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
dielectric characteristics	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
physico-chem. stability	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
corrosion resistance	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
resist. insects/micro org.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
ease maintenance/cleaning	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
flexibility, ease inspection	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Figure 12 : Performance Requirements Matrix of interactions between performance requirements for a typical floor slab (including flooring and possible suspended ceiling).

Source : Ciribini, "Space and Components; the Computers and Industrialized Building", IF, Vol.3, No.1, 1971.

by Educational Facilities Laboratories. These programs included the SCSD program in California; Toronto's SEF program; RAS program in Montreal; the URBS program of the University of California; and the SSP program of the State Department of Education in Florida, as well as the ABS program of the universities of California and Indiana.

The SEF program in Toronto is a further illustration that environmental as well as building service concerns can be directly and objectively dealt with by using performance requirements, (see fig.13). This effort to quantify qualitative requirements for atmospheric, visual, acoustic, mechanical and electrical services with enough open-endedness so as not to get over-precise and rigid, proved to be a useful way to move from program requirements to building requirements.

The notion of engaging the performance concept in the procurement process of the above systems building programs stemmed directly from the concern that traditionally conceived and conventionally built facilities were not serving user needs satisfactorily. Underlying all these programs was the assumption that performance design was a better way to fulfill user needs satisfactorily.

3.1.2 People Participation

The establishment of performance requirements requires participation from many groups of people. These participants

Level	Square Feet 175/	Area
Intermediate	Teaching Station	Common Area

Environmental Criteria

Atmospheric Criteria	Desirable	Tolerance	Remarks				
Temperature	outside > 90 F°	78°	± 2°				
temperature	< 0 F°	72°	± 2°				
Relative Humidity	outside > 90 F°	50%	± 5%				
temperature	< 0 F°	30%	± 5%				
Outside Air	CFM per sq ft	0.3 to 0.8	> 0.15				
	CFM per person	15 to 30	> 8				
Air Changes	per hour	6 to 8	> 5				
Air Movement	velocity: FPM	25 to 40	± 10				
Room Pressure	in. WG	+0.10	> +0.05				
Air Filter Efficiency	> 5μ	80%	> 65%				
	< 4μ	45% to 80%	—				
Odors Body, Chemicals							
Population	8 sq ft/person	0					
Heat Gain	source	watts	BTUH				
	Lighting	2 to 4/sq ft					
	AV equipment	—					
	Projector	—					
Visual Criteria							
Visual Performance Index (VPI)	63.0	Ft Candles	N/A				
View Out Op'l	View In Op'l	Blackout Yes	Privacy No				
Daylight Op'l	Level Control	Yes					
Acoustic Criteria							
Ambient Noise Level: NC 35 max							
Reverberation Time	Frequency: cps	125	250	500	1000	2000	Acoustic treatment of floor and ceiling is recommended. Reverberation time calculation is not meaningful. Speech reinforcement may be required.
(in seconds)	max	N/A					
	min	N/A					
Generated Noise Level	Frequency: cps	31.5	125	500	2000	8000	
(in db re .0002 dynes/cm ²)	design level	58	77	89	75	60	

Services

Mechanical Services	Remarks		
CW No	HW No	Steam No	Gas No
Air No	Drain No	Exhaust No	
Other			
Electrical Services			
PA Yes	Intercom Yes	Handset Yes	Bell Tel No
Program System Yes		Clock System Yes	TV Terminal Yes
Computer Terminal No		Underfloor Duct System	No
Power 120V - 1φ for AV equipment			
Other Consider induction loop system			

Figure 13 : Example of SEF Environmental Criteria
 Source : Griffin, "Systems", Educational Facilities Laboratories, 1971.

approach the requirements from separate points of view. Each group will play a different role, based on its set of values, its interest, its own perception of wants and needs and may bring with it a different hierarchy of common values or even a different set of values.

In order to emphasize the various points of view, it is useful to identify the groups and the attributes to their generalized concerns as might fit their roles. These are outlined as [14]

- 1) The administrative group concerned with
 - a. Reducing the time for planning and construction
 - b. Cost control if not cost reduction and
 - c. Quality control
- 2) The professional group represented by the designer is concerned with
 - a. Opportunity for innovation in terms of the finished building
 - b. Inherent human values and
 - c. Visual quality
- 3) The client user group is concerned with
 - a. Hope of greater satisfaction of its needs
 - b. Knowing how these needs may be met
 - c. Occupying and testing the finished building
- 4) The client owner group is concerned with quality, cost reduction and cost control

With so many different groups involved, the establishment of performance requirements must be rational enough to withstand the scrutiny of these many individuals. Yet, it must be analytical enough to allow for the classification and interrelation of the expression, i.e. the needs, the opinions and attitudes of participants.

3.1.3 The Performance and the Systems Concepts [17]

There has been a proliferation of definitions, descriptions, and considerable confusion in current architectural, engineering and construction literature on the distinction and relationship between the performance and systems concepts. It would be useful to establish a clear theoretical separation of these two concepts. Although there is great effectiveness in their simultaneous application to many types of project, each also has the capability for independent application to certain aspects of the building process.

The impression given in the literature and related material is that performance and systems, as far as building is concerned, are inseparable concepts, or even that they are synonymous. Vilett commented that it is a misconception to understand that performance concept is an integral part of the systems approach. Some aspects concerning the distinction between the two should be understood as follows;

3.1.3.1 Range of Applicability

The systems concept is usually viewed on its applica-

bility only to the larger scales of reference. The performance concept, on the other hand, is practically applicable to the smaller scales of reference. For example, one can speak of the performance of a nail in terms of withdrawal resistance, shear strength, corrosion resistance, etc. whereas a nail, although certainly a component of many building systems, is not itself a system in any meaningful sense. A large scale e.g. individual buildings can and should be viewed as a system instead of merely as performance.

Regarding the above view point, one can assert that there is a basic difficulty of developing performance specifications particularly at the higher levels, such as that of the complete building. This is so because higher levels of building process are objectives in nature and their associated requirements are, in general, less materialistic and less readily defined in unequivocal terms than lower level ones. The performance concept is use particularly for description a desired end result.

Thus, it is assumed that the systems concept is most applicable when the problem at hand is large-scale and more or less complex, and includes values difficult or impossible to quantify and calls for an emphasis on the system component interactions. The performance concept, on the other hand, is more relevant to problems associated with individual components, when the emphasis is more properly on

measurable properties. However, there is a considerable area of overlap in which problems are best addressed by some integrated form of the two approaches. (see fig.14)

3.1.3.2 Difference in the Problems Solved

In correlating the previous aspects, the reasons for their difference of application scope lie in the differences between the problems the two concepts were developed to deal with in the first place.

The performance concept was developed by industry and large customers of industry, to overcome inefficiencies caused by design preconceptions, to permit or encourage innovation and to provide a better competitive situation between different products, performing the same function. The means applied to obtain such results is the performance requirement and its form of a regulation or a specification. The intention is to provide designers and manufacturers with specific criteria while minimizing irrelevant constraints.

The systems concept, on the other hand, as developed first by scientists involved in basis research, and later has been applied to engineering, logistics, military operations, management and industry in general. The proper applications of the "systems approach" are only in those situations requiring serious consideration of the effects of interaction between system components.

Generally speaking, there is a primary shift of

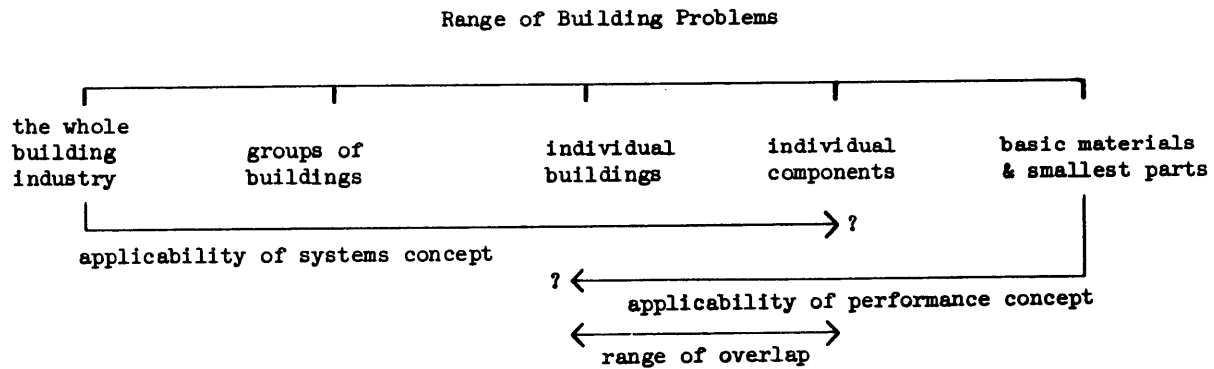


Figure 14 : The Relationship between the Performance Concept and the Systems Concept.
 Source : Vilett, 1972.

emphasis in each respective approach of the two concepts. The performance concept emphasizes ends rather than means, whereas the systems concept emphasizes means to organize the whole rather than emphasizing the parts.

3.1.3.3 The Two Concepts Are Not Integral

There is, to some extent, disagreement on the point that the performance concept is inseparable from the systems approach to building problems. In other words, the performance concept as an integral part of the systems approach.

Vilett commented on this point that;[18]

"It is incorrect to say that because the systems approach necessarily involves the identification of objectives and measures of performance, it therefore incorporates the performance concept. The latter term appears applicable only to situations in which it is both desirable and feasible to precisely specify measurable characteristics of physical objects without reference to the particular means of producing them. Such situations are by no means invariably present in all building industry problems which could benefit from the systems approach. Conversely, the performance concept can be usefully applied to problems in which the systems approach has no particular relevance."

He illustrated two examples for each case as the following:

An example of the first type of situation would be the development of a master plan for a group of buildings such as a university campus or a new town. The systems approach could be applied to the generation of the plan. Implementation of the plan could proceed by conventional design and construction procedures. Although "objectives" would cer-

tainly have to be clearly stated in terms which would allow reasonably unequivocal evaluation of the plan, there would not necessarily be any need for specifying the detailed "performance" of building subsystems or components, or for that matter, for the use of proprietary building systems in any form.

An example of the second type of situation would be the development of an innovative building product for the improved joining of specific components already in use. Performance criteria could be established for rigidity, watertightness and other physical properties of the joint, allowing equal consideration of mechanical fasteners, welding, adhesives, etc. the systems concept, as distinct from traditional engineering procedures, would not be applicable in any practical sense in this case.

3.1.3.4 Inherent Disadvantages

Generally, both the performance and the systems concepts have certain inherent disadvantages which must be carefully weighed against their presumed problem-solving capabilities in any particular case. Implementation of the performance approach, for example, usually requires the development of precisely defined test procedures and a corresponding test program. It also may require special legal documentation which at present has relatively little precedent. While application of the systems approach may involve very elaborate analyses of the problems and

evaluations of alternative solutions which may not be justifiable in terms of time or cost-benefit.

In closing, it should be understood that the two concepts can be employed simultaneously in a broad range of applicability to various types of building problems, particularly in the area of building system industrialization. Far from being mutually exclusive, they are usually complementary and in practice are more often found in some combination than singly. There are cases in which a problem would be best solved by such a joint approach, for example, the application of the performance concept to the development of building products with a systems analysis of their context.

Lastly, a conceptual basis of which a clear distinction between the performance and systems approach is made should be approached by the building industry. Thus, their real values should not be dissipated through inappropriate or superficial applications.

3.1.4 Performance Specification

As addressed before, in order to state desired attributes of buildings in relation to user needs, Performance requirements must be developed. These will take the form of declarative statements. To quantify those statements, performance criteria are, then, developed. Each contains a measure or a range of measures of the needs and involve, in

most cases, a numerical statement of the requirements. To know whether or not a criteria is met in the solution, performance evaluation techniques or tests must be developed. These may be physical tests, simulation, or the judgement of experts.

Combining performance requirements, criteria and tests of any given system constitute a performance specification of that system.

The major practical application of the performance concept in the building industry is the development and use of performance specifications in the procurement of buildings. (see fig.15) Performance specifications, as an attribute of performance concept are stated without regard to the specific means to be employed in achieving a solution. All solutions satisfying a performance specification are acceptable.

To be a viable instrument for procurement of building hardware, a performance specification must have three kinds of statements as its attribute: namely the requirement (a qualitative statement which identifies user needs), the criteria (a quantified statement, converted when possible from the requirement in order to provide a guide for attaining compliance with the intent of the requirement), and the tests (indicating the method of assessing materials, components or systems for compliance with the criteria).

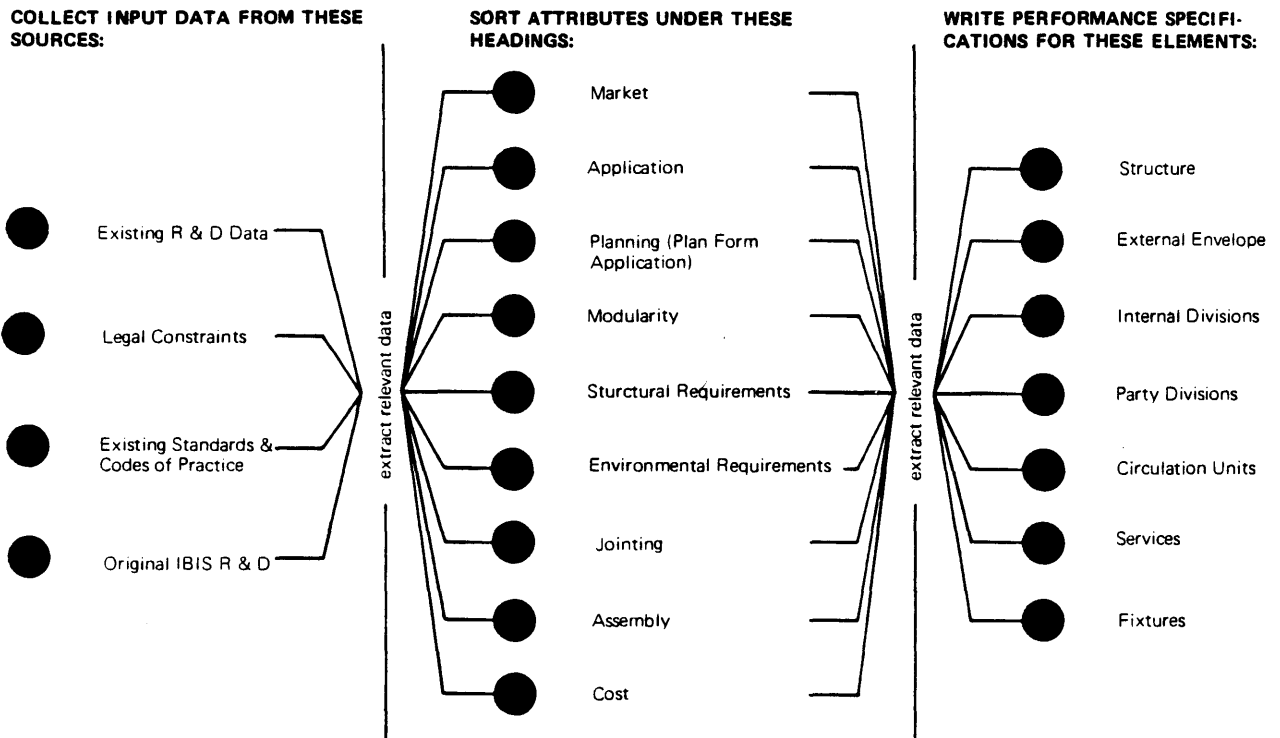


Figure 15 : Developing Performance Specifications.
Source : Claxton, "IBIS; Industrialized Building in Steel", IF, Vol.1, No. 3, 1970

Criteria levels must be thought of as indeterminately tentative because of two prominent aspects of performance;

- 1) The final level of the performance required of a material component or system depends on its inevitable interaction with other materials, components and systems.
- 2) Desired performance levels are continually subject to change, due to the information feedback mechanism which is a part of the performance approach.

The test should be specific and solution-independent, if it is to be objective in verifying compliance of different solutions with each criteria. If such a test does not exist at a certain level, clearly a performance specification cannot be employed at that level.

To give an example of a performance specification statement, the Public Buildings Service Performance Specification for Federal Office Buildings (National Bureau of Standard 1970) is illustrated as the following;[2]

"control air motion: this sub-system in use shall distribute air to the space such that air motion in the Occupied Zone shall be no less than 20 FPM nor more than 50 FPM. (Occupied Zone: all space from the finished floor to 78" above the finished floor excepting spaces closer than 2" to a partition.) To be tested by field measurement of system prototype."

The structure of this statement contains: A user requirement (control air motion), criteria (how much and where) and a test method (in this case, prototype testing in the field). These three are the essential elements of the performance specification for the physical system procurement. If any portion is missing, it is not possible to use it as a procurement document for performance specifications.

The performance specification documents state the function each sub-system has to perform in the finished building. Regarding quality control procedures, they specify the criterias to be observed, set the rules necessary for the development of integrated components and sub-systems interfacing responsibility.

In addition, the documents state the test by which performance will be judged, and the way a design proposal will be evaluated, and so on. Using a performance specification document, all specific requirements can be expressed in quantitative, technical terms with required tests, in order to communicate with manufacturers at the stage of product design. Architects and engineers are responsible for the writing of performance specifications and quality control and should leave product design to manufacturers. Generally, performance criteria provides sufficient information needed by manufacturers to develop the desired product in compliance with the requirements. Performance specifications, moreover, offer additional means for the product quality

control.

Before their final publication, the issues addressed in the specification document should be criticized and commented by industry representatives and be agreed upon after adequate discussion. Otherwise, it would lead to a lack of manufacturers' interest and participation in product development or the requirements and the criteria issued by the performance specification could not be met realistically.

3.1.5 Process Implications [9]

The application of performance specification as an instrument to procure building hardware requires some modifications of the building process. (see fig. 16) The performance concept requires traditional process participants to take on new roles, or to revise the schedule and order of their participation.

For example, architects and designers may be required to work for product manufacturers in their preparation of production design proposals responding to performance specifications. Furthermore, new roles for new participants are established, e.g. testing laboratories play a decisive role in the evaluation of proposals.

Finally, management schedules, and legal relationships must often be manipulated, changed and redefined to accommodate use of performance specifications. For instance, the signing of procurement contracts for building elements

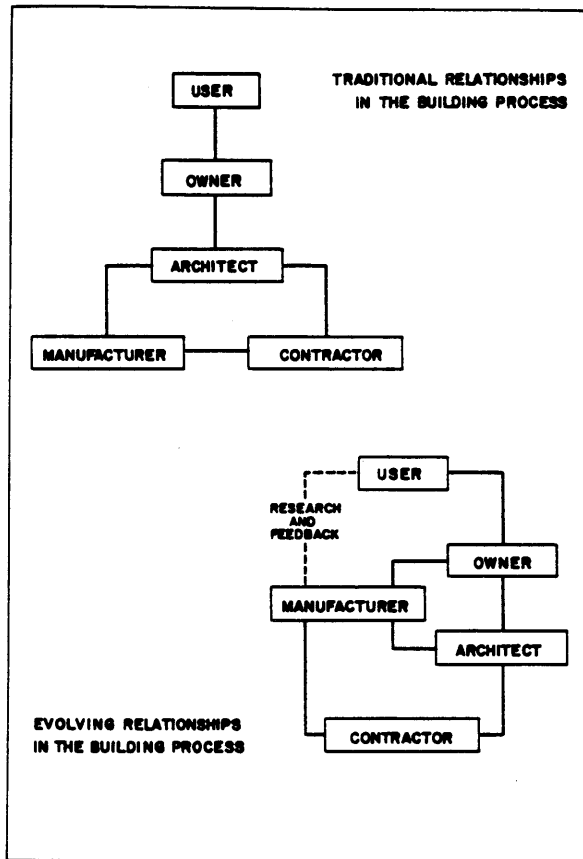


Figure 16 : Relationships in the Building Process.
Source : Bender, A Crack in the Rear View Mirror, 1973.

before actual buildings are finally designed, and the code compliance approval of buildings at a schematic stage in their design, are both significant in their legal and managerial implications.

3.1.6 Prescriptive Specifications

Presently, nearly all physical design and building specifications are documented in prescriptive form. Projected buildings are defined in terms of specific types of construction and materials in detailed drawings with verbalized specifications.

These traditional or "prescriptive" specifications are a way of assuring that what is procured will be identical to some "model" which has given satisfactory performance in the past. Prescriptive specifications often prescribe the materials of which the product is to be made, the dimensions it must have, the finishes and the shapes, how it shall be installed, and in many cases who shall make it. On the contrary, the performance concept develops criteria for building specification, based on performance requirements which do not suggest or preconceive a particular technological solution, or specify a given physical solutions. Performance requirements are non-prescriptive, generalized and objective in nature.

Developed within the performance concept, a performance

specification does not describe dimensions, materials, finishes, or methods of manufacture. It describes the performance attributes of building subsystems as required by users. It delegates responsibility for the actual design or selection of the product or system to the building component manufacturers and his design staff. The latter are given the possibility of freely selecting technical solutions that would answer, in their opinion, the set requirement. This approach provides the opportunity for manufacturers to exercise fully their potential for innovation, both for design and management.

Basically, every conventional material specification is based on an implicit performance specification. For example, in specifying a 10" brick cavity wall with running bond. Yet we may select specification on a performance basis that describes a wall which has the following characteristics;

- stability against lateral and vertical forces
- sound attenuation and other acoustic qualities
- thermal insulation
- color and texture
- surface imperviousness to weather

Conventionally, when a "specified" solution (a brick wall) has been found that it has given satisfactory performance to this specific task in the past, it will be selected again, based on past experience when one has to face the same problem. However, it is relatively restrictive in that

only a narrow range of familiar solutions to any particular problem is acceptable at any given time, though many solutions are available which would give equal or better performance. For example, if we are designing a space which contains reading and writing as its primary activities, one of the critical environmental requirement is adequate illumination. Notice that a performance statement will not specify that the requirement is lighting fixtures, but illumination. There are many solutions that fulfill the need of illumination which include lighting fixtures, windows, illuminated texts, candles, or some yet unknown device. All the solutions are acceptable as long as they fulfill the required environmental performance.

There are several advantages in using performance statements over prescriptive specifications as discussed above.

3.1.7 The Advantages of Performance Statements-Performance Criteria and Performance Specification

There are five important reasons suggested for the development and application of performance specifications in the building industry, as follows;[3]

1) Expression of user needs in the procurement process

Performance (non-prescriptive) requirements for buildings are derived primarily from analysis of the user needs of the building, i.e. tenants, operators and owners. The evolution of performance requirements from

user needs to performance specification is an attempt to develop procurement procedures for buildings assuming that users will be optimally satisfied.

2) Cost-effectiveness

Performance statements enable different technological solutions to a give set of requirements to be bid against one another. For example, if performance requirements are established for a structural system defining only such aspects of structural behavior as deflection and load-carrying capacity, structural frames may be bid against bearing wall structures, and/or against space frames. Thus, increasing the potential of obtaining the lowest possible cost for the desired quality on a competitive bias. This might result in the cost reductions as well. If requirements are established which pre-selects a concrete bearing wall structure as the generic solution, then one could only receive bids from different producers of that particular structural solution, which might not be a selection of the cheapest structure, or even the cheapest bearing wall structure.

3) Promotion of technological innovation and opportunity for greater quality

Non-prescriptive specifications allow any solution that achieves the required performance. Each sub-system is defined by its functions with procedures to assure its compatibility with other sub-systems. By using a mandatory interface approach, where a mandatory

interface is deemed to exist (e.g., where the parts of one sub-system touch, pass through), or where it influences the performance of another sub-system in a finished building, full advantage can be taken of the plant and skill resources of the sub-systems manufacturers, without extensive and rigid conventions of modular co-ordination, joints and jointing, and with only generalized dimensional co-ordination. Consequently, the approach tends to reward innovativeness over conformity, particularly when the achievement of required performance levels is not possible by means of existing hardware. Within the capabilities of technology and a sufficient, guaranteed market, the application of performance statements objectively encourages the research and development capabilities of the industry towards new solutions of greater quality. (see fig. 17)

4) Better design decision in procurement process

Because the use of performance statements relegates the responsibility for design decisions to points farther "down" in the building process, i.e., closer to the "output" end, it permits product design decisions to be made when more information is available to the designer (i.e. the manufacturer). Thus, at the point with richer information. Thus, better decisions can be made in product procurement.

5) Formal evaluation and feedback

By stating the described performance explicitly in

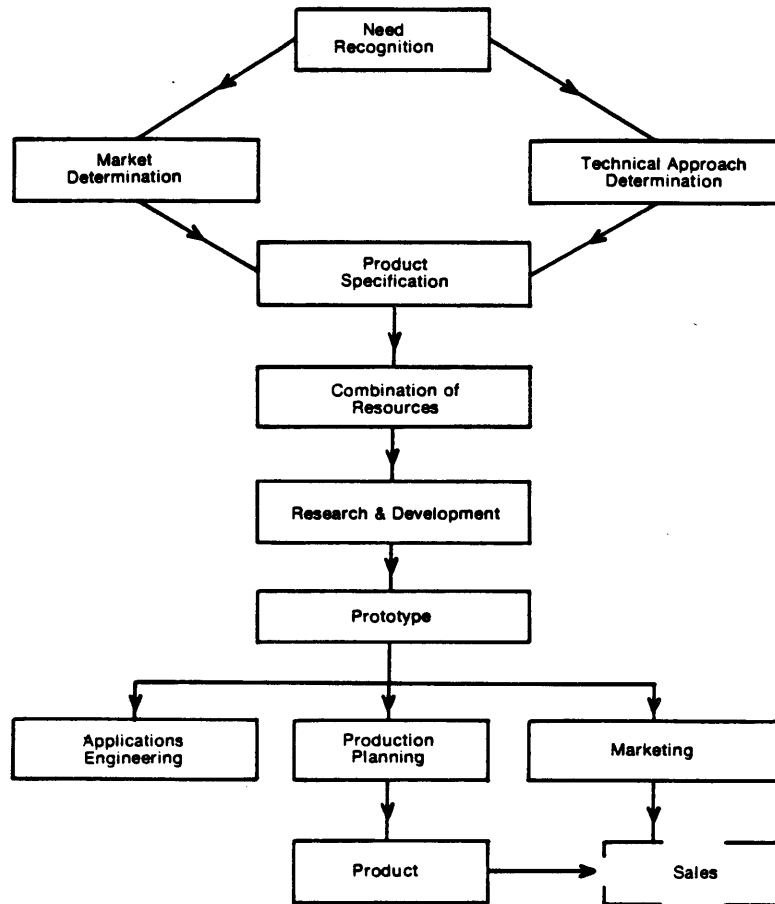


Figure 17 : The Elements of the Innovation Process.

Source : MacFadyen, "The Buyer; A Key Element in the Innovation Process", IF, Vol. 5, No. 1-2, 1974.

terms of criteria and test methods, a precise framework is obtained against which evaluation can be made. Since all hardware design assumptions are in the form of requirements, criteria and test methods, it is possible to examine the building in use and to evaluate the correctness of these assumptions. This creates the necessary information base for a system of formal evaluation and feedback.

3.1.8 Performance Evaluation

Performance evaluation is essentially a critical aspect of the performance concept. In order to find out whether or not a partition actually performs acoustically as well as it is supposed to, or find out whether an air conditioning system or a ceiling/lighting system performs in accordance with the performance specifications as manufacturers might claim, or, on a more subtle level, e.g. to find out whether the user requirements on which the performance development is based are formulated correctly.

There have been a number of efforts to evaluate systems building by means of performance-based programs which have been undertaken to date. For instance, Building Systems Development Inc. (BSD) experts have asked for field tests of performance as well as laboratory tests (which often do not correlate closely with actual field performance) in its system projects. The SEF program set three basic parameters; function, cost, and aesthetics, with varying emphasis from

system to system for evaluating performance.

Yet, lack of time and lack of serious effort to evaluate existing buildings which were designed on the basis of the performance concept make it difficult to claim general and/or basic desirable test procedures in current use, i.e. test procedures to be used to monitor products or sub-systems during design, production and erection, which would not slow down construction operations and which would also be sufficiently predictive to avoid excessive rejection of products already manufactured erected, and consequently to avoid job disputes and litigation.

It is clear that evaluation is an important issue in the performance concept and necessary to examine the correctness of user requirements and the interpretation of these requirements in performance terms, to monitor solutions' compliance with performance requirements and finally provide information for the feedback to the process.

3.1.9 Two Approaches of the Performance Concept in Building Systems Procurement

General speaking, there are two approaches, resulting from the application of the performance concept in building systems procurement which are: existing product selection and new product development. To comprehend these approaches, two building research and development programs, utilizing

the performance concept, each with a different approach and end result is given. These two programs are the URBS (University Residential Building System) program for University of California student housing and the ABS (Academic Building Systems) program for Indiana University and University of California academic building. These two programs were organized and directed by Building Systems Development, Inc. (BSD) and were based on earlier experience, namely the coordination of the School Construction Systems Development (SCSD), program which was the first program to utilize performance requirements in 1961. BSD developed performance specifications and/or requirements for both programs, based on analysis of user requirements.[11]

The approach to performance-oriented procurement used on the SCSD project, provided a point of departure for both the URBS and ABS programs. The URBS program followed generally the development process established in the SCSD project. An aggregated and guaranteed building market was offered by the university, and five "new" sub-systems and their components were designed and developed by industry for that market in compliance with performance specifications. To assure sub-system compatibility, performance specifications were also written to accommodate cooperation between manufacturers.

The universities sponsoring the development of ABS, on the other hand, were not able to guarantee a large

predictable market of academic facilities over a period of time. Accordingly, a different development approach was needed, which assumed the selection of existing, already developed products for its subsystems. In this case, a building system was designed by BSD in response to previously determined performance requirements and utilizing, existing components available on the open market.

In brief, the nature of the market and the degree of technological innovation involved make up the essential of distinction between URBS and ABS. A comparative summary of the two programs is presented below.

URBS

Client: The University of California.

Building type: Dormitories from one to thirteen stories.

Market: A market of 2,000 dwelling units over 3 years guaranteed by the University.

Development Approach: Procurement of a building system design consisting of "new" technological solu-

ABS

Client: The University of California along with Indiana.

Building type: Science and engineering buildings, including laboratory, shop, classroom and office spaces.

Market: Unlike URBS, no market for ABS facilities could be guaranteed by the two institutions.

Development Approach: Unlike URBS, development of a building system by coordinating and utilizing

tions to building components by manufacturers' response to performance specifications.

"existing", on-the-market technology.

Objectives:

Objectives:

: to provide an environment in which the student can express his individuality.

: to improve physical comfort and privacy within the student room.

: to do away with standardization of appearance in student rooms and buildings.

: to eliminate physical environment deficiencies: poor acoustics, inadequate ventilation, and restrictions on room decoration.

: to reduce the costs of ownership: construction, operation and maintenance.

: to increase the space adaptability so that it can be reorganized in response to student preferences, as well as changing administrative policies.

: to improve the performance of buildings subsystems in response to specified requirements.

: to provide equal performance for the same or lower cost, when compared with conventional construction.

: to accommodate major changes in space utilization quickly and economically.

: to facilitate application of improved planning methods for the simplification of schematic design and the refinement of cost control.

: to reduce design and construction time through more efficient procedures.

Subsystem divisions:

Subsystem divisions:

Structure/Ceiling
HVAC
Partitions
Bathrooms
Furnishings

Structure
HVAC
Partitions
Lighting/Ceiling
Services Distribution

Both the URBS and ABS program used performance-oriented statements of requirements to guide the development. Excerpts from the performance statements used for each programs are also presented in appendix A.[12]

Experience from these two programs shows that two kinds of problem were encountered in trying to set performance requirements for BSD that are worth presented here;[13]

"The first set of problems relate to trying to match proposed performance standards to both the needs and the resources of the user. Thus, the writer of performance requirements must be aware of the cost implications of the standards he is demanding from industry, and he may have to temper the user's expectations. This problem is particularly acute in a systems development program such as URBS, where expectations tend to be higher, and costs more conjectural. As an example the high acoustical standard of the HVAC system that were demanded resulted in a fairly high cost system. In one case, a potentially strong bidder decided, after many months of research and development, that the risks were so great of not being able to meet the standard that he did not submit a bid.

The second group of problems relate to defining the performance standards themselves. This is still a fairly new act, and information is incomplete. More work is necessary in relating performance standards to user needs. And more knowledge is necessary in the definition of standards and, in particular, of test procedures. In the URBS program, much difficulty was experienced because of the inability of the variety of acoustic consultants involved to reach agreement on appropriate definition of standards and test procedures. In addition, the relevance of the acoustic standards, to the user needs and resources, remains in question."

In summary, the performance statements used in URBS were part of a set of specifications used as contract documents, to procure compatible building sub-systems, designed by manufacturers, while performance statements used in the

ABS served only as design guides to the actual building system by BSD, by selecting existing sub-systems and their components in the open market. (see fig.18) The performance concept can, therefore, be used in two different ways for building system procurement, as illustrated above. A generalized approach to building system is shown in fig. 19,20.

The development of the use of performance requirements from the SCSD program to the URBS and ABS has demonstrated that performance requirements may be used quite effectively to procure existing, on-the-market building components, and are not restricted solely to the procurement of new technology, as has often been mistakenly assumed.

It is within this thesis' scope and its specific intention to accept the systems approach and the performance concept as an integral concept in the procurement process, resulting in building systems. Nonetheless, the reader should always keep in mind that the systems approach does not have to be necessarily integrated with the performance concept, nor does it have to result in building system development. Furthermore, it should be noted that performance requirements may be used in the procurement of more conventional construction as well. The use of performance requirements, therefore, need not necessarily be linked only to building systems. In general, performance or non-prescriptive requirements may be used in place of conventional prescriptive specifications, if accompanied by non-prescriptive

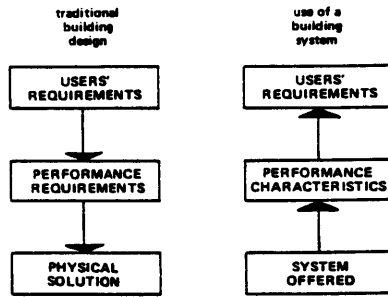


Figure 18 : Sequence of Concern at Building Design and System Selection.

Source : Camous, "Information about Building Systems", IF, Vol. 3, No. 1, 1971.

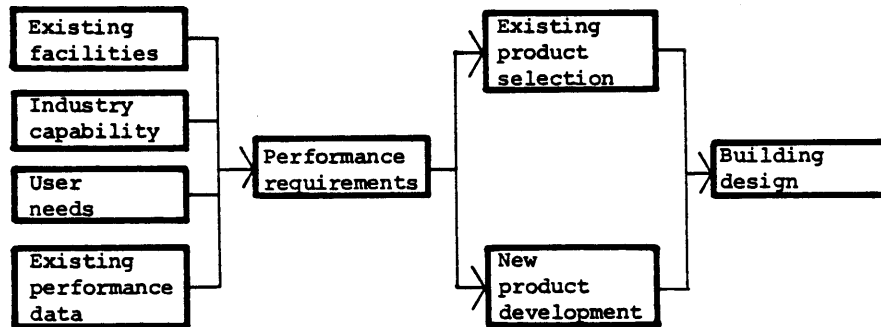


Figure 19 : Generalized Approach to Building System Procurement.

Source : Arnold, Bender, Meyer, "Paths to Performance - Some Recent Projects Employing the Performance Concept, 1972.

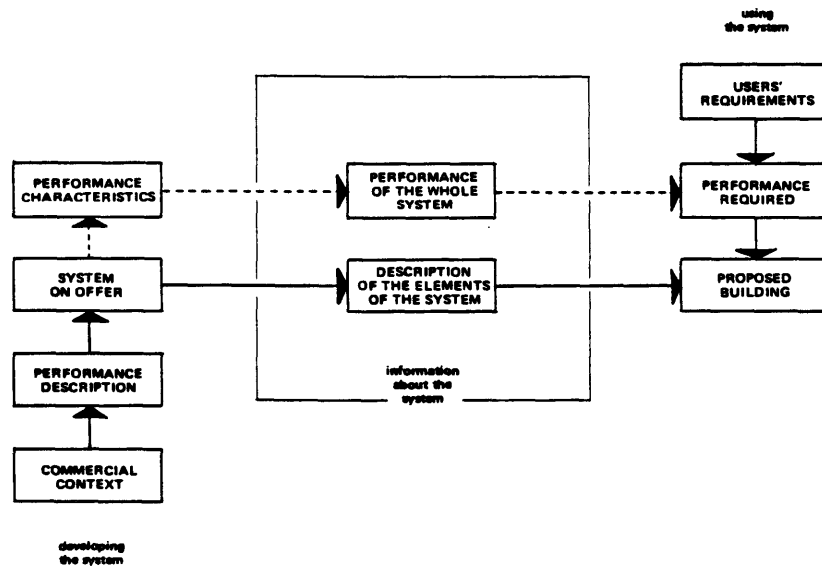


Figure 20 : Flow of Information from System Producer to Building Designer.
Source : Camous, "Information about Building Systems", IF, Vol. 3, No. 1, 1971.

drawings, which substitute for conventional working drawings. Drawings which indicate modules, interface conditions, general building configuration, proportions, etc. of building elements are all that is necessary or desirable when performance requirements are used. In closing it should be noted that the performance statements follow a different hierarchy in their development, (see fig.21). Therefore, they can be utilized usefully on many levels, such as the use of performance requirements in the procurement of conventional construction, the use of performance criteria in existing product selection, and the use of performance specifications in new product development.

3.1.10 Sub-systems Performance specifications

Performance requirements can be established at two levels to find practical application in the systems approach to building. First, at the building type level, e.g., office building, hospital, academic building, et. and, secondly, at the building part level. The first level of performance requirements, i.e., that of building type is not of interest here and beyond the scope of this thesis. The author will, therefore, proceed to the relevant, second level, of performance requirement establishment, which concerns specifications for the various subsystems of a building.

The establishment of such performance specifications is

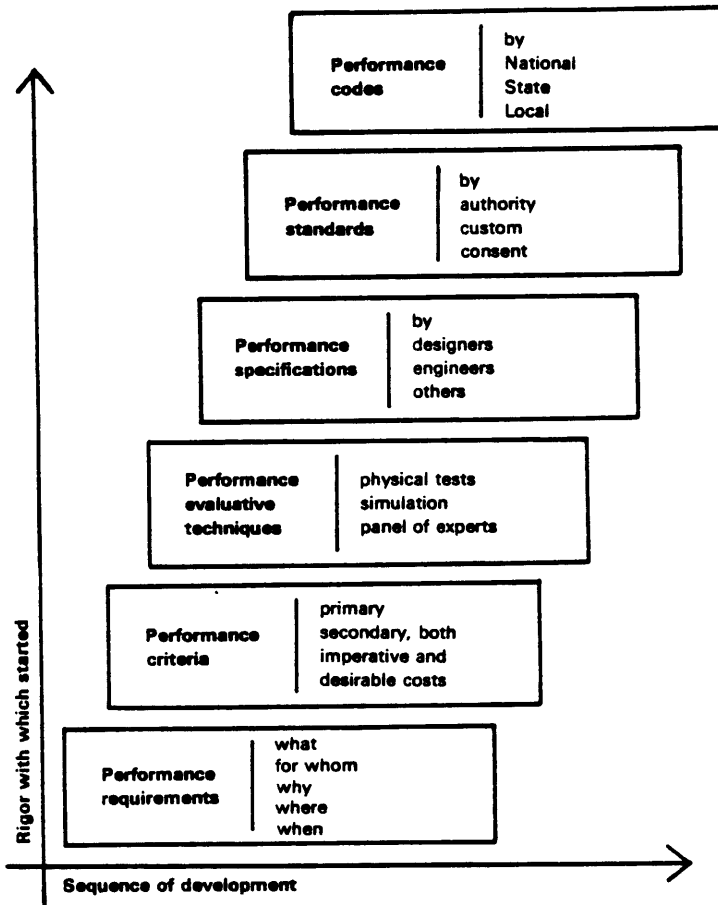


Figure 21 : The Performance Hierachy.
Source : Dietz, Industrialized Building
Systems for Housing, 1970.

characterized by dividing a building into a number of elements, usually defined as subsystems. Each subsystem performs a unique function in a complete building or (building system) which is not duplicated in whole or in part by the function of any other sub-system. To perform a required function, each sub-system may consist of several components. Under this mode of functional definition, solid walls, windows, doors and grilles all form parts of the exterior enclosure subsystem, while the heating, cooling and ventilating provisions, together with all their controls and supplementary electrical services, would comprise the environmental subsystem.

Generally, subsystems can be classified in many categories, such as structure, environmental controls, lighting/ceiling, interior space division, exterior enclosure, plumbing, electric-electronic, caseworks & screens, roofing, interior finishes, etc. Each generic building type and each building systems program usually classifies its sub-systems differently. Principally, systems building defines the required performance of each subsystem in performance terms primarily as a means for building system procurement.

3.2 USER REQUIREMENTS

Given the above described concept of performance, we know that performance requirements can only be established if user requirements are known. User requirements mean not only what the user wants to do, or how much space to do it in, or what kind of good environment is needed, but also what kind of quality, at what kind of cost, what time frame is necessary or expected, and so on.

The development of user requirements for a building is a mandatory step in the systems approach for any specific program that employs the performance concept in its product procurement. Without well-defined user requirements, it is not possible to prepare project-related performance concept for hardware research, development and selection.

3.2.1 The Importance of User Requirements

Buildings are built to satisfy the needs of the people who use them. Yet users are often unrepresented in the decision process which affect how buildings are built and how they are to perform. In the conventional building process of today, most valuable information about user needs is lost, misplaced or never generated to begin with.

In any building, including system-built types, users should obtain facilities, functions, amenities, environmental comfort and standards that suit their physical and

psychological needs. As mentioned before, industrialized buildings based on sophisticated technology can fail if user requirements are not considered in their aspects. The Systems Building approach views users as a key component in the hardware design and/or selection. It is prudent to carry out a building program in such a way that all optional elements of design and construction have been systematically coupled with an analysis of user needs in the different stages of the program progress, namely;[4]

- 1) The conceptual stage-user acceptance of program
- 2) The development stage-user self-identification through organizational analysis, to establish user requirements, such as spaces, functions and environment
- 3) The acquisition stage-the development of product design, related to performance required by users
- 4) The construction and operational stage-user occupancy.

Robbie, Technical Director of SEF, stated the importance of users as follows;[15]

" To view the future building design, the user must be the environmentalist and the responsibility for creating an environment to fit with his needs, while the architect is a resource who can set a framework for the user to operate within."

Traditionally, the designer's knowledge about implicit and explicit user needs is more or less empirical, e.g., he retrieves existing functional requirements from existing buildings. His decision toward design solutions is based on such empirical knowledge is often prejudiced, or disguised

and regimented, by accepting without question criteria of existing practice and existing solutions. Consequently, in order to arrive at a better understanding of the real user requirements, the system study team critically review and check adherence to (or departure from) traditional knowledge and practice. A survey and research should be undertaken to define and understand all the important factors necessary for defining user requirements. Issues about users' activities and users' characteristics as a basis for defining the user requirement will be discussed in the following paragraphs.

3.2.2 Users' Activities

Users' activities are the first place to commence, since they dictate the function of a building and further express the users' reaction/adaptation to the building. However, it is not possible to study all activities but only those which

- are important to the users
- are affected by the design of the system (or sub-systems)
- affect the design of the system (or sub-systems)

The following checklist is offered to guide relevant research activities related to user requirements:[5]

- 1) Cooperation with actual user groups. Noted that the results may merely be relevant for user experience with existing buildings, and thus exclude unknown require-

ments or needs.

- 2) Theoretical studies. For instance, based on knowledge from physiology, psychology, or sociology
- 3) Surveys, inquiries. The results from these are often limited to special conditions and by users' existing experience.(see 1)
- 4) Behavior observation. This is limited to activities, directly accessible through observation
- 5) The analysis of existing buildings. This excludes new prototypes or "unconventional solutions"as evidence.

The last three types are most useful for identifying existing problems. A description of for whom and under which conditions the activity may be observable is of interest from the methodological point of view, but it is too detailed to mention here.

The extent to which one should go into detailed activity studies is closely connected to the problem of choosing the activities. The main point is that the study has to be detailed enough for identifying essential requirements. However, bias may result when some activities are studied in more detail than others, of equivalent importance.

Cronberg stated many aspects by means of which the activities can be analyzed as the basis for establishment of user requirements' establishment as follows;[6]

- 1) Who performs the activity ? The person(s) performing the activity must be identified. The users' characteristics, the number of users and their relations have to be included in the activities analysis.
- 2) What is needed to perform the activity ? e.g. temperature, humidity, air movement, light, sound, energy, water
- 3) What are the consequences of the activity ? Not only does an activity result in fulfilling its purpose, but it also has subsequent effects both for the users and the environment.
- 4) What space, spatial relations and spatial boundaries are required to perform the activity ? This is the most basic premise for an analysis of activities, related a the design.
- 5) What is the purpose of the activity ? The purpose may be clearly defined as an expected result. The purpose of a particular activity may be different, depending on by whom, and where the activity is performed. The activity purpose is important as a way to measure the efficiency of an activity.
- 6) Activities could be analyzed according to time spent, when they are performed and how often they occur. Also, the sequences and the interdependence of activities are important when defining the functional relation between different parts of buildings and their surroundings.
- 7) Movements required to perform the activity. The pattern

of movements is relevant for giving dimensions to space and equipment and for their inter-relations.

From the activity analysis, the various kinds of spaces, functional requirements and their interrelations, including the required service and equipment, are obtained.

3.2.3 Users' Characteristics

To identify users' requirements, a relevant knowledge of users' characteristics is necessary, involving many different disciplines, each with different terminologies and approaches, which are beyond the scope of this study. Suffice it to mention that users' characteristics are traditionally divided into physiological, psychological and sociological categories.[7] The emphasis should be placed on changes of users' characteristics through a building's life cycle and the consideration of individual variations.

3.2.4 The Formulation of User Requirements

According to Cronbergs, The formulation of user requirements involves two different types of information already addressed;

- 1) Information on the users' characteristics combined with
- 2) Information on the users' activities. (see fig.22,23)

Both have to be gathered and analyzed in an operative way. On this basis, requirements can be formulated and should be stated and structured

-in terms recognizable and relevant to the users

Halldane	Cronberg et.al.	Pena & Focke	Harris
1. <u>Operational Goals</u> What is the design for?	1. <u>Choosing Activities</u> relevant to function	1. <u>Establish Goals</u>	1. <u>Problems</u> relate problems to different groups of community
2. <u>Parameters</u> What are the factors to consider in design?	2. <u>Defining Users</u> and their relevant characteristics	2. <u>Collect, Organize and Analyze Facts</u>	2. <u>Course of Action</u> mobilization of resources to solve the problems
3. <u>Synthesis</u> How are the factors related?	3. <u>Identifying & Structuring</u> user requirements on the basis of step 1 & 2	3. <u>Uncover and Test Programmatic Concepts</u>	3. <u>Activities</u> display alternative sets of activities for each course of action
4. <u>Performance Criteria</u> What attributes and magnitudes are needed for the factors to meet the goals?	4. <u>Defining the Given Conditions</u> (such as climate, law, restrictions etc.)	4. <u>Determine Needs</u>	4. <u>Environmental Characteristics</u> quantifying environmental requirements
	5. <u>Identifying & Structuring Performance Requirements</u> on the basis of step 3 & 4	5. <u>State the Problem</u>	

Figure 22 : Summary of Some Varying Procedures in Identifying User Needs.

Source : Saeterdal, "Review of Papers", in National Bureau of Standards, Performance Concept in Building: Vol. 2, 1972.

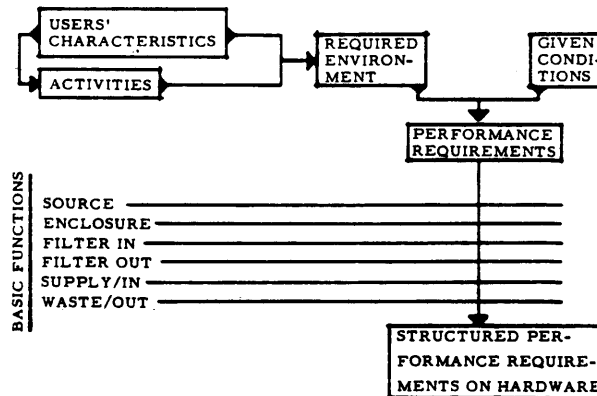


Figure 23 : Requirements Formulation.

Source : Cronberg, "On Structuring Performance Requirements for Building", 1972.

-independent of the given conditions

-as qualitative and/or quantitative information, depending on available information,

and should be grouped under the following headings [8]

- 1) Requirements of accessibility/usability, referring to easy and comfortable access to their attributes and qualities, necessary or desirable for the use of the building or its parts when performing the activity.
- 2) Requirements of safety/protection referring to the qualities of the attributes, concerning the personal safety and other risk factors for the health and well-being of the occupants as well as the protection of their property.
- 3) Requirements of perception/comfort, according to users' reaction (both psychological and physiological) to the built environment, the structuring of information by the users in response to their experience of the designed environment, and their ability to orient and identify with it.
- 4) Requirements of social adjustability, according to social changes of the occupant(s).

Different ways of formulating and structuring user requirements should be tried out, revised and adapted to particular needs in design, to ease communication with the users and between different fields of research. Generally reports of user requirements, particularly in a systems

building program, embody detailed discussion of a different kinds of space and tabulated environmental criteria for each space, which contain a required service, e.g. air conditioning, audio-visual communication, acoustical comfort, required electrical services, etc.

Such user requirements, combined with information about given conditions, i.e., a given specific context and constraints will form the basis for finding out what performance is required of the building hardware. Thus, given conditions will balance the performance required in order that the performance obtained will have the best possible consequences on actually possible or economically feasible solutions. Such solutions could possibly be the result of manufacturers' research and development of new products (or building systems) or the selection of hardware (or systems or subsystems) available in the market that correspond to a required performance.

CHAPTER 4

BUILDING SYSTEMS DEVELOPMENT

-SYSTEM DESIGN AND PROCUREMENT-

4.1 INTRODUCTION TO BUILDING SYSTEM

Prof. R. Bender defines building systems as the following [1]

"The building system has been called a 'kit-of-parts'. It consists of a group of components and subsystems which can be combined in a great variety of configurations to provide a large number of solutions to any given problem. At one end, it is based on the belief that mass-production processes are best utilized when a wide variety of design can be developed from a minimum of parts. At the extreme, it realizes the volume of production necessary to research the user requirements and the performance characteristics of these components as well as the design, manufacturer and distribution of them is so complex that it requires a reorganization of the market. The form of the industry and its context will be affected by this reorganization."

A building system simply means a kit of building parts with sets of rules for their assembly into total operating systems to yield some desirable level of performance. The value of a building system lies in the characteristics of its elements made compatible within the system. Building systems differ from conventional buildings in that they are inter-related and coordinated building parts which have the capability of being assembled into a wide variety of building forms, while conventional buildings are building parts which have the capability of being assembled into only one configuration, i.e., the building for which they were

designed. (see fig.24) The concept of a building system is analogous that of the early printing press. Once the alphabet and rules are invented, there is no limit to what can be written with the system.[1]

Generally speaking, the notion of building systems in the modern sense has its source in the radical change brought about by the industrial revolution and its subsequent effects on materials, building products, processes and design in construction. A distinction should be made between traditional construction systems which refer to the conventional process of assembling traditional building elements on the site by cutting, fitting, bending, etc., and industrialized building systems which refer to either fully compatible, pre-engineered elements, or total building packages. The stages in the evolution, from craft-based construction to industrialized building are shown in fig. 25.

As was emphasized in Chapter 1, the term "building system" should not be confused with "system building" which deals with the management of the total building construction process and includes all phases of the building process, from production to final erection.

In the planning/design of a true building system, each sub-system, its components, elements, pieces of equipment, service, etc. must be conceived on the basis of overall system requirements which are conceptual, programatic, practi-

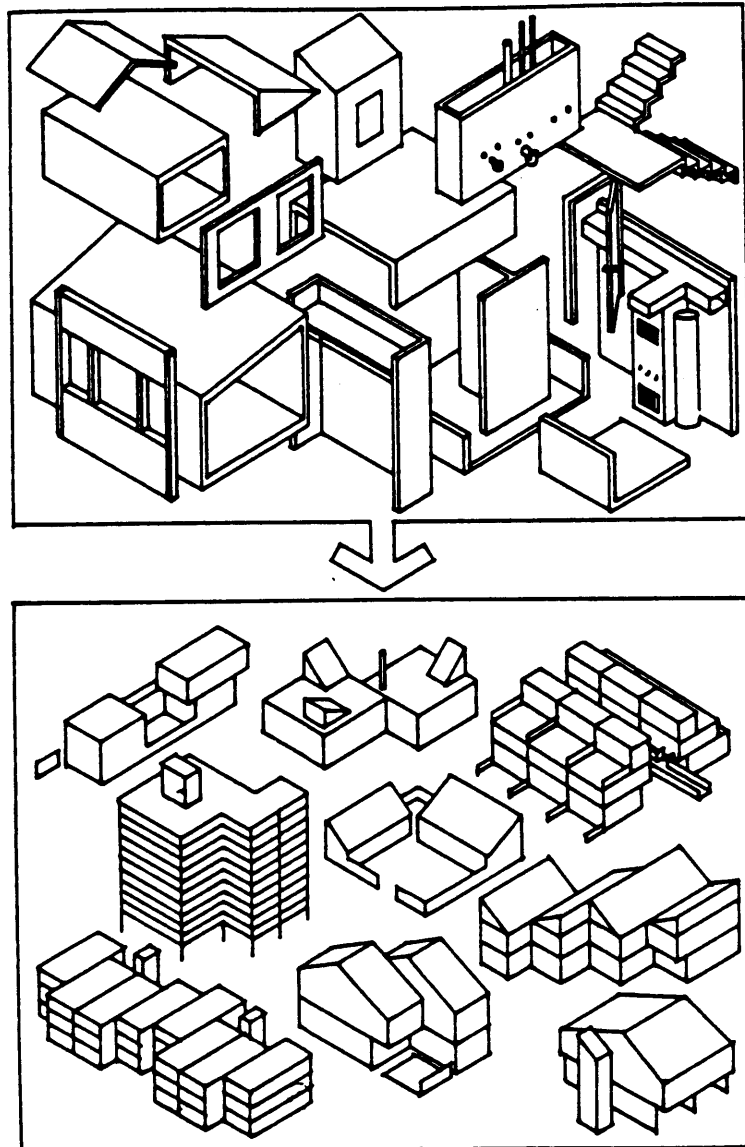


Figure 24 : Building Systems:
"Kit-of-Parts"
Source : Bender; A Crack in the
Rear-View Mirror, 1970.

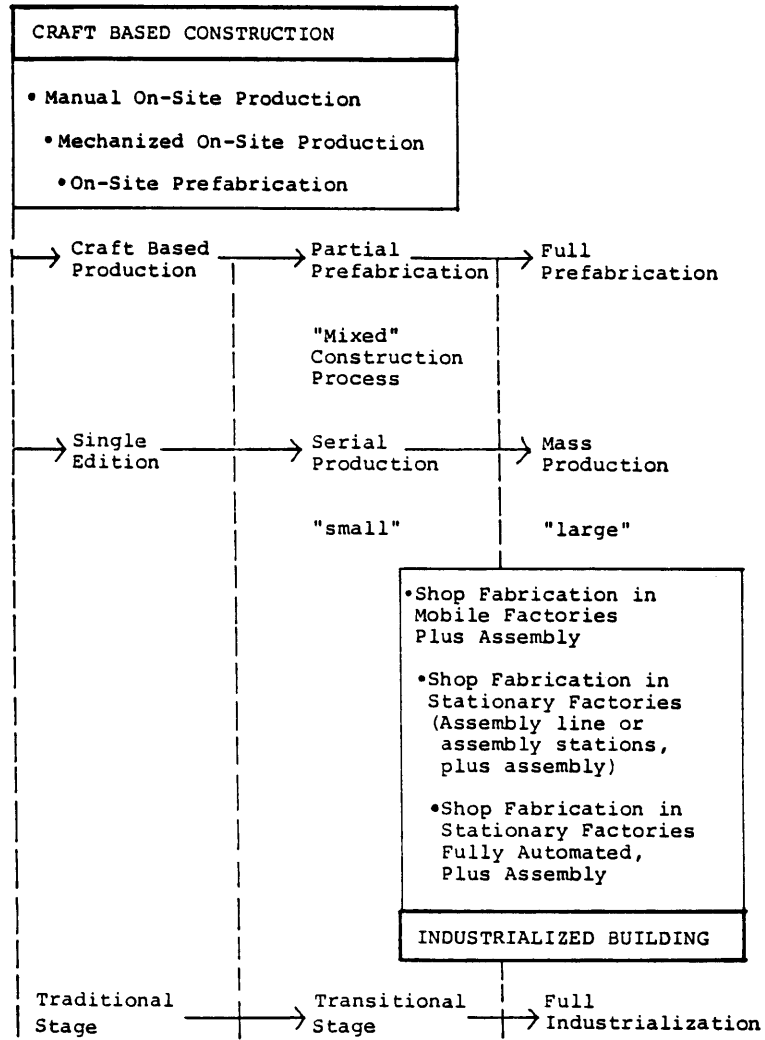


Figure 25 : Stages in the Evolution of Industrialized Building.
 Source Dluhosch, "Building System" M 345/0091.

cal and so on, and, which serve the goal established by the program as addressed in chapter 1, of which the satisfaction of user needs and requirements is a primary concern. In the light of the above, there are a number of basic considerations in building system design, to mention a few;[9]

- All system elements should favor, as much as possible "open" combinations
- A building system must be capable of expansion, both horizontally and vertically
- Full flexibility of all service media (ducts, pipes, wiring, etc.) is desirable, both vertically and horizontally, without undue or unnecessary modification of the basic structural elements
- Provision should be made for suitable tolerance allowances arising from different production and/or assembly methods and their accumulation in the assembly phase.

More information for these basis considerations is attached in Appendix C

Classification of building systems is normally based on "type-specific" rather than "material specific" considerations most building systems are capable of being realized by more than one material and systems depending on a single material for their design are rare. Accordingly, the conventional way of classifying building systems is generally based on type of structural support system, i.e., panel

systems, box or volumetric (space-enclosing) systems. In addition, any of the preceding systems may be generically classified as either "open" or "closed" system. The big question for a systems building program to be considered is which approach should be taken between the development of open or closed building system for its hardware solutions.

4.2 "OPEN" VERSUS "CLOSED" SYSTEM

During the last decades, two distinct but related approaches to the development of industrialized building systems have emerged, which are known as the "open" versus the "closed" system approach to industrialized construction. Along with the mechanization and rationalization of conventional/traditional construction practices and process, the evolution of open and closed systems was accompanied by progressive industrialization and prefabrication of components, elements, and structural systems as well as complete, whole building systems.[7]

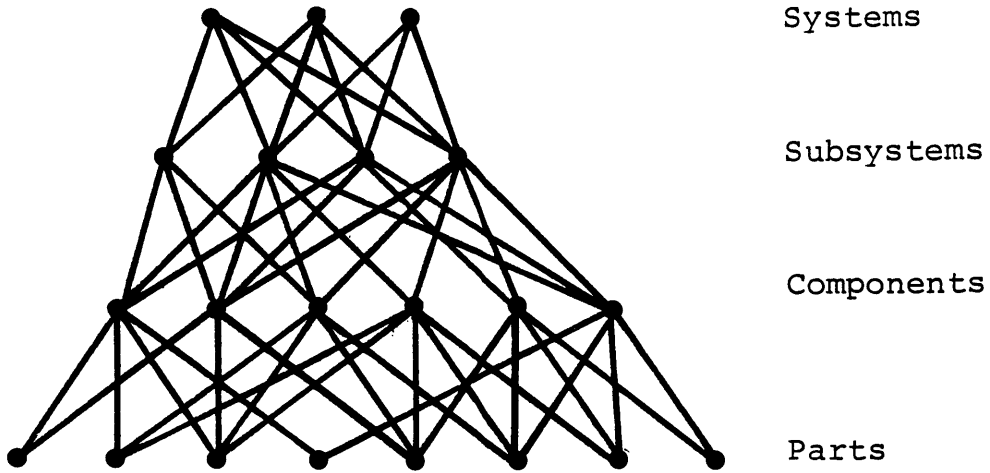
In a closed building system, its sub-systems, components and parts are compatible only with the other subsystems constituting that particular program and are not interchangeable or transferable to another system. (see fig.26,27,28) The choice of a closed systems approach offers two possible alternatives in its system design;

- 1) System designers design the required building system in a completely prescriptive manner and have industry bid against system designs and specifications. This

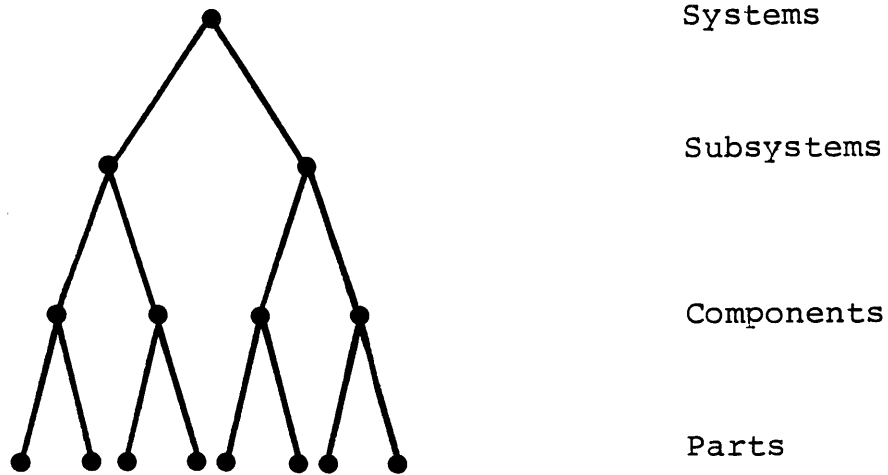
approach, relating to a designed system task, makes it necessary to establish a large technical bureaucracy. The system designed is limited in its concept, technique and quality by the skill of the design team.

- 2) A system team prepares a performance specification for requisite subsystems and requires the bidders to bid in closed teams for all subsystems, with a general contractor. Usually, the structural subsystem contractor acts as coordinator for the group or there is a project manager, taking the role of coordinator. The SCSD and RAS systems were designed by this approach.

In an open building system, its subsystems, components and parts are interchangeable with other systems. (see fig.26,27,29) Implicitly, the desired interchangeability of subsystems and their use for numerous alternative combinations of plans and/or geometrical forms for projects varying in size and design is the reason which had led to the development of more or less open systems. Subsystems of an open system are usually of different origin and can be arranged to form a number of compatible combinations, i.e., their use is not confined to a single system. The more "open" a building system is, the more its coordination principles allow for interchangeability of subsystems and components, and, by this characteristic, provide for increased planning flexibility and the possibility of variability during the life-time of the building.[2] In the broadest sense,



Schematic Lattice Diagram of Possible Combinatorial Options in OPEN SYSTEMS



Schematic Lattice Diagram of Fixed Combinatorial Options in CLOSED SYSTEMS

Figure 26 : Building System Types;
Comparison between "Open" and "Closed" Systems
Source : SUCF - BOSTI, 1970.

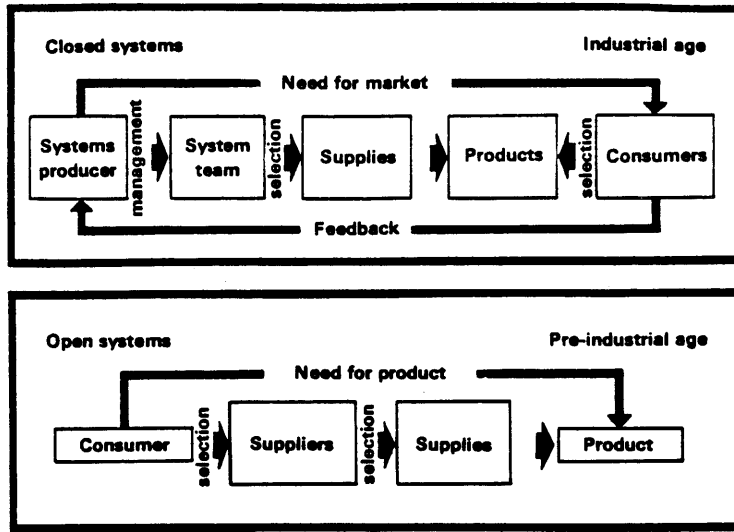


Figure 27 : Closed and Open Systems;
The relationship between consumers and products.

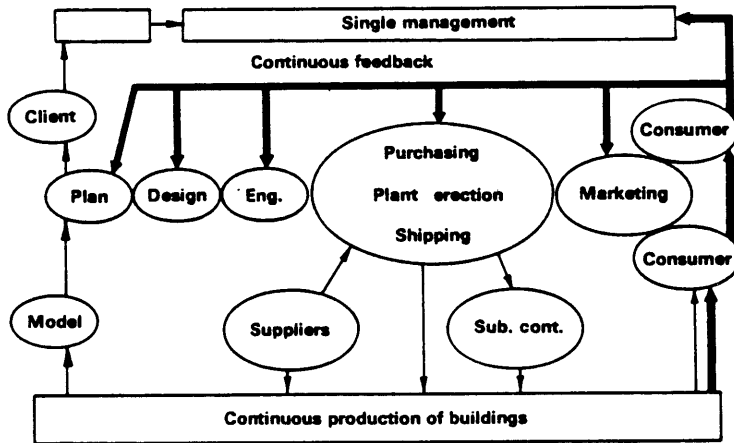


Figure 28 : Closed Building System.

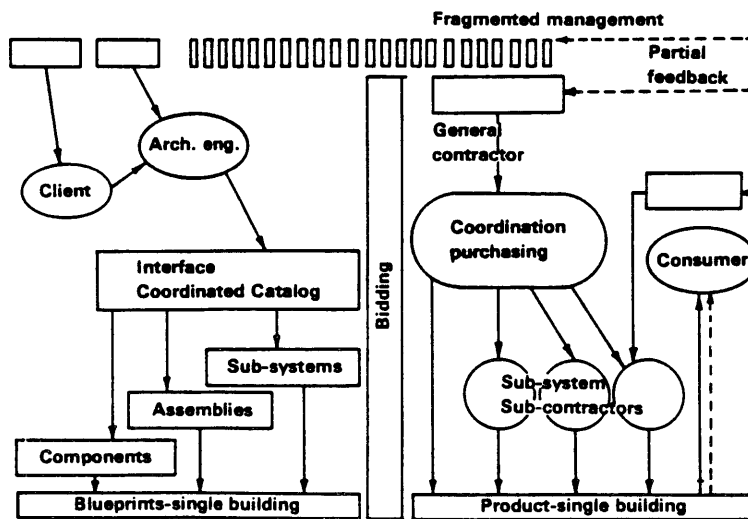


Figure 29 : Open Building System.
Source : All illustrations in this page; Rothenstein, "European Panel Systems", 1970.

such interchangeability leads to a comprehensive "open" sub-systems and components market. Obviously, the development of a series of national and international open systems would be of great value to manufacturers, designers, builders and users.

Consequently, by means of the open system approach, numerous building systems can be generated by the various combinations of their respective subsystems. For example, in the case of the SEF open system, and the RAS closed system, although the number of manufacturers bidding for both programs was comparable, and generating the difference in total building systems claimed to be compatible by the bidders, RAS identified only eleven such systems. Of these eleven building systems, only three satisfied the budget limit set by the program, while in the SEF program, which was governed by the same conventional construction cost limit, 4,000 building systems were identified and qualified.

The next paragraph will examine the advantages and disadvantages of closed and open system approaches, it may be useful to learn from the real experience. Therefor, RAS program directed by IRNES in Montreal, which used the closed system approach and the SEF program in Toronto, will be depicted to show the differences between the two approaches.

4.2.1 Closed System-Its Advantages and Disadvantages-

A well-designed closed system can, under ideal condi-

tions, produce a more efficient integration of subsystems. Such internal coordination possesses a certain control capability, i.e., closed systems can maintain their product performance within specified limits at predetermined levels. Subsequent to a tentative bid award before mock-up testing, IRNES knew precisely what kind of connections, component supports, diffusers and other hardware elements etc., it was getting. For these reason, RAS cited better hardware as the chief advantage of closed system.

By requiring documented compatibility among our five sub-system bidders, we think we got technically better, more architecturally elegant subsystems integration than SEF.

In addition to better integration. RAS claimed better prices obtained, to quote;

A manufacturer was required to detail a practical technique for integrating his subsystems at each interface, he know precisely what material and labor it took to integrate his subsystem with others. With this information he could bid an exact price. In SEF, however, each manufacturers might have included a little extra in his bid, to allow for unforeseen contingencies.

Based on this claim, it can be argued that, theoretically, an open system should produce greater economy, since one can ideally choose the most economical candidate in each category on a competitive basis.

A serious disadvantage in closed systems lies in the difficulty of product substitution. If, for any reason, one sub-system contractor in a closed system withdraws from the construction program, the entire program may be seriously

threatened, since there may be no readily available substitute for the first contractor. Furthermore, if any contractor causes delays in a closed system, it may result in raising costs and slowing progress. In a similar emergency situation, there should be no difficulty in an open system approach, such as SEF in finding a substitute contractor, since open system bidding process makes several other manufacturers' subsystems compatible with the subsystems of the winning overall building system.

In an open system made up of numerous subsystems, e.g., ten subsystems, in the case of the SEF program, the chances of getting all of the best subsystem proposal in a single building system are relatively small. Accordingly, the owner might not get the best possible product, as there is the danger that he will get locked into a weak system, if any of the subsystem contractors is incompetent. Conversely in the case of closed systems, the manufacturers of each subsystem of the winning overall system, are largely insulated from competition and, thus, total cost could be higher than the price of an open system.

4.2.2 Opened System -Its Advantages and Disadvantages-

Variety of building systems, generated by various combinations of interchangeable subsystems, and countless combinations of alternative solutions for different plan options, is the greatest benefit gained from the open system approach. Each of the almost limitless combinations of

compatible building subsystems is potentially capable of forming a building system with its own unique cost and performance characteristics. For example, the SEF program offered more varieties and the stimulus to competition was higher than the benefits of thorough and immediate coordination of its subsystems. Given these assumptions, and assuming that appropriate bidding procedures can be evolved, an open systems approach assures the owner that he will get the best available system at a competitive price. Ultimately, an open system yields many benefits, e.g., manufacturers get bigger markets, consumers gain greater freedom in product selections, and so forth. Open systems approach encourages competition and stimulates innovation more than the closed systems approach. It not only stimulates more competition initially, but also provides for cyclical renewal of competition entry into the market. However, new subsystems must be compatible with existing subsystems at their many interfaces.

If the concept of an open system is to be carried through to its practical realization, it promises to move the building industry into a more competitive position, and to utilize the full resources and skills available in the building industry, in an integrated manner as well as helping the building industry to introduce innovation and improve efficiency.

Nonetheless, there is an obvious disadvantage of

fostering promiscuous compatibility under the open approach. Open system approach requires extremely complex measures of coordination, quality control, and programming. This -in turn- calls for considerable research and decision-making coordination . Achieve open system compatibility and "free" interchangeability of subsystems is a formidable task. Rigorous dimensional coordination is the critical consideration for subsystems integration and open system compatibility. However, in the example of SEF, it was the belief that the competitive benefits from the open systems approach will outweigh the many difficulties of subsystem intergration mentioned above. RAS, on the other hand, sacrificed variety of products to superior integration of its subsystems.

In conclusion, the question of which approach is better cannot be answered, in view of the many considerations involved. Viewed in such a broad perspective, the open vs. closed system controversy can be resolved by seeing each as a different strategy to enhance the building industry' s capabilities to respond better to competitive pressure. In industrialized system building programs, the choice of either a closed or an open building system is, however, a critical issue. It should be noted in this context that building systems should always be judged in their market context and not abstractly. In addition, if a market can be found for products of the unsuccessful bidders, this would be a big step towards creating a truly open system. Essen-

tially, in order to devise both open and closed system, it is vital to consider all interests and every aspect of the building industry in order that the vast effort necessary to bring into being more efficient building systems will find optimal response within the industry as a whole.

4.3 BIDDING PROCEDURES

Aside from other reasons that made RAS an essentially closed system, as opposed to the open SEF system, there is the issue of the difference in bidding procedures between the two programs. In general, bidding building systems on the basis of performance criteria or performance specification, the procurement procedure must be developed to permit manufacturer to innovate and bid systems of their own design, while still maintaining the ability to secure patent rights and to control product design.

The first pioneer program which used the performance concept was the SCSD program in California in the early '60s, while its basic concepts were also used extensively for the SEF program in Toronto, the RAS program in Montreal .[16] The application of the performance concept in building system procurement is based on the assumption that building subsystems of a compatible character will be bid by several manufacturers.

Once the market has been organized, each program can be made different for each bidding procedure. Differences in

bidding techniques depend on the determination of the program owner, whether to develop a closed or an open system. To develop a closed system, all subsystems will be bid together as a group, and the bidding team with the lowest cumulative price is awarded the contract. While subsystems are bid independently results in an open system. It is the difference in bidding procedures which is essential, whether a given system program is to be considered as a closed or an open building system.

As an example, the SCSD program developed performance specifications and put these out to bid on the basis of a total system.[17] This resulted in a package of integrated subsystems, making up an overall closed building system. In such a case, the subsystem manufacturers which make up the consortium of bidding, are usually dependent on one of the major subsystem manufacturer in the group, or else the group is coordinated by a project manager. (see 4.5) The operational procedures of SCSD, after submissions were received, was that the managing architect subsequently selected the best of each subsystems from the various bid groups. These were, then, integrated into a new building system called the SCSD system, (see fig.30). This means that the subsystems submitted within any individual system bid do not necessarily have to be considered as fixed entities, but can be re-combined in an interchangeable manner for each new program or system in a coordinated, but "open" manners.

RAS Montreal, used some similar procedures; organized market, preparation of performance specifications and request of system bids. Also, each group of bidders proposed a totally integrated and interfaced package of compatible subsystems. However, instead of selecting the best subsystem from each system submitted as in SCSD, RAS selected the best total system, (see fig.31). The RAS subsystem manufacturers, bid as a closed system team, and the total price of the five major subsystems competed against a similar bid total, tendered by other competitive teams.[17]

In Toronto, the SEF program, the market was organized in a similar manner by the Metropolitan Toronto School Board, and the performance statements were similarly prepared. Instead of bidding the total system, each subsystem manufacturer bid individually, with the price of each subsystem related to its compatibility with the other subsystem with which it had to interface. Every subsystem catalog of the SEF program was selected and assembled on the basis of price and interface capability, (see fig.32).[18] In SEF bidding procedures, each manufacturer had to make his subsystems compatible with two other manufacturers' subsystems at each mandatory interface, whereas RAS required compatibility with only one manufacturer at each interface. This was so because in the SEF open system had to assure subsystem integration as a critical step.

Griffin described SEF bidding procedures as

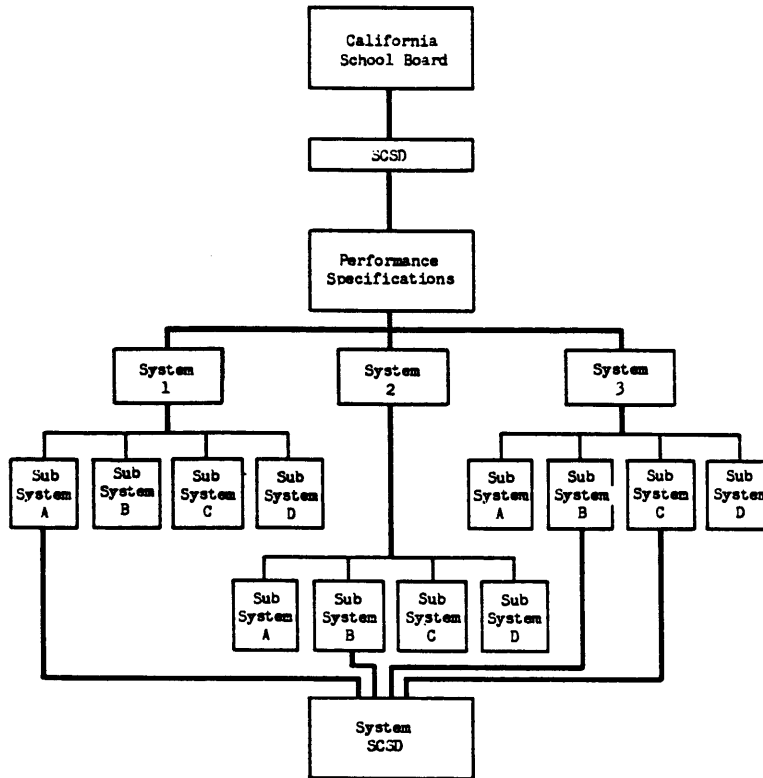


Figure 30 : SCSD Bidding Procedure.
Source : A Systems Approach to Building. 1969.

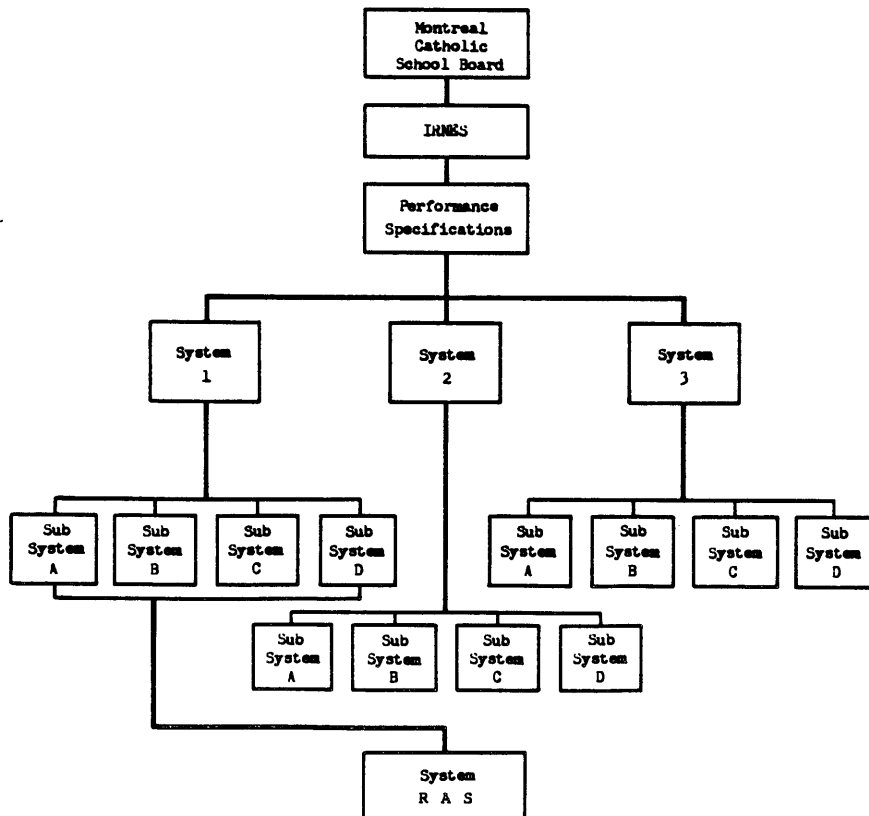


Figure 31 : RAS Bidding Procedure
Source : A Systems Approach to Building, 1969

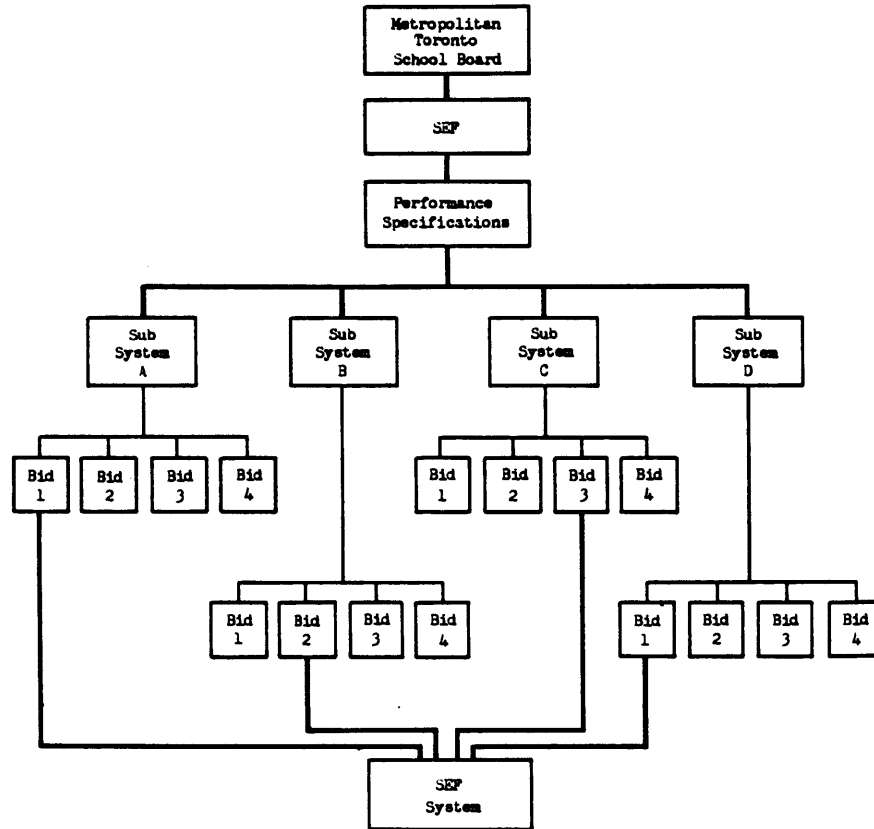


Figure 32 : SEF Bidding Procedure.
Source : A Systems Approach to Building, 1969.

follows;[12]

SEF' s bidding procedures resulted in the open building systems which necessitated rigorous enforcement of its bidder prequalification criteria regarding to its success. Manufacturers and other prospective bidders had to present proof of their financial capability and their manufacturing and installation expertise to carry at least 250,000 sq.ft. of construction per month. A total of 60 bidders applied for prequalification; before bids were due, the total had dwindled to 30. Proposal from 30 bidders for 10 subsystems produced 13,000 possible building building system. Analyzing this data is the job for computer which was programmed to identify only those subsystems which claimed by manufacturer to meet all SEF performance and economic criteria. In a further refinement that was needed to cut the problem down to manageable size, the SEF staff programmed the computer to identify the least costly subsystems meeting the mandatory interface and performance criteria and evaluated in accordance with the aesthetic and functional criteria.

Thus, there are two principals in bidding procedures;

- 1) The concept of stimulating one consortium to bid on a total system, representing the entire project, and
- 2) The concept of a broken down system, in which each subsystem is bid separately in such a fashion that the subsystems can be selected and combined to form various alternative building systems. Bidding subsystems independently is likely to create a higher degree of competition, but results in more complex bidding conditions for both the bidders and the project staff. In the team approach, a higher degree of integration is possible than if the bidders are working independently. The RAS program, which bid subsystems as a group, probably achieved the highest integration and the fewest interface problems of any of the major educational building systems programs in North America.[15]

To award a bid, the low bidders are tentatively identified on the basis of the results of a computer testing program. Following the tentative bid award, the victorious bidders will begin to work on final design details and prepare system catalogs containing detailed technical information, drawings, quoted unit prices for all components in their subsystems and so on. These catalogs will be used by architects and engineers who work on an individual project for the building system to be designed.

In general, and in order to bring a systems building program into being, a series of interrelated constraints must be established, e.g., an overall time schedule, including program budget, escalation clauses, etc. Insofar as building system design and development is concerned, performance criteria or performance specifications, including bidding procedures, need to be established. These include mandatory interfaces for each subsystem, subsystem bidders' prequalification, quality control procedures, dimensional coordination, professional subsystem coordination, continuity of professional liability, etc. In bidding a system or subsystems, all relevant codes and standards have to be met, in addition to target and performance specification.

It is strategic to use the simplest possible bidding documents and procedures to avoid scaring off undecided manufacturers. The final publication of tender documents should be in a form which is technically and commercially

attractive to induce bidders to participate in a high quality program and to reach as many as possible.

4.4 SUBSYSTEMS COMPATIBILITY AND SYSTEM INTEGRATION

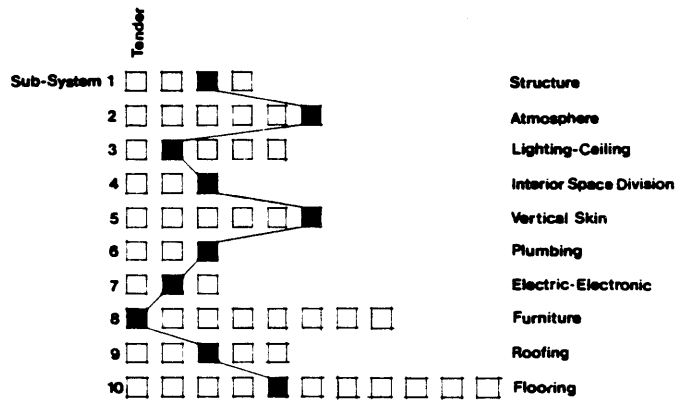
The essence of a building system lies on its concept of building, comprised of a number of subsystems, which collectively form a whole system. Subsystems can be defined as an identifiable, complete, designed, physically integrated, dimensionally co-ordinated, installed series of parts which function as a unit without prescribed performance limits.
(see fig.33)

In any building system design, it is very important to define and document the general requirements and functions for each respective sub-system, in terms of the constraints imposed by the program and resources available and to define their generic properties in terms of performance standards. In the initial stages of developing subsystems it is necessary to explore the full potential of all material, technology and construction options while maintaining an attitude of maximum impartiality towards alternative options.

To determine the form of system most suitable for a given program, and to make a good choice in the selection of materials and suitable process of production and assembly, detailed performance criteria and specification are not necessary, aside from those criteria that are indispensable for making such decisions. The range of feasible alternatives is obtained by taking all specific requirements of

1	2 3 4 5 6 7 9	
2	1 3 4 5 6 7 9	
3	1 2 4 5 6 7	
4	1 2 3 5 6 7 10a 10b 10c (not required)	
5	1 2 3 4 6 7 9 10a 10b 10c (not required)	
6	1 2 3 4 5 8a 9	
7	1 2 3 4 5 8a 10a	
8a	4 5 6 7 10a	Sub-systems 8a and 8b will be required to interface with the sub-systems noted and <u>not</u> vice versa
8b	10a	
9	1 2 5 6	
10a	4 5 7 8a 8b	
10b	4 5	

Mandatory Interface



Open Systems Approach

Figure 33: SEF Subsystems.
 Source : Robbie, "The Application of the Systems Approach to School Building in Toronto", 1969.

1	2	3	4	5
Structure	Atmosphere	Lighting-Ceiling	Interior Space Division	Vertical Skin
6	7	8a	9	10a
		Caseworks		Carpet
		b		b
Plumbing	Electric-Electronic	Seating	Roofing	Gym Floors
		c		c
		Standard Furniture		Hardware

Subsystem Division

each subsystem into account and equating them with alternatives that are optimized in terms of program constraints and their performance. Presently, the development of alternative solutions nearly all employs computers for simulation.[3]

In subsystem design and development, the integration of subsystems into a total system, which requires their mutual compatibility is of importance. The required compatibility and mandatory interfaces for each subsystem are principally stated in the performance specifications (see fig.33,34). The careful description of mandatory interfacing responsibilities between subsystems is the key to success in assuring high quality, cost and time performance, without resorting to the use of a closed system.

It should be clear that the essential qualities of a good system lie in its subsystem integration and compatibility. The criteria for achieving compatibility are interrelated performance characteristics, convention of physical interfacing, application of dimensional systems and modular coordination, respect for spatial and/or technical norms and standards, control of joints and interfaces, versatility of components' joinery and so-called "by-passing" systems*.

* Note: In by-passing systems of coordination, diverse elements, components or sub-systems are allowed to meet within a considerable latitude of allowable joint tolerance, which allows elements to "by pass" each other by means of adaptable joints and connections.[8]

Structure Lighting-ceiling HVAC April, 1971	Anning-Johnson AJ Armstrong C-60/30 Armstrong C-60/60 Butler LC-300 Ceiling Dynamics LAMBDA V Ceiling Dynamics MOD 11-V Ceiling Dynamics MOD V Ceiling Dynamics OMEGA V Comwed FIVE PLUS FIVE Donn COORDINATOR Keene SPEC 10 Keene SPEC 30 Keene SPEC 50 Keene SPEC 60 Keene SPEC 70 Keene SPEC 80 Lok Mc-5A, C Lok CUSTOM Luminous Ceilings TEC 11 Luminous Ceilings TEC V Luminous Ceilings TEC VI Luminous Ceilings TEC VIII Soundlock SOUNDLUME Sunbeam IS1000 Sunbeam IS5000 Sunbeam IS6000 SYNCON	Butler SPACE GRID DYNA-FRAME Francon RAS*** Haven-Busch JOISTRUSS** Inland-Tyerson Macomber V-LOK P.C.A. DUOTEK** Romac MODULOC SYNCON
Satellite Carrier Air Conditioning Chrysler Airtemp MZU Trane CLIMATE CHANGER* Worthington CMC MULTITEMP*		
Self-Contained Acme SERIES "E" American Air Filter MZRM Dunham Bush RTMZ ITT Nesbitt RTMZ Lennox DMS-1 Lennox DMS-2 Lennox DMS-3 Mammoth ADAPTA-AIRE Mammoth ADAPTA-ZONE Schemenauer MULTIZONE* York MULTIZONE*		
Structural Butler SPACE GRID DYNA-FRAME Francon RAS*** Haven-Busch JOISTRUSS** Inland-Tyerson Macomber V-LOK P.C.A. DUOTEK** Romac MODULOC SYNCON		

*** indicates product in development.
 ** indicates product on market, but not in full production.
 * indicates data incomplete on this product.

Figure 34 : Subsystem Compatibility.
 Source : Griffin, "Systems", Educational Facilities Laboratories, 1971.

In system design and procurement, a set of coordinating principles is, therefore, to be established as a basis to assure mutual compatibility between structure, wall/partitions, equipment/furniture, mechanical service infrastructure and space. All elements which make up the subsystems must be capable of being integrated within the rule system of the modular grid and the dimensional criteria chosen, including dimensional range, the accommodation of all possible junctions and joints, tolerance allowances (manufacturing expansion/contraction, assembly, etc.) and handling ease.[9] Such complex considerations, concerning compatibility and integration are indispensable in building system design and procurement, (see fig.35,36).

A system's set of coordinating principles is comprised of the dimensional system, the basic module and modular increment, and planning grid. In fact, the basis for standardization is to be found in these principles. The dimensional system must accommodate both the functional and technical requirements of a building system. The basic dimensional range (or series) should offer such sizes and their combinations as to accommodate all ranges of the various functions mandated by the program and provide spaces for each individual project in the program. In addition, these sizes and ranges of spaces made possible by the dimensional rules should be capable to accommodate all equipment, furniture, standard building elements, and the installation and

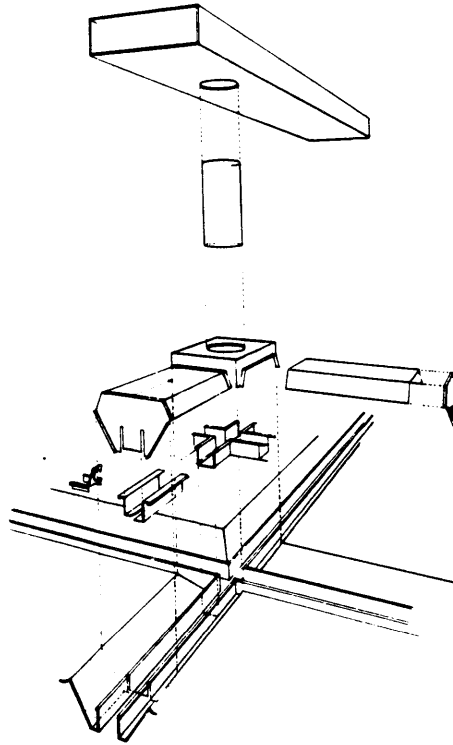


Figure 35: RAS; Airconditioning and lighting components integrate gracefully in ceiling.
Source : Griffin, "Systems", Educational Facilities Laboratories, 1971.

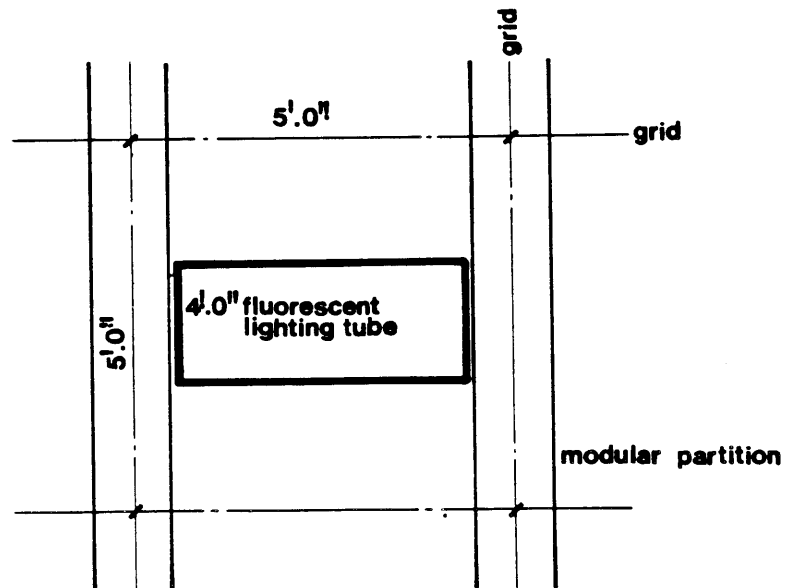


Figure 36 : Horizontal Planning Grid
Source : Robbie, "The Application of the Systems Approach to School Building in Toronto", 1969.

distribution of mechanical/electrical services. Modular coordination and its related dimensional systems are to be applied to all elements of a given building system.

Once the above principles are established, then it is possible to proceed with the design of subsystems and their components. Each element, e.g., structure, non-bearing elements, equipment/furniture, mechanical, electrical service can be conceptually designed separately. Within the discipline of modular system, makes it possible to design each as discrete, but still mutually compatible sub-systems.[11]

Thus, in summary, it is mandatory for each subsystem to adhere to the rules of modular and dimensional coordination, including joint and tolerance allowances, and to conform with all engineering requirements, as well as applicable codes and regulations.

4.5 MANAGEMENT COORDINATION IN SYSTEM DESIGN [15]

The importance of coordination of components and of methods in systems building has been emphasized as the major advance as compared to the traditional building process. Coordination through management is another important characteristics of systems building, and an equally important attribute of building systems development.

In order to develop an effective building system, collaboration between building product manufacturers is essential. Diverse industrial groups and fragmented conventional

practice are now called upon to coordinate much more closely with each other in cooperation to solve new problems requiring new products that none of them has been equipped before to solve alone. In the systems approach, manufacturers, developers, contractors, and sub-contractors are formed into a group with a management consultant as their coordinator. The success of building system development relies upon industrial cooperation.

To design new products to meet performance specification requires technical cooperation which leads to the formation of such an affinity group. Technical cooperation has to be accompanied by some administrative control of production and assembly.

In practical terms, a coordinated group has been usually composed of two or more separate manufacturers from different product lines who have pooled some of their resources at managerial, sales and technical levels. Once established, one manufacturer may will act as the group leader, or the group may choose to retain a consultant project manager to coordinate their activities. Such coordination by a project manager which achieved practical success is the example of RAS, which will exemplifies the kind of activities performed by the consultant project manager and demonstrates his range of influence. In the RAS program, five manufacturers formed a group to bid to RAS specifications which resulted in advantages both for the client and

for a group. These advantages derived from the development of an integrated system of five subsystem manufacturers were carried over even into the construction phase.

Having formed the group and established the role of the manager, various advantages which have been addressed previously, emerge:

- 1) The project manager is the representative for -say- five firms who speak to the owner with one voice. Queries can be made and answers analyzed from five viewpoints all at once.
- 2) The advantages and disadvantages of any of the owner's requirements can be assessed, and changes can be requested responding to the needs of all the members of the group simultaneously.
- 3) The net result of this approach is a decrease in the total bid cost, i.e., the group bid. (see fig.37)

To operate firms as a group is not useful only for reaching a satisfactory solution to system design, but stimulates a continuation cooperation between the members of the group as an entity into the vital production and erection phases as well. If there is no pre-coordination, a system may fail due to continuous and uncoordinated modifications after the termination of the design stage.

Other ways to coordinate building systems development programs are possible which are not necessarily dependent

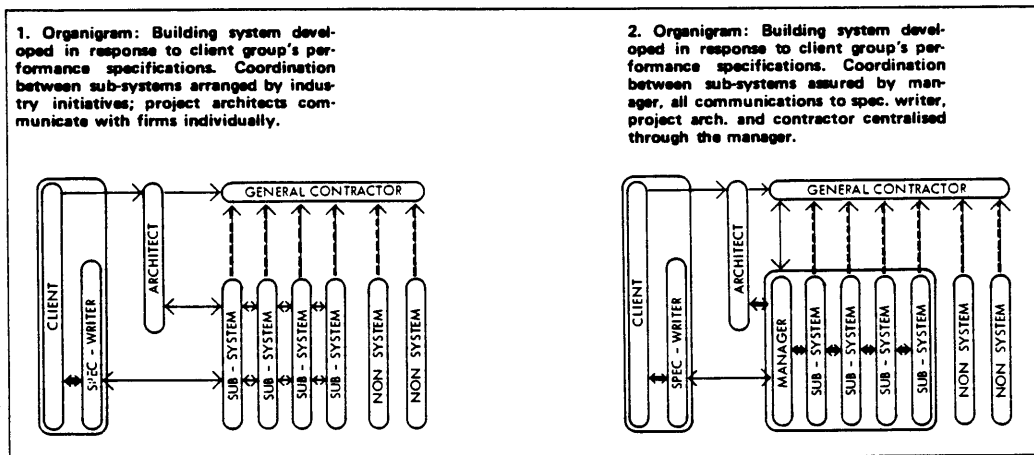


Figure 37 : The Management Consultant in System Building.

Source : Hughes; IF, Vol. 1, No. 1, 1969.

upon an owner to prepare performance specification and invite bids. For example, the initiative may come from a design group with industrial participation invited on the "promise" of a market for their products. In any case, the needs are similar, i.e., group participation of activities which require coordination, which is to say that the systematic formalization of the design and execution process in building require coordinated management and sound research for solving the complex problems of performance requirements.

4.6 SYSTEM DESIGN - GUIDELINES FOR DEVELOPMENT OF BUILDING SYSTEM HARDWARE [6]

Building system design is significantly different from the design of individual building design, and thus traditional design procedures are not applicable. A failure to recognize this can lead to frustrating and costly development experiences. The difference between building system development and traditional building design stems from two causes;

- 1) System solutions are not specific to any one building problem

In a traditional situation, the architect takes cognizance of the specific needs of his client and works out a solution which "fits" them, (see fig.38). Normally, he works empirically towards a solution on the basis of previous experience of similar problem

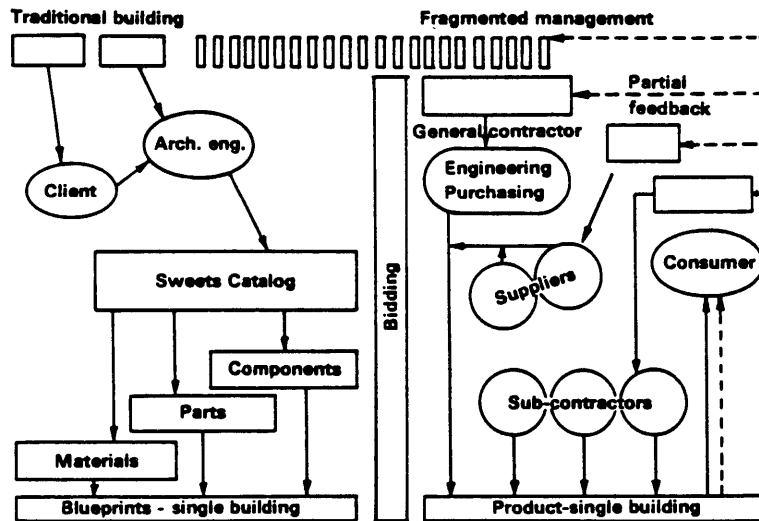


Figure 38 : Traditional Building.
Source : Rothenstein; Eropean Panel Systems, 1970. (in Industrialized Building Systems for Housing.)

solving which has yielded satisfactory results. His success in solving his clients problems lies in the exactness of the fit between needs and solution. In building system design, on the other hand, a solution has to be developed in accordance with a "program" of clearly stated generic as well as specific needs.

2) Systems require sound research and development major commitments during all phases of the process

A building system requires commitment of thoroughness of research and development which is normally much more extensive than research and development for an individual building.

The editors of "Industrialization Forum" have proposed guidelines for system hardware development consisting of the following steps:

- Step 1 Form the System Development Team
- Step 2 Check-out the potential Market
- Step 3 Analyze the Building Types within the Market
- Step 4 Analyze and Evaluate Existing Systems
- Step 5 Commence System Design
- Step 6 Make a Formal Check of the System Design
- Step 7 Start Field Tests
- Step 8 Make Major Management Decisions
- Step 9 Start Production

These steps are depicted in fig.39

4.7 TESTING THE SUBSYSTEM INTEGRATION AND FEEDBACK

The last stage in building system development is to test the integrated subsystems and their interacting compatibility to prove their compliance with

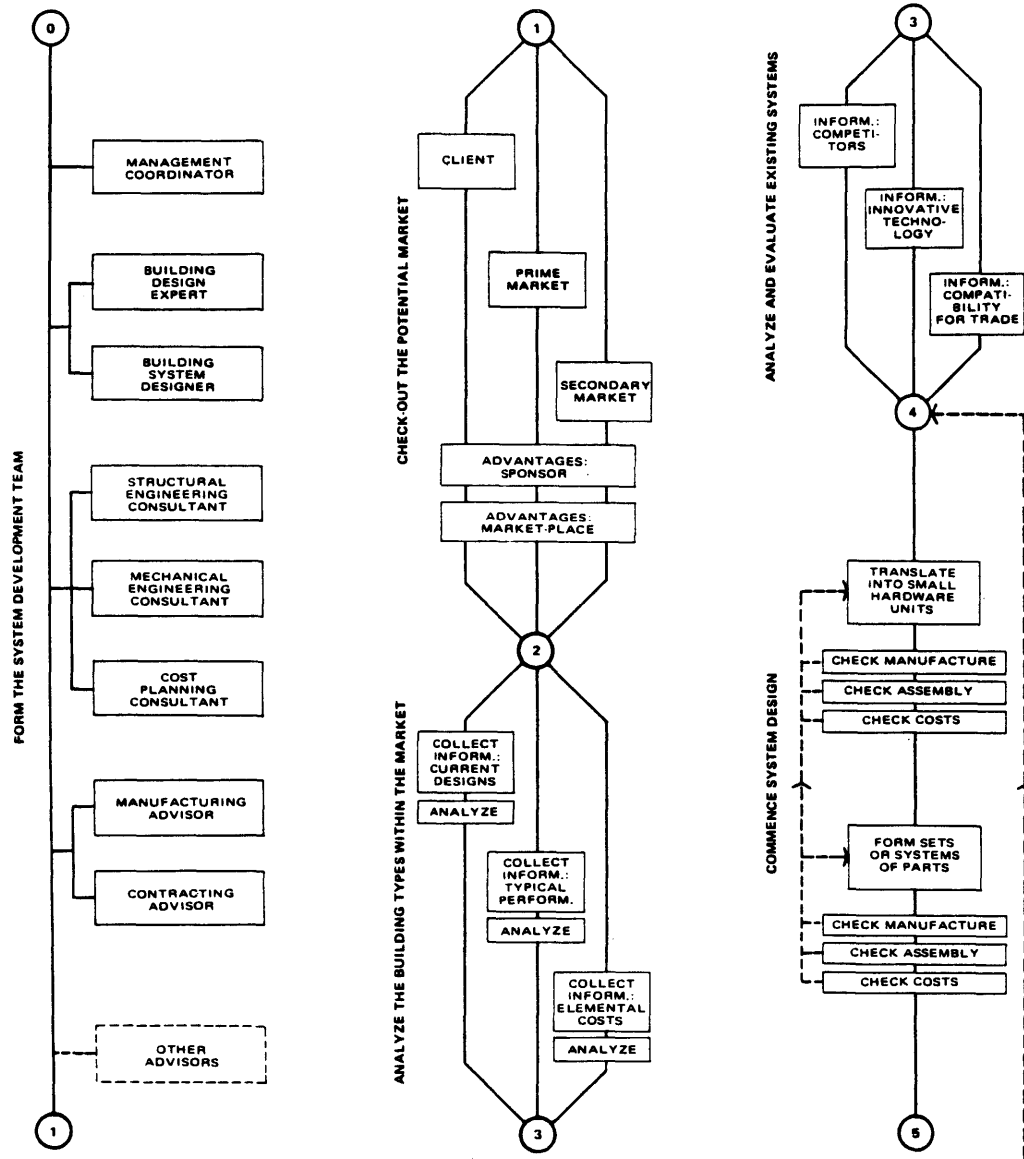
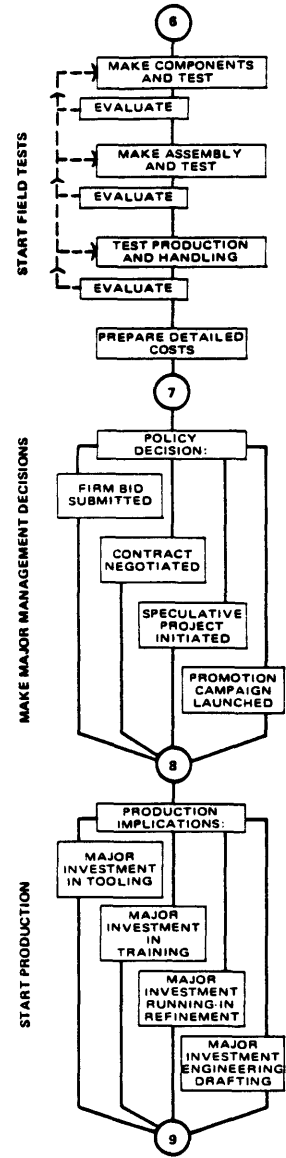
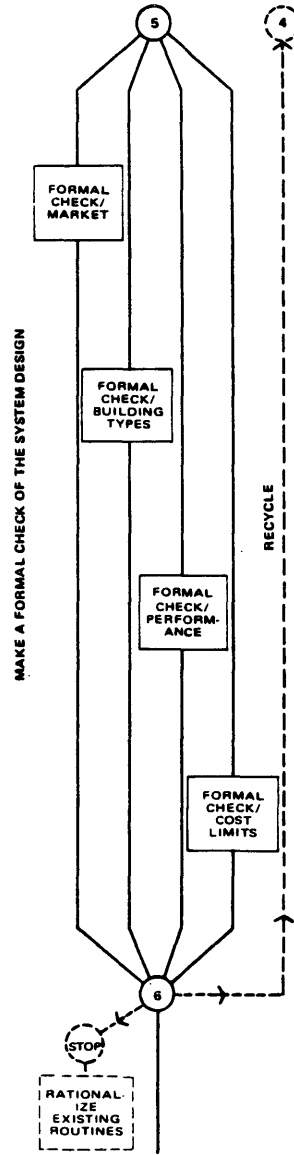


Figure 39 : Developing the Hardware of a Building System.

Source : The Editors of IF, Vol. 1, No.3, 1970.



performance specifications, e.g., whether or not the partitions could be readily connected to the ceiling assembly. If the tentative winners pass the test, they receive final bid awards. To prove compliance with requirements requires prototype development and testing, including the extension of simulation to actual size and in real world conditions. Prototype development is mostly used for obtaining detailed information on the performance of theoretically well researched solution. In systems building, prototype has the important function of proving the performance of the whole system, especially the compatibility of subsystems with regard to basic functioning and interfacing requirements.

By virtue of testing and prototype development related to field conditions, feedback can be obtained before starting mass production of products developed, e.g., assembly sequences, shipping and lifting-into-place schedules, component fit, finishing requirements, factory production costs versus on-site costs., etc.

One of the best demonstrations of prototype development and performance testing given after bidders' submissions of proposals was for the SCSD system in 1964.[4]

"As a condition of bidding, the Commission required that a trial building enclosing 3,600 square feet-the area served by a single air-conditioning unit-should be

erected by the winners on the Stanford campus. Soon after its completion in November, 1964, the building provide dramatic demonstration of the flexibility for which its components were designed. Overnight, between two days of meetings of the Board of Educational Facilities Laboratories in the building, a new room was produced by removing 120 feet of interior partition, installing 25 feet, and changing the surface of 80 feet of partition. The lighting was rearranged by moving 300 square feet of ceiling panels, seven air-conditioning zone were reduced to five, two thermostats were removed and one changed in position, and the building was tidied up in time for the next morning's meeting. Only 59 man-hours of work were required."

From feedback of technical experiments and from experience in use, standards established through theoretical investigation can be developed. Investigation, testing and feedback are a major parts of systems approach for establishing standard and for verifying its applicability.

4.8 BUILDING SYSTEM GENERATION

Systems building programs take one of two general forms

1) Primary or developmental systems building programs

Such programs are developed from scratch. New performance statements are written, large markets are organized to accommodate new building products, developed by manufacturers and so on. This results in:

A FIRST- GENERATION PERFORMANCE SPECIFICATION is one which develops, receives or assembles information from users or for users in terms of their needs in building performance. It organizes this information in such a way that it can be used as a procurement document to which industry may respond.[5]

A FIRST-GENERATION BUILDING SYSTEM is a building system which is a first response to a performance specification. It normally involves research and development of

hardware procurement by the manufacturers.[5]

2) Secondary systems building program

Such programs merely exploit the speed, economy, flexibility and quality of building system products already developed under the primary programs. These secondary programs need little research and development, and therefore, they can thrive on smaller markets than developmental programs. As such, the result is

A SECOND-GENERATION BUILDING SYSTEM is a first generation building system, which through successful application elsewhere, is reused by other groups or programs or only slightly modified. These systems and components acquire an "off-the-shelf" quality in the condition that they are adopted on the basis of their rules. Fully open systems, developed through bidding like SEF in Toronto are likely to generate the second generation systems.[5]

It is noteworthy that buying a "system" is not comparable to buying other building products or service. In the development of a specific building system mandated by the systems building program requirement, system's nature is subject to its requirements within a given context and constraints. To be able to use any system at full potential, one should concern its nature thoroughly; the stages at which decisions are made, the contractual situation involved, type of market, resource, etc.

Primary program developments such as SCSD, SEF, RAS

manage to surmount many initial difficulties and get the stage for other systems' evolution and progress. The product development work undertaken in these primary programs which may be called first-generation building system established a new market for both consumers and suppliers. After the first generation of system-built buildings, the secondary generation no longer needs to start from first principles, since there is now sufficient knowledge, experience and technology available for other projects, including single buildings by means of the systems approach. Secondary systems building programs, though equally indispensable in developing systems building as a normal process, can select available products that fulfill their needs, with some necessary modifications, in accordance with their context.

By exploiting existing products, secondary systems building programs can vastly expand the market for these products. According to free enterprise theory, the expanded markets will attract more manufacturers into competition and enable them to offer a multitude of compatible modular subsystems. Consequently the building industry should produce a giant coordinated catalog from which architects can choose structural framing, lighting/ceiling, partitions, curtain walls, air-conditioning, furniture and other subsystems. Ideally, such a catalog could expand from relatively few commer-

cial be available subsystems on the market today into hundreds in the future, all conveniently catalogued for direct comparison of performance, durability, architectural elegance and economy.

At this stage in systems evolution, and by virtue of the examples of primary school systems programs, systems-developed components are available by the hundreds in school buildings all over North America.[13] The URBS program, developed late in 1965, and inspired by the earlier success of the SCSD program extends systems building into the construction of student dormitories. EFL initiated the project, and contributed two-thirds of the \$600,000 cost of administering it.

"A successful URBS program would doubtlessly become a prototype for housing the nation's proliferating college student population, expected to grow from 7.2 million in 1970 to 9.7 million by 1977." Stated Griffin in favor of URBS; a secondary building program.[14]

In addition, Toronto's SEF has inspire two systems building programs in Boston and Detroit. These secondary programs vary in size from statewide programs to a single school, e.g., Florida's Statewide Schoolhouse Systems Project and a single school project in Merrick, New York. Both, though of widely varying scope, realized similar systems promises and equal economy.

If second generation programs can sustain the momentum of developed products in use, then, systems building will

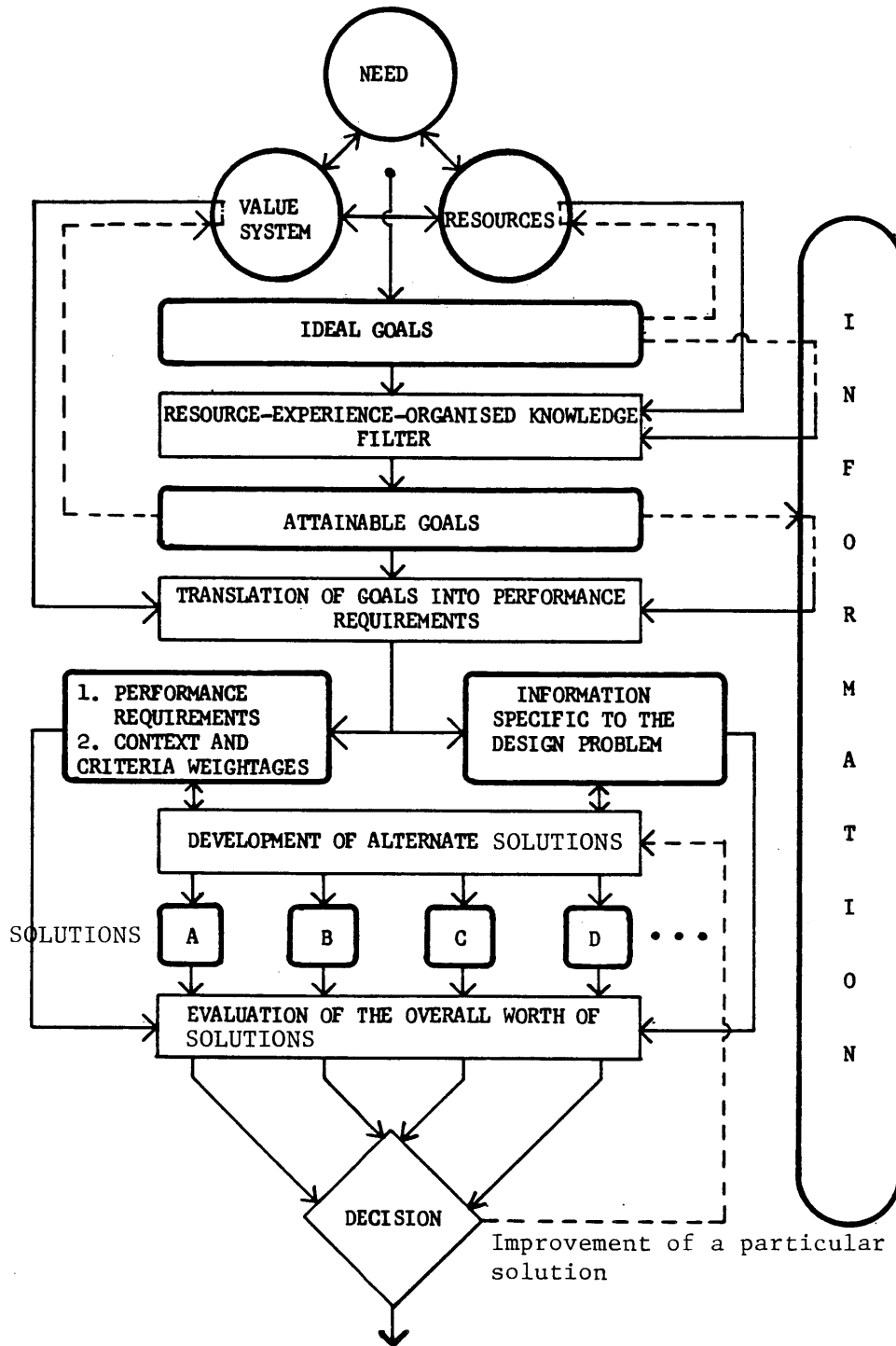
become a self-generating process, resulting in further generations of building systems. Without successful secondary programs, technological innovation becomes too risky for manufacturers and too much of an economic gamble, the building industry inevitably revert to traditional practice.

CONCLUSION

Up to this point, the subject matter of this thesis has been treated at a comprehensive , but fundamental level, dealing with the application of the systems approach to building in general; its development, its various facets, concepts, and the examination of its theoretical as well as practical framework. The conclusion includes the illustration of the systems approach development process in fig.40 and summary to reinforce your understanding, state inherent problems and difficulties in the application and development of systems buildings and system design and procurement as well as offering some comments and recommendations.

In broad terms, a systems approach simply means that a problem is solved in an orderly manner that defines the goals, analyzes the means to achieve them and then carefully organizes the actual process to achieve such goals. To apply the systems approach to a particular problem in the building industry simply means to view the industry, or a group of buildings, or even a single building, or a functional category of components, or a production process, primarily as a whole, and subsequently, proceed from the general to the particular with a minimum of preconceived notions.

The systems approach to building known as "systems building" is simply a building process that takes into consideration every relevant activity and element involved, in



To Detailed Design Phase

Figure 40 : "Systems Approach" Development Process.

Source : Haider and Khachaturian;
"A System Approach for the Evaluation of
Performance of Buildings in Design Process",
1972.

a balanced manner. Its aspects include finite and tangible features as well as peripheral and/or intangible qualities with the ultimate goal of efficiency, economy, quality, and rationalization of optimization. In addition, the systems building is a way of approaching the provision of the built environment in accord with user needs as a primary concern. Systems building is meant to provide a optimal quality environment for people.

The application of systems building is universal in the sense that; conceptually, it can be applicable to any context and, physically, to any building type. Benefit gained from its application, are based on an analytical approach to building process and well organized procedures of managing, designing, and constructing buildings. Systems building, though universally applicable, once applied is contextual, i.e. resulting in building processes and products in accordance with their context and constraints. Under the systems approach, buildings are conceived in view of their full life processes as part off their program, design, and construction.

There is a popular misconception, concerning the application of the systems approach to building, which is that its goal is invariably the need to develop or use a building "system" in the sense of kit-of-parts hardware. Theoretically as well as practically, a system-process (software) is not necessarily tied to a specific system-product

(hardware), nor does such a product necessarily call for such a process in its design and procurement. Furthermore, systems building need not result in any change of the materials methods of building. What is required as a prerequisite in its application is, indeed, the radical rearrangement of building methods, techniques, and in particular the application of managerial and science-based skills.

The systems concept associated with the performance concept is a strong tool to procure building products in compliance with user requirements. This necessitates that system design and procurement depends on skills and disciplines different in many ways from traditional design procedures. The development of a building system requires extensive research, development, and cooperation from building product manufacturers on the basis of aggregated markets. All items mentioned depend on a primary systems building program which cannot be sustained by a single edition project, and which requires great efforts, in terms of time, and other resources. Once developed, a building system derives its nature from the context in which it is designed to work.

Evidence shows that systems building results in great benefits, accruing to the building industry as well as the users. Nonetheless, it also demands from the industry a performance at high levels which is often unprecedented. Skills in management are indispensable. Each party involved in the

process should be familiar with the principles of systematization and the discipline of orderly operations. Moreover, the ability to work together as a team and the ability to analyze, synthesize and evaluate on the basis of science-based procedures are critical. The development of systems building must aim toward a "real world" state. Development, inspired by unrealistic expectations, and judged merely on the basis of an abstract idea, rather than a realistic possibility, is usually extremely wasteful and may lead to expensive and embarrassing failures.

The above mentioned requirements for system development and implementation are complex, and thus, often difficult to be carried out. The industry itself must consciously select the degree of system application compatible with its capability. It is important to objectify the application of the systems approach, and the way in which it is to be developed, in order to obtain expected values. In other words, a selected system application must be convenient, to some degree to the user, otherwise it is not useful. Moreover, the application of the systems approach, if inappropriately used, may lead to a waste of effort, time, and precious resources.

The demanding requisites of the systems approach can be significantly helped by establishing building research agencies at the national level and making these agencies responsible for spearheading development by disseminating

knowledge and broadening of professional building research and development capacities throughout the building industry.

There is no doubt that the use of systems approach has already caused radical changes in the building industry. Interest in systems has been demonstrated to be high among architects, engineers, manufacturers and clients, all of whom are becoming involved in the new process. In order to make information on systems building available to all of the participants in the building industry, it is important to maintain liaison with manufacturers producing building systems or industrialized components.

Finally, it is important to keep in mind that the establishment of the "Systems Approach" requires sustained continuous effort on the part of all actors in the building construction and design field, to assure the steady progress and to direct the power of technology to the benefit of the user, and thus all mankind.

Appendix A

Excerpts from the Performance Statements Used for URBS and ABS Programs

1. Example Structure Performance Statements

(a) URBS

Fire Rating: Low-rise structures shall meet the requirements for type IV one-hour construction in the UBC 1967 Edition as a minimum requirement. High-rise structures shall meet the requirements for Type I construction in the UBC 1967 Edition. These buildings will be 5 to 13 stories.

Vertical Loads: Roof loading - Live load: 20 lb./sq. ft. Code reductions may be applied in accordance with UBC 1967 Edition. Dead load: allow 10 lb./sq. ft. for roofing, insulation and miscellaneous, in addition to dead load of structure/ceiling.

Floor loading - Live load: 50 lb./sq. ft. Code reductions may be applied in accordance with UBC 1967 Edition. Dead load: assume 20 lb./sq. ft. for partitions and 6 lb./sq. ft. for non-URBS items. In addition to dead load of structure/ceiling, also allow for HVC component category equipment.

(b) ABS

Fire Rating: The structural system shall conform to the requirements for type I (UBC) or Type A (NBC) construction to provide the following fire ratings: slabs, beams, girders - 3 hr.; columns - 4 hr.; and grid frame - 4 hr.

Vertical Loads: All structural components shall be designed to support the following superimposed loads. Uniform live loads: roof - 40 psf; floor - 70 psf; and ceiling - 20 psf. Concentrated live loads: Floors shall be designed for a concentrated load of 2,000 pounds placed upon any space 2'6" square. Uniform dead loads: The following minimum dead load values, applicable for high normal weight aggregate concrete only, shall be assumed, which include

structural weight, partition allowance, and weight of HVC and service equipment.
Roof - 91 psf; floor - 102 psf; and ceiling - 10 psf.

2. Example Heating/Ventilating/Cooling Performance Statements

(a) URBS

Heating/Cooling: Design temperature - The indoor dry bulb air temperature shall be maintained between 73° and 77°F within the occupied zone whenever the MRT is approximately equal to that temperature.

When the MRT in an occupied zone differs from the air temperature, the design temperature shall be reduced 1.4°F for each 1.0°F. MRT elevation above the air temperature, and vice-versa.

If the overall variation in the air temperature cycle is 2°F or more at any point in an occupied zone, the rate of change of temperature shall not exceed 4°F per hour.

If the overall variation in the MRT cycle is 1.5°F or more at any point in an occupied zone, the rate of change of MRT shall not exceed 3°F per hour.

Ventilation: Fresh air introduction - As required for odor dilution: 20 CFM per person. Assume the following occupant loads. Spaces: FLA (incl. bathroom and internal circulation), public corridor, lobby and stairway - 100 sq. ft./person, 0.2 CFM/sq. ft.; Library, hobby room, darkroom, laundry, office, lounge not in FLA - 50 sq. ft./person, 0.4 CFM/sq. ft.; classroom, music practice room, conference room, seminar room, study room and typing room not in an FLA - 20 sq. ft./person, 1.0 CFM/sq. ft.; and recreation room, TV and hi-fi rooms - 10 sq. ft./person, 2.0 CFM/sq. ft.

Air motion within occupied zone - 10 fpm minimum, 35 fpm maximum when cooling, and 45 fpm maximum when heating, in any direction.

Filtering - Filter all air supplied mechanically to occupied spaces. Filters shall be not less than 45% efficient when tested in accordance with the

national Bureau of Standards Dust Spot Test Method (atmospheric). Filtering for room air tempering supply air at the terminal shall meet industry standards.

(b) ABS

Heating/Cooling: Room temperature - The subsystem shall have the ability to maintain 73°F on a summer design day and 73°F on a winter design day. Each control zone shall be locally and independently adjustable to maintain the set temperature plus or minus one and one-half degrees ($\pm 1\frac{1}{2}^\circ$).

Room relative humidity - The subsystem shall have the ability to maintain relative humidity within the range of 30% to 60% at a 73°F room temperature, when room sensible heat ratios are in the range of 90% to 100%.

Ventilation: Room air quantities - The minimum total air circulation rates shall be as follows. Offices - 1 CFM/sq. ft., 6.7 air changes/hr.; classrooms - 1-1/2 CFM/sq. ft., 10.0 air changes/hr.; laboratories - 2 CFM/sq. ft., 13.3 air changes/hr.; corridors - 1/2 CFM/sq. ft., 3.3 air changes/hr.; and toilets and janitor closets - 2 CFM/sq. ft.

The maximum air circulation rate shall not exceed 3 CFM per square foot.

Outside air ventilation - The design shall include the following minimum outside air quantities. Offices - 25 CFM per person; classrooms - 15 CFM per person; laboratories - 20 CFM per person; corridors - 1/4 CFM per square foot; and lobbies - 1/4 CFM per square foot.

If the function of an area of the building is undetermined, use 1/2 CFM of outside air per square foot.

An additional requirement is that the system shall have sufficient outside air to make up for 100% exhaust laboratory rooms, fume hood and special exhaust systems, and result in building pressurization.

Room air velocity - Air motion within the occupied zone, between 3" and 72" above the floor, shall be between 20' and 50' per minute.

3. Example partition Performance Statements

(a) URBS and ABS

Fire Requirements: All partitions shall be non-combustible. The smooth finish and textured finish panels shall have a maximum flame spread not greater than 25. All others shall have a flame spread rating not greater than 225.

The ASTM E84 Tunnel Test shall be used for all flame spread determinations. The ASTM E119-61 test procedure shall be used for determining all fire-resistive construction standards.

Acoustical Requirements: Acoustical test procedures shall follow ASTM E90-61T "Laboratory Measurement of Airborne Sound Transmission Loss of Building Floors and Walls" except that large panels (9' x 14') shall be used and not the small panels (1'6" x 6'6") permissible under E90-61T. Acoustical tests shall be performed under field conditions.

All solid panel types shall provide an STC rating of not less than 40.

All panel types containing glass shall provide an STC rating of not less than 20.

Provide doors having an STC rating of not less than 27. Raised thresholds with a maximum height of 3/4" above site floor will be permitted. Bidders shall submit drop seal and sweep seal designs for specific approval if they wish to have such seals considered.

Glass doors shall provide an STC rating of not less than 20.

Impact Strength Requirements: Perform impact load tests in accordance with ASTM E72-61, Section 12 of 13. Conduct tests on doors and partition panels 8' in height with the largest stud spacing provided. Impact shall be midway between studs. For five drops of 2', panel shall not fracture, and the temporary deflection shall not exceed 1". The permanent set shall not exceed 1/16".

Perform this test with standard connections to URBS structure/ceiling and carpeted concrete floor. Door closers and checks shall not be used in this test.

Each panel type except glass, tackboard and chalkboard shall withstand the impact of an 8-oz. 1 1/2" diameter steel ball dropped 18" without cracking or chipping.

Surface Durability Requirements: Abrasion: Textured panel - Use Wyzenback method under Federal Specification CCC-T-191B, Method 5304. There shall be no exposure of base or backing material after 300 double rubs.

Smooth panel and doors - After 150 cycles on Gardner Model 105 Washability and Abrasion machine, using cheesecloth over felt pad, the change in gloss shall not be greater than $\pm 5\%$ as measured by Gardner 60° glossmeter.

Humidity resistance - 100 hours in atmosphere with 100% humidity and temperature of 70° - 75°F with no appreciable deterioration.

Washability - 100,000 brush strokes while continuously wetted by a 5% solution of trisodium phosphate in a Gardner 105 Straight Line Washability Machine without any softening, color change or more than slight abrading of the surface. Perform this test over the joint of laminated surface materials.

Ultra-violet resistance - There shall not be appreciable color change after 150 hours at approximately 150°F in the Atlas Fadeometer.

(b) ABS

Demountability: For the two panel types, one-hour fire-rated and non-fire-rated, the following shall apply as minimum standards of demountability.

A single panel in the center of a 12' run shall be capable of being removed and replaced in one hour by two men.

100 linear feet of partition shall be capable of being removed, moved and re-erected nearby in 80 man-hours, or 40 hours by two men. This moving process

shall be accomplished with minimum soiling of the building.

The weight of no element of this partition system shall exceed 200 pounds.

4. The Systems Developed

Based on a complete set of performance statements including the examples presented above, building systems were developed for both the URBS and the ABS projects. Brief descriptions of each of the systems developed are presented below with drawings illustrating each system presented at the end of this paper.

(a) URBS System Description

Spatial Concept: A flexible living area (FLA) consisting of a one-hour fire-protected envelope defined by floor, partitions and ceiling; up to 2,000 sq. ft. in area; and designed for 10 students maximum.

Structure/Ceiling Subsystem: A combination precast and cast-in-place concrete structural frame was developed. Included was all structural work above the ground floor level: columns, beams, floors, finished ceilings, roofs, access panels, balconies, stairs and shear walls. Also included was an electrical raceway attached to the ceiling through which electrical wiring was run to the partitions. All structural elements were fire-resistive, of reinforced concrete, with domed voids occurring in 18"-deep, hollow floor slabs. These voids accommodated supply air ducts, plumbing and electrical services, while also serving as a plenum for air return. Spans ranged from 13'4" to 45'0".

Heating/Ventilating/Cooling Subsystem: All mechanical equipment required for heating and ventilating with cooling optional was provided. Areas up to 2,000 sq. ft., subdivided as desired into various living arrangements, were serviced by multi-zone units. The ventilation capability permitted up to 100% outside air. Chilled water and hot water were supplied from a central campus plant, or by the URBS factory-packaged mechanical unit. Component elements

provided for bathroom heaters, air distribution, kitchen hood and room exhaust.

Partitions Subsystem: Fixed or demountable one-hour fire-rated partitions with a wide selection of surface colors, textures and materials were provided. Fixed partitions were 8, 10, 12 or 14 feet high; demountable partitions were 8 or 10 feet high. Opposite faces of partitions could be removed and replaced independently. The component design provided for concealed electrical services, and included picture hanging devices and vertical supports for shelving, counters and cabinets.

(b) ABS System Description

Spatial Concept: A space module which was a one-story block of building volume, dimensionally coordinated with the integrated subsystems. The space module had an area of 10,000 sq. ft. $\pm 25\%$ with a variable but limited aspect ratio. This resulted in a total of about 40 different space module alternatives, each of which could be internally organized in various ways to accommodate a range of functions.

Structure Subsystem: A girder, beam, slab system was designed which could be constructed from cast-in-place concrete, precast concrete, fire-protected steel. Bay sizes were 20' x 20' to 30' x 40' in 10' increments. Lateral forces were taken by a perimeter grid frame. Floor-to-floor heights were either 16'10" or 14'7".

Heating/Ventilating/Cooling Subsystem: All three services were provided for a mechanical service module of 10,000 sq. ft., $\pm 25\%$, by a single-duct reheat system. One fan room was included in each space module. Either a building boiler room or campus central plant could be used. A plenum return was used with ducted special exhaust. Up to 30 temperature control zones were provided at each floor with a roof exhaust.

Partition Subsystem: All partitions were demountable, and of one height. No partitions penetrated the ceiling. Gypsum facings with high quality paint or vinyl finish were used. A 5' x 5' planning module was used; off module locatoinis were permitted where required. Lab utilities were outside partitions; switch legs, control wiring, isolated electrical outlets were within the partition.

Lighting/Ceiling Subsystem: A suspended-ceiling was designed with integral lighting fixtures, providing a uniform ceiling height for each space module, of nominally 9'0". Two types of access to service space were developed: an access ceiling and a catwalk ceiling. A 5' x 5' module was used in the design.

Utilities Distribution Subsystem: All verticals were concentrated in one mechanical tower per space module. All horizontals were zoned in service space above each floor. Two types of access were provided: horizontal by catwalks and vertical through access ceiling.

Abbreviations

BSD	Building Systems Development, Inc.
SCSD	School Construction Systems Development
URBS	University Residential Building System
ABS	Academic Building Systems
STC	Sound Transmission Coefficient
HVC	Heating, Ventlating, Cooling
UBC	Uniform Building Code
NBC	National Building Code
psf	pounds per square foot
MRT	Mean Room temperature
FLA	Flexible living area

CFM Cubic feet per minute

fpm Feet per minute

HVAC Heating, ventilating, air conditioning

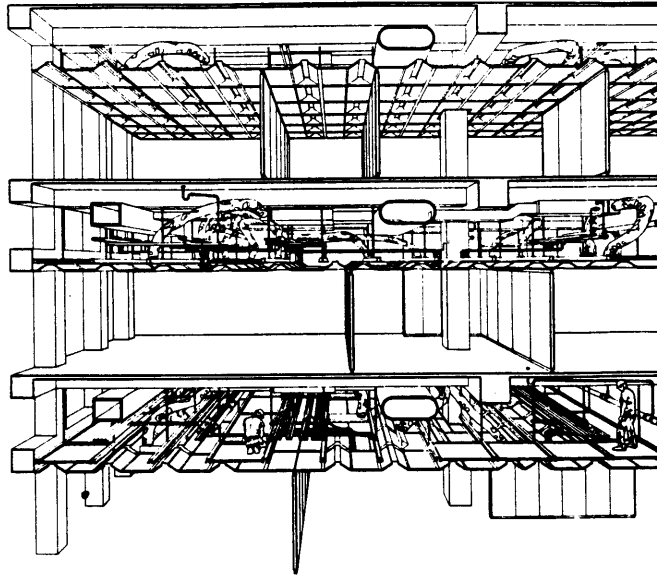


Figure 41: Perspective showing the ABS System components.

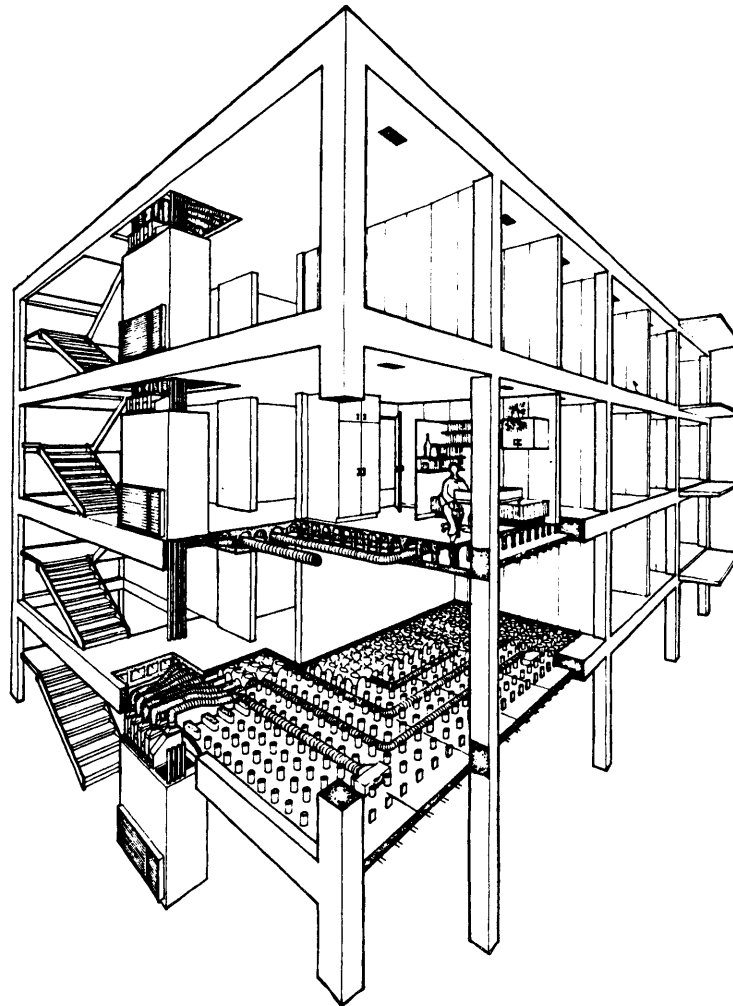


Figure 42: Perspective showing URBS system components.
Source : Meyer, Bender, Arnold, 1972.

Appendix B

Basic Considerations in the Building System Design, An Excerpt
from Course Notes for Workshop/Seminar 4.59, Spring 1984

- The modular ordering system must take into account the various proportional relationships, resulting from combinations of the basic module and combination, addition, subdivision, and multiplication of diverse materials, elements, sub-systems, etc., as well as spatial configurations.
- The resulting combinations have to be of harmonious proportions and related to human scale as well.
- Combinatorial ability should not be seen as an end in itself, but as a means to satisfy a calculated range of anticipated (or even unanticipated) alternatives.
- Spaces, as a result of their special function or character (special shape, large spans, odd or unique functional requirements) cannot be easily adapted to the discipline of the modular order, should be treated as non-system elements. However, provisions should be made to provide for their orderly integration with the overall building system at the interface between the two. In other words, joints and junctions between system-determined and non-system-determined elements should follow the rules of the coordinating (modular) order and thus be standardized as much as possible.
- All system elements should favor, as much as possible, "open" combinations (i.e., optimum flexibility/variability), in order to provide for optimum architectural freedom for individual project design within the system of the modular order) and to avoid imposing unnecessary restriction on the number of feasible plan solutions. The ideal is to strive for greatest possible variation with the smallest number of standard elements. In other words: No

standard building types, but buildings made up of standard elements. The aim is to achieve the greatest possible adaptation of freely combined elements/components to different spatial needs, for different floor combinations (and/or heights), and responding to different programmatic requirements. In addition, the resulting building system must be capable of adapting to different site and soil conditions.

- The building system must be capable of expansion, both horizontally and vertically. This means possibility of initial implementation with - theoretically - later "unlimited" expansion/additions.
- Multi-story solutions must be possible (within a pre-determined range). In addition, all vertical (bay) elements must permit stepping back as well as forward, as stories are added or as changing conditions call for.
- The choice of the basic structural system is contingent on the above and, thus, only partially determined by purely statistical considerations.
- Columns (if any) and other structural bearing elements should be placed into the grid in such a way, as to avoid meeting non-bearing elements in the same band (same center-line). If it proves impossible to accommodate all functional requirements by a standard bay of single size, the combination of different size bays should result in a minimum number of additional elements, and the resulting spatial combinations should be compatible with the rules of the coordinating (modular) rule system.
- Fixed vertical circulation elements (stairs, elevators), or other stiffening elements (shear walls, braces) - whether standard or non-standard - must be integrated into the overall (standardized) positioning of other, system-determined, structural elements, especially at their joints, and without the need for additional "special" (non-standard) elements.

- It should be possible to accommodate spaces of varying depth at each floor, depending on functional needs and/or adjacency requirements. Thus, the system must be capable of producing solutions of both narrow and wider cross-sections.
- It should be possible to subdivide each floor area freely, either as part of changing program needs, or as a result of future alterations, at minimum cost.
- Full flexibility of all service media (ducts, pipes, wiring, etc.) is desirable (for laboratory and instruction space allocation), both vertically and horizontally, without undue or unnecessary modification of the basic structural elements. All service lines should be easily accessible for repair, replacement or removal/addition.
- Similarly, all non-permanent (changeable) elements of the system must allow for change, removal, upgrading or addition at any time (including their integration with the service infrastructure).
- The overall concept of the whole building system should - as far as possible - be independent of any particular material in all its aspects, to leave the field open for the both technically and functionally most appropriate options (subject to economical factors).
- Provision should be made for suitable (and realistic) tolerance allowances arising from different production and/or assembly methods and their accumulation in the assembly phase.
- Elements should be of proper size and weight to be compatible with transportation and handling capacity available.
- Given the system-determined dependence of all elements, a careful assessment of the life-cycle expectancy and maintenance/repair requirements must be made for each during their full use cycle, to predict replacement needs and maintenance and operation costs.

Appendix C

Glossary: Source Development Study VA Hospital Building System, 1972

Adaptability - the ability to respond to, or be readily adjusted to, changing conditions.

Assembly - 1. a group of attached components considered collectively. (Example: a pre-hung door). 2. a design configuration composed of a specific arrangement of service modules.

Building Subsystem - one of the coordinated groups of components, each performing a major function, which combine to form a building system.

Building System - 1. any specific building production process or method. 2. any set of coordinated building components intended for application as a group.

Compatibility - the state of functional, economic and aesthetic coordination between two or more systems or components.

Component - a part, or assembly of parts, in a system.

Constraint - a condition establishing a limit on the nature or effectiveness of a system or activity.

Conventional Design and Construction - existing traditional building methods as they are currently applied.

Cost-Benefit Analysis - the comparison of alternatives in terms of the anticipated performance and cost of each.

Cost Effective - 1. comparing favorably to other alternatives in a cost-benefit analysis. 2. providing desired performance at a comparatively low cost.

Dimensional Coordination - 1. the selection of dimensions to allow exact fit. 2. the use of a common set of dimensions.

Fast-Track - an accelerated scheduling technique characterized by the overlapping of activities traditionally performed in linear sequence, requiring early commitment to general decisions, but allowing postponement of detailed decisions.

Feedback - information on the current effectiveness of an ongoing process or activity, applied to its control or modification.

Flexibility - 1. adaptability. 2. having alternatives.

Integrated Subsystem - any of the pre-coordinated subsystems specifically within the scope of a particular building system.

Interface - 1. a common boundary between two systems or components. 2. a boundary detail designed to maintain a specified relation between adjacent systems or components.

Life Cost - total owning cost during life span.

Life Span - 1. the period between the manufacture of a system or component and the time at which its annual owning cost exceeds the annual owning cost of a replacement. 2. the period between the manufacture of a system or component and the time at which it can no longer meet the needs of its user. 3. the shorter of the two above periods.

Modular - 1. having commensurable dimensions. 2. capable of arrangement with exact fit in more than one sequence or direction. 3. composed of or containing predetermined dimensional and/or functional units such as repetitive structural bays or service modules.

Modular Coordination - dimensional coordination utilizing commensurable dimensions.

Module - 1. the common divisor of a set of commensurable dimensions. 2. a dimensional pattern restricting the location of a specified building component. 3. a unit of space defined by a special set of dimensional

and/or functional characteristics.

Optimize - 1. to maximize desirable characteristics and/or minimize undesirable characteristics. 2. to establish functional and economic balance among the performance characteristics of two or more systems or components.

Performance Criterion - a performance parameter so quantified or described that a system or component can be examined or tested for compliance.

Performance Parameter - a variable characteristic for which a specific value, range of values, or general comparative level must be established to describe a system or component in terms of desired performance.

Performance Requirement - a statement to the effect that a certain system or component must comply with a certain performance criterion or set of criteria.

Performance Specification - a performance requirement stated in a legal form to serve as the basis for bidding by manufacturers or contractors on their own designs, often including a detailed test procedure, or reference to a recognized test, by which compliance may be established.

Product - a material, component or system manufactured off the construction site.

Prototype Design - a basic system design establishing the performance and dimensional limits within which alternative detailed designs may be produced to accommodate specific conditions at various times and places.

Range - the limits between which a performance parameter may be required or allowed to vary, stated as a criterion.

Subsystem - 1. a system considered as a component of a larger or more general system. 2. any component, or group of components, which has internally the characteristics of a system. (Example: the distribution components of a mechanical system.)

System - a set whose elements (termed components) are organized toward a common objective, and are characterized by interdependence in their individual contributions to that objective.

Systems Analysis - examination of the effects of the interactions between the components of a system on the individual performance of those elements and on the total performance of the system.

Systems Approach - a strategy of problem definition and solution which emphasizes the interaction between problem elements and between the immediate problem and its larger context, and which specifically avoids traditional methods of independent or ad hoc treatment of the various elements.

Systems Integration - 1. the combination of a group of relatively independent parts into a coordinated whole to improve performance through controlled interaction. 2. the joint use of a component by two or more systems.

Trade-Off - choice between alternatives based on evaluation of differences in characteristics such as cost, performance, appearance, etc.

User Needs - those conditions the users of a building consider necessary or desirable as environment and support for their activities, without particular reference to how such conditions are to be provided.

User Requirements - 1. user needs. 2. performance requirements established directly by a user.

Appendix D

Abbreviations Used and Related

ABC	Academic Building System
BSD	Building Systems Development, Inc., San Francisco, California
BSIC	Building Systems Information Clearinghouse (financed by EFL to maintain industry liaison on systems building and to make information on systems building available to schools, colleges, architects, engineers and manufacturers)
CLASP	The Consortium of Local Authorities Schools Program
IRNES	Institut de Recherches et de Normalisations Economiques et Scientifiques
MCSC	The Montreal Catholic School Commission
RAS	Recherches en Aménagement Seolaires (RAS undertaken for the MCSC by IRNES)
SCSD	California's School Construction Systems Development
SEF	Metropolitan Toronto's Study of Educational Facilities
SSP	Florida's Schoolhouse Systems Project
URBS	The University of California's University Residential Building System

REFERENCES

INTRODUCTION

1. Grebler, Leo and Leland Burns, "Construction Cycles in the United States Since World War II," in AREUEA Journal, Vol. 10, 1982, p. 138.

CHAPTER 1

1. Auerbach, H.C., "The Systems Approach to Building: What is it?" in Lectures and Proceedings of a Series of Regional Conferences Held in Seven Cities in Canada, September 30 - November 6, 1969, Department of Industry, Trade and Commerce, Ottawa, U.S.A., P. 12.
2. Ibid., pp. 16-17.
3. Ibid., p. 19.
4. Brandle, Kurt, "The Systems Approach to Building: A Core of Information," ASCA Learning Package, 1974-1976, p. 7.
5. Ibid., p. 4.
6. Brill, M., Lecture Notes on Systems in Brandle, Kurt, "The Systems Approach to Building: A Core of Information," ACSA Learning Package, 1974-1976, p. 7.
7. Churchman, C.W., "The Systems Approach," Dell Publishing Co., Inc., New York, 1968.
8. Ibid., p. 29.
9. "Development Study - VA Hospital Building System: Application of the Principles of Systems Integration to the Design of VA Hospital Facilities," Research Study Report Project No. 99-R047, Prepared by the Joint Venture of Building Systems Development and Stone, Marraeeini and Petterson, January 1972, Vol. 3, pp. 1-3.
10. Dluhosch, E., Unpublished Class Notes, M346/00991, on "Building Systems," Department of Architecture, M.I.T., Cambridge, p. 4.
11. "Handbook of Architectural Practice and Management," London: Royal Institute of British Architects, 1965 (in Brandle, Kurt, "The Systems Approach to Building: A Core of Information," ACSA Learning Package, 1974-1976, p. 60.
12. Johnson, R.A., W.T. Newell and R.C. Vergin, Operation Management, Boston: Houghton Mifflin Company, 1972, p. 5.
13. Ibid., p. 149.

14. Parsons, D.J., "Performance: The New Language of Design," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 132.
15. Rittel, Horst, "On the Planning Crisis: Systems Analysis of the First and Second Generations," in Bedriftsokonomien, No. 8, 1972, p. 390.
16. Vilett, John, "The Relationship Between the Performance Concept and the Systems Concept," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by Bruce Foster, Philadelphia, 1972, p. 208.
17. Vilett, 210.
18. Ware, T.E., "Performance Specifications for Office Space Interiors," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 361.

CHAPTER 2

1. Dluhosch, Eric, Unpublished Class Notes, Course 4.59, on "Building Systems II," Department of Architecture, M.I.T., Cambridge, Spring 1984, pp. 1-2.
2. Ibid., pp. 3-4.
3. Ehrenkrantz, E.D., "The System to System," in AIA Journal, May 1970, p. 57.
4. Griffin, C.W., "System: An Approach to School Construction," Educational Facilities Laboratories, February 1971, p. 55.
5. Ibid., pp. 79-80.
6. "The Potential for System Building," Prepared by Building Systems Development Inc., for the Post Office Department, Washington, D.C., 1969, p. 7.
7. Robbie, R.G., "The Application of the Systems Approach to School Building in Toronto," in Lectures and Proceedings of a Series of Regional Conferences Held in Seven Cities in Canada, September 30 - November 6, 1969, Department of Industry, Trade and Commerce, Ottawa, U.S.A., p. 62.
8. Ibid., p. 64.
9. Ibid., p. 76.

CHAPTER 3

1. Brandle, Kurt, "The Systems Approach to Building: A Core of Information," ACSA Learning Package, 1974-1976, p. 89.
2. Brill, Michael, "Techniques for Developing Performance Specifications for Buildings," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 173.

3. Ibid., p. 174.
4. Caulfield, D.A. and V.K. Handa, "The User's Role in Programming and Project management," in I.F., Vol. 5, No. 5, 1974, p. 58.
5. Cronberg, Tarja, et al., "Human Requirements for Buildings," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 15.
6. Ibid., p. 16.
7. Ibid., p. 17.
8. Ibid., p. 19.
9. Hattis, David, "The Relationship of the Performance Concept to the Planning Process-Developing Performance Requirements for Community Mental Health Centers," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 77.
10. Karlen, I., "Performance Concept and the System Approach," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 191.
11. Meyer, W., R. Bender and C. Arnold, "Paths to Performance - Some Recent projects Employing the Performance Concept," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, pp. 303-316.
12. Ibid., p. 307.
13. Ibid., p. 311.
14. Pena, W.M. and J.W. Focke, "Performance Requirements of Buildings and the Whole Problem," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 43.
15. Robbie, R.G., "The Application of the Systems Approach to School Building in Toronto" in Lectures and Proceedings of a Series of Regional Conferences Held in Seven Cities in Canada, September 30 - November 6, 1969, Department of Industry, Trade and Commerce, Ottawa, U.S.A., p. 70.
16. Robbie, R.G., "The Performance Concept in Building: The Working Application of the Systems Approach to Building," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, p. 204.
17. Vilett, John, "The Relationship Between the Performance Concept and the Systems Concept," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, pp. 207-212.
18. Ibid., p. 211.

19. Ware, T.E., "Performance Specifications for Office Space Interiors," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, pp. 357-374.

CHAPTER 4

1. Bender, R., "A Crack in the Rear-View Mirror: A View of Industrialized Building," Van Nostrand Reinhold, 1973, p. 63.
2. Brandle, Kurt, "The Systems Approach to Building: A Core of Information," ACSA Learning Package, 1974-1976, p. 5.
3. Ibid., p. 78.
4. Ibid., p. 80.
5. Brill, Michael, "Techniques for Developing Performance Specifications for Buildings," in Performance Concept in Buildings, Joint RILEM-ASTM-CIB Symposium Proceedings, Edited by: Bruce Foster, Philadelphia, 1972, p. 178.
6. "Developing the Hardware of a Building System," Guidelines Prepared by the Editor of I.F., in I.F., Vol. 1, No. 3, 1970, pp. 23-28.
7. Dluhosch, E., Unpublished Class Notes, "Building Systems," M346/0091 p. 1.
8. Ibid., p. 9.
9. Dluhosch, Erich, Unpublished Class Notes, Course 4.59, on "Building Systems II," Dept. of Architecture, M.I.T., Cambridge, Spring 1984, p. 13.
10. Ibid., pp. 14-16.
11. Ibid., p. 22.
12. Griffin, C.W., "Systems: An Approach to School Construction," Educational Facilities Laboratories, February 1971, pp. 36-37.
13. Ibid., p. 74.
14. Ibid., p. 83.
15. Hughes, Robert, "The Management Consultant in System Building," in I.F., Vol. 1, No. 1, 1969, pp. 19-22.
16. King, Jonathan, "Building Systems," in I.F., Vol. 5, No. 1-2, 1974, p. 3.
17. "The Systems Approach to Building" in Lectures and Proceedings of a Series of Regional Conferences Held in Seven Cities in Canada, September 30 - November 6, 1969, Department of Industry, Trade and Commerce, Ottawa, U.S.A., pp. 198-201.

18. Ibid., pp. 200-201.

SELECTED BIBLIOGRAPHY

- "Academic Building Systems (1): Environmental Study - Science and Engineering Buildings," (no date available).
- "Academic Building Systems (2): Cost Performance Study - Six Science and Engineering Buildings," July 1971.
- "Academic Building Systems (3): Information Manual - Procedures, Planning Concepts, Subsystems," December 1971.
- Alexander, Christopher, "Systems Generating Systems," in Aloa News, (no date available).
- Banham, R., "Theory and Design in the First Machine Age," The Architectural Press, London, 1960.
- Bernhardt, A., "Building Tomorrow: The Mobile/Manufactured Housing Industry," The M.I.T. Press, Cambridge, 1980.
- Bobrow, Philip, "Experimental Changes to the Architectural Process," in I.F., Vol. 5, No. 5, 1974, pp. 9-20.
- Bryant, V.C., "Performance and System Building: The University of Alaska's Experience," in I.F., Vol. 8, No. 3, 1977, pp. 21-28.
- Building Systems Development, Inc., "Academic Building System - Design Report," University of California and Indiana University, January 1971.
- Caulfield, D.A. and V.K. Handa, "The User's Role in Programming and Project Management," in I.F., Vol. 5, No. 5, 1974, pp. 57-58.
- "Comprehensive Building Systems: Threat or Promise?," in Building Research, Vol. 3, No. 5, Sept.-Oct. 1966, pp. 8-41.
- "Construction Policies and Industrial Building Systems in the Arab Countries and Iran," Proceedings of the WAEP Symposium, Vienna, Austria, September 11-12, 1978, Gunther Haase.
- Cowan, H.J., "System Building," Principal paper Delivered at the Federal Conference of The South Australian Division of the Building Science Forum of Australia, Sydney, March 24, 1970.
- Dawson, William, "Managing the Procurement Process; a Case History from a Major Industry," in I.F., Vol. 5, No. 1-2, 1974, pp. 49-58.
- Dietz, A.G.H., "Building Technology: Potential and Problems," Paper Presented at the American Institute of Architects Convention, Chicago, June 26-27, 1969.
- Dluhosch, Eric, "Design Constraints of Conventional Prefabrication Systems in Housing," Dept. of Architecture, M.I.T., Cambridge.

- "Effect of Buildings on Human Behavior," in Building Research, Vol. 2, No. 4, July-Aug. 1965, pp. 3-18, (6 Articles).
- Ehrenkrantz, Ezra, "The System to Systems," in A.I.A., May 1970, pp. 56-59.
- "Feasibility Study - VA Hospital Building System," Prepared by the Joint Venture of Building Systems Development and Stone, Marraccini and Petterson, Oct. 1968.
- Ferguson, Francis, "Architecture, Cities and the Systems Approach," George Braziller, New York, 1975.
- "First California Commission on School Construction Systems - Contract Documents and Performance Specifications," July 1963.
- Fischer, Robert, "Systems Building: What it Really Means," Special Report No. 9, Architectural Record, January 1969, pp. 147-154.
- Gaintlett, James, "Constructional Appraisal of Building Systems," in I.F., Vol. 1, No. 4, July 1970, pp. 19-26.
- Gerischer, Wolf, "The Building Systems Roulette," University of California, Berkeley, 1971.
- Giedion, S., "Mechanization Takes Command," Oxford University Press, Inc., London, 1969.
- Handler, A.B., "Systems Approach to Architecture," American Elsevier Publishing Company, Inc., New York, 1970.
- Hasbrouck, Douglas, "Managing the Design-Build Process Using Performance Documents: The Dormitory Authority Experience," in I.F., Vol. 8, No. 3, 1977, pp. 29-36.
- Heath, Tom, "Programming and User Involvement: An Issue Based Approach," in I.F., Vol. 5, No. 5, 1974, pp. 3-8.
- Heldenbrand, J.L., "Development and Application of Design Performance Standards for Energy Conservation in Building," in I.F., Vol. 8, No. 3, 1977, pp. 9-20.
- Holden, Richard, "Procurement; The University of Alaska's Experience," in I.F., Vol. 5, No. 1-2, 1974, pp. 63-76.
- Haskins, E.M., "Computer Aids for System Building," in I.F., Vol. 4, No. 5, 1973, pp. 27-42.
- Howell, Sandra, "Needed: Performance Specifications for Using Behavior Science," in I.F., Vol. 5, No. 5, 1974, pp. 25-30.
- "International Systems Building Round Table Conference," Synopsis by: S.R. Greenfield, Proceedings Edited by: D. Wilson and J. Cummings, Boston, November 17-19, 1971, Boston Architectural Center.

- Jones, P.M., "Performance Standards," in I.F., Vol. 4, No. 4, 1973, pp. 27-32.
- "Models and Systems in Architecture and Building," Edited by: Dean Hawkes, The Construction Press Ltd., England, 1975.
- Nauckermans, Herman, "The Relevance of Systematic Methods for Architectural Design", in DMG-DRS Journal, Vol. 9, No. 2, April - June 1975, pp. 140-144.
- "Now Tactics for Building: Experience/Analysis/Recommendations from the Detroit Public Schools Construction Systems Program," Edited by: W.C. Cleland, Detroit Public Schools, Office of School Housing, Detroit, 1975.
- Parenteau, Henri-Paul, "The Management of Modular Design," in I.F., Vol. 3, No. 1, 1971, pp. 35-44.
- Parsons, David, "Building Performance: Concept and Practice," in I.F., Vol. 3, No. 3, 1972, pp. 23-32.
- Paul, R.J., "Systems Building and Educational Facilities," Unpublished Paper presented to Prof. Eric Dluhosch, Dept. of Architecture, M.I.T., Cambridge, spring 1983.
- "Performance of Buildings Concept and Measurement," Proceedings of the 1st Conference on "Man and His Shelter," Maryland, U.S.A., September 23-25, 1968, Edited by: W.W. Walton and B.C. Cadoff, N.B.S., Washington, U.S.A.
- "Performance Specifications for Building Subsystems: A Florida Schoolhouse Systems Project," Florida Bureau of School Facilities, (no date available).
- "Proceedings of the Symposium on System Building and Prefabrication," Baghdad, March 1-4, 1976, Scientific Research Foundation - Building Research Center, Bagdad, Iraq.
- Rabeneck, A., "Whatever Happened to the Systems Approach?" in Architectural Design, Vol. XLVI, May 1976, pp. 298-303.
- Raeber, John, "Procurement; A Case Study from The Private Sector," in I.F., Vol. 5, No. 1-2, 1974, pp. 45-48.
- Richard, R.B., "Repertorie Des Systemes De Construction Industrialise's en Habitation," Universite de Montreal, Mai 1978.
- Rittel, H.W. and M.M. Webber, "Dilemmas in a General Theory of Planning," in Policy Sciences, 4, 1973, pp. 155-169.
- Rojanavanich, Pisit, "Systems Approach for Housing Prototype Improvement - Case Study: Thailand," S.M. Arch. S. Thesis, Dept. of Architecture, M.I.T., June 1983.
- Schmid, T. and C. Testa, "Systems Building: An International Survey of Methods," Praeger Publications, New York, Washington, 1969.
- Schmitz, Gunter, Unpublished Class Notes, Course ARC 464/595-D on "Intermediate Building Technology," State University of New York at Buffalo, spring 1977.

- Schodek, Daniel, "Evaluating the Performance of Buildings," in I.F., Vol. 4, No. 5, 1973, pp. 11-18.
- "School Construction Systems Development," A project prepared for the Educational Facilities Laboratories, Inc., New York, (no date available).
- Sinapoli, Nicola, "Modular Design for System Building," in I.F., Vol. 4, No. 5, 1973, pp. 3-10.
- Sullivan, B.J., "Industrialization in the Building Industry," Van Nostrand Reinhold Co., New York, 1980.
- "Systems Building," Proceedings of the Systems Building Conference, Maryland, U.S.A., February 24-26, 1972, Edited by: K. Reinschmidt.
- Testa, C., "The Industrialization of Building," Van Nostrand Reinhold Co., New York, 1972.
- Thake, Stephen, "Procurement and Productivity - The Scope for Change," in I.F., Vol. 5, No. 1-2, 1974, pp. 9-18.
- White, Joseph, "Improved Building Procurement Means a Changed Building Process," in I.F., Vol. 5, No. 1-2, 1974, pp. 39-44.
- White, Joseph, "The Systems Approach: Steps in Generating a System," in I.F., Vol. 1, No. 3, 1970, pp. 5-10.
- Wigglesworth, Gordon and David Widson, "Procurement Methods - Their Effect on The Industrialization of Building," in I.F., Vol. 5, No. 1-2, 1974, pp. 19-28.