THE ANALYSIS OF A PROTOTYPE
RESEARCH BUILDING AS SYSTEMS
utilizing precast concrete construction

by

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Respectfully,

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ABSTRACT OF THESIS:

This thesis is a study of the technology of buildings as systems. The objective is to design a prototype building to be used for research and development. The building is to be conceived as a total system of circulation, services and construction. The system is such that shall allow for expansion at any point as well as for demountability of some of its structural parts. The building will have a maximum continuity of its divisable space, modular division of this space, and a modular supply of services. The building's construction is based on the use of reinforced concrete and conceived as a total prefabricated system of components with a total standardization of its form-work. Erection of these components is obtained without the use of scaffolding. The system itself allows for its own support during erection. All these systems integrated and functioning together determine the usable building design.
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PREFACE:

This thesis is a study of the technology of buildings as systems resulting from the contemporary needs for large spaces with flexible and multiple uses. This technology includes not only that of structure but also the technology of mechanical distribution--air handling and piping--and of construction, which includes how the structure is formed as well as how it is joined together.

In the introduction I have included four quotations from recent writings which focus upon the problems which are the inspiration for the study itself. The first two by Gyorgy Kepes refer to the inherent structural patterns found in nature, to their growth potential, and to the inherent stress patterns in the structure of buildings which, like nature, are shaping or giving form to our contemporary buildings. The third by one of the few theoretical research persons in architecture, Christopher Alexander, refers to a process of design in which the various physical relationships of a building are broken down and studied as sub-systems and these determine the form or shape of the building. The last quotation by Curt Siegal imposes the importance of understanding construction and the need for penetrating the technology of buildings in order to serve architecture.
It is hoped that with these quotations the proper background is attained so that the purpose of this thesis study is better understood and that once understood the study itself becomes self-explanatory.
INTRODUCTION:

"From inorganic structures to plants and animals, from the movements of animals to their social behavior patterns and to human relations, structure is central. A dramatic focus of structure awareness has been reached through understanding of the molecular structure underlying the generic mechanism of living forms. Inherent in the spiral structure of the complex molecule DNA is the ability to reproduce itself. Thus, a built-in program of growth and development is provided for an infinite variety of unfolding structures of living forms."

Gyorgy Kepes

Structure and Art in Science
"The ever increasing size of contemporary buildings has brought the problem of structure to the forefront. Structure has assumed such formal importance as to become the central feature of architectural design. In structural architecture the forces of compression, tension, moment, and shear become a clearly legible pattern of stress and just as clearly legible a pattern of neutralization of stress—visible and comprehensible, demonstrative of the properties of the materials with which the forms are executed."

Gyorgy Kepes

Structure and Art in Science
"This is a theory about the process of design; the process of inventing physical things which display a new organization and form in response to function.... A form that fits its purpose is a response to many specific physical relationships, each of which must be solved successfully..... These physical relationships interact, and a problem can be solved only when these interactions can be patterned into small and relatively independent sub-systems...
The form that the building will take derives from these sub-systems of physical relationships.... Once the physical relationships of a problem are stated, there will be a best form for that problem as stated.... Even though a better statement of the problem may always yield a still better form. The ultimate object of design is an environment.... which has no relationships in it that are not working to some specific purpose."

Christopher Alexander

The Theory and Invention of Form
"Architecture necessarily includes a technological component..... Modern architecture, being the architecture of a technological age, cannot afford to forego a clarification of the technical problems that determine form.... Since modern architecture rests more heavily on technology than the architecture of the past, it cannot be properly understood without a corresponding knowledge of construction... We are faced with the need to penetrate far more systematically and extensively than has hitherto been customary or reasonable, into the mechanical, statical, and natural (physical) relationships, upon which the development of structural forms is based..... We must make an effort to grasp the contemporary significance of technology, the importance of which was never questioned in earlier times, together with all the consequences of its pre-eminent position as a form-determining element, and bend them to the service of architecture."

Curt Siegal

Structure and Form
PURPOSE:

The objective of this study is to design a proto-type building to be used for the research and development of ideas to further space exploration.

For this research facility there are two major kinds of spaces; the permanent and the flexible. The permanent space includes those which serve the basic needs of the building. These needs are: vertical pedestrian circulation; mechanical rooms; vertical mechanical services; electrical and plumbing supply; wash rooms and maintenance storage areas.

The flexible space breaks down into two categories: A simple and not too large area where scientists and administrative personnel work independently or in groups. The activity in these areas is such that it is desirable to have natural light. The second is a more complex area for laboratories and workshops where three dimensional pieces or components are developed as experimental work in preparation for final production by the regular industry. This latter space requires large column spacing and a highly flexible system of services to meet any and all demands of the use described above.

The physical relationship between these spaces varies with the kinds of projects developed. Since it is difficult to predict at a given time the necessary areas and location for such act-
ivity, it is possible only to determine the location of the permanent services.

The building is to be conceived as a total system of circulation, services and construction. The system should be such as to allow for expansion at any point as well as demountability of some of its structural parts. A cohesive system of expansion must include not only that of the flexible spaces but also, that of the permanent services. It is desirable that any expansion have a minimum effect on the original building in terms of structure and of the building's uses.

In order to satisfy these conditions, the building should have a maximum continuity of its divisable space, modular division of this space, and a modular supply of services. The building's construction should be based on the use of reinforced concrete and conceived as a total prefabricated system of components with a total standardization of its form-work.

In summary, a synthesis of structure and mechanical services must result in a flexible and spatial arrangement to satisfy the varied demands of research. Its result must be an articulation which forms the basis for architectural expression.
DESIGN PROPOSAL:

PATTERNS:
In order to stimulate a less formal solution the design process began with an analysis of various geometric patterns of growth. These patterns are those which reflect the following criteria: They must follow the principle lines of structural stresses; allow for vertical free space within its boundaries for principle services and vertical circulation without interrupting the continuity of structure; consist of components which indicate a variety of shapes and outlines which could conceivably be consistent with a building design; and allow for a sufficiently large spacing of columns. Although abstract in nature the pattern selected (fig. 1) forms the basis or becomes the outline for the development of the total system in terms of an actual building design.

GROWTH:
To facilitate growth the pattern must have within it a basic unit that, when isolated, is dependent only on its own inherent properties. This basic unit (fig. 2) when repeated many times results in the geometric pattern of figure 1, and has no limitation to its boundaries. To allow for even greater flexibility in terms of growth the basic unit must consist of a number of components (fig. 3) which, although in a constant relationship to each other, can be added or subtracted pro-
BASIC UNIT:

COMPONENTS:

column capital

column strip

center span

column capital
vided that a basic unit is always maintained. (fig. 4)

THE MODULE:

Inherent and vital to the basic unit and its components is a decision as to the modular unit upon which the location of partitions and the distribution of services is dependent. The size of individual offices is the criteria for the location of partitions. The size of standard light fixtures and other services as well as their distribution also becomes a criteria. As a result of previous class experience and further class research based on these criteria, the modular unit was determined to be the most efficient at five feet by five feet.

Based on the modular unit, studies were made of each of the sub-systems of vertical circulation, mechanical circulation, structure, and construction, concerning their relationship to each other and to the geometric pattern.

VERTICAL CIRCULATION:

It is desirable as mentioned before that vertical circulation be independent of the structural system or that it should not interrupt its continuity. Within the basic unit are four different possible locations which meet this standard. (fig. 5 a-c) There is also the possibility for open spaces between levels for light courts or two-story uses providing vertical continuity of the building spaces. (fig. 5 d)
COMBINATIONS OF BASIC COMPONENTS (growth patterns)

figure four
Possible locations of vertical services (5a-c), and vertical openings (5d).

figure five
Studies were made to determine the number and size of stairs and general services needed for a total population of 5,000 persons.

Services for a Five-Story Building:
(Information based on 1,000 people per floor and 120,000 square feet per floor)

Stairs (4) 10'-0" x 25'-0"
Elevators (10) 5'-0" x 7'-0"
Service elevators (1) 8'-0" x 12'-0" with adjacent room

Toilets:

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urinals</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Water closets</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Lavatories</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

Janitors closet 120 sq. ft.

Electrical Panel room 160 sq. ft.

Telephones (8)

Drinking fountains (5)

This information allowed for the design of a core containing such services. The resulting design—shown on the drawings—represents only that solution which applied to the particular building design and does not fulfill the solutions for each possible position shown in figure 5.
MACHANICAL CIRCULATION:

Basic to the design of the kind of building outlined in the purpose of the problem is the modulor distribution of air. This means that diffusers should be distributed or located in such a pattern that all conditions of space requirements are met with the proper amount of conditioned air, whether warm in winter or cool in summer. It also means that a perimeter zone of about fifteen feet be considered with additional coverage to equalize the effects of the exterior weather conditions. The geometric pattern and the resulting structural system allows for these requirements.

To provide a more flexible system for growth and to cut down on the run of duct work, it was decided to use a very large column containing the vertical duct-work as well as pipes and other services. Each column, containing both return and supply ducts, services a square area which is equivalent to the column to column spacing. In this area the ceiling diffusers are distributed, ten feet on center both ways, within the five foot module. The main ducts are distributed in such a relationship to the pattern that they are not affected by vertical services nor by openings between levels.

The size of the columns allow for the service of three to four floors in either direction, up or down, from a mechanical floor. This mechanical floor must be so situated as to provide easy access to fresh air and also allow for exhaust of
used air. To satisfy these requirements the entire top floor of the building is devoted to mechanical services.

STRUCTURE:
Due to the size of the building design proposed, and to the desire for repetition of elements, the use of prefabrication is justified. However, it is difficult to prepare and prefabricate large elements consistent with the seventy feet by seventy bay size. Therefore, a way of dividing this into smaller units must be determined for ease of handling and shipping as well as for ease of forming or pre-casting. The difficulties encountered in satisfying this requirement are in pre-tensioning the elements and in how the elements are joined together once at the building site.

In this design a manner of dividing is proposed in which pre-tensioning is relatively simple, the elements are stable in themselves, and when simply joined together a two-way system is obtained in which the full depth of the elements together work as one unit.

The two main prefabricated elements work independently as beams in the first stage. When they are joined together they form the upper and lower chords of the slab construction. These main elements have been pre-tensioned at the fabricating plant in the direction of their length. When joined together they are post-tensioned at right angles to their length to form a two-way system.
A depth of five feet from the bottom of the lower chord to the top of the upper chord allows sufficient space in between for horizontal duct-work, plumbing, and electrical raceways. This space is interrupted structurally by a third element, the shear members. These members are small and are positioned in such a pattern as is necessary to solve the problems of shear within the structure. (fig. 6) All three members are post-stressed vertically for continuity. Directly over the column a much larger shear member is required in order that the loads be properly transferred to the column.

CONSTRUCTION:
It is important in the design of pre-cast structures that the techniques involved in constructing or fitting the elements together be carefully considered. The elements themselves must be designed so as to be efficiently formed, easily transported, and efficiently lifted into place.

A grid consisting of the lower chord only is installed first in order that it act as the scaffolding for the other structural members as well as for duct-work or any other services that could be put in place prior to placing the remaining elements. In order to avoid scaffolding this grid portion for the column and shear capital area would be assembled on the ground and hoisted into place upon the column. The shear members and floor slab members would be lifted in place and the whole section post-stressed to form a continuous two-way
Position of shear members in one quadrant of basic unit.

figure six
structural "umbrella" or "mushroom". After two of these "mushrooms" were erected on their respective columns the column strip portion could be erected, the lower grid members forming first their own scaffolding and resting in place on the two "mushroom" sections. The central span portion follows the simple system but only after four "mushrooms" are erected and the column strip areas between are also in place.

CONCLUSION:
Each system elaborated upon was a result not only of its own inherent problems, requirements, and limitations, but also the result of its interaction with the other systems involved. All these systems integrated and functioning together combine to determine the usable building design. It does not determine the building shape or form beyond the basic unit. This shape or form results from a careful manipulating of the total system, and in the introducing of open spaces so that a suitable and workable building emerges based on the primary space requirements of the users.
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