BUILDINGS AS SYSTEMS -
A RESEARCH BUILDING FOR SCIENCE
AND TECHNOLOGY

by

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In partial fulfillment for the degree of Master in Architecture I hereby submit this thesis entitled, "Buildings as Systems - A Research Building for Science and Technology".

Respectfully,

V. Raymond Smith
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PREFACE

Parts I, II, and III of this thesis were written in collaboration with Selma A. Hershdorfer, Charles B. Hook, and G. Norman Hoover in the hope that a more complete background of the thesis subject might be presented.
ABSTRACT

This thesis explores the application of the concept of systems to buildings. By the use of technological and functional criteria to develop a totally integrated system of construction, it is expected that a building expression of enduring quality and usefulness will be produced - one that is free from the compromising influences of current fashion and individual mannerism. In order to study as completely as possible the aspects of systems as applied to all buildings, a building with complex requirements was chosen - a Research Building for Science and Technology suitable for use as both an academic and nonacademic facility.
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I. INTRODUCTION TO SYSTEMS

A system is a specific combination of elements which participate in the performance of a given function. They unite to form an integrated whole with a resultant pattern reflecting the regular interaction or interdependence among the parts. The original elements constitute the basic units whose repetition and varied combination determines the characteristics of the system.

Natural systems develop spontaneously in response to physical laws. Almost all patterns found in nature reflect the effect of consistent forces and the specific responses of organisms to their environment. Environmental conditions also determine the various combinations of atoms or the formation of inorganic compounds. The physical and chemical characteristics of these compounds constitute regular and predictable systems.

Man has engaged in systematic research to discover means of controlling the environment. Cities and transportation networks have been built in response to environmental conditions. These constitute patterns or systems - reflecting the nature of these conditions. Tools and machinery have been developed to control the physical environment while social
systems have been formulated to control the relationships among men, and hopefully, to harmonize them.

The following pages illustrate examples of natural and man made systems.
Decorative Patterns

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Lines of Force Between Two Plates
From Clerk Maxwell's Electricity, Vol. 1.
Variation of a single geometrical motive.
The movement of a circle whose center
is carried along the circumference
of another circle.
Herman V. Baravalle
Scripta Mathematica Vol. XVIII.I

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Photomicrograph: Prof. I. W. Bailey, Harvard University

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Bacterium + 3% Iron.
Photomicrograph: H.P. Roth, Massachusetts Institute of Technology.
Lissajous Figure; graph of the displacement path of a point on which two or more simple periodic motions are superimposed.
A complex wave rich in harmonics is varied in frequency at several rates.

Courtesy of R. K. Potter, Bell Telephone Laboratories, Inc.
Loads proportional to those acting on the actual objects are applied to a scale model made of transparent material, which is then photographed by polarized light. An unstrained model placed between crossed polarized screens appears uniformly black under these conditions. Whenever stress occurs, the refractive index of the material is altered and bright lines will appear which contour the principal stresses.
Mid-span Wake of an Airfoil of 18 inch Chord at 33 feet/sec.

Courtesy of Prof. F. N. M. Brown, University of Notre Dame
Section Through a Twig
(Foto: Bildstelle der Stadt Karlsruhe)
Figure 10.—Cataneo: Ideal City.
Die Separierung der Würfeloberflächen in drei getrennte, aber untereinanderabhängige Ebenen

Die Bewegungsbeziehung der Einzelteile in dem in sich beliebig unterteilten Kubus

Die räumliche Durchdringung der modular bestimmten Flächen eines Kubus, identisch mit positiv und negativ, oder konvex und konkav

Die separierten Ebenen des Kubus, nun zur Kombination von Dimensions- und Bewegungsbestimmung geworden, bedingen die Zeit als zusätzlichen, notwendigen Faktor zur Bestimmung von Meßwerten

Die Bewegungs- und Zeitkontrolle als zusätzliches Ordnungssystem sich durchdringender Flächen

Symbol für Maß, Bewegung, Zeit, in das sich jede gedachte Form im System einer angenommenen Beziehung einfügen läßt.
II. SYSTEMS AS APPLIED TO CONSTRUCTION AND ARCHITECTURE

Systematic thinking has been used in construction and architecture throughout history to accomplish certain goals. Recently, conscious attempts have been made to apply the concept of systems to architecture. Modern buildings embody a number of systems: structural, spatial, and mechanical, to name a few. The location and functional inter-relationship of structural elements can form a regular and consistent pattern. The relationship between varied spaces in a building, the progression from the exterior into the interior, and the subdivision of the total area into functionally and spatially differentiated parts form a hierarchial organization. Complex mechanical systems, which enable man to control the immediate physical environment more effectively, have been introduced into buildings. All of these systems combine to form a complete building. Thus, the building must be the result of the integration of the subsidiary systems, visually expressing the pattern which is the direct result of and which reflects this integration.

Modern buildings should satisfy all the requirements of life. As these change and/or grow, the building also
must change or grow. Thus, a pattern of adaptation and growth must be built into the total building system.

Some examples illustrating the use of systems in construction and architecture are discussed and illustrated below. In most of these, the structural elements are systematized into a consistent pattern. Some concentrate on the application of new materials to construction systems. Others concentrate on systems of assembly. They investigate various methods of prefabrication and the application of these methods to various buildings. A third group, generally classified as space frames, manipulates the structural elements to develop light and long-span structures based on the repetitive use of a minimum number of units.
THE DOCTRINE OF DURAND

J. H. P. Durand was a student of Boullee. When Napoleon established the new Ecole Polytechnique, Durand was appointed as professor of architecture. He published his lectures as *Precis Des Lecons* in 1802 and 1805. These books made his teachings generally available, and Durand's doctrine had extensive influence in Germany and Northern Europe in the 19th Century.

He synthesized and systematized the diverse strands of theory and practice developed in France during the previous 40 years. He deals as a "constructor" with materials and their proper employment. He defines the goal of architecture, the structural means and the principles derived from those, and he investigates ways of combining architectural elements.

Durand proposes that columns be equally spaced - the spacing being determined by circumstantial requirements - and arranged along parallel, equidistant axes. These axes are cut perpendicularly by other parallel equidistant axes. All columns should be placed at the intersections of these axes and the wall along these axes. For the third dimension these axes should be projected into the vertical plane. Decorative design should be avoided. All plans,
sections, and elevations should be designed within the grid lines set by these axes in three dimensions. Durand was interested in varied skylines provided by central and corner towers and in the incorporation of voids in architectural compositions.¹

¹ J. H. P. Durand, *Precis Des Lecons D'Architecture* (Paris, 1809); from Part II.
COMBINAISONS HORIZONTALES,
de Colonnes, de Pilastres, de Murs, de Portes et de Crucées.
THE CRYSTAL PALACE

The Crystal Palace was designed by Paxton in 1850 to house the first international exhibition in England. Paxton was a builder of glass and iron green houses, and derived his idea of setting the glass into metal frames from the structure of veins which support lily leaves. He was not interested in specific buildings, but in the structural technique and the possibility of its universal application.

The Crystal Palace consisted of cast iron framing members with glass panel inserts. The columns were hollow and the capital and base were crystallized into mechanical couplings. Three types of shallow lattice trusses were used: cast iron, wrought iron, and wood. The roofing was based on a standard size of glass panel. All connections were standardized and identical.

The whole structure was made up of small simple parts and was planned on a modular grid. It enclosed an imposing, tall nave with galleried aisles. The regular rhythm of the structure provided a grid of coordinates defining the space. Full grown elm trees were enclosed within the structure.

Although the building was 1,851 feet long, it was erected in less than four months, due to a system of
erected developed by Paxton especially for the building. The entire concept was hailed as a technical and architectural achievement of the time. ²

Joseph Paxton
Contemporary wood engravings of the planned structure (c) and of the prefabricated elements during assembly (a & b).
Wachsmann is interested in the mechanics of building, in mass production techniques, prefabrication, and the industrialization of the building industry. One of the great virtues of industrialization is the ability to manufacture uniform, high quality products. This process can have its full effect only through standardization. Industrialization of the building industry requires the prefabrication of building elements, or standardization of building parts into components which can be mass produced. Thus building becomes a process of assembly. The prefabricated parts must conform to a system of modular coordination, and such parts must be capable of producing buildings where all the complex mechanical and electrical services and equipment are integrated with the structure. This integration is to be achieved through the coordination of modules, defined as the material, performance, geometry, handling, structural, element, joint, component, tolerance, installation, fixture, and planning modules. Only such buildings can provide perfect environmental control and satisfy all the requirements of this age, according to Wachsmann.

In a system of assembly, joints and connectors are of
utmost importance. They are the essential formative elements in the system, indicating zones of contact and defining any object they enclose. Adoption of a particular joint depends upon technical considerations and on the nature of the problem. "Connectors may be independent mechanical systems, ...., or they may be formed directly from the material of the structural member itself, ...., or they may be independent key elements, forming numerous individual pieces, first assembled with the structural members on the site." 3

Wachsmann develops the partition wall system, the building panel system, the Mobilar system, and a space structure. In all of these, the joint is the key element. In the partition wall system, a joint with a constant profile which connects twelve elements in a single point is developed.

The building panel system was derived in collaboration with Walter Gropius. They developed a frame section based on an axial modular raster. These sections were joined with a hook type metal clip. A 40 inch planning module and a 4 inch internal module based on the study of sizes of fixtures and dimensional requirements of building elements

3. Wachsmann, p. 90.
was selected. Next was the development of a system of plumbing assembly and electrical installations to be built into the panels, and finally the switches and receptacles were distributed into a system of fixed points determined by the module.

The Mobilar system is a tubular steel design. The problem was to use the advantageous statical properties of tubular cross sections in steel construction. This lead to the development of a new truss joint and a movable wall panel assembly. In this system, tubular members of various standard lengths are used. These have offset eye plates welded to each end and they can be assembled in any combination of trusses, purlins, columns, etc.

Wachsmann was commissioned by the Air Force to design a space structure for building hangars. The problem was to design a prefabricated, demountable assembly system which could be combined into buildings of any size or shape with a minimum number of joint types. He developed a universal connector which closed around the main members like a ring from which secondary members radiated in all directions, in any combination, at any angle. The connector was composed of five standard elements. Tubular sections
and cables were used as structural elements.\footnote{Wachsmann; this discussion taken from various parts of the book.}
Konrad Wachsmann
Structural system for large size airplane hangars, 1950-53.
a) Standard steel pipe elements (in tetrahedral frames) and their connections.
b) Various views of the connectors between the modular pipe sections.
Die Sequenz des Aufbaus der Halle durch die Montage immer gleicher Standardteile ohne Baugerüste nur mit Hilfe von Kränen für eine maximale Belastung von 5 t

Innenansicht in die Längsrichtung der Halle
EIFFEL TOWER

Gustave Eiffel's tower is a system of heavy struts broken down into fine lattice-work. The systematic use of rivets, small angles, and plates made possible atactical effects previously inconceivable. Even though the lattice-work is two dimensional, the member arrangement system, together with the assembly system, forms a sort of space frame. 5

Ein asymmetrischer Knotenpunkt verschieden aufgebauter Stahlträger mit klarer Trennung von Druck- und Zugstäben.
R. Buckminster Fuller's Domes

Since 1922 Buckminster Fuller has been working with structural systems. He uses the term "synergy" to define the way whole systems act as more than the simple sum of their parts. Fuller has developed his geodesic domes based upon the following facts. In an all-motion universe, all phenomenon interactions are precessional - lines of force are not straight, but tend to curvilinear paths. These paths are inherently "geodesic", i.e., the shortest distance between points on a curved or spherical surface. With the automatic tendency of energy in networks to triangulate, Fuller assumed the most economical structural energy web to be a fusion of a tetrahedron and sphere. The sphere encloses the most space with the least surface, and it is strongest against internal pressure. The tetrahedron encloses least space with the most surface, and it is strongest against external pressure. The uses and applications for these domes are enormous. 6

Richard Buckminster Fuller
"Tensegrity II" in Dearborn, Michigan, 1993.
View from below of geodesic aluminum dome, diameter 93 ft. 2 in. (left).
Fuller Research Foundation
Geodesic dome of cardboard at X Triennale in Milan, 1954 (right).
Diameter 38 ft. 1 in.; height 18 ft.

Jeffrey Lindsay, with student team.
Dome structure of tension and compression members, 1987 (left).
View from below of the experimental model erected in 1:1 scale (right).
THE UNISTRUT SYSTEM

The goals of the system are to achieve durability, flexibility, expandability, demountability, and reusability. It is geared to mass production techniques and consists of standardized and interchangeable parts.

"In the Unistrut space frame the members form the edges of alternating erect and inverted pentahedrons whose bases create two parallel planes and whose sides create a series of tetrahedrons which interlock with the pentahedrons. For economy in production, handling, and erection, all framing members are identical and are assembled with identical connectors so designed as to require only one bolt at each end of each member."  

FRAMING SYSTEM
COLUMN CAP ASSEMBLY

SA 2/1c

type I

0 1 2 3 4 FEET

ROOF ASSEMBLY - SA 2/4
connecting bolt 1/2 x 4" HHCS
space-frame connector plate 106042
struts connected by double batten 102643
doubled-up space-frame struts 1047/5
double-strut clevis 106157

space-frame strut 1047/5
bearing-ring 105086

COLUMN ASSEMBLY - SA 2/1a

double-strut clevis 106157
doubled-up space-frame struts 1047/5
space-frame connector plate 106042
space-frame struts 1047/5
"CLASP" SYSTEM

A system of prefabricated component parts for school construction was developed in England in 1957. It is called CLASP for the "Consortium of Local Authorities, Special Programme."

The components are factory-produced on a 3'-4" module with an almost unlimited range of combination possibilities permitting the architect wide latitude in actual design. This module adequately meets the different requirements in educational buildings, yet is not so small as to present complications in manufacture or assembly. External walls can change direction at intervals of 6'-8" and 10'-0", or any combination of these two dimensions. Steel Columns can be located at any intersection of the 3'-4" square grid; partitions are centered on the grid lines with changes in direction possible at 3'-4". Window sills are at 2'-0", 2'-8", or 3'-4" above finished floors. Transoms and door heads are at 6'-8"; floor to ceiling heights can be at 8, 10, 12, 14 or 16 feet.

Factory made components in the CLASP system include steel frame units, parts for the heating system, precast concrete panels, window frames, aluminum sliding windows and ventilating louvers, finished rubber floor, eave units,
roof lights, light-gauge steel panels, internal doors, prefabricated partitions, and sanitary fittings.

Savings provided in the use of this system come from letting of contracts on the basis of estimated quantities for all the buildings in the annual program. The manufacturer can run the complete quantity ordered all at once or produce in times of slack, and stockpile.

The consortium continues to invest one-fourth of one-percent of its gross yearly construction expenditure in research and development, to further improve the system.  

CLASP schools are set on concrete slabs varying from 6 to 8 inches thick. One requirement in their design was to accommodate some ground movement because many must be erected in old mining areas. For this reason the vertical columns are pin-jointed, and are stabilized by spring-loaded diagonal wind braces. Also for this reason, window frames are wood (Siberian redwood) although sash are aluminum. At left is a diagram showing typical column and slab meeting; above, the typical column head. All columns are square. All components are kept comparatively small and light to avoid the necessity for large machinery to handle them on site.

Diagram at lower left indicates the vertical flexibility of the system, and typical details are shown at the top of the facing page. (Roof gutter is drained through a prefabricated rain-water head fixed to the fascia.) Below, opposite, is the window schedule for the CLASP system, totaling 30 units, with a vast possibility of combinations by the local school architect. About 150 standard drawings are issued to show the components and assembly details of the CLASP system, so architects need spend only half as much time on production of drawings.

CLASP can be built to a height of four floors, and has been used for other building types besides schools. The British War Office Computer Building in Winchester (right) was assembled from these same components. Drawings here are from British Ministry of Education Building Bulletin 19, The Story of CLASP, obtainable (price 9s. 6d.) from Sales Section, British Information Services, 44 Rockefeller Plaza, New York 20, N. Y. Other British building bulletins may be secured from the same source.
Carl Koch developed a system for house construction, based upon the following steel components:

1. An exterior wall system of prefinished panels where the ribbed design eliminates the visible joint between the interlocking panels.

2. A window wall system of C-sections that can frame fixed or sliding glass and a variety of wall panels.


4. Intermediate floor-ceiling with integral air distribution.  

A modular system of flexibility is built into the Japanese house. The overall plan and size of the space is determined by the number and arrangement of 3 ft x 6 ft x 2 1/3 in. rice straw mats called tatami. The space is divided into smaller areas by modular opaque movable screens called fusuma. Similar screens, but semi-transparent, called shoji, are also used when a play of light is desired. Above the movable screens a system of panels and wooden slats complete the vertical dividers. This modular system of spaces can be seen in the Katsura Imperial Villa.
Tatami may be arranged in varying patterns to produce rooms of different sizes.

Top row: Left: eight mats arranged in the old formal style usually reserved for temples, palaces, or aristocratic mansions. Right: four and one-half mats, usually used for tea ceremony rooms. A wood panel may be substituted for the half mat.

Middle row: Six, eight, ten, and twelve mat rooms. The mats are arranged to avoid the intersection of four lines.

Bottom row: Fifteen and eighteen mat rooms. The pattern may be extended indefinitely, but the proportions of a room will be limited to those shapes produced by mat combinations which avoid four intersecting lines.
III. AIM AND GENERAL REQUIREMENTS OF THESIS

The aim of this thesis is the development and use of technological and functional criteria as a basis of architectural design - a method that, hopefully, will produce a building expression of enduring quality and usefulness based on a totally integrated system of construction free from the compromising influences of current fashion and individual mannerism.

The specific problem is the design of such a system emphasizing the interdependence between the structural and mechanical components for a Research Building for Science and Technology suitable for use as both an academic and nonacademic facility of between 1,000,000 and 1,500,000 ft² in area. By exploring the needs of such a building with its complex requirements, it is felt that the utmost familiarity with the problems involved in solving any building as a total system can be achieved. To satisfy all the criteria the system will have to accomplish the following:

1. Provide optimum initial conditions in terms of space, services, circulation, and environment while anticipating and facilitating modifications required by changing usage and growth.
2. Provide maximum flexibility through the use of large uninterrupted floor areas with a modular sub-division based on illumination requirements, minimum room and corridor widths, and accessibility of utilities; demountability for local expansion; noise and sun control - all as an integral part of a unified solution.

3. Produce a functional building based on logical construction that will obviate obsolescence while achieving all the qualities of excellent architectural design.

The following items explain in greater detail the components and requirements necessary to organize and develop such a building as a unified system.

A. **PERMANENT AND TEMPORARY SYSTEMS IN BUILDINGS**

The permanent systems within a building are those which are expected to remain substantially intact and unchanged throughout the life of the building, regardless of the building use at any given time. These would include the following:

1. **Structural system (skeleton of the total system)** - Included in this system are structural components such as foundations, columns, girders, beams, load-bearing walls, structural slabs; and non-movable enclosing surfaces such as
exterior walls, roofs, floor slabs. Also included are core areas, with major circulation, exit stairs, open stairs or ramps when part of the major public areas or corridor system, elevators, and escalators; public toilets; service areas including janitor/maintenance rooms, storage, electrical, and telephone closets; and major mechanical service chases.

2. Service Stations - large main mechanical equipment rooms.

The temporary systems are those which are expected to, or which foreseeably might change during the life of the building. These would include the partitions, secondary corridors and stairs, mechanical services, lighting, and acoustical control. It is conceivable that the original mechanical system may become obsolete, thus requiring replacement during the life of the building.

B. KNOWN SPACE REQUIREMENTS

A Research Building for Science and Technology functioning as both an academic and non-academic facility serves two primary space needs: laboratories and teaching areas. Laboratories require ease of access to the maximum mechanical and utility services provided in the building. In some instances, laboratories have heavier live load requirements and need greater ceiling heights than normally
required elsewhere. Wall space is, in general, more valuable than window area. Freedom from distraction and interference is often of prime importance.

Teaching areas, including office and lounge space, generally do not have the need for the maximum mechanical services or heavy load capabilities, but do require planning flexibility and greater heights for large lecture halls. They also have the need for freedom from distraction and interference.

In addition to these primary space needs, there is the requirement for workshops for all kinds of construction and instrumentation, drafting rooms, libraries, and storage warehouses. Parking within the building may also be a consideration.

C. UNPREDICTABLE NEEDS

Unpredictable needs are, by definition, difficult to anticipate, but it is reasonable to expect that continuing development of science and technology will produce needs that may significantly alter present teaching and research requirements in terms of space and the size, amount, and complexity of mechanical services and equipment needed. The building system should then be able to accept a maximum
number of possible functions and expect modification throughout its life span.

D. FLEXIBILITY

It is the assumption that within the building any existing space may be called upon at some time to serve a different function. It is thus mandatory to achieve maximum flexibility in the total system. To assure this several premises are set forth including the establishment of a minimum area per floor of 40,000 ft$^2$ as a planning requirement, the use of large span structural bays to provide large continuous areas of uninterrupted space, and the centralization of services into vertical cores serving the maximum allowable floor area, thereby consolidating the permanent (non-flexible) components of the system as far as possible.

The structural system should be flexible to the extent that floor to floor heights can be varied within the building, bays or portions of bays can be left out, and secondary corridors, stairs, and ramps can be introduced within the framework to increase spatial variation.

Except when made an integral part of the structure, the mechanical services should be totally flexible, with the possibility of bringing the maximum number of services into
the smallest space expected to need them.

E. **HIERARCHY AMONG THE COMPONENT SYSTEMS**

Systems: Planning, Life Circulation  
Structural  
Mechanical  
Acoustical Control

Hierarchy among the component systems relates initially to the elements forming the organization of the building as a whole: planning, areas of human activity - life, and the controlling patterns - circulation. These include the major entrances, public spaces, interior courts, and the major focal points of activity - the cores. Related to these are the lobbies, elevators, and large stairs connecting into the main corridors which in turn distribute into the secondary corridors and stairs.

The structural system relates to the overall hierarchy of the building in that the major structural bays and columns establish an overall visual order, subdivided into the structural module that establishes the planning order.

Integrated into and relating to both the life of the building and the structural system is the mechanical system. The mechanical components distribute from the mechanical
rooms through major arteries in the cores or through the supporting structural elements into the secondary channels, finally sub-dividing into feeder lines to individual modules. Of the mechanical components, lighting and air supply/return predominate, with piping, power, and signal lines the lesser elements.

Integrated into the modular sub-system is another system - acoustical control, whereby sound absorption and isolation are achieved.
IV. SPECIFIC REQUIREMENTS FOR DEVELOPMENT OF THESIS

The general requirements for developing this thesis were given and discussed in the previous section. Additional requirements to set limitations where necessary in order to develop a system for a definite building are given below:

Space Requirements - Smallest usable space...100 ft$^2$

Largest needed space...6,000 ft$^2$

Span - Not less than 40 ft in the longest dimension; can be varied or equal within the building.

Live Load - 125 psf

Only two adjacent floors may be connected vertically with an opening in either floor.

Floor to ceiling height shall be 10'-0" and except where two floors are connected vertically.

Building population to be figured at one person per 150 ft$^2$ of total floor area; 60% men, 40% women.

Permanent and temporary services to be provided:

Elevators - (See "Building Planning and Design Standards," by Harold R. Sleeper for selection process).

At least two service elevators should be provided.
Stairways - (See National Building Code for requirements.) In general, the door of a room opening onto a corridor shall not be more than 150 ft from a fire stair, and fire stairs shall be enclosed and not farther apart than 250 ft.

Restrooms - Provide a minimum of one fixture for each 30 persons served. For men the number of fixtures can be equally divided between water closets and urinals. Number of lavatories will be equal to 75% of fixtures provided.

Janitor Closets - Minimum 50 ft² per 30,000 ft².

Electrical Closets - Same as above.

Telephone Closets - Same as above.

Spare rooms should be provided for storage, public telephones, concessions, etc.

Services - Natural Gas

Compressed Air

Steam

Vacuum Line

Tap Water

Hot Water
Drain Line

Internal Communications

Air Conditioning (heating and cooling),
  duct space to be figured at the
  rate of 2 ft$^2$ per 1,000 ft$^2$ of total
  floor area served for an all air
  system. For induction unit systems,
  .2 ft$^2$ per 1,000 ft$^2$ can be used.

Artificial Lighting - 80 watts per 25 ft$^2$

Electrical - 110-220 AC, 28-30 DC, fixed
  frequency signal (100 KC).

Acoustical Control - reverberation time
  shall be 1.2 seconds. Provide for
  acoustical isolation between rooms.
V. THE SOLUTION

A. General Description

The building, made of precast and poured in place concrete, is 505 ft by 385 ft, with a gross area per floor of 194,500 ft² and a total gross area of 1,360,000 ft². There are seven levels, two below grade and five above. The lowest level is given over to all the mechanical functions except the cooling towers (located on roof), the next level is used for parking, the ground level is the entrance level (with mezzanine), and the next four levels are used for the various other functions required. The building line on the entrance level is set back 60 ft from the main outside wall line, and the top floor is cantilevered 15 ft.

All levels above the second level are set back from the center of the building, allowing natural light to penetrate these floors and to skylight a double level space at the center of the entrance level.

The module size chosen was five ft sq, based on the minimum usable corridor width (interdepartmental) and the minimum size space required.

Basically there are two kinds of modules. One contains
the air conditioning room distribution system and the other contains the remaining mechanical systems: piping, electrical, and communications. These alternate by rows in the direction of the one-way structural span. All modules provide illumination and acoustical control by the use of a panel which spans between the structural webs. Partitioning of spaces occurs on the grid set up by this modular arrangement.

B. **Structural System**

1. **Floor System and Bay Size** - A two way system of floor framing was seriously considered, but because great quantities of space were required to allow passage of all the services through the structure and because of the desire to keep structural penetrations to a minimum (to better control acoustical transmission between rooms), it was determined after much study that a one way system would work best. Due to the construction depth required (4'-11") for the structure because of space needed at the critical point to permit passage of services, it was found that the joist span to girder span could be adjusted so that the depth of the girder would be much less than the depth of the joist. The two depths were adjusted so that the difference
was just enough to provide the maximum depth required for passing services through the structure. The governing factor in this case was the size requirement for the air conditioning feeder ducts.

Another factor governing the structural dimensions is the module size, in that it is desirable to be able to bring partitions directly against the ceiling to better control sound transmission from one room to another. This results in a web spacing between joists of 5 ft.

The resultant structural bay then consists of precast, prestressed concrete double te joists 4'-8" deep with webs 6"-12" thick and 5 ft on center, and flange edges 10 ft apart. These joists, which span 62 ft and are discontinuous, are joined integrally with poured in place concrete girders 3 ft deep and 1½ ft wide. The girders, spanning 24 ft between columns, are continuous throughout the length of the building. Thus, the building is made up of nominal 30 ft by 65 ft bays: seventeen with their long sides placed together in one direction and five connected by 15 ft long structural slabs in the other direction.

The structural slab is covered with a 3" topping of concrete, which ties the entire slab together and transfers any wind loads to the cores, preventing racking of the building.
2. **Columns** - The columns are poured in place, and are used as additional vertical chases to handle part of the air system.

3. **Cores** - There are four cores in the building integrated into the structural system and placed such that the requirements for stairs will be met and so that sufficient vertical shaft space is provided in order to distribute the mechanical services. The cores will be made of poured in place concrete.

4. **Structural Implications on Circulation** - Since a one way system of bays discontinuous in one direction and connected by short span slabs has been chosen, resulting in columns spaced rather close together, the building was shaped and orientated so that the narrow area between the columns would become, for the most part, permanent circulation paths within the building. Also, the area on both sides of the cores between corridors is expected to become permanent corridors.

5. **Enclosing Walls** - The enclosing wall of the building on the two levels above the entrance level is made of precast concrete modular window units, and are non load bearing. The other enclosing walls are metal and glass to permit maximum natural light, as they are protected by generous overhangs and thus require less protection from
C. **Building Erection Process**

Visualization of the erection process of the building is as follows: First the foundations and columns will be formed and poured. Then the floor joist double tees will be placed in position on supports near both ends. The girder form work will then be placed and poured, making the joists, girders, and columns work as an integral unit. The cores will be formed and poured as the building is raised, level by level. Before the next level is begun, a 3" thick concrete topping will be placed over the entire rough floor, forming the finished floor and also becoming part of the 6" thick slab spanning between bays, and between bays and cores. After a level is formed and when deemed desirable, the modular window units can be placed.

D. **Mechanical System**

1. **Air Conditioning** - Air conditioning is accomplished by dividing the building into two distinct zones - exterior and interior - and providing a separate system for each. There is a 2½ ft overlap between zones.

The exterior zone extends from the outside wall of the sun.
building to a point 15 ft inside. This dimension was chosen on the assumption that no room less than 15 ft deep would be placed next to an outside wall. The system consists of air induction units under each window, and is serviced from the mechanical floor through the exterior columns by a high velocity air duct, hot and cold water pipes, and return and condensate pipes. The air, which is provided by eight air handling units in the basement mechanical floor at the rate of .2 ft$^2$ per 1000 ft$^2$ served, is not returned directly, but is used to maintain a slight over-pressure at the exterior of the building, finally to leak back through the interior zone return system.

The interior zone is heated and cooled by an all air two duct system. One duct supplies the air at a constant temperature and the other duct returns a portion of the air to the air handling units. Fresh supply air is brought into the basement mechanical floor through four large tunnel plenums (1,500 ft$^2$ each) at each side of the building, and is exhausted in a similar manner. There are sixteen large air handling machines for this system, four for each quarter of the building. These machines condition the air and send it through the vertical shafts in the cores where it is taken off at each floor through duct mains which run through
the main corridor ceilings and supply the feeder ducts, which in turn carry the air to the individual modules to be let into the usable spaces of the building. All feeder ducts are sized to supply and return an overlapped area 33% greater than is actually supplied and returned (three rows of modules instead of one row plus half of the rows on either side of the supply/return row) in order to take care of any combination of room sizes. Air is supplied and returned on a ten foot module, alternating in both directions to achieve maximum flexibility for the placement of partitions. This arrangement always provides an even number of supply and return outlets in any possible room size. Each outlet is sized to service 225 ft² (6 modules) but actually, in most cases, supplies only enough for 100 ft² (one module plus part of each surrounding module, totaling four modules). This overlap permits adjustments to be made at the outlets for taking care of various combinations of room sizes. Local requirements for more or less heat will be taken care of locally by reheating/cooling coils. The air in the system is returned along the same path as the supply air to the mechanical floor. Before it gets there, 5% will be lost and 20% will be redirected to condition less important spaces in the building such as the parking level, electrical
and telephone closets, etc. Thus only 75% of the air will be sent back to the air handling units to be mixed with 25% fresh air and sent through the system again.

The corridor area on the east and west sides of the cores are supplied directly from the main vertical shafts. On the restroom side of the cores the air is pulled through the restrooms and exhausted to the roof, and on the elevator side the air is returned directly into the vertical return shafts.

The building requires a total of 6,800 $ft^2$ of cooling tower area, based on a figure of .5% of the gross area. These cooling towers will be evenly distributed on top of the building directly above the four cores. All refrigeration units and boilers are on the mechanical floor.

Vented hood ducts from laboratories will be taken through the structural floor joists in three $2 ft^2$ precast holes per joist to permit passage of services opposite to the structural direction, to a column, where it is taken to the roof to be completely exhausted from the building. These precast holes will be plugged when not used, or plastered around ducts when used in order to control sound from space to space.

If necessary, a vent hood duct can go directly into
the column from the space, as when a clay pipe vent duct must be used.

2. **Piping** - All piped services originate and terminate in the mechanical floor, and distribute in sixteen vertical chases within the cores to the areas served, similarly to the air supply system. It is possible to distribute these services to every module in one direction, and every other module in the other direction, except for the rows of modules occurring on column lines.

E. **Electrical and Communications Systems**

The main electrical and communications rooms are located in the basement mechanical floor. Vertical riser conduits distribute these services to sixteen closets located within each core on every floor, and are further distributed down the corridor ceilings to the usable floor area similarly to the piping system.

F. **Illumination and Acoustical Control Systems**

The artificial lighting is integral with the panels used for acoustical control, and provide 80 watts per 25 ft² floor area at desk height. These panels, which fill a module each, are designed to be made of metal or fiberglass. Some of these panels are modified to provide air outlets for
the air system. Absorption is applied to the recessed surface of the panel, and provides approximately one-half of the absorption required. The rest of the absorption will be provided when the space is occupied with people and objects. A gasket is placed around each panel edge to insure a tight fit when next to an adjacent surface such as a joist web or a partition. In some spaces, such as large laboratories, these panels will not be required, and ordinary light fixtures will be provided instead. Where acoustical isolation is desired, the panels can be provided and the spaces between filled with a special connector, and/or the space above the walls and between the structural members can be sealed with plaster. Also, the return air must be directly ducted to the main ceiling return duct instead of being allowed to return unaided through the panel.
VI. CONCLUSIONS

The development of a building as a total system results many times in compromises between the various systems themselves. For instance, if it is determined to use 60 ft as the most desirable span, the depth of the resulting structure may be too shallow to accommodate the mechanical system at its critical point, thereby resulting in a construction depth too deep for structural requirements. If it is determined that a two-way system of floor construction is most advantageous for the passage of services through the slab, at the same time the problem of acoustical control is made paramount, due to the required amount of perforation in the structural members. If it is determined that a module size of 4'-8" would be most desirable for maximum flexibility of partitioning space within the building, it is also found that a module size of 5'-0" or 6'-0" is needed in order to bring the maximum services to a space. Thus, the problem of inventing a total system is to bring the various subordinate systems together in the most logical manner possible.

The system I propose in this thesis is logical in most respects. There are some obvious advantages and disadvantages inherent in the system. The desire to minimize large vertical shafts in the building in order to gain uninterrupted
floor areas for maximum partitioning flexibility lead to the concentration of main service risers in the permanent core areas of the building. The desire for minimum structural penetration for acoustical control and the assumption that services should go only one direction at a time for maximum ease of installation and accessibility after installation led to the belief that a one-way system of floor construction would be best. Other advantages gained by employment of long one-way floor members are that they can be precast and prestressed before arriving at the building site, thus allowing for greater economy in construction costs and erection time. Greater spatial variety within the building is also gained, in that the use of this system allows that members be left out when desired, thus creating any needed vertical arrangement of interior space.

One disadvantage of this system is that a building as large as this requires great quantities of mechanical services. If it is desired to minimize the vertical shafts in order to gain uninterrupted floor areas, it then becomes necessary to increase the slab construction depth beyond that necessary for structural requirements in order to have sufficient room for passage of services horizontally
There is a point at which it is not reasonable to increase the depth more; in this case 4'-11" was considered maximum. This depth is not sufficient to extend the air system completely to the periphery of the building, thus requiring a separate system of supply for the exterior zone. This in turn necessitates the use of the exterior columns as vertical shafts for supply air and pipes, which in turn increase their size and require that the columns act the same on all four sides of the building. With the use of a one-way system of floor construction, it can be argued that the expression of adjacent sides should be different. Also, the corner column, not usable as a shaft for supply, becomes yet another element to contend with. Thus, the expression of the system on the exterior facades becomes a problem, but not one which cannot be overcome.

In summary, the system presented here meets all of the requirements for maximum flexibility and usability. Its main advantages are that maximum areas of horizontal space are left free from large obstructions by the concentration of services in the core areas and exterior columns, and the use of a one-way system of slab construction lessens the problem of acoustical control and permits space within the building to be varied vertically where desired. Its main disadvantage lies in solving the problem of visual
external expression, due to the columns having to be larger and identical on all sides of the building.
# SOURCES OF ILLUSTRATIONS

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