A BUILDING FOR TECHNOLOGICAL AND
ACADEMIC RESEARCH

by

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B. Arch., North Carolina (1963)

Submitted in Partial Fulfillment of
the Requirements for the Degree
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BUILDINGS AS SYSTEMS
FOR SCIENCE AND TECHNOLOGY

by

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BUILDINGS AS SYSTEMS
PREFACE

The three individual theses are presented with a common introductory discussion on systems in general, the use of systems in architecture, and the overall goals and requirements for a building system. It is hoped that thereby a better understanding of the aims of the individual thesis material is obtained.
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SYSTEMS IN GENERAL

A system is a set of things or ideas in which each member of the set is bound to the others, or relates to the other members through clearly defined dependencies and interactions. A system differs from a mere set in that the members of a set, while conforming to certain external criteria, have no defined functional relationship among themselves. Subsets of systems may form discrete systems by themselves as well, having a higher degree of organization.

The ability to differentiate among objects and to impose criteria allowing the distinction of sets of things lies at the base of human comprehension and perception. The ability to then create a discipline among the members of a set is the basis for human effectiveness; the resultant functional possibilities of these systems is their essential quality in terms of their meaning for human beings.

The ability to function or operate is seen as the key difference between a pattern and a system. All systems have patterns, but not all patterns operate.
Illustrated here are examples of patterns of spots, but also of cross sections of living matter which are seen to have a visual pattern. The living matter is a functional system which must operate properly or cease to exist. The vital interrelationships between the various cells and fluids are expressed by the pattern seen in section.

In architecture, patterns from geometry may be employed to effect a system of vital functions of the building, but a pattern of geometry imposed on a building does not necessarily constitute a system. More specifically, style as such is totally apart from system.
APPLICATION OF SYSTEMS TO CONSTRUCTION AND ARCHITECTURE

In order for a building to come into existence, some discipline must be imposed on the forces inherent in construction, services, and program requirements. The discipline imposed upon these forces constitutes a system or series of systems. Moreover, the development of this discipline may be itself systematic.

Proper systems, when applied to construction and architecture allow the solution of complex spatial, mechanical and constructional problems, thus increasing the power of expression of the designer. The results should be orderly, flexible, integral and economical. A system selected out of context, as is done in periods of eclecticism restricts the designer to the production of fashionable buildings which are not the expressions of integrated, functioning parts, and which can never approach the status of art.

The three families of systems with which the architect must deal, namely the structural-constructional systems, programming systems, and systems of services, must be integrated so that the effect of each on the others will be a positive one.

Architects are mainly concerned with physical
systems which control the form and spatial qualities of a building: geometry, structures and construction. The structural system of a building is necessarily reflected in the geometry but the basic geometry employed can exhibit different character for different buildings with the same structural system. For example, in specific Roman basilicae or Gothic churches the overall pattern of the system, the basic geometry which expresses the structural principles, is adapted or developed to meet special conditions. Thus each separate building has a unique geometrical language developed specifically to meet unique criteria, but which expresses certain general criteria and structural realities.

Modern examples of adaptation or deformation of structural systems based on "form-resistant" structures follow in the same tradition. An example would be shells cantilevered from single columns transformed into a series, with another form of ground plan but maintaining a symmetrical overall system. Here a large unifying system is developed from small sub-systems. This unification is the key objective of the designer of any large project. The possibility of achieving this unification depends very much on the proper choice of sub-systems. A unified system of
subsystems answering to the needs of a building type establishes a visual language which is then adapted to individual buildings.

Structural systems may or may not have geometrical or formal implications: form resistant structures such as shell may, while a structure composed of prismatic members may not. An example of the former case is the concrete vaulting which Freyssinet used for some locomotive sheds built at Bagneux in 1929 where a strong geometry has been generated to solve many problems simultaneously and simply.

An orthogonal network of small dimension may be the proper geometrical solution to a certain design (programmatical) problem; in this case the architectural solution demands a structural system which performs efficiently in this format. Often the problem will not be limiting and other criteria must be found in order to make a logical choice, although efficient performance often indicates one solution among the total possibilities. Other factors to be considered when selecting the structural system are the spatial character which is acceptable, internal flexibility, integration of mechanical services, and the system of construction.
Regarding this latter influence, it is to be observed that often the forms of a building are the necessary result of a constructional procedure. This is most clearly exhibited in the stone and brick architecture of the Romans where such constructional implementation as supports for the centering of arches and vaults are integral parts of the building design and remain as an architectural feature after the forms have been removed.

In the case of orthogonal systems over moderate spans, the constructional process will be one of the most important criteria in determining the configuration of the structural system.

The second series of systems which must be considered is the programmatical. This involves space requirements and interrelationships, but also implies the requirements for growth, transformation and flexibility. The solutions for these programmatical problems are in themselves systems, but the approach to their solution may also be systematic. Not only may the designer develop the habit of finding solutions based on systems, but he may resort to using linear programming based on accumulated data. Bay sizes, ceiling heights, distance between services,
are examples of programmatical problems which may be solved by the use of computers or other information sorters.

Finally, the mechanical and acoustical systems of the building must be regulated in order to be integrated with the other systems. A modular system must be applied for the mechanical services which will be in phase with the structural module. The two geometries must be complementary to allow each of the systems to become part of the total expression.

The two aims, that of integration and mutual inter-reinforcement of the systems and parts of a building, and that of flexibility, growth, and change possibilities are in some sense contradictory. Integration most obviously implies some sort of interdependence: the dependence of the mechanical module on the structural module, the dependence of the spatial modulation on both, for example. However, the criterium of flexibility implies an independence of each system so that it may be separately altered to meet changing requirements, while other systems may remain stationary. (If everything were to require change at once, then an entirely new building would be required.) Hence it is necessary to find systems that interlock, yet are independent.
SOME HISTORICAL DEVELOPMENT OF DESIGNING THROUGH SYSTEMS

In a sense, any construction of two parts or more entails a system since some relationship between the parts must obtain if the construction performs -- that is, at least resolves the forces within. As constructions entail more parts, it is imperative that the system which describes the relationships between the components becomes regularized, that the governing rules are few, and repetitive. The progress inherent in designing through systems is that more and more complex structures may be evolved with fewer and fewer rules involved in the construction. This is possible through standardization of parts, consistency of structural principles, consistency of spatial qualities. For example, it is not of structural necessity that the aisles of a Gothic church are spanned with groin vaults, as the nave, but rather within the framework of structural and spatial consistency.
Perhaps the most meaningful events in the history of architecture have occurred as a result of the attempt to span over and through space, so that the history of systematic building stems from systems of spanning.

1) The Hall of the Hundred Columns, Persepolis (518-460 B.C.) is an excellent example of the post and lintel system extended in two directions, using a regular square bay system, of constant height. The hall itself is a square, which is consistent with the use of a square bay, and the roof is flat. The concept of modular building is one of the greatest contributions to systematic construction in history.

The post and lintel system had certain dimensional limitations as well as presupposing the availability of certain materials, so that the history of construction is very much the history of searching for ways of spanning distances with the materials available, as well as, in later times, the search for new materials (steel and reinforced concrete). The arch was the principle on which most systems of spanning depended.
2) The Pont du Gard, at Nîmes (AD 14), is a system of linear series of arches, one above the other. The spans of the top tier of arches (14 feet) are very small compared to those of the two bottom tiers, but the constructional approach precludes any other form for this element which supported the water channel, rather than being a spanning element. In addition, some of the voussoirs of the intermediate tier were formed to project in order to support the temporary wooden centering for the arch. This feature became incorporated as a decorative element in arches used in other buildings.

3) The markets of Trajan, N.E. of the Forum of Trajan in Rome (AD 98-113) employ the barrel vault, which can be considered as the extension in space of the arch. Here the series of barrel vaults extend vertically as well as horizontally. The vaulting is clearly expressed in the end wall, which it intersects and is supported by.
4) San Marco, Venice (12, 13 and 15 centuries) is a fine example of the multiple use of the dome (or rotated arch) to span as well as to achieve a desirable spatial quality. It is employed not only at the crossing and in the four arms of the Greek cross plan, but in the narthex as well. The domes sit on pendentives, and are linked to each other by short barrel vaults (or deep arches).

5) Abbaye aux Hommes (ST. Etienne) at Caen (1066-86) is constructed using intersecting barrel vaults or groin vaults which are adapted not only to bays of different dimension and proportion (the large square bays are sexpartite), but also to the semi-circular ambulatory. Here the power of dealing with systematic approaches to building is well illustrated. Through perseverance, and the consistent employ of an idea, a problem whose solution is not at all obvious has been adequately handled: the vaulting of the round ambulatory.
6) The Halle des Machines from the Paris Exhibition of 1889 has a span of 375 feet which is achieved using steel truss three-hinged, four-centered arches. These principal arches were steel braced longitudinally as well. The systematic use of materials (steel and glass) and the systematic approach to fabrication (prefabrication of identical parts) result in a powerful solution. Modern systems approaches to building are based on the same principles.
DESIGN PREMISES:

The design of a building of a permanent nature to house academic research activities in the fields of science and technology; the building design to be approached as a total system consisting of life, growth - change within itself, circulation, spaces, structure, services.

Emphasis to be given to the interdependence between the structural, the mechanical, and acoustical systems using either precast reinforced concrete or cast-in-place methods of construction, while keeping the following considerations in mind:

Permanent and temporary systems in buildings due to the change in use through time:

a. Permanent systems:
   1. The air volume to be condition will for the most part remain constant throughout the life of the building.
   2. Area to be lighted.
   3. Communication.
   4. Sanitary systems.
   5. Fire stairs.
   6. Vertical circulation (elev. etc.).
   7. Sun control.
   8. Floor surface.
   9. Ceiling surface.

b. Temporary systems:
   1. Mechanical requirements of different spaces as they change from one use to another.
2. Possible need of some laboratories to full or partial exhaust.

3. Different acoustical needs of spaces.

4. Partitions.

5. Main horizontal circulation.

6. Laboratory services such as gas, drains, etc.

2. Foreseeable and unpredictable needs:

Spatially and mechanically the building must have room to change and grow within its structural skeleton if it is to have a long life. It must not only provide for the services and space requirements of normal and foreseeable conditions but also those conditions requiring more than normal mechanical services, such as chemical exhaust for laboratories, etc.

3. Hierarchy among components:

Within the successful building system there are many systems that must be integrated to form the final and buildable system. Depending upon the decision of the architect or the specialized purpose of the building, the structural system may dominate or the mechanical, or the acoustical system. That is to say the architect through some intelligent means must determine the hierarchy or value relationship between the many systems before the process of design may rationally begin. Obviously not all the systems can be designed separately. Some must make concessions to the more important systems that more directly satisfy the requirements of building - purpose - function.

4. Systems and Subsystems:

It has been said that a subsystem is not a subservient system but the theme of a large system and that systems have not beginning
or end; that the part is a system for the whole.

If the need is for a structural, mechanical, acoustical solution then these needs become the SYSTEM. The same needs are repeated many times throughout the volume - area of a building. As we go from the general aspects of a building solution to the smaller and more particular, we find that even though the particular volume - area may require less or perhaps differ in some minor degree, that still structural, mechanical and acoustical requirements must be satisfied for the part. Thus, if we can satisfy the subsystem we can construct a total system.

5. Flexibility of the permanent or temporary components:

Within considered limitations such permanent building systems as that of the air conditioning system and lighting need not be as flexible as some of the other systems such as the system of partitions and their possible arrangements, but at the same time the permanent systems must not inhibit the necessarily flexible systems of changing space and function.

6. Systems adopted to building with varied spacial configurations:

Geometry as related to construction methods has proven itself as an economical and efficient basis of architectural structure and, as such, a fundamental producer of space. Depending upon the basic geometry chosen there are many spatial configurations possible. It is to the credit of the designer, his background and experience, if he is capable in the preliminary stages of design: of synthesizing the major design requirements around a geometry of potentially rich spatial evolvement.
ABSTRACT:

The design of a building of a permanent nature to house academic research activities in the fields of science and technology; the Building Design to be approached as a total system; consisting of life, growth - change within itself, circulation, spaces, structure, services, etc.
SPOT COMPOSITION

I.

II.

III.

IV.

V.

VI.

Fig. 14. SPOT REPETITIONS
SPOT COMPOSITION — FIELD

FIG. 38. FIELD
35
FIG. 27. FIELD
Figure 15.8c
Figure 15.7a
FIGURE 336. Labyrinth, now destroyed, inlaid in the pavement of the Cathedral of Amiens. 13th century.
FIGURE 335. Labyrinth inlaid in the nave pavement, Cathedral of Saint-Étienne, Sens. 13th century.
69. SECTION OF A CLEMATIS STEM.
Nature's provision of vertical strength to resist the elements is here displayed. The central structure of pith (corresponding with marrow in bones), the surrounding tissues with reinforced canals carrying nourishment, the woody structure, and finally the outer cork confining and strengthening the whole, show clearly.
Intersections de Surfaces

Pl. 3
Complément.

Fig. 1.
Control of accuracy in production and assembly

Tolerances: The basic ideas of interchangeability and standardisation which run through the whole design demand a high degree of accuracy. But in machine production the higher the accuracy the greater the expense. It is, therefore, necessary to control the degree of accuracy of each part, so that it is no more than it need be. During the design specific degrees of accuracy were calculated for every part according to its function and assembly, from ±0.002 in. to ±0.001 in. for machined parts, and ±1/32 in. for sheet metal parts, to ±1/16 in. laterally and ±3/16 in. longitudinally between the complete body and the chassis.
IMPERIAL PALACE, TOKYO (JAPAN) IX CENTURY
STRUCTURAL BAYS

A. EXHIBITION HALL, Turn (draft, 12th century) (from plate 256)
B. KARMA, CILY (yarn, 12th century)
C. CRYSTAL PALACE, LONDON (wood, 19th century)
D. GALERIE DES MACHINES, PARIS (yarn, 12th century)
Opposite page: the spatial qualities of the Great Exhibition building are clearly displayed in this fine drawing.
This page: Downes's working drawings of the 1851 building. Below left: external elevation of end of transept; right: internal elevation of the same. Top right: section of nave and gallery roofs.
56. Querschnitte der Fahrbahn, des Konsolekabels und der Stützen / Cross-sections of the platform, of the hollow-arch and of the support, 1:100.

57. Gesamtschnitt mit Blick auf die Stützwände / General view with supporting wall.

58. Untereite / View from beneath.
Bibliography


North Carolina School of Design
2) Volume 5, 1956.
Dear Dean Belluschi:

I hereby submit the enclosed thesis entitled "A Building For Academic and Technological Research" in partial fulfillment of the requirements for the degree of Master in Architecture.

Respectfully submitted,

William Randall Bray
DESCRIPTION AND AIM OF THE PROGRAM:

The selection of the 4'-0" module was primarily the first design decision but only after the 5'-0", 6'-0" and 10'-0" modules had been considered within the needs of future design intentions.

The first of three design assumptions was:

1. That general building requirements will for the most part maintain constant floor surfaces.

2. That ceiling heights within a constructed building will be of a permanent nature. It is true that not necessarily should the ceiling be of such construction that it absolutely negates the possibility of changing ceiling heights if need be. But this thesis assumes that for all practical purposes the constructed ceiling will be permanent and not offer the possibility of eliminating random bays which would allow one, two, or even three storey floor to ceiling heights within the building. At the same time this thesis attempts to take advantage of two-way slab construction and to interrupt it in as few places as possible, since it depends on continuity within the system.

This suggested a beginning --- two parallel planes --- a floor and a ceiling. Beginning with the two planes established there is really only one other dimensional aspect remaining; that of the modulation of space within the parallel planes of floor and ceiling.... and thus the third assumption. If the secondary portion of the HVAC dispersal can be accomplished via space inscribing partitions, then there is really little need of the open acoustical sieve type structural slabs. Also there is no real need of providing every module with the capabilities of laboratories when in reality a large number of modules
will be offices, and spaces not requiring such extensive services. Therefore, I propose in this thesis mechanical supply via columns via major arteries or zones, then through the partitions into the spaces with the advantages of minimum structural penetration, maximum acoustical and temperature control. This thesis advocates the use of the partition for more than just merely visual and acoustical division of space. It is the link between the mechanical system general and the mechanical system specific — that is to say, the mechanical supply of a space is also the describer of that space. This is a direct relationship, for the floor spaces will only change as new functions require spaces —— and new spaces can occur only insofar as the flexibility of partitions and mechanical supply will provide.

The building is large 560'x560' (14 bays at 40'-0'') with eight habitable floors; to maintain its integrity it should not merely have the structural system and form of the many smaller buildings that have come before it with the only difference being a few more bays in one direction or other. It should have a structural scale in keeping with its dimensions. I think also that the major and minor spaces should be related, not just isolated holes in the building or floor slab left out but literally overlapping and interlocking from one space to the next and from building mass to building mass.

The structural bay is 40'-0'' by 40'-0'' as it is sufficiently large to satisfy most space requirements and it also allows a systematic mechanical penetration of slab via columns that at forty foot intervals is small enough (5'x5') to not be of core scale but still allow mechanical use.
The construction system is poured-in-place concrete with a standard coffer system for the floor slabs. Electrical conduits will be placed prior to concrete pouring and upon pouring become integral. Lighting fixtures will be attached later in each coffer void.
CIRCULATION:

A typical plan of the building is a square with an interior court. The building mass is divided into an upper stepped building and a lower stepped building connected together by four large cores which are grouped toward the center of the building. The pedestrian circulation is such that all major public areas are oriented toward the large cores. The large cores are easily seen on approaching the building as well as when moving around inside the building.

This building is a large building; therefore, it is important that the occasional visitor be able to easily perceive the major circulation. This he can do on approaching the building. The first impression the visitor sees will be two complimentary building forms, one above the other, both oriented to and around four cores. The viewer will also be able to perceive the large interior court which the four cores are centered around.

SANITATION:

The sanitation system is accomplished within the four major cores. There is also the possibility of additional toilets at the auxiliary fire stair and service elevator cores which are located at the extreme corners of the building. These four auxiliary cores also offer the possibility of grouping laboratories around them which require exhaust or wet vents.

STRUCTURE:

The basic module is 4'-0". The bay is 40'-0" x 40'-0". The floor
height is 14'-0" with a structural slab depth of 2'-6"; this leaves a clear floor to ceiling height of 11'-6". The slab is a standard poured-in-place coffer system acting in both directions of the 40'x40' bay.

The columns are spaced 40'-0" on center. They are essentially composed of four one foot square columns structurally laced together to form a rigid column that has an X cross-section and an overall dimension of 5'-0" by 5'-0".

The shear-heads are 12'-0" square with 36"x16" openings through each side. This leaves 8" of concrete across each top and 6" of concrete across each bottom to place steel reinforcing for continuity over the shear-heads.

**MECHANICAL:**

The major portion of the mechanical system is accomplished by dispersal through zones. These zones occur as voids in the structural system; and also show as zones in the reflected ceiling plan. After the mechanical services have been dispersed to the extent of the structural zones they are further distributed by the acoustical-service-space partitions that actually define the different spaces between floor slab and structural ceiling. The partitions are 6" thick and 11'-6" high, preformed of Plexiglas with pop-out panels for easy access to the wiring, heating unit, thermostat, and areas for pipes. There are three different units which make up the partition system and allow the system to maintain continuity through doors, partition intersections, and rooms within rooms.
Dear Dean Belluschi:

I hereby submit the enclosed thesis entitled "Buildings as Systems for Science and Technology" in partial fulfillment of the requirements for the degree of Master in Architecture.

Respectfully submitted,

Eugene L. Hayes

Cambridge, Massachusetts
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ABSTRACT

The investigation concerned the interaction of the many and diverse systems involved in the design, construction, and operation of a large technological research building. The objective was to create a synthesis of the idea, construction, mechanical and structural system to provide and environment in which a harmonious relationship exists between the systems, building, and man.
INTRODUCTION:

The word "systems" holds many connotations for people relative to their background, education, and profession. The definition most likely to be agreed upon is an order or method governing the organization of objects or materials. From this order a controlling framework or structure is obtained with which to form an integral whole.

The technological age we live in imposes such great demands while giving such great freedoms that a means of providing a direction and guidance is needed. Organizing and co-ordinating our ideas with a vocabulary of systems can minimize errors and arbitrary decisions and can allow for a logical exploitation and use of the technology available.

PROGRAM: Academic Research Building

To provide: a system of: life
growth
flexibility
circulation
structure
mechanical services

Needs: 1,500,000 square feet: private and public research and communal

Flexibility: to accommodate for small and large changes in space requirements and functional use

horizontally and vertically
Expansion: within the building

Structural Bay: modular division for partitions, mechanical services, and glazing

Mechanical: vertical and horizontal distribution with breakdown of main system to smaller zones which subdivide to provide for growth and change within the structure.

Construction: pre-cast post-tensioned reinforced concrete and or cast-in-place concrete

OBJECTIVES:

Spaces in, within, on, below.

Large structural units.

Easy installation of long mechanical units.

Easy access to change and maintain the mechanical system with minimum disturbance.

Mechanical system capable of serving spaces above and below horizontal mechanical spaces.

Maximum distance of mechanical services from cores of 150'.

Short return air distances to local fan rooms.

Integration of mechanical and structure phased such that maximum mechanical services exist at mid-span.

Modular co-ordination of partitions and structure.

Two-way flexibility of partition placement.

Maximum distance to fire stairs of 150'.

Maximum distance at elevators of 250'.
Expansion within structure vertically and horizontally.
Large floor areas near top of building to facilitate easy exhaust of fume hoods.
Large floor areas near top to allow skylighting of a large percentage of total area.
Horizontal acoustical isolation.
Sun control of building.
Easy maintainence and placing of glazing.
Large building occupying a small ground area and facilities below and around building for large group activities.

BUILDING DESCRIPTION

The structure contains approximately 1,500,000 square feet of gross area dispersed on four main levels and four mezzanine levels. The building cantilevers in and out from its base, which is composed of sixteen cores. The base dimension is 550' x 550'. The floors move outward forming an angle of 45 degrees to the ground until an overall roof dimension of 750' x 750' is attained. The exterior wall is a cast-in place, triangulated bearing structure which is used to transfer column loads to the base. The spandrel girder of the wall is sheathed with a pre-cast veneer and panel to aid in minimizing thermal expansion and contraction caused by sun. The wall is anchored back to the cores by a system of vierendeel girders.
A two-way intersecting system of 5' vierendeel girders spaced
12'-6" o.c. is used for the floor system on the main levels. The mezzanine floor system is composed of steel units, but with a depth of 16" since only conduit and waste drains are within this floor.

The columns are spaced 50' o.c. and with the bay being divided into sixteen units by the girder system. These units are subdivided by steel channels anchored to the girder, giving a module of 3'-10" o.c. This unit is infilled with large tectum coffers, panels, or 3'-8" x 3'-8" fluorescent lighting units. In larger spaces the steel channel will be placed in only one direction to carry the lighting fixtures. The small rooms are sealed acoustically by the tectum units, and in the larger rooms if these panels are undesirable, special panels to seal the viereneel girders will be used; but if pipes and ducts are penetrating the openings, acoustical isolation would necessitate plastering around the mechanical services.

The main floors with a 5' depth are used to carry all the main services and have the capacity of serving either up or down, depending on local conditions.

The cores are units 50' x 50', housing a combination of mechanical chases, stairs, elevators, storage, and toilets. Mechanical services are in two chases each containing 600 square feet. The chase is 12' x 50' with the capability of bringing services out both 12' sides and one 50' side. A main circulation
corridor is always adjacent to this 50' side with secondary circulation corridors or lobbies facing the other sides of the cores. The main circulation is a permanent system of corridors and lobbies with corridors of 8' or 12' widths depending on the requirements. The system also has the capacity to accept a 4' corridor within the modular co-ordination of the building although initially a corridor of this width is not anticipated. This type corridor would have a maximum length of 25' before intersecting a larger circulation corridor.

Since the building is structurally stable after the completion of each main floor, the building would be constructed in stages similar to the Western Platform method used in wooden frame houses. The cast-in-place triangulated wall would be constructed by special staging from the main floor levels with the precast vierendeel units being placed after, post-tensioned, grouted. Then a flat slab is cast-in-place over the girders. While the building is under construction, some of the secondary girder units may be omitted to facilitate the bringing of materials and equipment up through the building since the large cantilever would make it difficult for a crane or boom to function without special provisions being made.

The mechanical services are supplied in two chases in every core which is spaced 100' o.c. Local fan rooms (8) exist on each main floor to reduce the duct work which would become enor-
mous if all air was returned to a central mechanical room before it could be recirculated. The 20% of new air required is supplied from the roof by means of the vertical chases. Each fan room would serve areas varying between 17,500 square feet and 60,000 square feet. The pipes are supplied from each core serving areas varying between 5,000 and 34,000 square feet. The spacing of the mechanical on a 12'-6" module with the main air duct supply and return occupies the two center units and main pipes in the two end units of the 50' bay. This places the main pipes over the main circulation corridors and the ducts which have the largest volume in the center of the span when the vierendeel units may have larger openings because of the decrease in shear. The air is supplied by a dual-duct, high velocity, air system. The building would be divided into zones varying between 17,500 and 60,000 square feet with a few centralized mixing boxes in each zone, but also having the flexibility of mixing boxes placed in individual spaces to accommodate local conditions. The exterior zone is handled also by air which is supplied at floor level. Due to the nature of the building and the shelter it provides to its own surface, the usual exterior zone doesn't exist and only the draft effect needs to be counteracted.

The use of a large structural module facilitates the use of larger length pipes and ducts which make the installation, changing, and maintenance of the mechanical services much easier.
Also the 5' structural depth provided is advantageous in this respect since the bulk of the mechanical services in this type of building are enormous. The normal services which must be accommodated are:

- hot water and cold water
- steam
- gas
- vacuum
- compressed air
- electricity 110 AC, 220 AC, 28-30DC
- telephone
- television cambles
- computer cables
- ventilation (fume) hoods
- waste vents and drains
- soil stacks and vents
- vacuum (maintenance cleaning)
- air supply and return
- toilet facilities (1 fixture/4,500 sq. ft.)

The columns are cross-shaped, therefore allowing for small mechanical services such as vents to be placed within the corners of the column.

The fume hoods will be placed and used primarily on the top floor of the building, allowing the vents to go directly through the roof since many of these hoods must be exhausted individually and cannot have horizontal runs.

The cooling towers are placed on the roof, situated between cores to facilitate easy supply and return of the water to the local fan rooms. The boiler is below grade and beyond the perimeter of the base. Services are supplied through a large sub-basement which is contiguous with all the cores. This level is used primarily for mechanical equipment, workshops,
and storage.

Illumination is provided by 3'-8" x 3' x 8" fluorescent units which are supported by the sub-system of steel channels. In large rooms the channels may run in only one direction to support the lighting units. In the smaller spaces the channels are two-way to provide flexibility of arrangement of lighting, acoustical panels and diffusers. Exterior rooms also have supplementary incandescent lights which are outside the glazing to provide for night lighting of the building but also to eliminate the distracting interior reflections that exist at night.

Horizontal isolation is used for acoustical control of the rooms except in special cases where horizontal isolation is undesirable. In such a case local solutions will be required due to the diversity of conditions. The acoustical units are 3'-8" x 3'-8" tectum coffers or panels, depending on local conditions within the building.

Partitions are of a wide variety due to the diverse functions, varying from executive offices to workshops. A system of modular panels with varying veneers will be used in office spaces. Exposed or plastered concrete block walls will be used in the workshop and laboratory spaces. All the partitions will carry either to a structural girder or be anchored to a steel channel giving a two-way flexibility.
The exterior envelope of the building is a structural wall which also provides sun and weather control for the exterior glazing. Exterior balconies surround the four main levels providing an exterior space for relaxation, but they are depressed so that the rail is not a visual barrier from within the building. The balcony railing also serves as a veneer for the spandrel girder of the wall to insulate the structure from the sun to help control the thermal expansion and contraction. This balcony also provides a means for easy maintenance of the glazing.

The attempt has been to use the existing parts and components of the systems to perform as many overlapping functions as possible and allowing the non-existence or voids of the system to be used for the integration of separate systems.

CONCLUSION:

Architecture cannot be an art; architecture cannot be construction; architecture cannot be a science; architecture cannot be a system. It must be a synthesis of all these aspects and their many components given strength and direction by an overall controlling idea.

The "system" cannot exist alone nor can the "idea", each needs the other in order to be useful and to have meaning.
Each responds to, modifies, and develops the other until a total synthesis is reached. It is hoped that this synthesis will provide a means and a direction in which to proceed.
June, 1964

Cambridge, Massachusetts

Dear Dean Belluschi,

I hereby submit the enclosed thesis entitled "Buildings as Systems" in partial fulfillment of the requirements for the degree of Master in Architecture.

Respectfully submitted,

Joseph Delano Hoskins

JDH/bjs
The building presented in this thesis, an academic research building for science and technology, is the result of an attempt to solve by rational and systematic means some of the more difficult problems facing architects today. Indeed, finding a suitable architectural expression which reflects our contemporary civilization in terms of correct building is the only means by which the state of confusion which exists in architecture may be overcome by the individual designer. Specifically, my aim has been to design an integrated structural and mechanical system of construction which provides flexibility in terms of space, circulation and services. At the same time, the system must yield results which will allow changes through use in order to forestall obsolescence. Finally it is hoped that the system has been elaborated into an architectural expression which has meaning for the society of today.
The primary objective is the development of an integrated mechanical-structural system of construction providing maximum flexibility and capability of future change. The following programmatic requirements were established:

1. A total gross floor area of 1,000,000 to 1,500,000 square feet.
2. Minimum area per floor of 40,000 square feet.
3. Constant ceiling height on each level, although floor to floor heights can vary.
4. Live load of 125 psf throughout.
5. Toilets, exit and elevator capacities calculated on 150sf of gross area/person.
6. Maximum distance to fire exits - 150 ft.
7. Planning module based on illumination requirements and minimum widths of rooms and corridors.
8. Local structural demountability for vertical expansion.
9. Accessibility of all utilities mandatory.
10. Noise control from room to room necessary.
11. Sun control as part of the unified solution.
In addition to these requirements, suitable space must be provided for:

1. Laboratories:
   a. Instructional
   b. Research
   c. Testing

2. Workshops

3. Classrooms

4. Seminar rooms

5. Small Auditorium

6. Studios

7. Drafting rooms

8. Departmental libraries

9. Administrative/Staff area

10. Faculty/Assistants offices

11. Lounges

12. Storage

13. Maintenance

14. Mechanical equipment.
One of the considerations which precipitated this design solution was the desire to use factory cast linear units of concrete. The size of the unit is such that it can be easily shipped by standard methods. At the same time the useful bay size is large enough to accept any possible function.

The resulting structural system is a series of mushroom units, 40' by 40' cantilevered from central columns arranged in checkerboard fashion in alternating squares. Other panels composed of units of the same size and with the same external appearance are arranged in panels 40' by 40' filling the structure and making a continuous system by means of a specially designed joint which can take any unbalanced moment. The basic unit then is a precast linear unit, pretensioned in either the top chord (mushroom units) or bottom chord (infill units).

The floor system which results is a two-way orthogonal grid with a network of perforations in the vertical members. The grid module is 5'-0" by 5'-0" with an effective depth of 4'-6". The
columns are on a rotated orthogonal grid at 45° to the sub-module and 56' on center. The bays at the perimeter have a cantilever of 20' all around on the typical floor. Rotating the 56' grid 45° results in a projected dimension of 80' between columns. Overall the building is seven bays of eighty feet plus cantilever, by five bays of eighty feet plus cantilever.

There are two typical sub-units which comprise the system. Both are approximately 40' long with cast in intersecting diaphragms on 5' centers. The units are "T" beams in typical section with openings for the mechanical services cast in in the area around the neutral axis. In the area over the columns, the units are pretensioned along the top for the negative moment, while the second type of unit which forms the infill panels is pretensioned in the normal way along the bottom chord. The units are joined at the point of zero moment by means of bolts which are grouted to prevent corrosion. Groups of units are post tensioned at 10' centers in the direction at right angles to the pretensioning, resulting in a slab which is continuous over spans of 80' and cantilevered 20' each way in the direction of the 40' dimension.
Columns are precast concrete, each comprised of two similar parts. Connections between the parts are welded and vertical connections are bolted and prestressed. The columns are hollow to allow the passage of storm water leader and drains and all the wet mechanical services. Fume hood exhausts too are carried in the columns and through the roof. Cores which have their own slab system are arranged throughout the building in such a manner that the maximum distance between stairs is 300'. Air risers, electrical closets, janitor closets, toilets are incorporated in the cores. Elevators and stairs are included in each core, and a service elevator is included in the cores which incorporate toilets.
MATERIALS

Precast concrete was selected over cast in place concrete for the following reasons:
1) Easy and speedy construction at the site.
2) Parts can be fabricated on a 24-hour basis.
3) Factory control of raw materials assures uniformity and high quality.
4) The shapes which best facilitate mechanical equipment passage are not easily formed on the site, and poor results even with experienced labor are likely to result, in poured in place concrete.

Additionally the building can be "weathered-in" quickly and the mechanical trades can proceed even during inclement weather without damage to the installation or physical hardship.
CONSTRUCTION

Precasting: Precast units will be made on a modified "T" beam precasting bed and steel forms. Steam curing, prestressing, factory control of raw materials and regulated conditions insure high strength, uniformity and predictable finish of the components.

Post-tensioning: Post-tensioning across the units can be performed by any of the proprietary methods, and adequate room is left for the jacks. The cables may be run in open slots which are later grouted by the topping slab or through cast in annular passages as indicated in the drawings. Since all cables are the same length, the Roebling method of post-tensioning with threaded-end cables may be the most satisfactory.

Erection: The erection procedure in very general terms may be outlined as follows:
1) Footings, basement, retaining walls, etc.
2) Columns.
3) Temporary supports across units.
4) Placement of units.
5) Post-stressing
6) Procedure repeated for infill panels.
7) Repeat 1)-6)
The topping slab is poured after the precast floor system is completed and serves a passive structural role as a shear plane. Since the entire structure is precast, construction is paced by the speed of assembly and not by the curing of the material. Mechanical systems are installed after the structure is completed, or after each floor is completed.

MECHANICAL SYSTEMS

The main air risers and returns are located in the cores and supply each floor from mechanical equipment rooms located in the basement and on the roof. The areas between the cantilevered construction (galleries forty feet on centers) are the main supply and return air branches. These are always served by an air riser of the correct function, tangent to the gallery. Both the branches and the main risers are sized on the basis of two square feet for supply and two square feet for return per thousand square feet of area served. Each supply branch has a complementary return branch in an adjacent module. The hollow columns carry the wet mechanical services and gas risers. Alternate galleries are allocated to
the plumbing supply. Incidental connections made in the plumbing in the individual laboratories are exposed. Fume hood exhausts also are carried in the columns to fans on the roof. Fume hood leaders are run exposed in the labs and connect at the columns through openings on the four faces of the precast columns.

Lighting fixtures and air diffusers are incorporated in the same sheet-metal construction which is hung between the rib of the precast structural system. The fluorescent tubes are four feet long (40 watt) and four per bay are used. Air is returned around the perimeter of the lighting-diffuser units. Acoustical control is provided where necessary in the same unit by completely closing the module. Daylight is provided by means of glazing around the perimeter and by lightwells and openings in the construction.

Mechanical equipment such as fans, boilers, pressure vessels, pumps, and compressors are grouped on one subterranean floor which connects all cores.

Partition positions are regulated by the five foot structural module. Details were developed which allow for both negative and positive deflection without damage to the partition.