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June, 1965

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Dear Dean Belluschi:

This thesis, entitled "PROTOTYPE BUILDING SYSTEM FOR A RESEARCH AND DEVELOPMENT FACILITY", is submitted in partial fulfillment of the requirements for the degree of Master in Architecture.

Respectfully,

Bruce McDonell
I would like to acknowledge the invaluable help and guidance of:

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I. BUILDINGS AS SYSTEMS

The systemization of a building at the design stage is essentially the integration of many diverse and often opposing systems. These systems can be thought of as flows...flow of stress through the structure, flow of services through the various mechanical systems, flow of occupant activity through the spaces defined by the building envelope. Each of these systems has an optimum flow which in almost all cases is multidirectional within a given volume, secondarily through a surface,thirdly through a line, and lastly confined to a point in space. Optimally, the flow of people within a building would be unrestricted horizontally and vertically for greatest flexibility. Optimally, the flow of stress in a structure would move in a direct vertical line to the ground from any point in the structure. For optimum use electrical fields should exist homogeneously in the space defined by the building envelope so electrically powered components would need no wires or plugs, and be unrestricted in the position of their use.

It is, of course, obvious that such optimum systems cannot coexist. Unrestricted horizontal flow of people makes any vertical transmittal of structural stress impossible, and the optimum structure would be a solid volume making human use impossible. It follows, then, that the need is for an integrated general system preserving as much as possible the optimal nature of the various component systems.

To achieve an integrated general building system it is, then, necessary to ask--and answer--two essential questions: What is the specific optimum nature of each of the component systems? And, since each of the optimum component systems must be compro-
mised to some degree to integrate with the others, what is the level of importance of each of the component systems within the general system, and how much can each be compromised?

The answer to the first question is obviously many lifetimes of study, and even then the answers are never static but constantly changing. One can only operate at the level of individual knowledge and the availability of expert advice.

The answer to the second question is in many ways unanswerable because of infinite variables and is subject in the last analysis to the ingenuity and creativity of the designer. However, certain basic principles can be stated.

In building, the primary consideration is the space enclosed and served by the building envelope. The nature of this space, its geometry, scale, its total environment are determined and dependent upon the building envelope. However, the envelope is the servant of the space. And, as such, is in secondary importance to the space served. Thus, the optimum nature of the space enclosed is the primary criteria for the establishment of the general building system, while the mechanical system, electrical system, structural system, etc. are servant in nature. As servants they must perform efficiently and must never detract from the primacy of the space molded to the human use involved.

Spacial use can be divided into two categories: highly specialized use with unique requirements; and general or universal use in which one particular function, with minor variations, is repeated on a large scale. Such universal spacial uses comprise by far the majority of buildings in use. Such building functions have two distinct and important requirements: flexibility and growth;
flexibility to achieve an infinite variety of spacial arrangements to suit variation of the function, and growth to allow expansion (or contraction) of the function consistent within a general system in harmony with the function.

A general system for such a universal use space can, therefore, have component systems used repetitively, allowing only for variety of spacial orientation and allowing economy and perfection consistent with a mass-production technique.
II. GENERAL DESIGN CRITERIA OF THESIS

The subject of the thesis is the design of a building system for a Space Research Facility. The Research Facility is to be designed with a floor area of approximately 600,000 sq. ft., and is to allow for expansion. Future expansion of the facility should not deform or cause special conditions within the system.

A. SPECIFIC SPACE REQUIREMENTS

Space should be provided to accommodate research labs of varying sizes, individual and general office space, workshops and storage space. Public and semi-public spaces such as lobbys, library, restaurant and meeting rooms should also be provided. It is possible only at a specific instant in the life of the building to define a given size, number and shape to all of these various spaces. In a research facility of this kind, change is the only constant factor. As research projects advance from conception to completion, and as new projects of different scope are initiated the size and relation between various spaces will also constantly change. Public spaces will also reflect this change. It is, therefore, necessary to design a system to allow for internal change, as well as external expansion.

B. FLEXIBILITY

As has been seen, flexibility is the crucial element in the space requirements. Horizontal flexibility dictates long span structures and consolidation into cores of other vertical elements such as stairs, elevators and mechanical chases to minimize interruption of horizontal flow of activity. Vertical flexibility should allow varying floor-to-ceiling heights.
Certain laboratories, as well as various public areas, will need large vertical spaces.

Certain of the component systems have varying requirements of flexibility. The structure, cores and major mechanical chases are considered as permanent systems and are not affected by the constant change of functional spaces. The local mechanical services, lighting, acoustical treatment and partition systems are temporary in nature. They are constantly affected by change of the functional spaces, as well as by technological advances and are, therefore, to be designed to be easily rearranged or replaced when obsolete.

III. SPECIFIC DESIGN CRITERIA OF THESIS

Stairways: Access to an enclosed fire stair should be a maximum of 150 ft. from any point in the building.

Elevators: A minimum of two service elevators (8'-0" x 10'-0") and 10 passenger elevators (5'-0" x 7'-0") should be provided.

Building occupancy: to be figured at the rate of 1 person/300 sq.ft. of floor area (60% men, 40% women).

Floor to ceiling height: should be 10'-0", except at areas of special use.

Structural span: should be not less than 40'-0"

Janitor closets: should be figured at the rate of 1 sq. ft./1000 sq.ft. of floor area.

Electrical closets: should be figured at the rate of 1.4 sq. ft./1000 sq. ft. of floor area.
**Restrooms:** provide a minimum of one w.c./30 people; urinals and lavatories can be figured at 75% of this rate.

**Air Conditioning:** The velocity of supply and return in a low velocity system should be 1000 C.F.M.; high velocity supply only should be 4000 C.F.M. maximum. For interior zones, coverage should be figured at the rate of 1 sq. ft. of duct/1000 sq. ft. of floor area served for supply and return with a low velocity system. Exterior high velocity zones should be a maximum of 15 ft. in width.

**Mechanical Room:** With a central supply system, the mechanical room should be 10% of the total floor area served.
Each of the component systems within the building has distinct optimum requirements. However, certain of the systems develop similar and related requirements that suggest a close integration. The spacial use of the building suggests large, open, horizontal surfaces, with a very flexible partition system. To reflect this flexibility, the structural system is a uniform two-way grid and the mechanical services are brought to every point on the grid. Since the structural and mechanical systems are so closely integrated it follows that they have the same vertical point of support and supply: the column. This, then, frees both systems from a direct and restrictive relationship to the core. The core becomes a consolidation point for all other permanent systems, and its placement then depends on its own module (240' on center, due to fire stair regulations) and not on a direct relation to other systems with different requirements. This organizational system allows a great flexibility in the design of the building since the self-sufficient planning unit is one tributary area of column and floor (60' x 60' with appropriate edge conditions at the cantilever). The planning unit's relationship to the core is one only of distance, and not one of size, shape or spacial disposition. The lack of rigidity in spacial organization of the integrated structural and mechanical systems is obvious.

A. STRUCTURAL SYSTEM

The structure is a two-way, two-dimensionally triangulated, poured-in-place system, based on a 6'-8" module and designed as a flat slab with excess concrete removed. As has been said, the two-way system more accurately reflects the freedom and flexibility of the spacial use. The span has been made as
large as possible (columns 60' on center) to achieve maximum uninterrupted horizontal space, without excessive deflections. The minimum depth of the structure (3'-6") was set by the space necessary for the flow of mechanical services between the upper and lower chords of the structure. Triangulated members separate the upper and lower chords of the structure. Thus, horizontal shear is taken in either tension or compression, and no secondary moments develop within the slab. The triangulation is within two-dimension vertical planes and is, therefore, more efficient than three-dimensionally triangulated structures in that a triangle on the face of a cube of a given dimension achieves larger angles than triangles forming a pyramid of the same size. The increased angle achieves greater structural efficiency for a structure of given depth. The diagonals in this structure are one half of those in a pyramidal structure due to its geometry, and are shorter, minimizing buckling.

The module of 6'-8" was chosen because two modules (13'-4") is the minimum comfortable laboratory width, one module is a minimum corridor width to permit passage of people in two directions, two modules represents a comfortable public corridor, one-half module (3'-4") accommodates a doorway with frame and is a good storage depth, and one and a half modules (10'-0") is the floor-to-ceiling height.

The decision to develop a poured-in-place structure was based on the economy possible with this method, as well as an attempt to develop a new method of forming that could achieve the efficient structural shapes now possible only with the more sophisticated methods of forming used in pre-cast concrete. The
forms developed are fiberglass and are light enough for one man to handle. They are placed from below after the reinforcing cage is assembled, permitting more efficient steelwork.

B. ERECTION SEQUENCE

The columns are always poured one floor above the previously poured floor. Special prefabricated scaffolding provides point supports only for the steel work and forms. Reinforcing cages are preassembled on jigs and are lifted onto the point supports. The fiberglass forms are then connected to the point supports and rotated into position from below and locked in place. After the concrete has set (one or two days) the fiberglass forms are removed from below and are reused elsewhere. The concrete cures while being prevented from vertical deflection by the point supports. Fire cover for the lower chords in tension is provided by a precast member installed after the concrete has cured. This prevents cracking of the concrete at transition points into the diagonal members. The precast member also allows a more finished surface at the point where the structure is exposed at the ceiling.

C. MECHANICAL SYSTEM

The low velocity, supply-return air conditioning system is contained in the columns as well as are the pipes and both serve all of the tributary areas of the column. Such a system means short horizontal runs for both the ducts and pipes, minimizing the depth of the space in the floor necessary for their passage. Since this depth usually dictates the structural depth, the advantage is obvious.

Perimeter zones will be reinforced by a high velocity system
with no return duct. The resultant over-pressure will prevent outside air of a different temperature or dust from entering the building through small openings, cracks or doors.

The mechanical room is located in the basement and feeds up the columns. The cores carry exhausted air to and fresh air from the roof, as well as special pipes and ducts that are used only in certain areas of the building.

D. OVERALL BUILDING

The building conceived within this system has two levels of scale that illustrate the flexibility of the system. The lower floors are irregular in plan, reflecting special uses: lobbies, entrances, etc. Man's ability to feel and set limits to a space declines as the limits of the space recede from him. The lower portion of the building, then, reflects more of a human scale and as the building rises, forms and spaces become more regular and, therefore, more easily definable from a distance. The upper portion of the building then becomes a strong form that organizes the more intimately scaled spaces below, creates a "statement" definable at the urban scale of highways, bridges, and great distances, and forms a nucleus that controls and is dominant over future growth and expansion of the Research Facility.