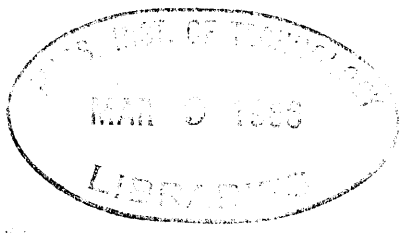


A BUILDING SYSTEM

BASED ON GROWTH

by

JAMES ROBERT BONAR

B. ARCH., UNIVERSITY OF SOUTHERN CALIFORNIA

(1964)

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER IN

ARCHITECTURE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1965

Signature of Author .....
James Robert Bonar

Certified by .....
Eduardo F. Catalano
Thesis Supervisor

Accepted by .....
Lawrence B. Anderson
Chairman, Department of Architecture

June, 1965

Pietro Belluschi, Dean
School of Architecture and Planning
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Dean Belluschi:

In partial fulfillment of the requirements for the degree of Master in Architecture, I hereby submit this thesis entitled, "A Building System Based on Growth."

Respectfully,

James Robert Bonar

ACKNOWLEDGEMENTS

I am grateful to the following persons for their invaluable advice and assistance during the development of this thesis:

Professor Eduardo F. Catalano - Thesis Supervisor

Mr. Leon B. Groisser - Structures

Mr. Waclaw Zalewski - Structures

TABLE OF CONTENTS

INTRODUCTION 1

AIMS OF THESIS 2

GENERAL CONSIDERATIONS 2

SPECIFIC REQUIREMENTS FOR DEVELOPMENT OF THE THESIS 3

ORGANIZATION OF ACTIVITIES AND SPACE 6

GEOMETRY AND SPATIAL HIERARCHY 6

CEILING HEIGHT AND MEZZANINES 8

STRUCTURAL SYSTEM 10

BASIC UNIT 10

VERTICAL SUPPORTS 10

SLAB 12

SELECTION OF SPAN AND COLUMN SIZES 14

CORE 15

MEZZANINE 16

SEQUENCE OF CONSTRUCTION 16

SYSTEMS OF ENVIRONMENTAL CONTROL 19

DISTRIBUTION OF SERVICES 19

CALCULATION OF AIR DUCT SIZES 20

PIPING OF LIQUIDS AND ELECTRICITY 21

ILLUMINATION 21

ACOUSTICAL ISOLATION 21

ENCLOSING WALLS 21

PHOTOGRAPHS OF DRAWINGS

INTRODUCTION

Large scale contemporary building, as structure, is capable of withstanding centuries of use and exposure. However, as spatial arrangement or mechanical system, it ceases to function effectively after very few decades. This short lived utility occurs because new standards are induced by technical and social innovation. Reorganization of space and services, inhibited by structure, can not adapt well to the new requirements and obsolescence results. Thus the measure of a building's life in terms of adaptability rather than physical endurance may be the pre-eminent value.

This thesis is concerned with the consideration of adaptation over time. It develops the idea that building can be advantageously conceived as an integration of its components into a system capable of responding to growth. It embraces a concept of building system wherein the assemblage of interrelated entities of structure, mechanical services, and spatial order are conceived in terms of adaptation to change: i.e., growth wherein the added increments are assimilated into and enrich the life of the total organization.

AIMS OF THESIS

The aim of this thesis is to develop a building system that, defined by functional criteria resolved into an integrated system of construction, will produce a building of enduring usefulness and positive architectural expression.

By exploring the needs of a building type requiring a substantial size and having complexity in spatial relationships and services, it is felt that the utmost involvement in the problems of solving a building as a totally integrated system based on growth can be achieved. The specific problem is the design of a building system to produce 600,000 square feet gross floor area to be used for the development of scientific and technological ideas for furthering the exploration of space.

GENERAL CONSIDERATIONS

To satisfy the functional criteria, the system will have to accomplish the following general requirements.

1. Provide for maximum flexibility in initial use location plus adaptability to changing future use through the development of large uninterrupted floor areas modularly ordered for subdivision based on consideration of optimum space sizes, distribution of air and illumination, accessibility to utilities, control of noise and sun, and handling of component parts.

2. Provide for systematic growth of the building through geometric articulation of space and through construction techniques that facilitate inclusion of reasonably small increments of addition into the life of the building or that allow the assimilation of the building into a larger scale development.

3. Provide for the integration of the variety of mechanical services and the structural parts such that they serve spaces as a unified system.

4. Produce a building system realizing our technolgical capabilities and economic limitations through the application of imaginative and responsible engineering.

SPECIFIC REQUIREMENTS FOR DEVELOPMENT OF THE THESIS

The following is a summation of limits assumed at the outset of the problem or developed by analysis of the building type.

Building Area: Approximately 600,000 square feet gross area.

Building Population: One person per 200 square feet; approximately equal percentages of male and female occupants.

Structural Span: Not smaller than about 40 feet for the purpose of developing adequately sized flexible space; not larger than about 60 feet to maintain reasonably economical structural section.

Live Load: 100 pounds per square foot of floor area.

Material and Method: Cast in situ concrete. Concrete is selected because of a desire to explore its positive quality of durability which allows it to be at once the basic structure, fireproof,

and the finish material. The cast in place method is chosen in order to investigate the possibilities of standardization of forming techniques at the site.

Smallest Useable Office Space: Ten feet width.

Horizontal Modular Order: Five feet. This dimension is selected to accomodate standardized commercial lighting components, to produce the smallest acceptable office space, and give a reasonable increment for growth of the flexible space. No more than two adjacent floors may be connected vertically with openings not protected against the passage of the heat and smoke from fire.

Activities to be Housed:

Laboratories and work shops that may develop three-dimensional components in all stages preceding final production.

Computation centers.

Auditoria.

Cafeterias.

Libraries.

Offices and conference rooms.

Automobile storage.

Permanent Service Spaces to be Provided:

Passenger and service elevators. See Graphic Standards for quantity criteria.

Stairways: Every point in the building must be within 125 feet radius of one fire stair and have access to a second. Fire

stairs shall be enclosed and not farther apart than 300 feet.

Restrooms: Provide for a minimum of one toilet fixture for each 30 persons served. For men the number of fixtures may be equally divided between urinals and toilets. The number of lavatories will be equal to not less than 75% of the fixtures provided.

Janitor Closets: Minimum of 50 square feet per 3,000 square feet of floor area.

Electrical Closets: Minimum 50 square feet per each 3,000 square feet of floor area.

Permanent and Temporary Services:

Air conditioning (heating and cooling): Duct spaces to be sized at the rate of two square feet per 1,000 square feet of floor area served (includes supply and 100% return). For induction units, .25 square feet per 1,000 square feet can be used.

Artificial lighting.

Acoustical control of noise transfer between activities.

Miscellaneous relatively small scale utilities including fire hose outlets, drains, hot and cold water, natural gas, vacuum line, compressed air, internal communications, and electrical current systems.

ORGANIZATION OF ACTIVITIES AND SPACE

The following are the considerations leading to the development of the system's geometry and spatial hierarchy:

1. The relationship among activities: laboratory to laboratory, laboratory to office, services to served spaces.
2. Relation to contemporary technology and methods of construction.
3. The organization as perceived by the people who move in and around the environment. Provisions for a coherent order with a sense of stability through changes in time are sought.
4. Flexibility, adaptability, and growth.

GEOMETRY AND SPATIAL HIERARCHY

The automobiles occupy two levels below the laboratory-office floors approximating the elevation of the adjacent grade. This placement facilitates access to streets and the possibility of assigning each person vehicle storage close to his office or laboratory activities. The automobile levels are linked to one another vertically by two ramps for the cars and by five cores placed equidistant apart.

The cores provide vertical circulation throughout the building for all large scale services including people, equipment, and low velocity air. Small scale vertical circulation of structure, drain lines, and high velocity air takes place within the structural supports.

Spatial continuity among the laboratory-office floors is developed by omission of floor elements at selected positions within the geometric system. The first and second floors are opened to one another by the

largest space. This occurs at the centroid of the plan. The third and fourth floors are connected by two open courts and smaller scale spaces located about the centroid. The upper and lower floors are linked by the introduction of natural light passing through the courts into the larger scale space.

The strongest order of the plan is the relationship between core and structural bays surrounding it. Each core faces four spaces of 60'0" clear width. These extend at least 90'0" from its face uninterrupted. The clusters are self-sufficient planning modules based on considerations of reasonable structural span, cross sectional area of ducts that will remain within the space between structural members, maximum distance to fire stairs, and a reasonable scale and geometry for growth increments.

The geometry of this cluster allows the units to develop spatial continuity with one another directly in addition to circulation around the core. It also orients the center span of the slab toward an advantageous position for air movement risers within the core. This means that the largest volume of horizontal air movement occurs where there is the least need for volume of structural material. Finally, this geometry provides for systematic growth by units as small as one structural bay without altering the character of the building as a whole.

At scales larger than one cluster, the circulation always relates the cores to the larger scale spatial foci previously mentioned. The

necessity to always refer to these spaces is a disadvantage of the geometry of spiral clusters because it lacks the ability to create direct linkage of the cores. As the building grows it tends to make circulation roundabout or chaotic. In this design the problem has been partially overcome by placing structure on a two way modular order of 30'0". This allows more direct circulation between the peripheral points of the building.

CEILING HEIGHT AND MEZZANINES

The laboratory-office floors provide spaces of floor to ceiling height of 16'0". This dimension is valuable in developing the environment for each of the facilities to be housed. The computation center requiring extensive and continuous revision of services under the floor plane will introduce panelized walking surfaces. Similarly, the sloping or stepped planes for auditoria may be developed within the 16'0". Laboratories having facilities that require overhead service have adequate access. The generous ceiling height will visually enhance the larger laboratories and secretarial spaces.

Where smaller, more cellular spaces are required for offices and storage facilities, short span (15'0") mezzanine floors may be hung to produce two spaces of 7'6" clear ceiling height. The mezzanine floors may make large areas of service space contiguous with their laboratories.

If the mezzanines are programmed into reserve, they may provide an economical means of growth with a minimum of disruption of the building as a whole because this growth has a minimal connection to

the permanent building systems of mechanical services and structure. It also affects only those local zones receiving it.

STRUCTURAL SYSTEM

The following are the considerations leading to the development of the structural design:

1. Development of complete and independent structural units for future growth by increments.
2. Supports spaced to provide flexible floor areas.
3. Develop geometry to integrate mechanical services into the structural order and to serve each division of space in as equal manner as possible.
4. Develop an order for circulation of people implied by the location of permanent structure.
5. Develop a cast in place concrete system that will utilize our 20th Century technological potential for standardization of parts and mechanization of methods.

THE BASIC UNIT

The basic structural unit is composed of a slab and four supports. The slab is a plate 105 feet on each side and equally stressed both ways. It is four feet deep and presents a flat upper surface and a coffered under side corresponding to a five by five feet modular order. The plate rests on supports located at the four corners of a square 65 feet on a side and 20 feet in from its periphery.

THE VERTICAL SUPPORTS

The supports are clusters of vertical members tied together horizontally at each floor. They serve to: 1) transmit all load

vertically to the foundations, 2) convey small scale mechanical services vertically (perimeter high velocity air supply, fire hose lines, drain and vent lines, and miscellaneous small pipes), 3) relate structure to the modular order of activities in order to produce maximum flexibility.

Integration of the columns and modular is achieved by confining the structural material to the horizontal module of 5'0" by 5'0". The actual size of each cluster is 4'10" by 4'10". This allows substructure, the mezzanine floors and wall partitions to develop adjacent the column in the same manner of connection as at any module.

For their vertical run, the mechanical services within the column are confined to an area 2'10" square at the center of the cluster. They make the transition between vertical and horizontal within the same space and leave the column for the horizontal run through small (1'4") openings into the coffers of the slab. Access to the vertical duct space for servicing is gained by concentrating the structural material at the four corners of the cluster. At the lower parking floors, where the stresses in the columns are very high and the requirements for servicing is minimal, this opening is 1'4" wide. In the upper laboratory floors where more services and frequent access are required, the structural stresses are lower and a 2'10" wide access is achieved.

The principal job of the supports is to transmit the dead and live loads vertically down to the foundations. To do this the structural concrete and steel are placed at the edges of the column module. On the highest floor, the section consists of four 1'0"

square shafts of concrete and steel placed at the corners. The section is continuous for two floors down for simplicity of detailing, handling, and erection. At the top two floors each shaft contains one equal leg "X" section oriented to facilitate the flow of concrete around it. The first and second floors have an equal area of steel added, one half to each of two sides of the shaft to produce an "L" section. At the three lowest levels, a final increment is joined to the legs equal to the previous addition. The rate of force growth in the columns is slowed at the parking floors by an increase in the frequency of supports. At these levels the slab is supported by columns thirty feet center to center each way.

The concrete section is increased by the addition of 2 inches of material on two sides of the shaft for each laboratory floor and one inch for each parking floor. The response of the concrete column to increase in stress at every floor is easily made by repositioning elements within a reuseable formwork.

THE SLAB

The slab design is selected to respond to forces in the same three categories as the supports. It must: 1) convey forces from load horizontally to the supports, 2) order the distribution of mechanical services, 3) define a modular order for the organization of diverse activities.

For the collection of loads the slab acts as a two way system. Within the limits of a rectangular geometry and a single operation cast in place process the ribs are articulated to radiate out from the column placing concentration of material at the points of greatest stress.

The transition of loads from the horizontal slab to the vertical support is made within the three module by three module (15' by 15') portion of the slab surrounding the column. This is organized to act as a column capital or shear collar. Shear is taken from the corners of the capital by diagonal tensile members to eight shear members, two projecting out from each of the four sides of the column.

Outside of the shear capital, the diagonal located in the vertical walls of each coffer, stiffens the corner nearest the support. This produces a rigid frame which responds systematically to the decrease in shear force moving away from the support.

Toward the mid span the methods of casting, more than the stresses, determine the size and placement of the web members. Because the concrete, to develop high strength characteristics, must be stiff not liquid, the slab is formed to facilitate ease in pouring. The thickness of the slab is governed by the need to collect loads but also the desire to envelop within its configuration all of the mechanical services. The resultant depth to span ratio is 1:15. This allows sufficient space between top and bottom chords for all air movement and miscellaneous pipes. The larger scale services (low velocity air supply and return) utilize the large openings at mid span for their main run and work out toward the supports where openings between coffers are greatly restricted.

The rectangular geometry of the coffers wherein no diagonals appear in plan section permits the service of each modular unit equally by light fixtures and air diffusers. The use of an order incorporating more triangulation would have yielded a more efficient load

carrying structure. However, the savings accruing here would be lost because of the inflexibility resulting from variations in the standard modular units that make exceptions to the system of mechanical service.

The in-economy of structural action inherent in the rectangular order is further compensated by the use of standardization in the casting technique. All coffers are formed by an identical reuseable frame and four inserts that produce the varying sized openings connecting coffers.

SELECTION OF SPAN AND COLUMN SIZE

The following are the considerations leading to a Composite Steel and Concrete Column and a Maximum Basic Unit Span of 60'0".

The decision to place some mechanical services in the 5' by 5' column, even though they are both few and of a small scale, resulted in a column section primarily steel. To achieve a column section of reinforced concrete (i.e., less than 10% steel) would have compromised the effectiveness of the building system as a whole beyond reasonable limits. The column section to be 90% concrete and carry the stresses produced by slabs of the selected size requires two modules (10' by 5') developed either into a part or all of four modules to preserve the two way action of the slab system. If the column occupied only a part of four modules it would render sixteen modules per unit exceptions to the modular system. This would frustrate standardization of mezzanine floors, wall partitions, lighting fixtures, and possibly

air distribution. If each column were developed to occupy all of four modules and the span remained constant it would substantially inhibit flexibility. Because of the increased ratio of area of structure to space (presently 1:110 as opposed to 1:30) an increase in span that could produce a better ratio would have two important disadvantages. First it would make the basic unit larger and therefore less reasonable as a relatively small increment of growth. The present area is 105 modules square or 11,000 square feet per floor. To produce the same ratio with sixteen modules of structure would yield an area four times this size. Second, within our technology, 60'0" is not an insignificant structural span. Most examples of similar building types use smaller spans . It therefore appears that this design already approaches the limit of economy of an uninterrupted floor system at this time.

CORES

The core is a self-sufficient structural element that occurs at the void made by the cluster of four slab units. The walls at the core periphery and those defining stair and elevator shafts within its volume provide the vertical structure. Because these walls must meet high standards of fire resistance and are relatively permanent, it is most reasonable that they also become the structure. Their configuration is simplified to produce economy in construction. Non-bearing partitions that rest on short span flat slabs provide access to mechanical equipment and develop the more complex divisions of space.

MEZZANINES

The mezzanine floors are 5'0" by 5'0" by 1'0" deep steel and concrete sub-structural units. Tied together by tension cables at the lower chord, they are capable of spanning 15'0". Lateral stability is provided by diagonal cables at the modular line. These become concealed where partitions are installed.

SEQUENCE OF ERECTION

1. Excavation and laying of foundations.
2. Casting of the cores by step forming and the use of hammer-head cranes.
3. Casting of floor slabs and their vertical supports.
   a. Demountable steel scaffolding is erected for the area of one structural unit. This scaffolding has vertical members modulated to correspond to the corner points of the slab coffers thus providing dimensional control for the system.
   b. 5'0" by 5'0" reinforced plastic forming pans are attached to the vertical members of the scaffolding at walking level and then elevated into final position. These forming pans are identical throughout the unit. The changes in section corresponding to changes in stress and the edge conditions are developed by the addition of a variety of secondary form elements. The reason for this procedure is that it produces significant economy of formwork. The basic form is large, is

difficult to handle, is more subject to damage and must remain as the support for the concrete for some time. Therefore, it has been reduced in complexity and weight by providing secondary forms. The more complex secondary forms can be fewer in quantity because they need remain in place for a very short time.

c. Placement of steel reinforcing.

Slab reinforcing for one unit is composed of nine 35'0" by 35'0" prefabricated steel cages that joint at the points of moment inflection. These cages are also supported by the 5'0" by 5'0" modular order of coffer intersection points. This enables the reinforcing to rest on the steel tube that will later serve as the hanger device for mezzanine floors.

d. Placement of electrical conduit and other inserts.

e. Placement of secondary or web forms according to the pattern of stress and edge conditions.

f. Concrete placement. The concrete pour is executed solely from the top side of the form.

g. Removal of secondary forms following shortly after the concrete set.

h. Removal of the primary floor pans following sufficient curing to allow the slab to rest on the scaffolding.

i. Removal of scaffolding.

5. Application of enclosing elements.

6. Application of substructural partitions and mezzanine floors, mechanical services, and finishes.

SYSTEMS OF ENVIRONMENTAL CONTROL

DISTRIBUTION OF SERVICES

Consideration leading to the development of the system of distribution:

1. Develop an order for the service of each division of space in as equal a manner as possible.
2. Coordinate the order of mechanical service with the geometry of permanent structural elements.
3. Develop a system that will facilitate future growth and revision.

The principal vertical distribution of mechanical services occurs within the cores. Some small scale services are circulated vertically within the structural supports. All horizontal distribution takes place within the top and bottom chords of the floor slabs.

Mechanical equipment is located in penthouses above the cores. This location has the disadvantage of making replacement of very large pieces of equipment difficult, but also has two favorable attributes that favor it as most reasonable. 1) The roof level is a continuous surface. This allows the concentration of all equipment at one generous level for ease in maintenance. 2) Fresh air is readily accessible. Space within the building need not be given over for the access to fresh air and combustion air.

AIR MOVEMENT

Movement of air is divided between the vertical risers within cores and those within columns. The core distributes the low velocity

supply to the interior zones and collects all return air. The supports carry only high velocity supply to induction units at the building periphery.

Horizontal circulation of high velocity air from the mechanical room to the column occurs within the roof slab coffers and is thus protected from exposure to the weather. The principal concentration of horizontal low velocity air occurs at the least dense spaces within the structure. It circulates as a large volume, only within the core and mechanical room.

CALCULATION OF AIR DUCT SIZES

High Speed Air Supply:

$$4000 \text{ ft./min} = \frac{.25 \text{ ft}^2 \text{ duct area}}{1000 \text{ ft}^2 \text{ floor area}}$$

Low Speed Air Supply and Return:

$$1000 \text{ ft./min.} = \frac{1 \text{ ft}^2 \text{ duct area}}{1000 \text{ ft}^2 \text{ floor area}}$$

Supply:

Periphery Zone

Maximum Area at Each Column Riser:

20'0" x 50'0" = 1,000 ft^2 floor area/floor

(1000 ft^2) (.25 ft^2/1000 ft^2) = .25 ft^2/col./floor

(.25 ft^2) (4 floors) = 1 ft^2/ col.

Interior Zone

Maximum Area at Each Core Riser:

90'0" x 90'0" = 8,100 ft^2 foor area/floor

(8,000 ft^2) (1 ft^2/1000 ft^2) = 8.1 ft^2/floor

(8.1 ft^2) (4 floors) = 36.4 ft^2/riser

Return:

Maximum Area at Each Core Riser:

100 ft^2 x 100 ft^2 = 10,000 ft^2 floor area/floor
(10,000 ft^2) (1 ft^2/ 1000 ft^2) = 10 ft^2/floor
(10 ft^2) (4 floors) = 40 ft^2/riser

PIPING OF LIQUIDS AND ELECTRICITY

The basic and more permanent services such as electricity, communication lines, and soil lines are located within the central riser of the core. Electrical and telephone equipment rooms are provided above the toilet rooms at each floor.

Other services, such as sink drains and fire hose cabinets require a homogeneous distribution at closer intervals than the core can provide. These are located at the supports.

ILLUMINATION

The structural module is planned to receive a standard size fluorescent lighting fixture of 4'0" x 4'0" between its bottom chords. The number of fixtures and their capacities is developed according to the programming of the space.

ACOUSTICAL ISOLATION

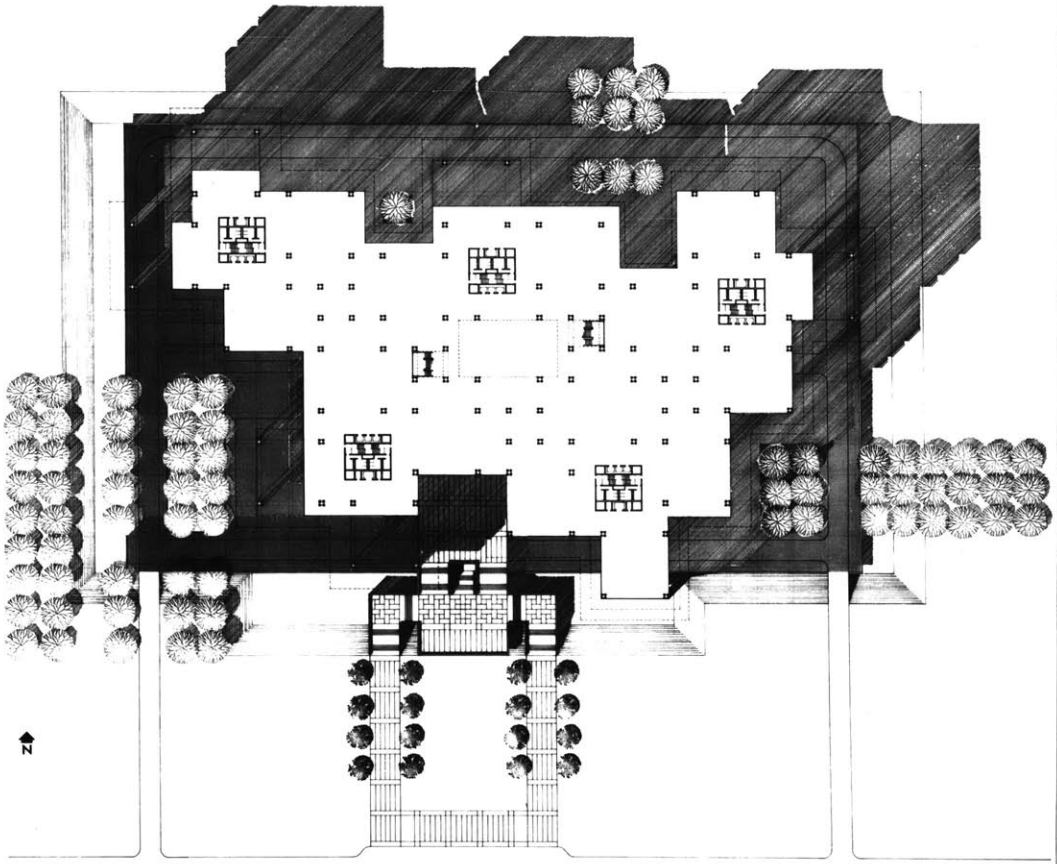
Acoustical isolation is developed by vertical partitions, by the mezzanines and by the addition of horizontal panels between the bottom chords of the slab.

ENCLOSING WALLS

The enclosing walls are of two kinds and of contrasting nature.

The lower two floors are simply sheathed in glass. They make no recognition of the mezzanines except for a sill which remains approximately within the same plane. At the two upper floors, the enclosure is composed of the glass and precast concrete elements that shade the upper one half of the facade at both levels. The concrete elements hang at two points from the slab above them. Their length corresponds to the height of the mezzanine and they are stabilized horizontally at the elevation of that floor.

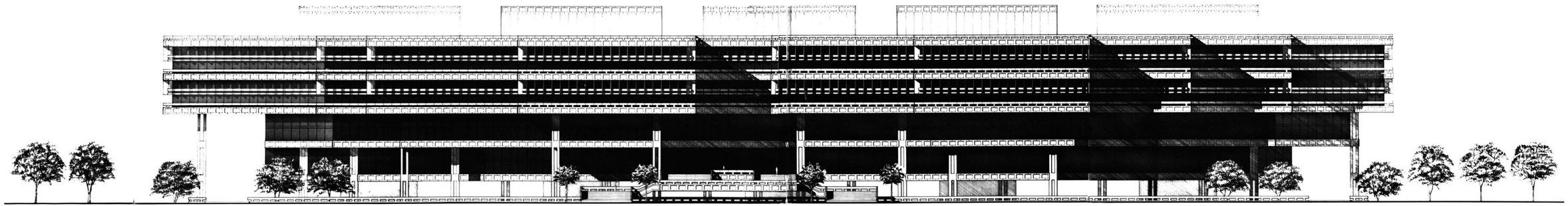
The purpose of this horizontal division is to develop a control over the visual quality of the system's growth by establishing a constant or stable reference. The upper floors provide this constant because, when viewed from the ground, they present a visually perceptible order within their undulation. This occurs because their relationship to the columns always remains the same. On the other hand, the lower floors more freely change their relationship to the columns and to one another. Their order is seen by reference to the floors above them. Growth by the peripheral addition of relatively small scale increments is thus accommodated with little difficulty at the lower floors while maintaining the basic character of the building.



FIRST FLOOR PLAN

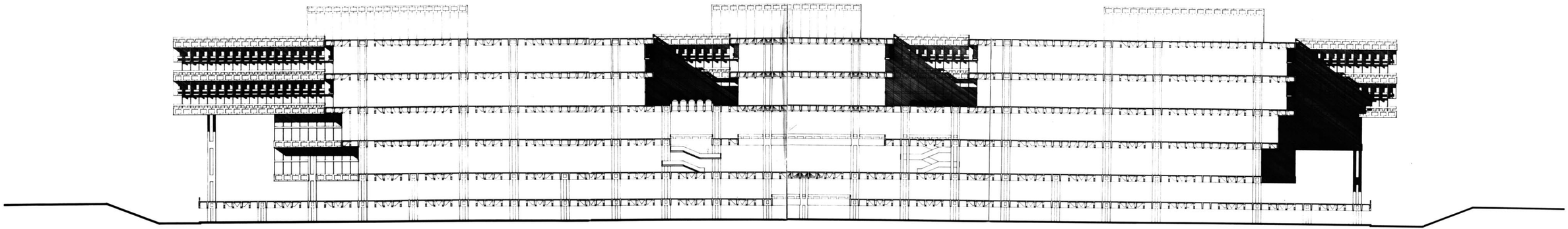
0 20 40 80 FEET

A BUILDING SYSTEM BASED ON GROWTH
FOR RESEARCH LABORATORIES : MASTER IN ARCHITECTURE THESIS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY : JUNE 1965 : JAMES R. BONAR



SOUTH ELEVATION

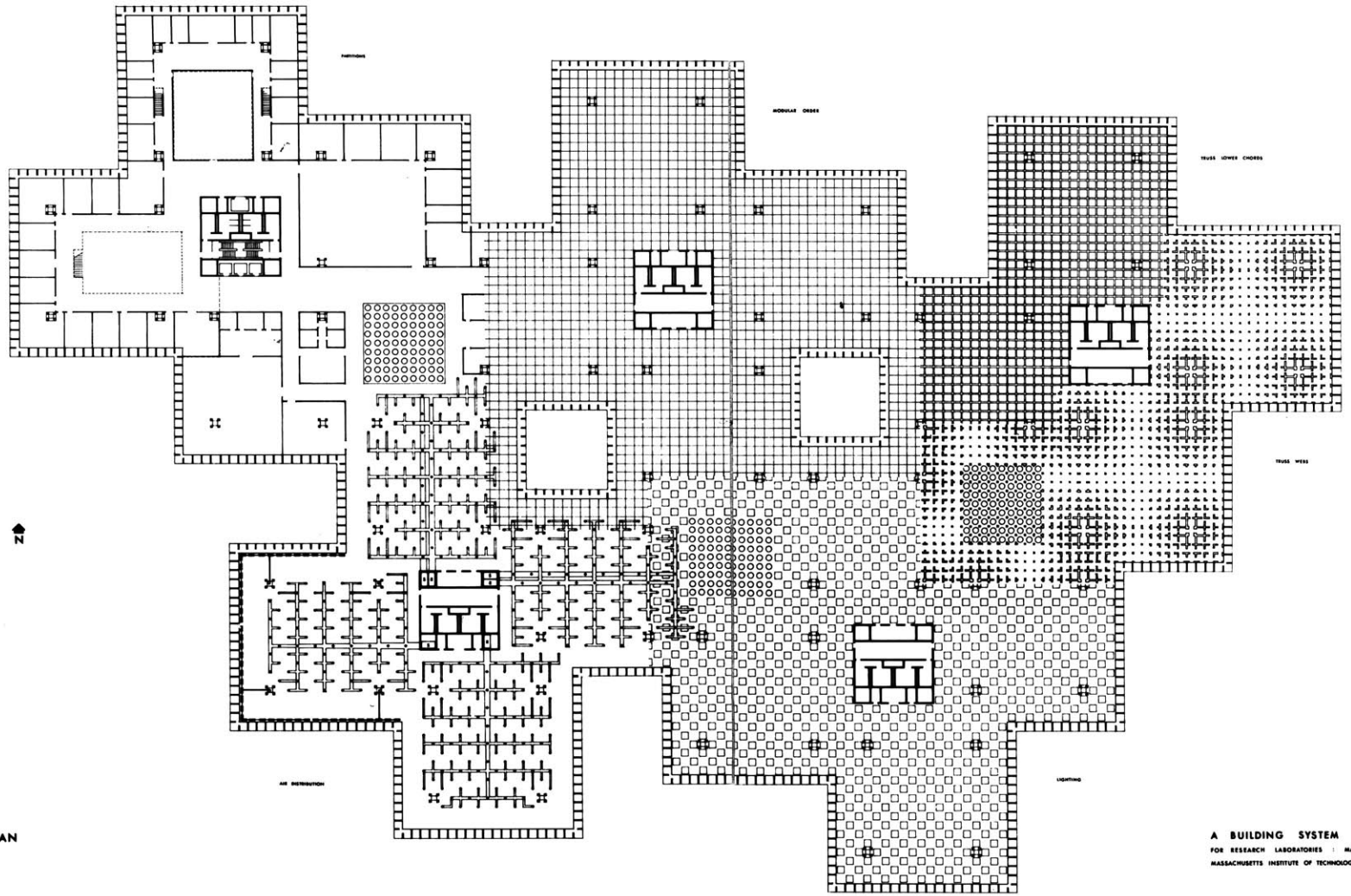
A BUILDING SYSTEM BASED ON GROWTH
FOR RESEARCH LABORATORIES MASTER IN ARCHITECTURE THESIS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY JUNE 1965 JAMES R. BOWAR



BUILDING SECTION

1/64"

A BUILDING SYSTEM BASED ON GROWTH
FOR RESEARCH LABORATORIES MASTER IN ARCHITECTURE THESIS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY JUNE 1965 JAMES R. BOHAN

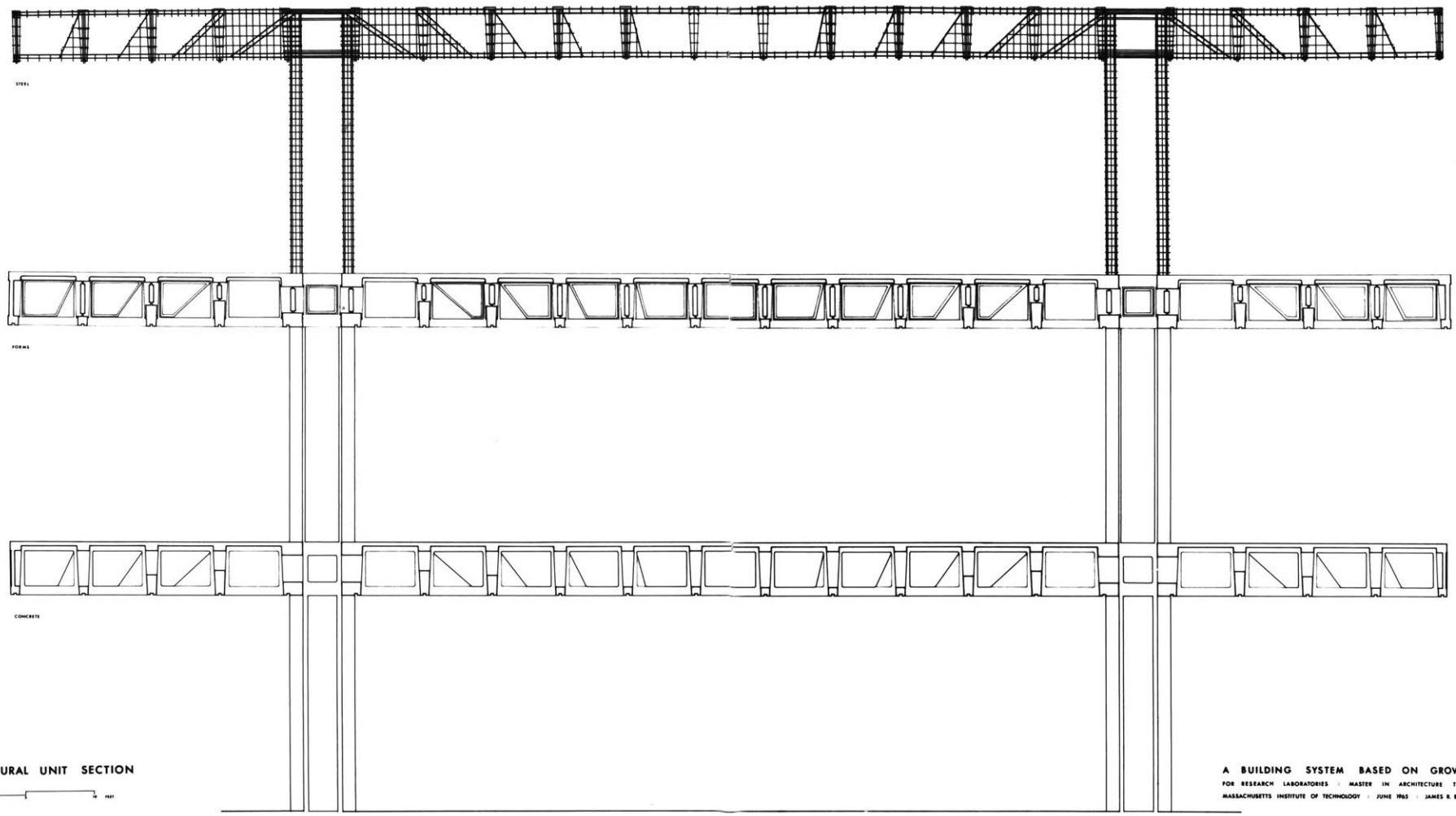


FOURTH FLOOR PLAN

A BUILDING SYSTEM BASED ON GROWTH

FOR RESEARCH LABORATORIES : MASTER IN ARCHITECTURE THESIS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY : JUNE 1965 : JAMES R. BONAR



STRUCTURAL UNIT SECTION

0 10 FEET

A BUILDING SYSTEM BASED ON GROWTH

FOR RESEARCH LABORATORIES : MASTER IN ARCHITECTURE THESIS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY : JUNE 1965 : JAMES R. BONAR