



AN INTEGRATED BUILDING SYSTEM FOR AN URBAN UNIVERSITY

by

PETER R. LEE  
(B. Arch., University of Minnesota)

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of the Requirements for the  
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Signature of Author

\_\_\_\_\_  
Department of Architecture

Certified by

\_\_\_\_\_  
Thesis Supervisor

Accepted by

\_\_\_\_\_  
Chairman, Departmental  
Committee on Theses

DEAN L. B. ANDERSON,  
SCHOOL OF ARCHITECTURE AND PLANNING,  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,  
CAMBRIDGE, MASSACHUSETTS

DEAR DEAN ANDERSON,

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE  
OF MASTER IN ARCHITECTURE, I HEREBY SUBMIT MY THESIS  
ENTITLED "AN INTEGRATED BUILDING SYSTEM FOR AN URBAN  
UNIVERSITY".

SINCERELY,

PETER R. LEE

AUGUST 1967.

FOR THEIR GUIDANCE IN THE PREPARATION OF THIS THESIS,  
I WISH TO EXPRESS MY APPRECIATION TO

PROF. EDUARDO CATALANO,

PROF. WACLAW ZALEWSKI.

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AN INTEGRATED BUILDING SYSTEM

DESCRIPTION OF PROBLEM

A subject of frequent discussion among architects is the question of whether significant architecture is initially conceived as form which is then realized through structure, or if structural capabilities of the time dictate the resultant form. Examination of lasting architectural efforts would yield valid examples for either point of view.

Whatever the merits of either side, a general consensus would be that regardless of which of these factors takes precedence in the usually unsystematized creative design process of the architect, the two elements, form and structure, must be blended in an inseparable synthesis in the ultimate building if it is to be a piece of architecture that will withstand the test of time.

For this reason, in the attempt to establish a meaningful test of the appropriateness of a building design, a valid criterion would be to examine the relationship of form to structure and whether a functional and visual integration has been achieved between the two. The design problem described in this report is concerned with the development of an integrated building system which will be used in the design of an urban university. It will be my purpose to explore the design of this system in the light of this

criterion of creating a synthesis of form and structure in the resultant product.

#### EXAMINATION OF SYSTEM REQUIREMENTS

A contemporary university is an organization of academic functions undergoing constant change and growth. A building system capable of meeting these needs must be designed for maximum flexibility in terms of both its structural and mechanical service characteristics. The following requirements would be obligatory for such a system.

1. large floor areas unencumbered by permanent walls or partitions.
2. a floor system capable of receiving non-load bearing partitions on a modular basis, allowing a variety of spaces to be organized within the configuration of the building.
3. the ability of the floor system to provide the basic services of air, light, and electric service to any enclosed space and additionally have the capacity of providing more specialized services as required.
4. the ability of any enclosed space to have proper acoustic characteristics including sound privacy from adjoining spaces.
5. the ability to group vertical circulation systems,



5. toilets, and other service elements in areas where they will cause the minimum impairment of the flexible organization of spaces on floor areas.
6. the system must be capable of vertical and horizontal expansion to meet future growth needs.

It is apparent from these criteria that the elements of this building system are both structural and non-structural in nature. The structural elements would consist of the floor construction and its supporting columns. The non-structural elements would be those service elements which occur on a horizontal plane paralleling the floor construction for availability to any portion of the floor, and those which occur periodically throughout the building in vertical shafts. The first group of floor services would include the following elements.

1. Ducts supplying conditioned air to ceiling located diffusers and returning circulated air to a central source.
2. Conduit to provide electric power for room lighting and service outlets. Additional conduit carried services would include telephone, inter-com, and closed-circuit television systems.
3. Piping of various types for water supply, waste removal, and specialized services such as gas and compressed air.

4. Acoustic treatment. Although this is not generally considered a building service, it is a necessary and integral part of any building system.

The second group of services occurring in vertical shafts would include the following elements.

1. Vertical circulation systems, including fire stairs, passenger freight elevators, and in certain instances escalators.
2. Toilets.
3. Service spaces including maintenance rooms, switchgear and telephone equipment rooms, and storage and receiving spaces.
4. Chases or shafts to carry floor services vertically throughout the height of the building. These shafts may sometimes be incorporated in columns.

#### ANALYSIS OF EXISTING SYSTEMS

To properly approach the design of an integrated building system it would be well to examine systems which are presently in common use to determine if they are adequate for their building needs, and if not, in which areas they have shortcomings.

An analysis of contemporary floor systems for multi-story buildings indicates that although most of them incorporate

the previously described combination of structural and non-structural elements, there usually exists little or no integration between them. This is particularly true in regard to the relationship of floor construction and floor related services.

The typical means used in dealing with these elements consists of assigning each a working depth within the total floor thickness. The structure is assigned the top portion of the floor, ducts are allocated to the central portion and lighting occurs at the bottom. If a ceiling is used, it performs the task of providing acoustic treatment to the space.

The merit of this system is that both during the design and construction process, it allows the persons responsible for each of the floor increments to work almost independently of the other. It does however, have its shortcomings. Principal among these would be the following:

1. Since the structural portion of the floor is limited to the upper part of the total floor thickness, it necessitates a design utilizing minimum depth of structural members. This often results in an uneconomical structure and definitely limits the size of the floor spans.
2. Since the service requirements of a building are

becoming more complex and space consuming, the overall thickness of floors must continually increase or the service elements must be forced into a space inadequate for their proper functioning.

3. This type of floor system does not readily lend itself to flexible partition placement and acoustic privacy. Structural blocking extending from the ceiling to the underside of the floor construction must be placed above partitions to insure their stability, and if this blocking is covered with sound retardant material to provide sound isolation to the enclosed space, it is usually a difficult process and one that seldom has totally satisfactory results.

#### DESIGN CRITERIA

In order to design a floor system which will more closely unite the structure and form of the system into an integrated whole, and aid in overcoming the previously mentioned problems of a non-integrated system, the following design requirements have been established as a working criteria.

1. To develop a floor system capable of being used to heights of 16 stories with bay widths ranging from 50 to 80 feet between column supports. Cantilevers up to  $1/3$  of the span should be permissible in any direction and it should be possible to create floor

- openings of varying sizes within the structural bay.
2. Building spaces defined by the floor system should be capable of being self-contained areas, supplied with lighting, electric service, air supply, temperature control and acoustic treatment as well as acoustic isolation.
  3. The floor system shall integrate structural and mechanical elements within a depth of floor construction not to exceed four feet.
  4. The non-structural components of the floor system shall be integrated with the structural components in such a manner that they form an obvious visual statement of interrelated form and structure.

#### PROPOSED SYSTEM

The proposed building system consists of modular pre-cast concrete units linked together by post stressing cables and supported by pre-cast concrete columns. By the varying use of two weights of structural floor elements, different spans between columns may be achieved. All service elements associated with the floor system are incorporated in a service module contained within the floor construction. These services are supplied or returned vertically throughout the building system by service shafts occurring in the building cores. These

cores also contain vertical circulation systems, toilets and service rooms.

### STRUCTURAL ELEMENTS

The decision to use concrete in this building system was based primarily on its fireproof qualities. Although steel may eventually be capable of being made fireproof through the introduction of ceramic materials in its forming, at the present time it is unsuited for exposed use in the multi-storied building type being studied.

The choice of using pre-cast rather than cast in place concrete was based on the following reasons.

1. Factory produced pre-cast concrete units may be formed in shapes that are not possible to achieve in on-site casting.
2. Quality control of mixes, placement of reinforcing, and dimensional exactitude is better achieved under factory conditions.
3. Production and erection of pre-cast concrete units is generally not affected by adverse weather conditions.

Concrete construction systems, whether cast in place or pre-cast, are usually categorized as being one way or two way systems. This distinction, although it is in common use and is used by the author, is not entirely accurate.

A better classification would be: Systems that transmit forces in only direction from a given point and those capable of transmitting forces in more than one direction from a given point. In the latter case, this transmission of forces could occur in more than two directions, depending upon the configuration of the structural members.

Two technological developments in the field of pre-cast concrete that have significantly influenced its structural capability are pre-stressing and post-stressing techniques. Pre-stressing involves imparting tensile stress to steel in the concrete prior to its forming. Post-stressing involves a similar process performed after the concrete is formed. Either system can be applied to both one way and two way structural systems, however, pre-stressing is generally used with the longer structural members associated with the one way system, while post-stressing is usually a part of the process of a two way pre-cast system, which usually consists of small structural units linked together with cables in tension.

The components of the proposed system consist of "table" shaped concrete structural units which will be referred to as the structural unit, and concrete connector bars which fit between the structural units at the base of the system. In addition, there are the concrete columns and

column capitols, this latter being a variation of the basic structural unit.

The structural units are 7'1" square in plan and 3'10 1/2" high. The top of the unit is a 4 1/2" thick concrete slab which is beveled at the edge to permit the placement of tension cables between adjoining units. Joined to the slab at its corners are four triangular shaped legs which converge toward the center of the unit at its base. The structural units are cast in two weights by means of varying the thickness of the concrete legs.

The connector bars are channel shaped units which are placed diagonally between the juncture of the legs of adjoining structural units. Tension cables which link the units at their base are contained in the open channel faces of these members.

The sequence of construction of a typical floor system would be as follows:

1. Erection of scaffolding
2. Placement of pre-cast columns and capitols
3. Placement of structural units radiating from column capitols
4. Placement units of connector bars between the legs of adjoining structural units



5. Linking of units to columns with post-stressing cables at the base of the system, where they are threaded through the juncture of the structural unit legs and laid in the connector bars
6. Placement of post-stressing cables at the top of the system where required, in which case they are between the slabs of adjoining structural units
7. Post-stressing top and bottom cables
8. Grouting of joints between legs of adjoining structural units and on top of cables in the connector bars
9. Pouring of floor slab topping.

The assembled floor system when viewed from below appears as a series of right angle triangles. This is a visual result of the intersection of the two lower chord grids, one formed by the legs of the structural units and the other by the connector bars which run at 45° angle to the line of the structural unit legs. Although this multi-directional ceiling grid offers certain planning possibilities not found in a one or two direction grid, its configuration is primarily based on structural and service element considerations.

In a more conventional two way structural system composed of a square grid system, forces applied at any point within

the structural bay are transmitted to the edge of the bay where they must be picked up by a larger structural member in the form of an edge beam or girder and then transmitted to the columns. The proposed structural system makes this edge beam unnecessary since forces applied within the structural bay are transmitted in generally direct lines to the supporting columns.

Since the stresses on the members in any structural system are greatest at the column points and at their minimum at the center of a span, the proposed system makes use of structural units of two different weights. The heavier units are used around the columns, the lighter ones are used at the center of the bays and a combination of the two are used in intermediate areas.

As previously stated, the integration of service elements also determined the configuration of the structural system. A "V" shaped open area is formed by the triangular legs of each of the structural units. This open space runs continuously in each direction of the floor system and provides an ample space for all present and future floor service elements. This space shall be referred to as the floor service module.

### SERVICE ELEMENTS

All floor services are contained in the service module occurring within the structural floor units. This service module is covered by synthetic fiber panels which are designed to have either sound reflective or sound absorbent qualities, depending upon the acoustic requirements of a particular building space. These panels are designed for easy removal to allow access to the mechanical components contained within the modules.

### LIGHTING

Lighting service occurs at the base of the module in the form of a continuous electric duct to which are attached four foot fluorescent fixtures. These fixtures sit directly above the concrete connector bar and make use of the service module panels as reflecting surfaces in providing an indirect source of illumination to the space below.

### ELECTRIC SERVICE

Electric service conduits and cables are contained at the top of the service module where they can be readily accessible to the spaces above the floor system. Four small diameter knock out holes are located in the slab of each structural unit for service access. For service

to partitions in the spaces below the floor system, conduit sections are cast in the legs of the structural units through which wires may be threaded.

#### PIPING

Unlike other services which occur throughout the floor system at regular intervals, piping services would not be predictable as to their locations. Laboratory areas might require several piping systems while a typical classroom or office area would probably require none. Where they do occur, they would normally serve spaces on the floor above, therefore, their location in the service module would be directly beneath the electric services.

#### AIR

The ample space contained in the service module allows a variety of choices in the type of air system employed. Whatever type system is used, the air ducts would generally occur in the lower portion of the service module, where they would connect to supply diffusers or return grilles located in the lower edge of the module panels. The angle of inclination of these panels provides a good air distribution pattern to the space below.

The air system proposed for this project is a dual duct,

high velocity system. Supply air in hot and cold ducts would be supplied at velocities up to 4000 CFM to mixing boxes where it would be proportionally mixed to meet the temperature needs of the area and reduced in velocity to approximately 1000 CFM. It would then be transported at this velocity in single ducts to the individual diffusers. Circulated room air would be returned in ducts to the central air source.

#### ACOUSTICS

As mentioned previously, the service module panels would act as sound absorbers or reflectors, depending upon the needs of particular spaces. These panels, in conjunction with the structural frame, would also provide acoustic sound control between adjacent spaces. Whether partitions occur on the ceiling grid, parallel to the column line or diagonal to it, sound barriers in the form of the legs of the structural unit or a double thickness of acoustic panels would prevent sound passage to adjoining spaces.

#### EXTERIOR HEATING

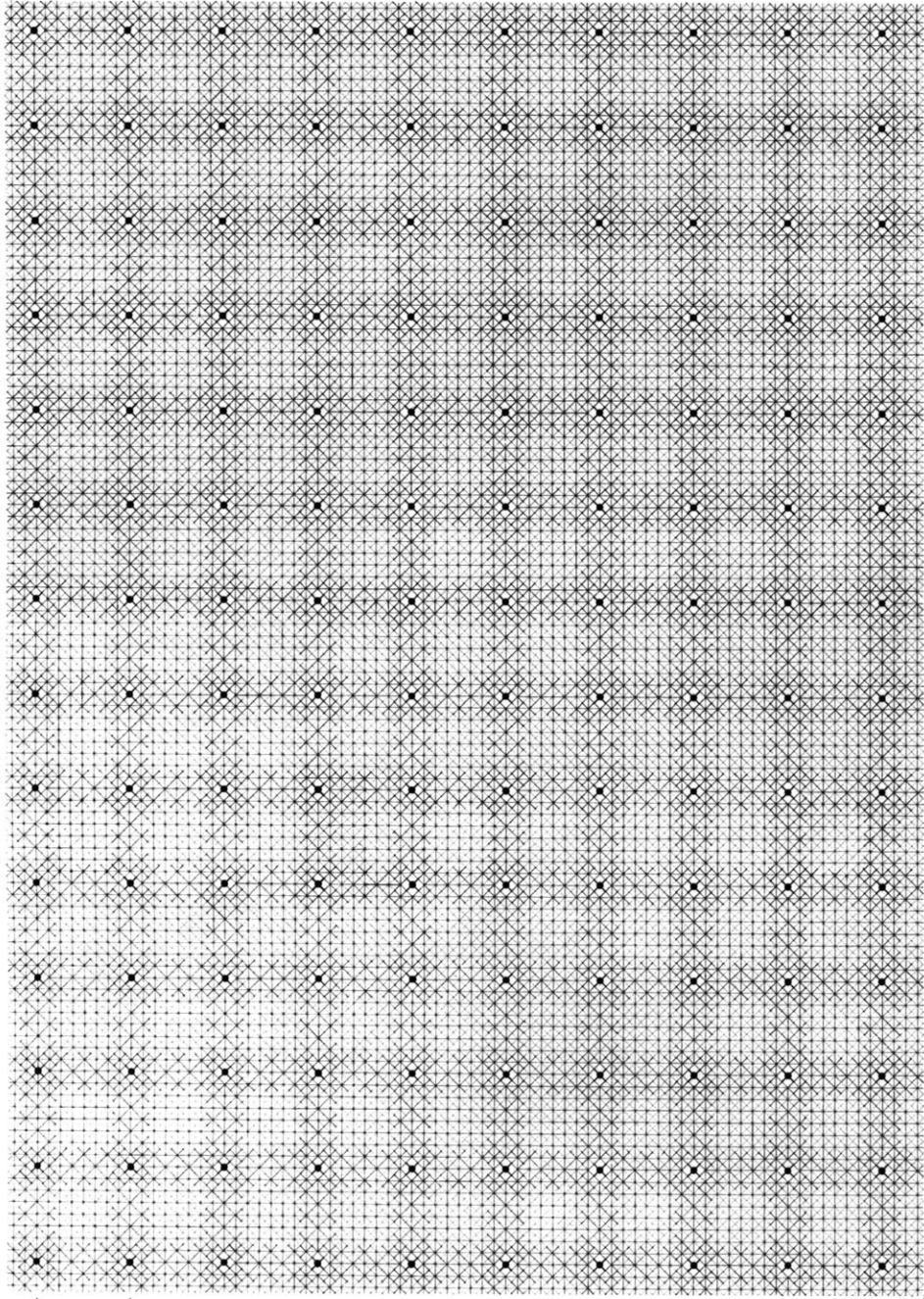
Where additional heat is required at the exterior of the building, this could be handled by either the existing air system or a separate hydronic system. In the case of

using air a separate peripheral heating zone with its own mixing boxes would be established and the air supply distributed through either ceiling or floor grilles. An hydronic system could be of the induction type or simple radiation.

#### SERVICE CORES

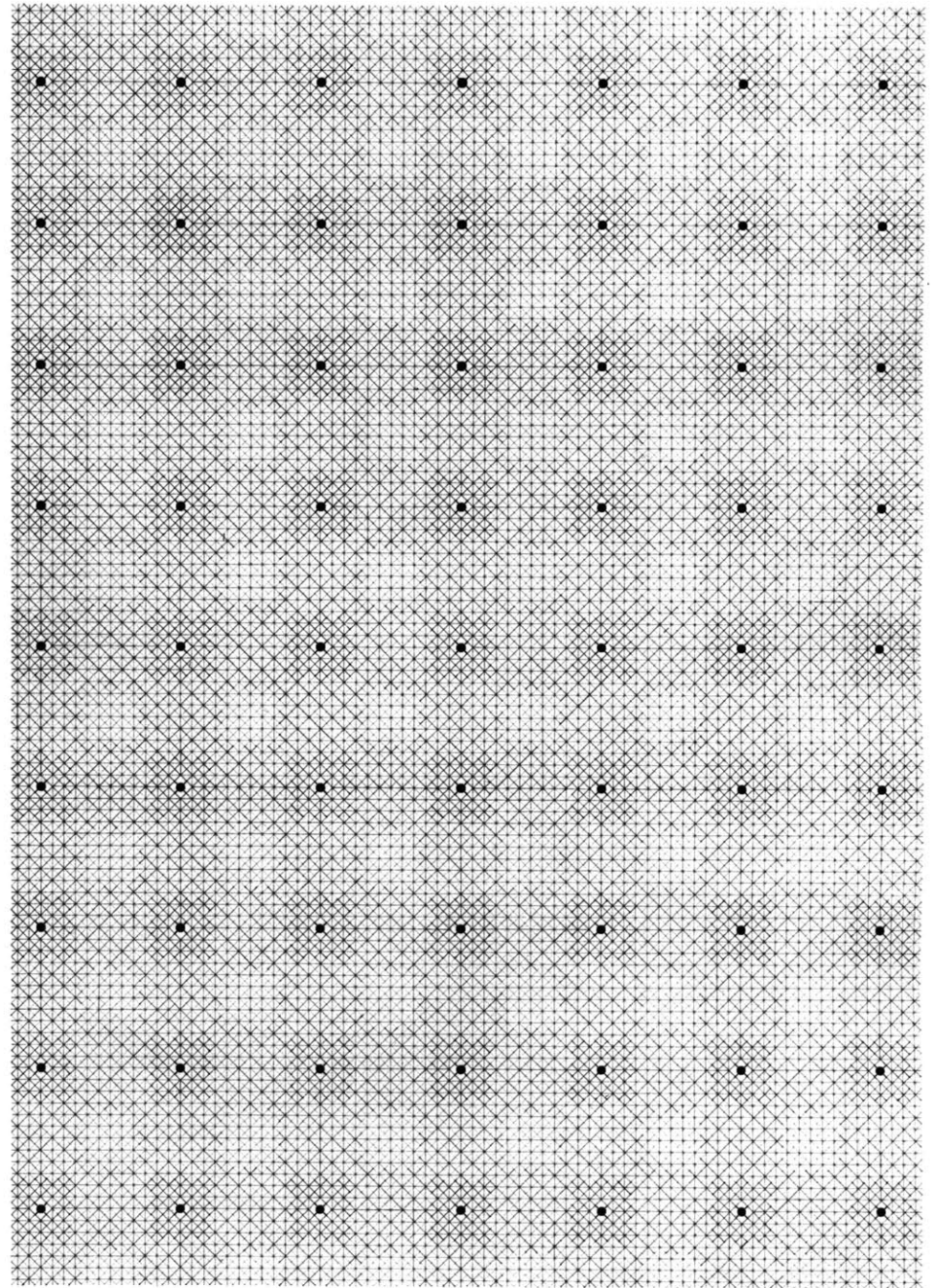
Regularly spaced service cores are used to carry the service elements vertically in the building to the different floors. These elements are located in shafts at the corners of the core structures. Placing these elements in the cores rather than the building columns, which is an alternate means of handling them, allows the columns to be kept to a size no larger than is necessary for structural reasons. Additionally core service shafts may be oversized to handle future service needs without significantly reducing the useable floor area in the building.

Other service elements included in the service cores are fire stairs, elevators, switchgear and telephone equipment rooms, and maintenance rooms.

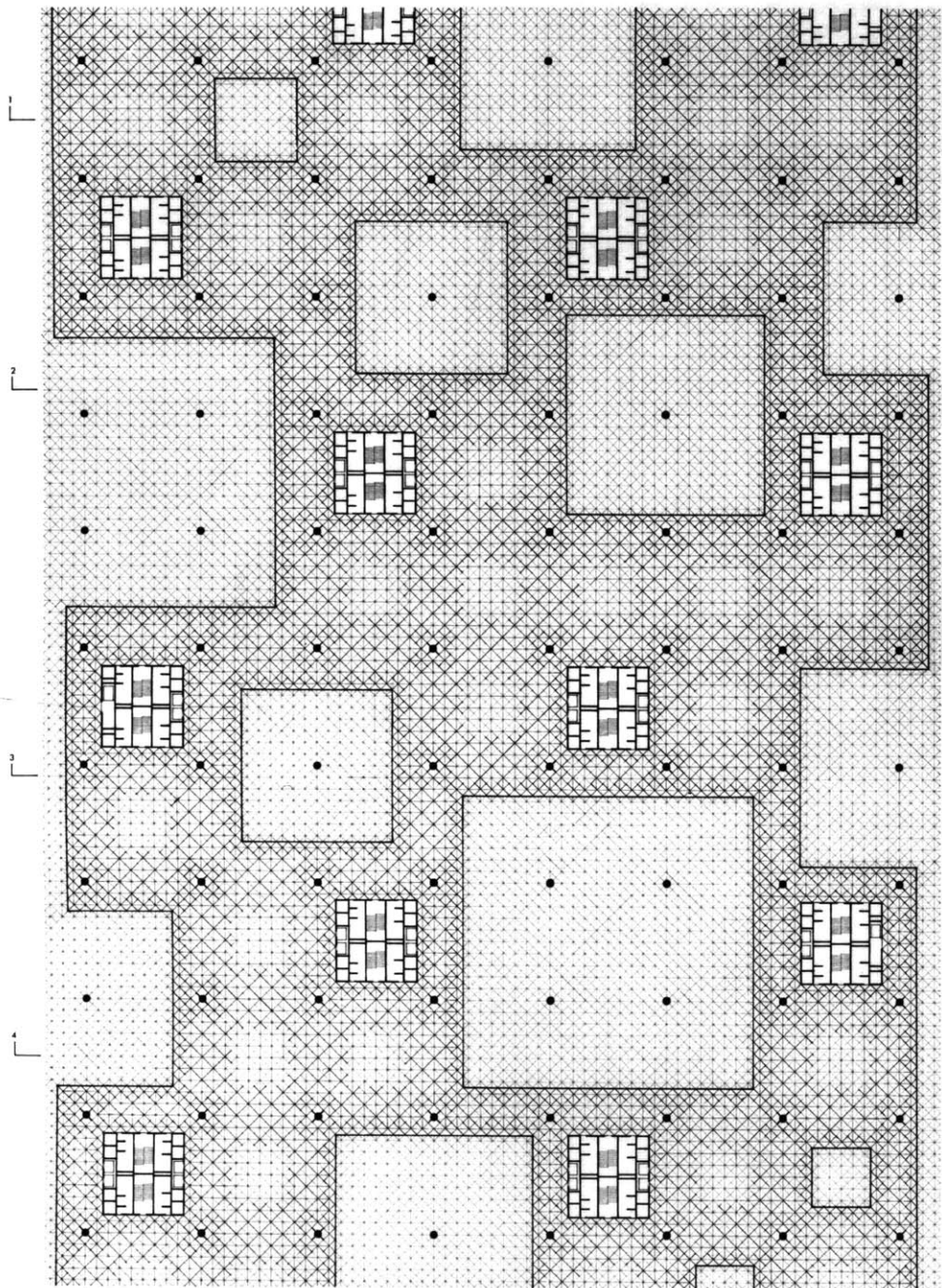


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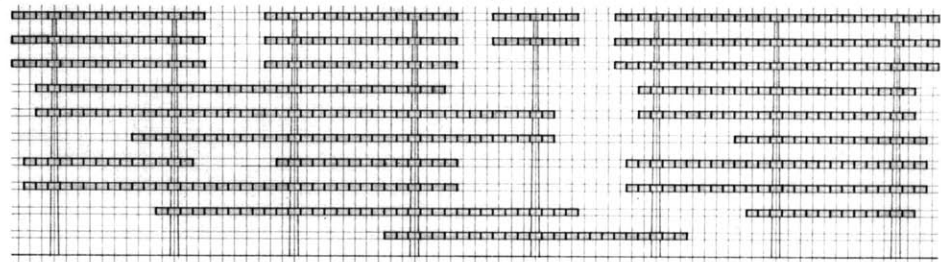
STRUCTURAL MODULE VARIATIONS



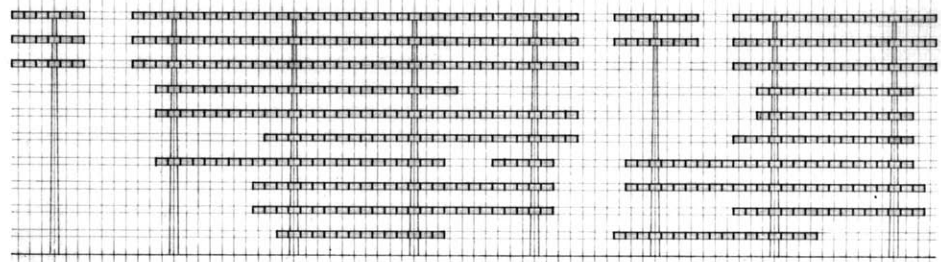
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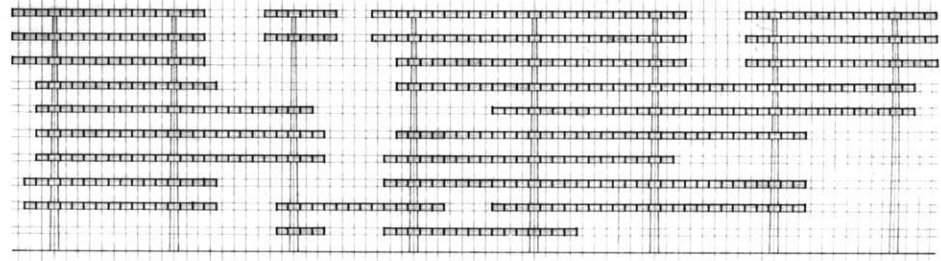
BUILDING VARIATIONS



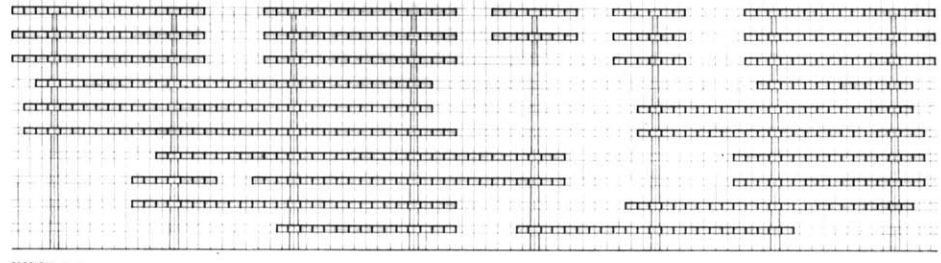
SECTION 1-1



SECTION 2-2

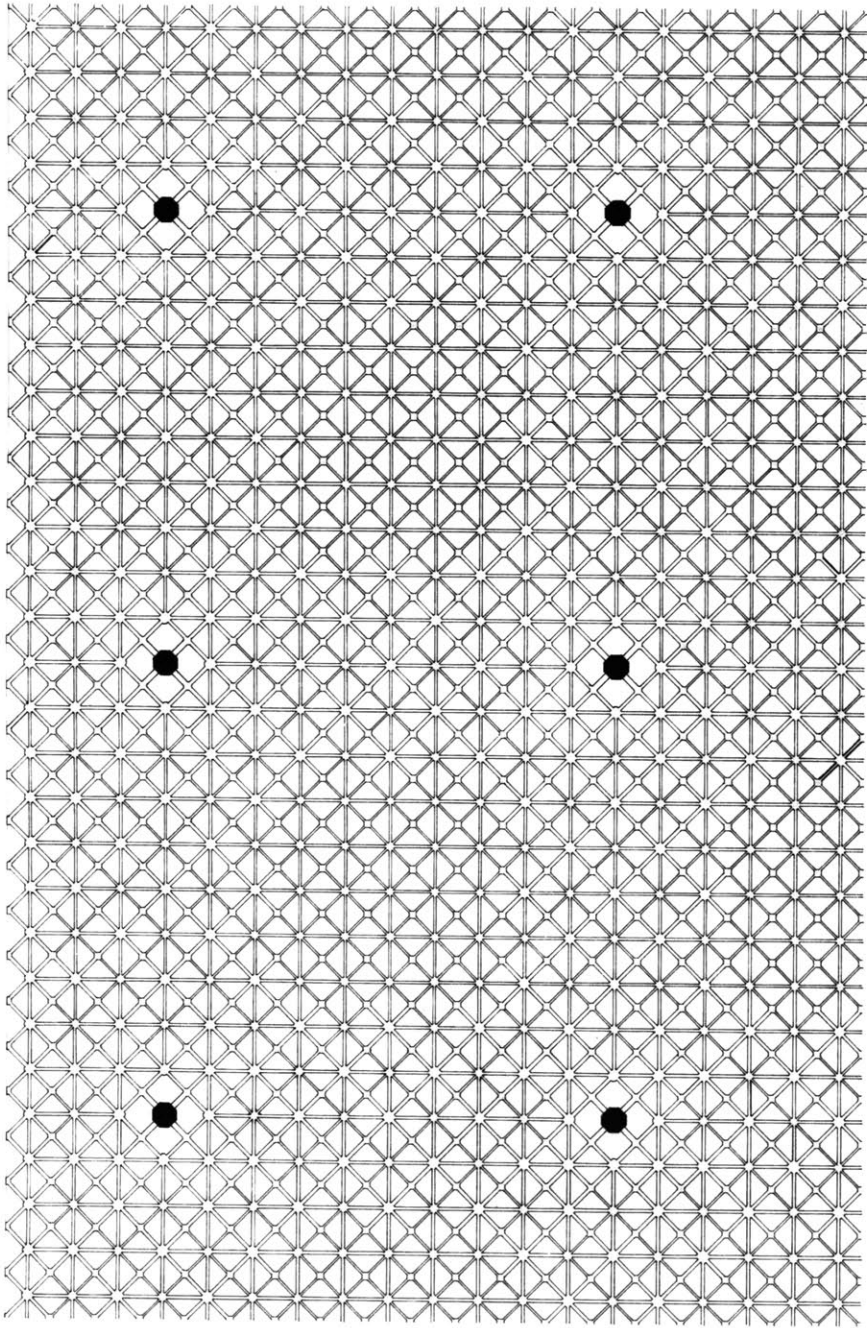


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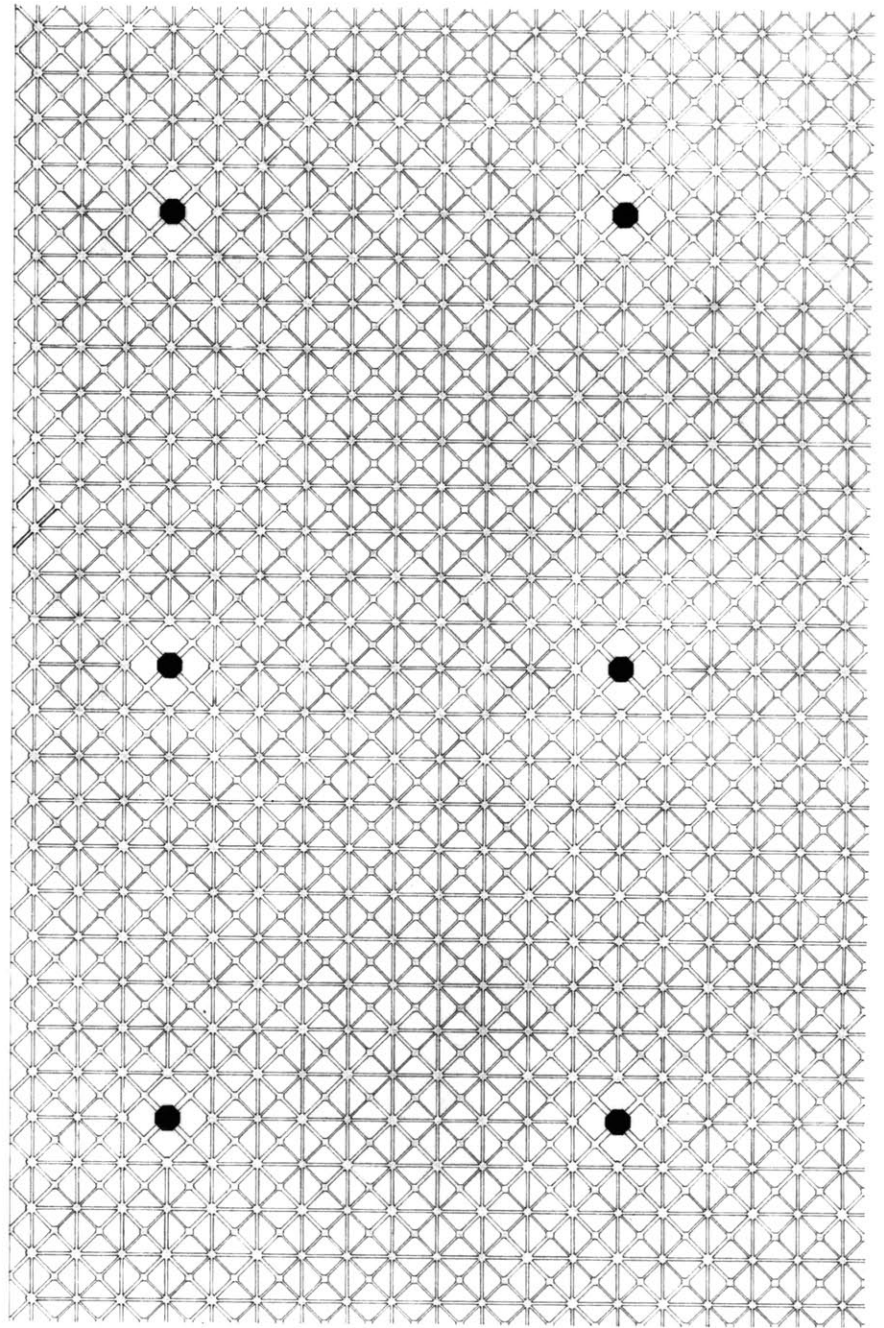


SECTION 4-4





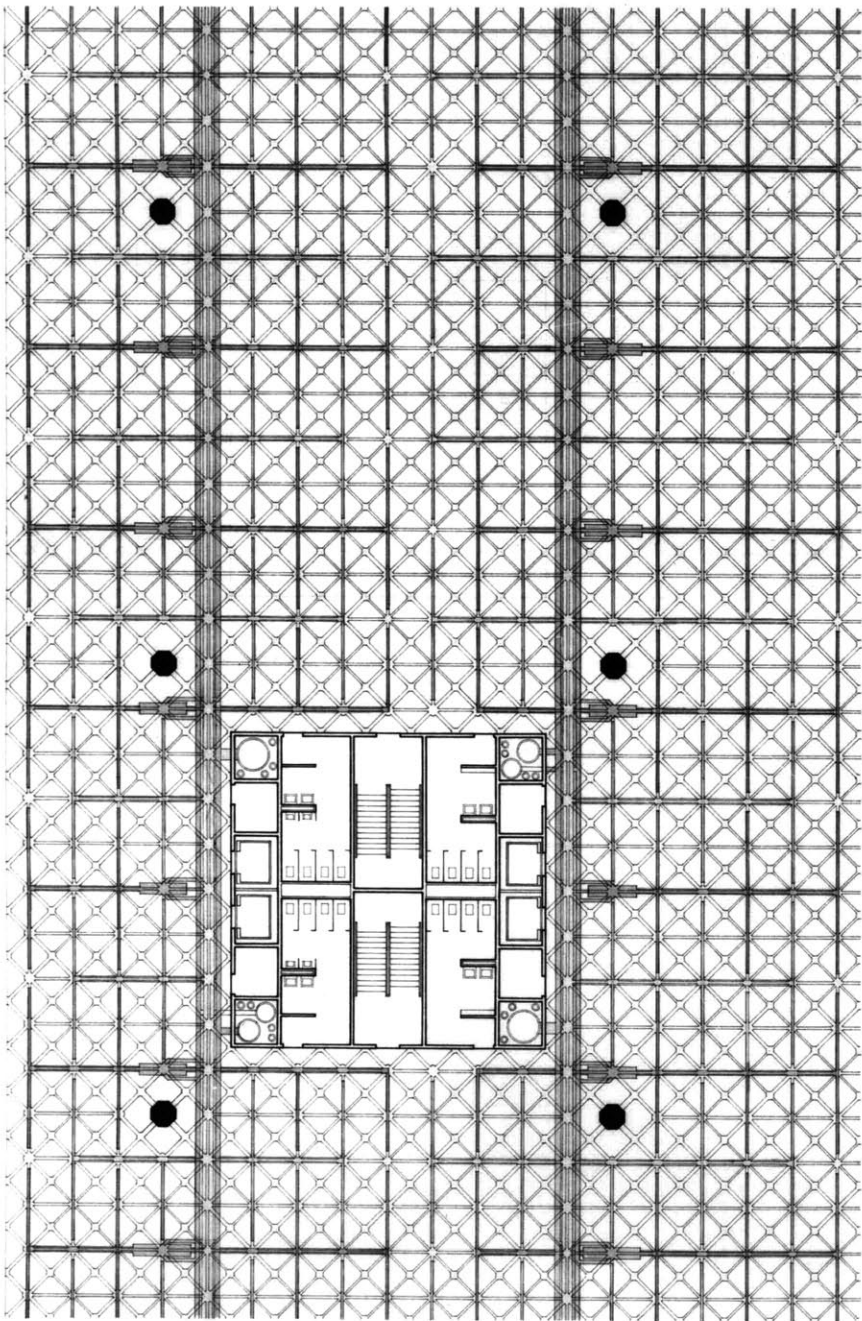
REFLECTED CEILING



LIGHTING VARIATIONS

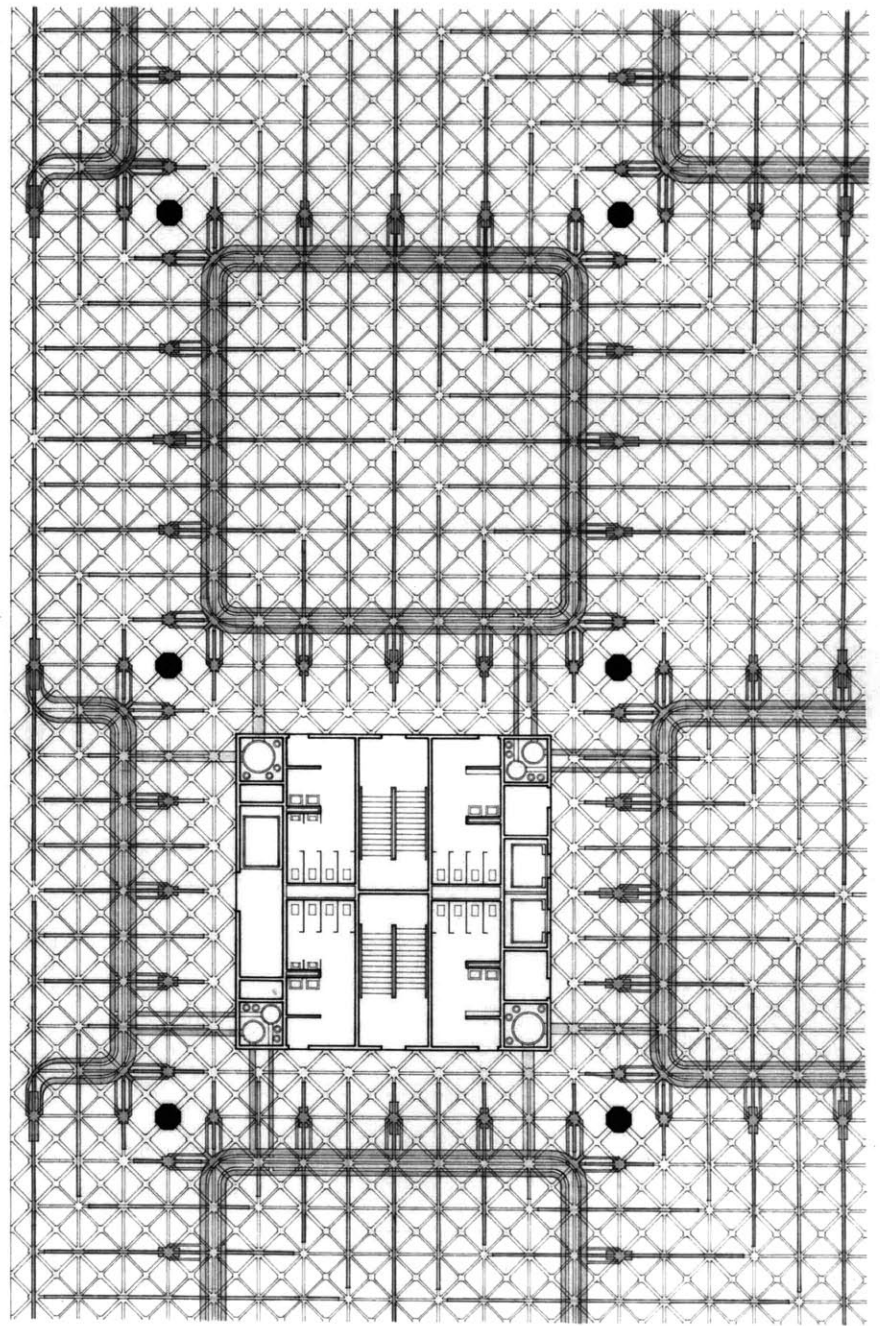
BUILDING SYSTEM

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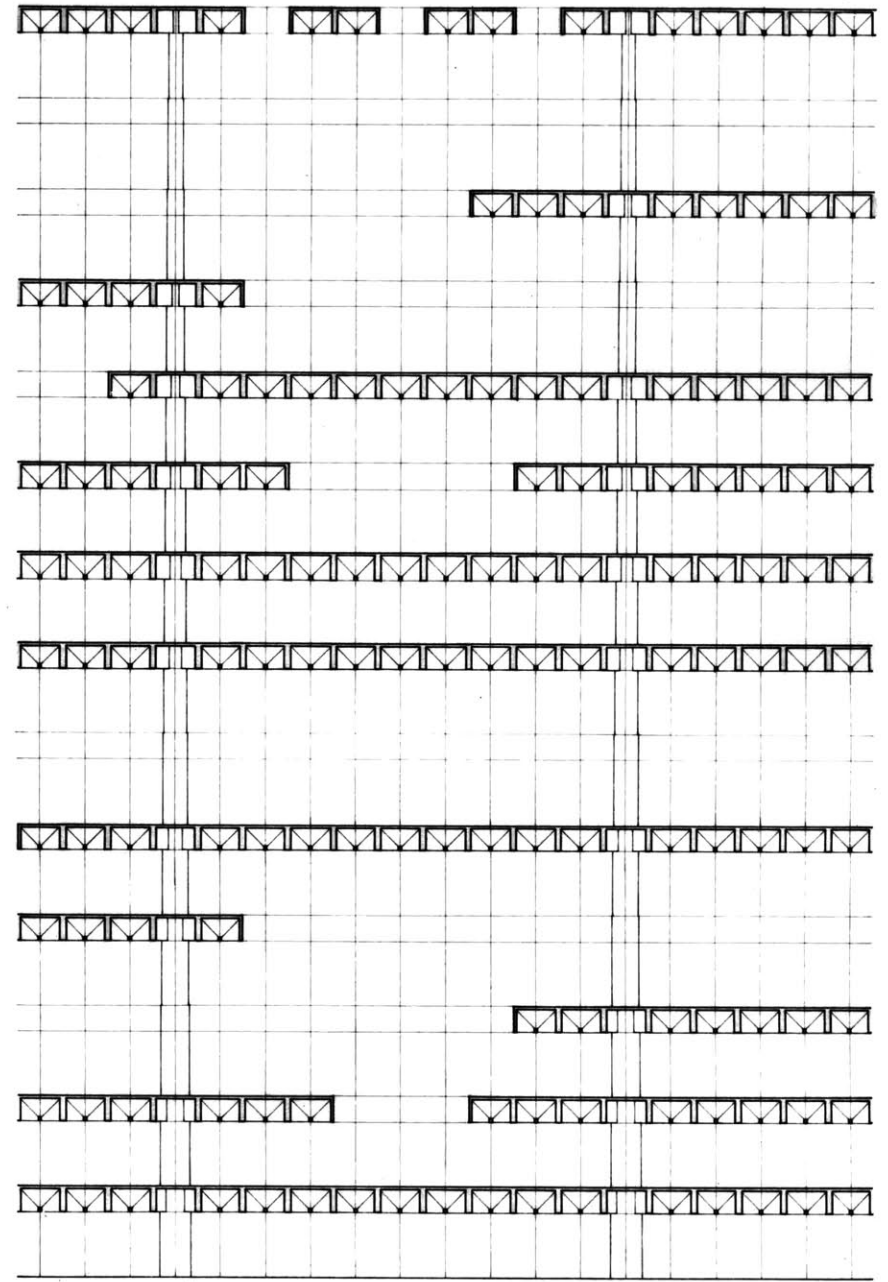
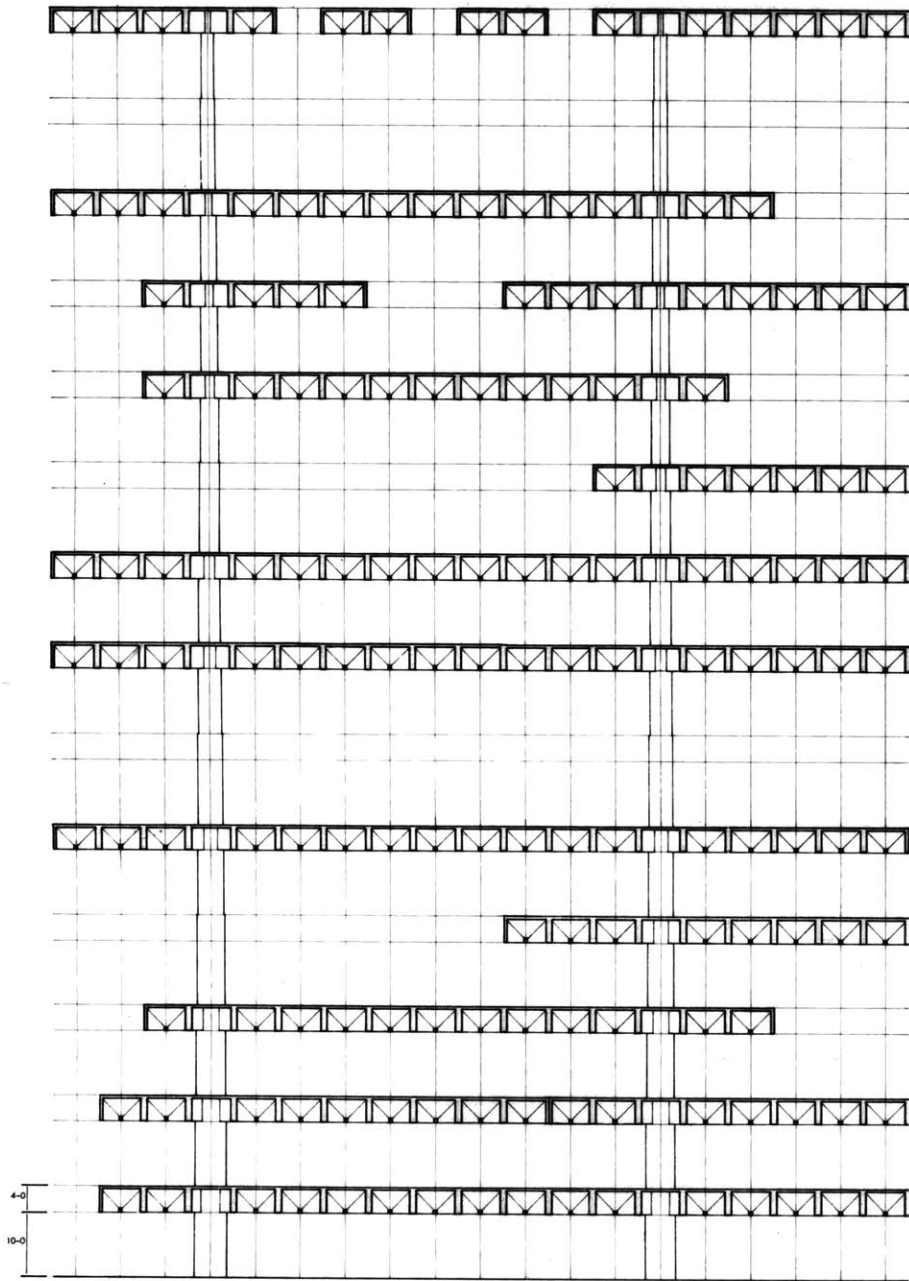


ALTERNATE MECHANICAL SYSTEM

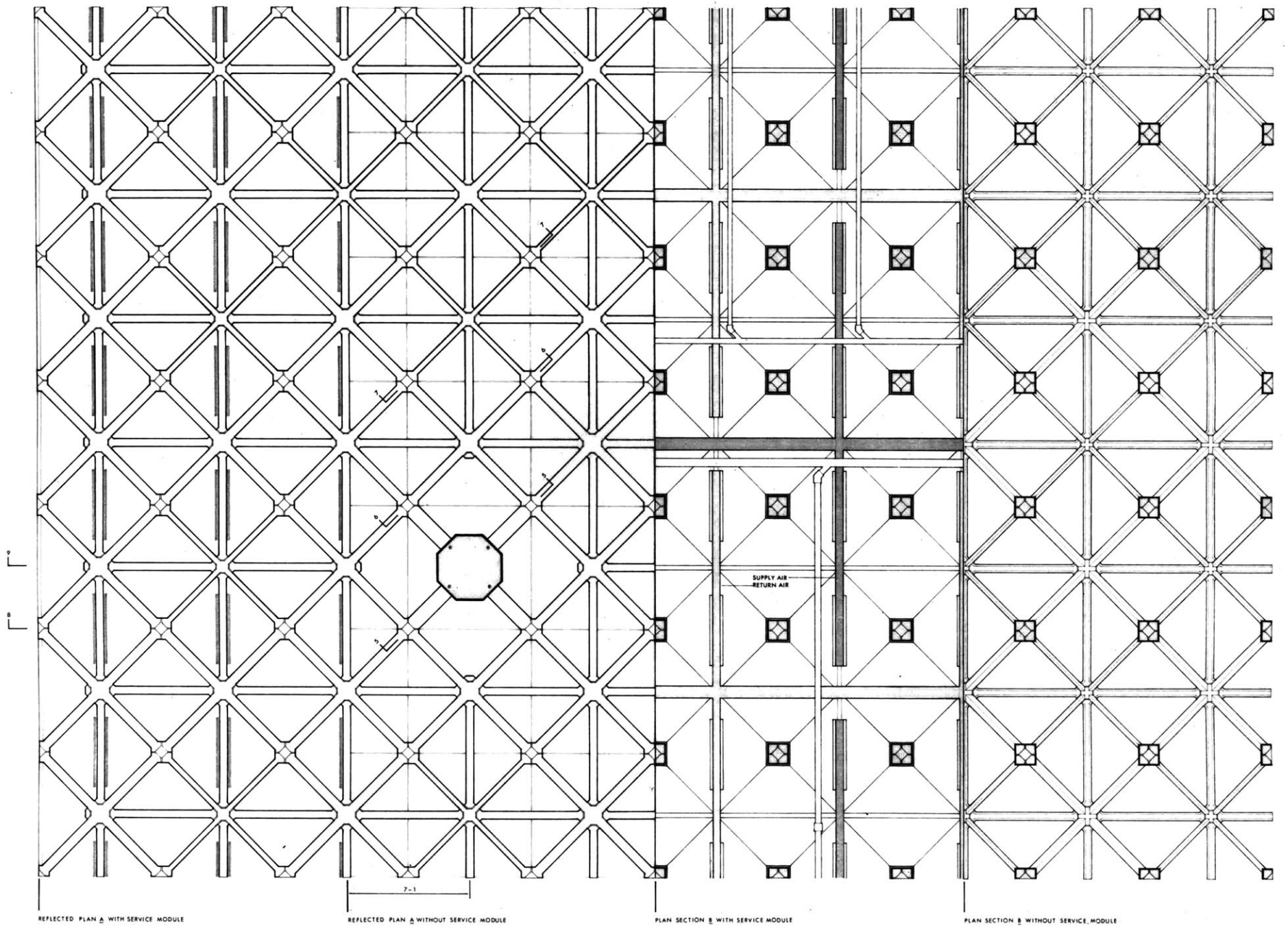
BUILDING SYSTEM



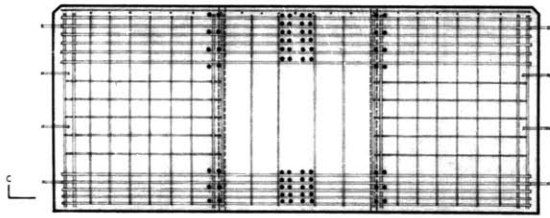
ALTERNATE MECHANICAL SYSTEM



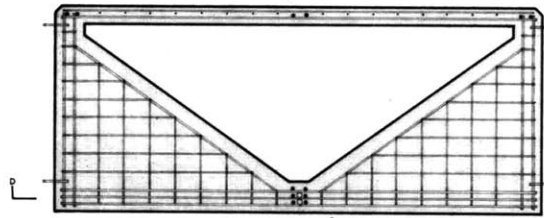
STRUCTURAL BAY SECTION VARIATIONS



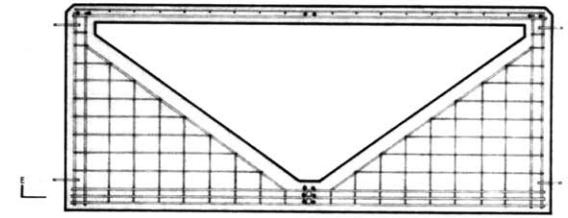
STRUCTURAL MECHANICAL DETAILS



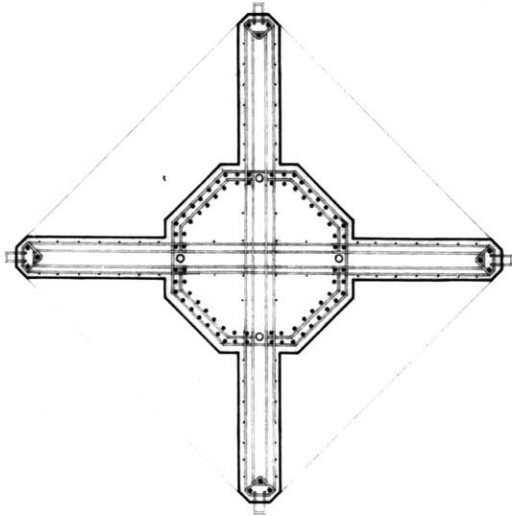
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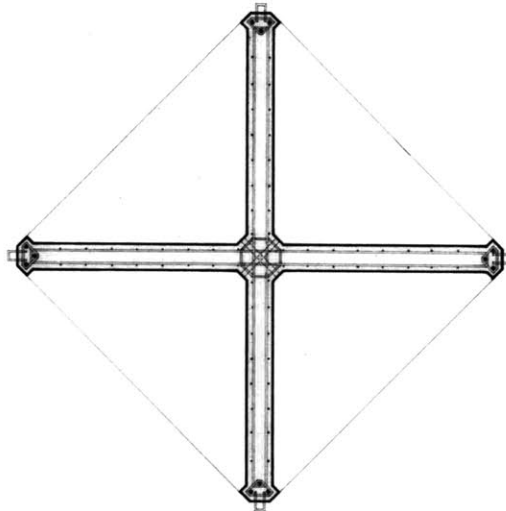
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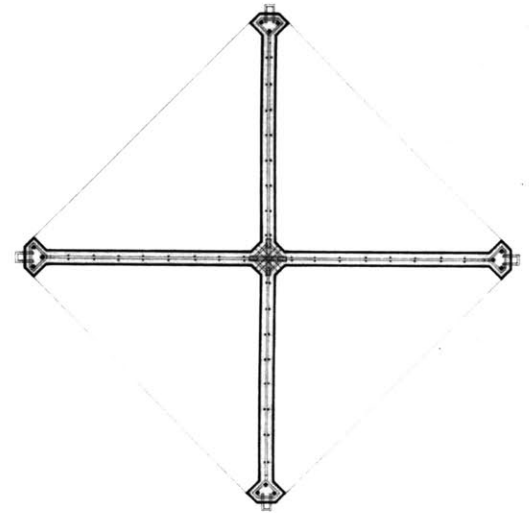
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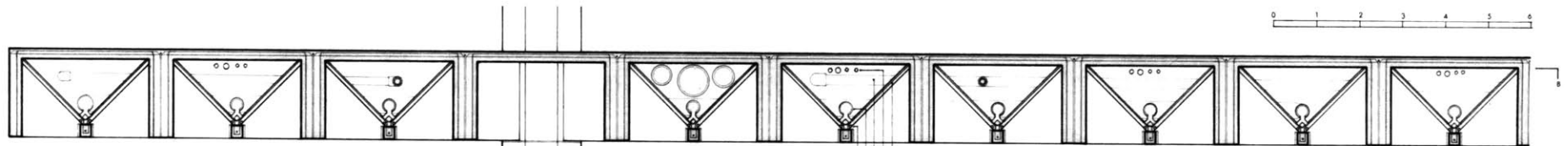
PLAN SECTION C-C



PLAN SECTION D-D

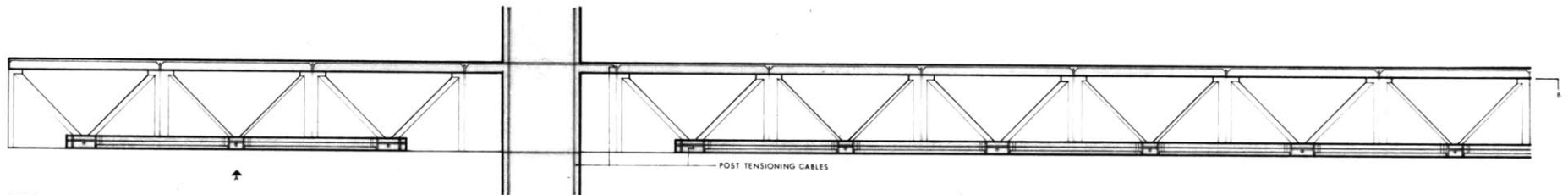
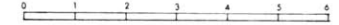


PLAN SECTION E-E



SECTION 8-8

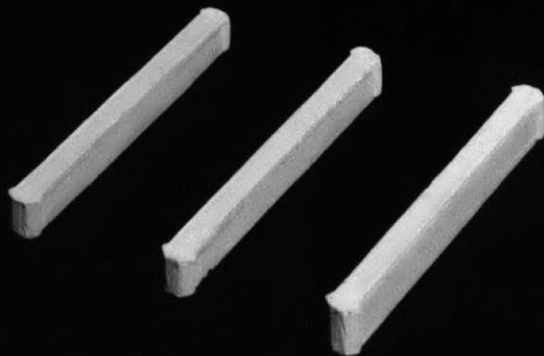
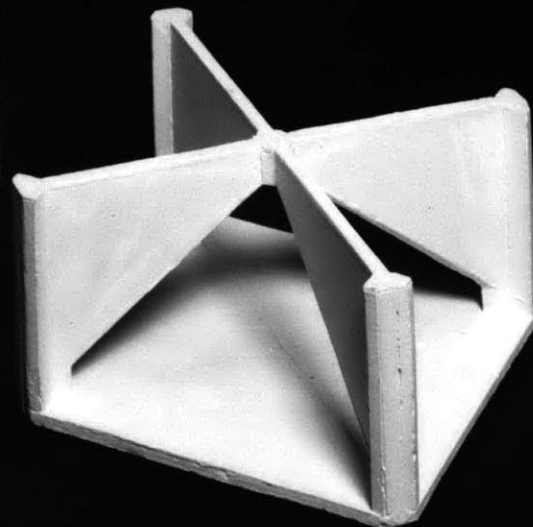
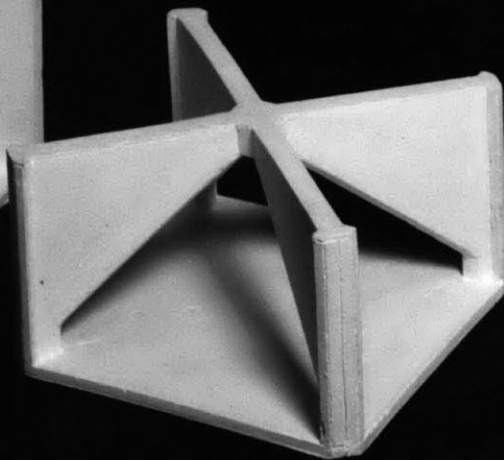
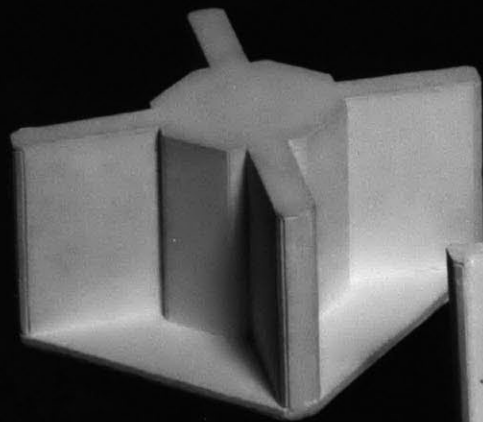
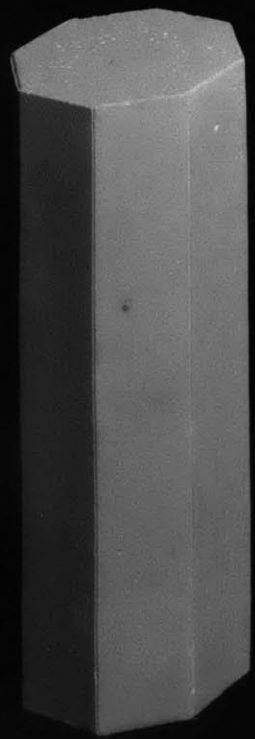
LIGHT  
AIR  
PIPING  
ELECTRICAL  
ACOUSTIC PANEL

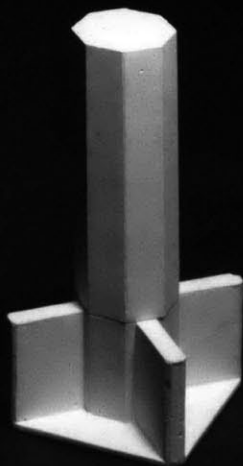
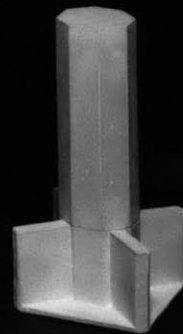
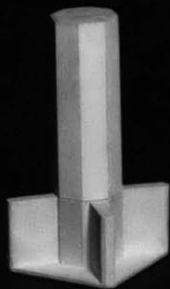
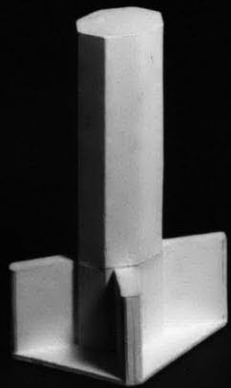


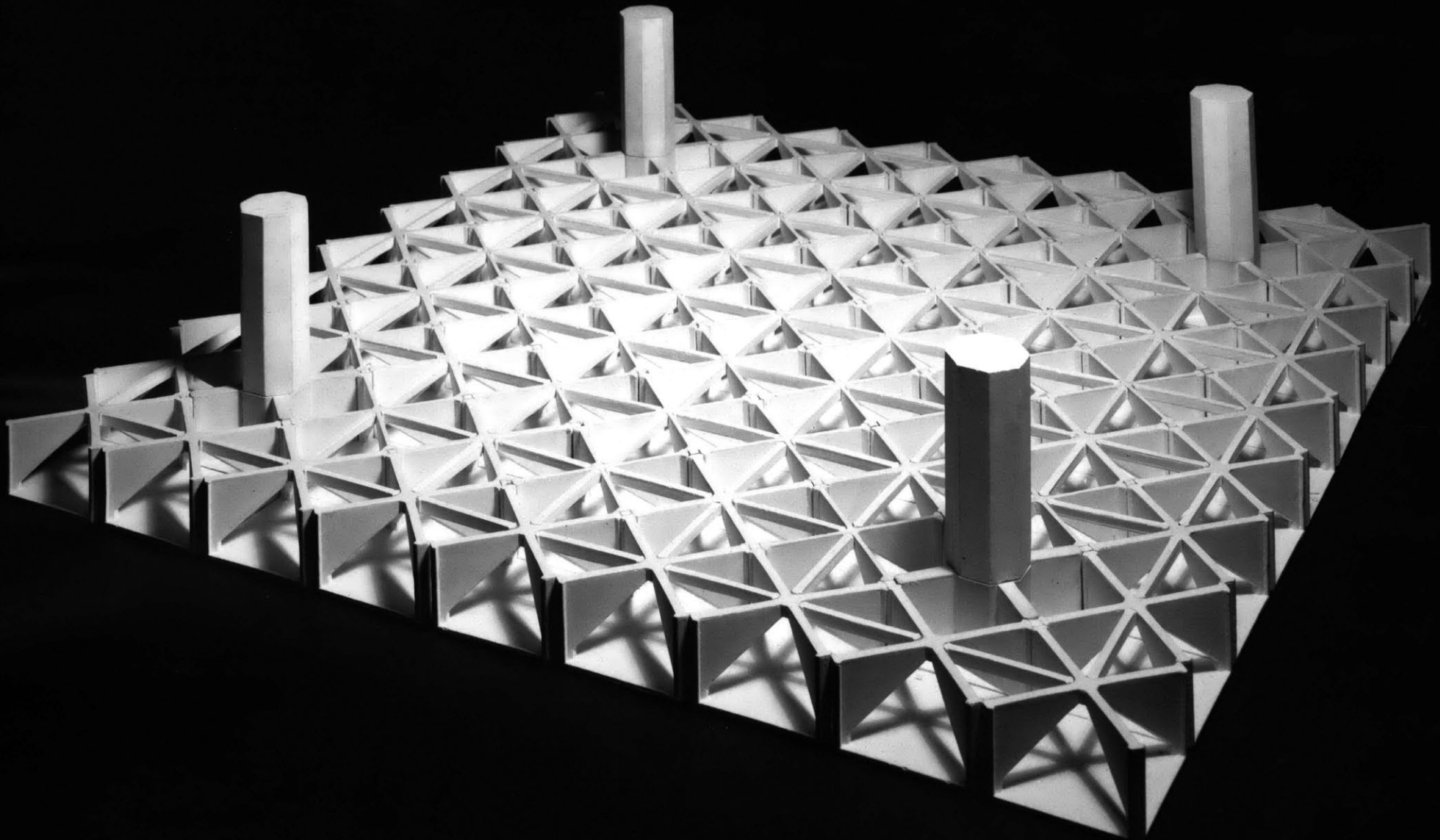
SECTION 9-9

POST TENSIONING CABLES

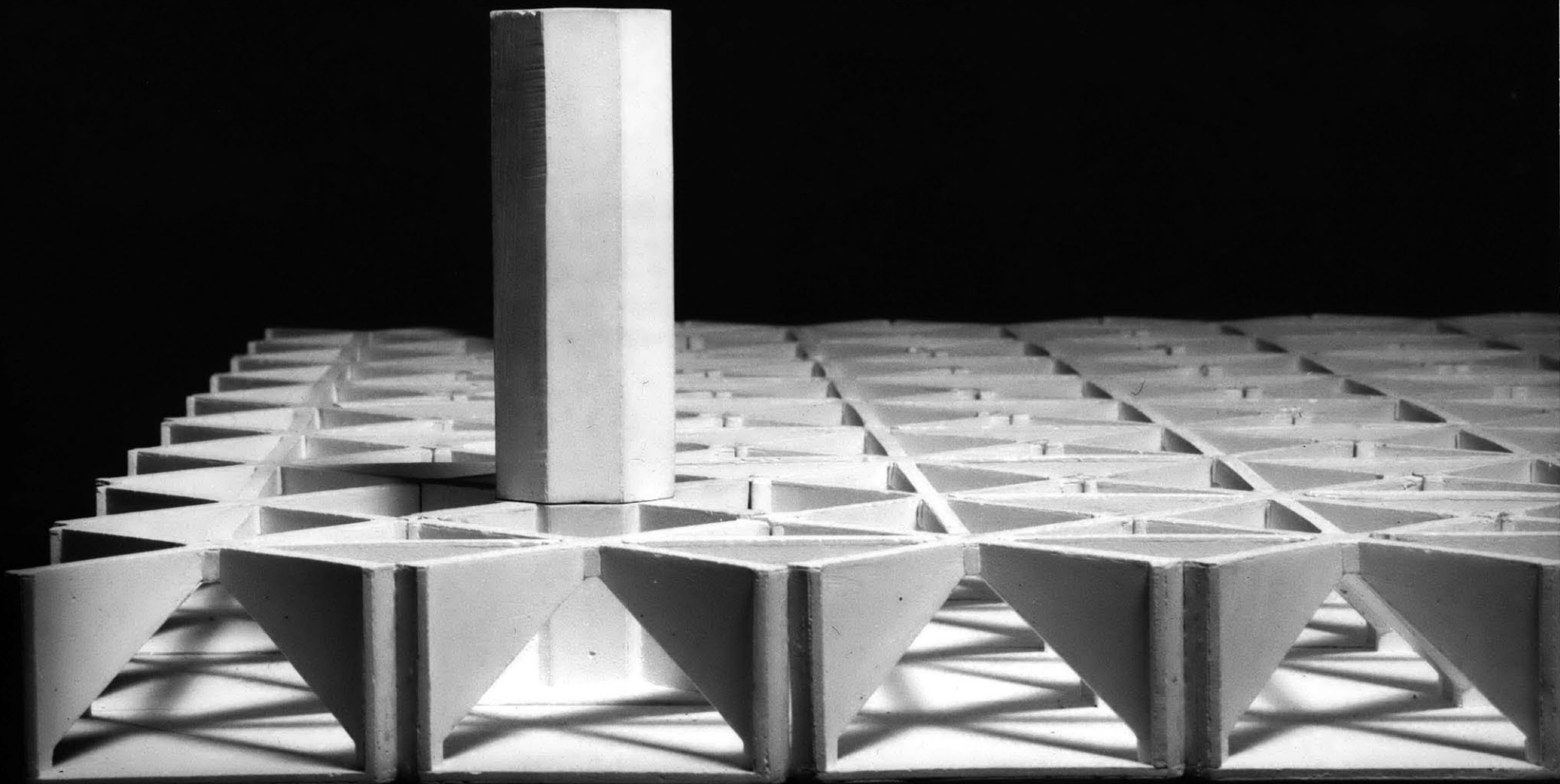
STRUCTURAL-MECHANICAL DETAILS











AN URBAN UNIVERSITY

DESCRIPTION OF PROBLEM

This project is concerned with the design development of an urban university, utilizing the integrated building system developed in the fall term and described in the proceeding section of the report.

The proposed university is intended to accommodate a student population of 6000 in its first stage and should be capable of expanding its facilities as future growth occurs.

The designated location of the campus development is near the center of a city of 800,000 population. The area contains older 4 to 6 story buildings which are gradually being replaced by taller new buildings as the area becomes absorbed into the continually expanding downtown area. Property values in the area are high and are expected to increase. The street system of this section, as well as the entire city, is a gridiron pattern with certain of the streets serving as main arteries connecting the downtown to the outlying suburbs. It has been determined that the present street system will be adequate to serve the needs of the new university.

COMPREHENSIVE PLAN

In keeping with the urban character of the area and in recognition of the high cost of land, it is proposed that the university be developed as a compact multi-story building complex.

The selected site for the initial stage of the university is an 8 block area of approximately 15 acres which is bordered on its south and east sides by main traffic arteries.

The first construction phase will consist of approximately two million square feet of building area devoted to academic, administrative, and social functions. Additionally, enclosed parking space for 2500 cars is to be provided. University housing will initially be provided in existing apartment and hotel structures in the area. Eventually these will be replaced by new housing built on land near the university.

The first stage facilities are intended to serve a four year general college program with no emphasis on any particular discipline. It is felt that the direction of academic growth can only be determined after the school has been in operation for several years, and for this

reason, a flexible means of providing change and expansion is required.

The opportunity to provide change within the initial building complex would be achieved by developing the structure as a series of repetitive modular bays incorporating an integrated floor system as was described in the first portion of this report. This would assure maximum flexibility of change as certain academic functions enlarge or decrease in size or require different building services within their existing space.

The opportunity to expand academic areas could occur both within and outside the initial complex. Expansion within the first stage would be accomplished by oversizing certain functions, such as the academic core facilities, which would include social and recreational functions, and additionally by incorporating expansion areas in the initial structure. These could take the form of service areas such as the parking levels, which could later be fitted with such services as to make them suitable for academic use.

Expansion outside the initial complex would normally occur when a particular discipline or department developed to the size where it could form a separate college of the

university. These new facilities would occur on land adjacent to the main building and be connected to it by street overpasses. Although the location and size of these expanded facilities could only be determined at the time of their need, they would generally encircle the main structure which would remain as the social and cultural center of the campus.

This loosely knit plan of campus expansion would offer several advantages in the development of a workable contemporary education facility.

1. The first building complex and each of the expanded facilities could be designed and built as self-contained, visually completed structures.
2. Each future expansion could be a direct planning response to the academic needs of that time.
3. The interconnected but separate building groups would offer the planner the opportunity to relate each stage of the campus to the city area adjoining it, and thereby achieve a stronger interaction between the campus and the city than would be the case if the school was an isolated entity.
4. A minimum disruption of the cities traffic network would be achieved by this planning technique.

FIRST STAGE DEVELOPMENT

The building space requirements to be provided in the first stage of the university development may be grouped into the following three categories:

1. Academic teaching areas 1,400,000 ft.<sup>2</sup>
  - Classrooms
  - Laboratories
  - Seminar rooms
  - Faculty offices
  
2. Academic core facilities 600,000 ft.<sup>2</sup>
  - Library and resource center
  - Theater and auditorium group
  - Athletic facilities
  - Student center
  - Administrative facilities
  
3. Service facilities 900,000 ft.<sup>2</sup>
  - Parking area
  - Mechanical rooms
  - Receiving and storage areas

Each of these groups requires a particular functional and spatial identity in the building complex, yet all are closely related in the total workings of the university. Since the limited site does not permit a horizontal linking of these functions, it is quite logical that a vertical

grouping be employed. The proposed design places these functions atop one another in a vertical sequence of: Service facilities, core facilities, and teaching areas. All are contained within a framework of modular structural bays and are interconnected by service and circulation shafts.

Beginning a half level above street grade and extending down two floors are the service facilities. Parking areas are located on the perimeter of these levels, while the mechanical space and receiving and storage area occur at the center. Access to the parking levels occurs at three points on the perimeter of the site. Core shafts emanating from these floors provide vertical circulation to the upper portions of the building as well as supply mechanical services to these areas.

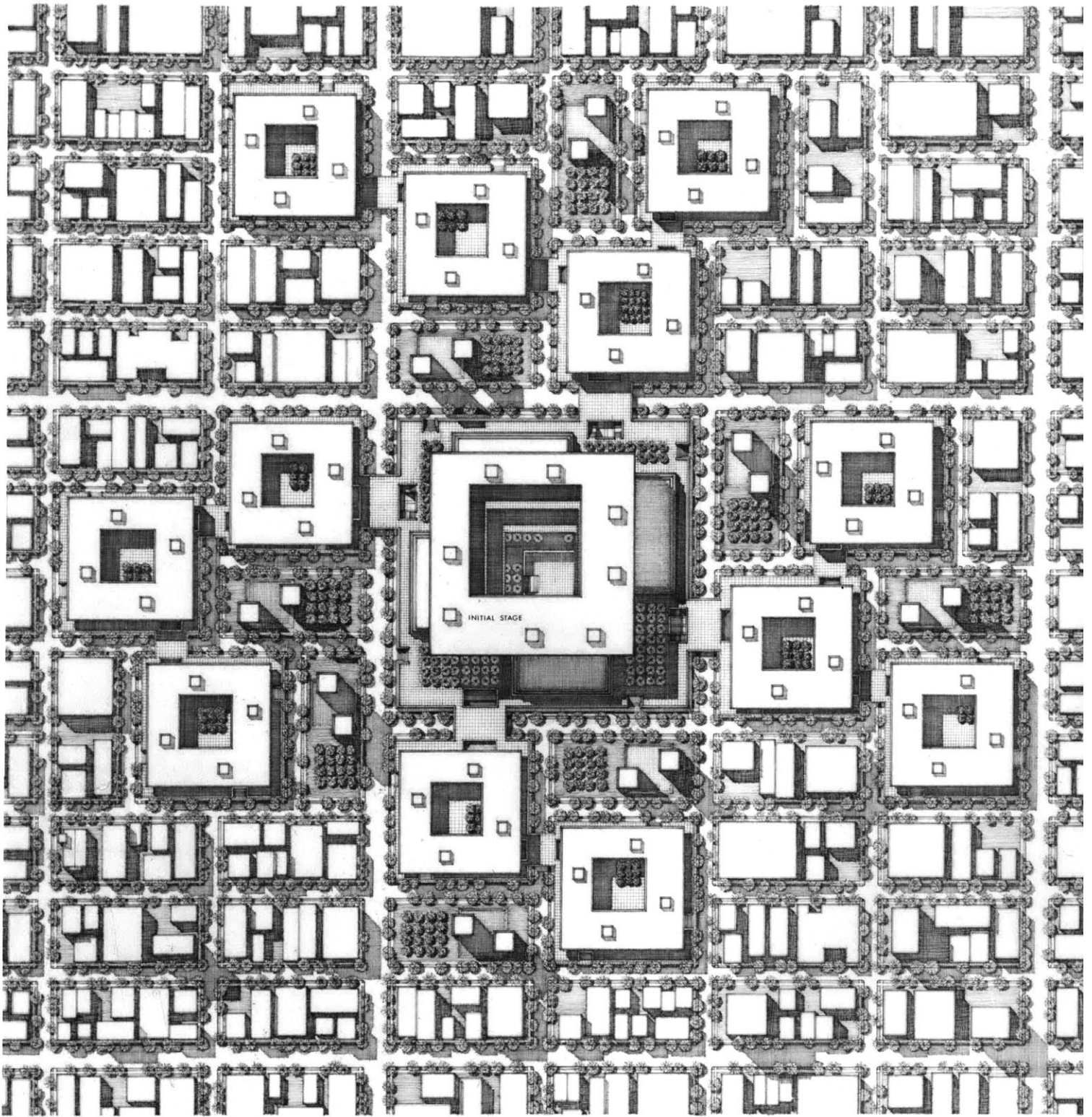
The main floor level of the building is a story and a half above street grade, thus permitting direct connection to future portions of the campus by street overpasses. The library, theater and auditorium, athletic facilities, and administration occur on this level in four buildings grouped around an open plaza. A sunken activity court occupies the center of this plaza and admits light to the student center located on the floor below. A service level for the other core facilities also occurs on this floor.



Balanced above the core facilities, and visually separate from them except for the vertical core shafts, are the teaching areas. These are contained in eight floors which form a hollow square. The floors on the interior of the square are stepped back on the east and south sides to permit sunlight to penetrate to the central plaza below. Additionally, the lower floors are stepped back at the perimeter of the square to emphasize the separation from the buildings below.

The structural bay used throughout the building is 56'8" square and consists of pre-cast concrete structural units on a 7'1" module which are linked together with post stressing cables to form an integrated floor system.

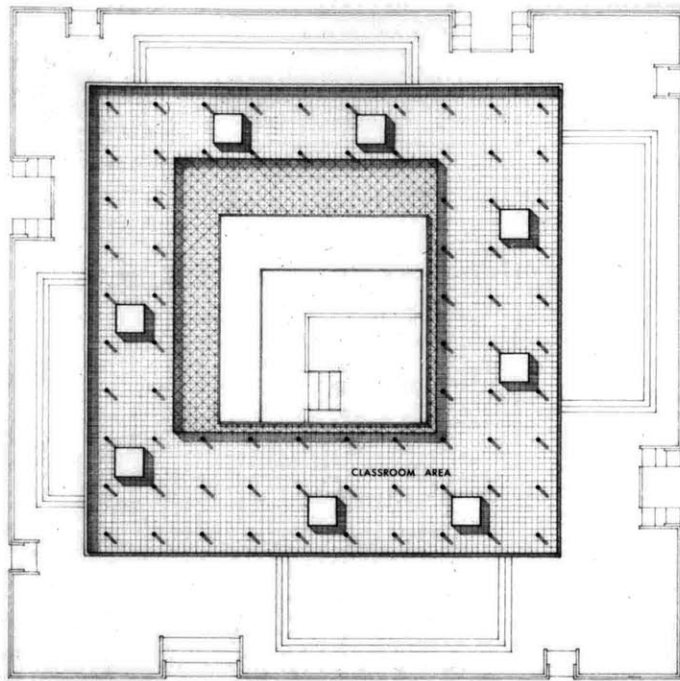
Where it has been necessary to provide certain functions with free span areas larger than the typical bay module, these functions, notably the theater and gymnasium groups, have been placed outside the main column grids which support the upper teaching area floors.



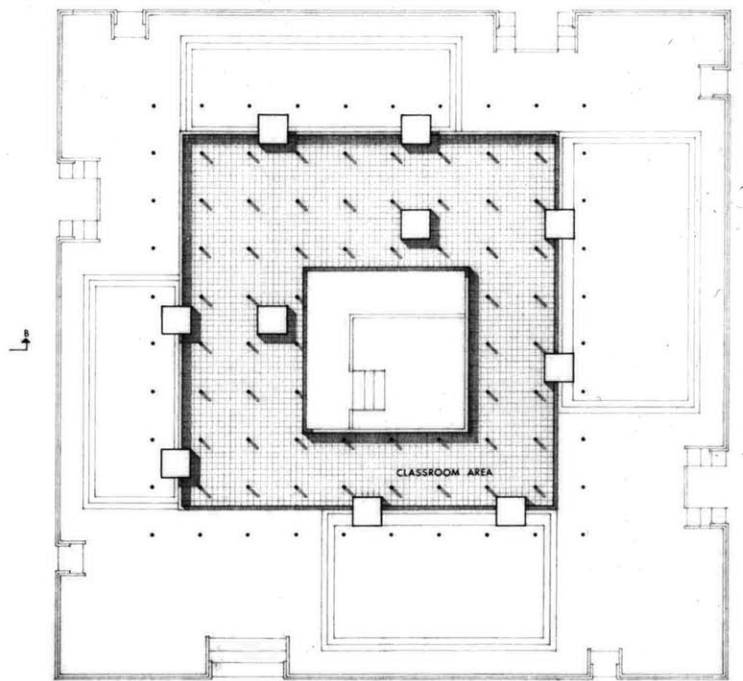
SITE PLAN SHOWING GROWTH PATTERN

MASTER OF ARCHITECTURE      SPRING 1967  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
PETER R LEE  
0    100    200    300    400    500    600

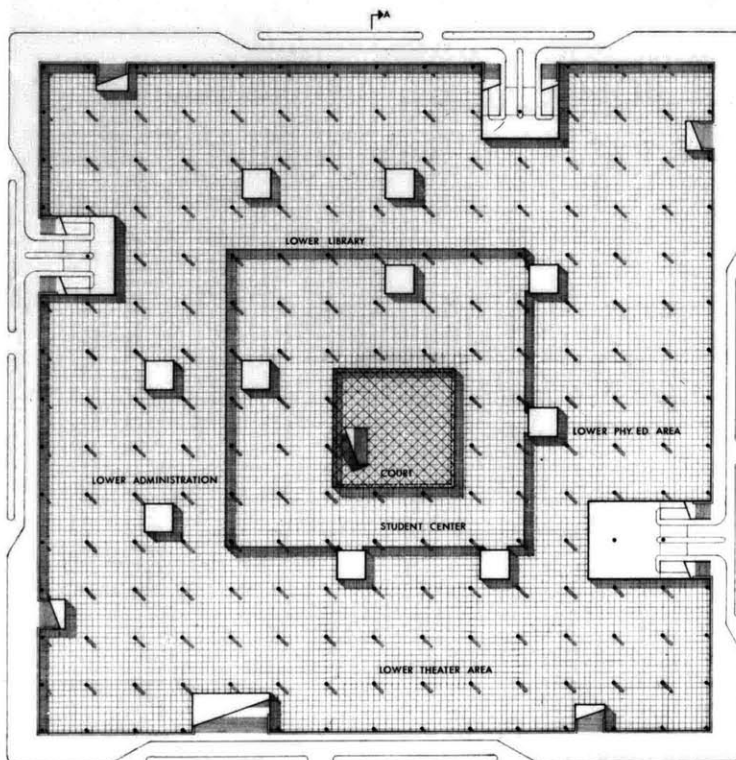




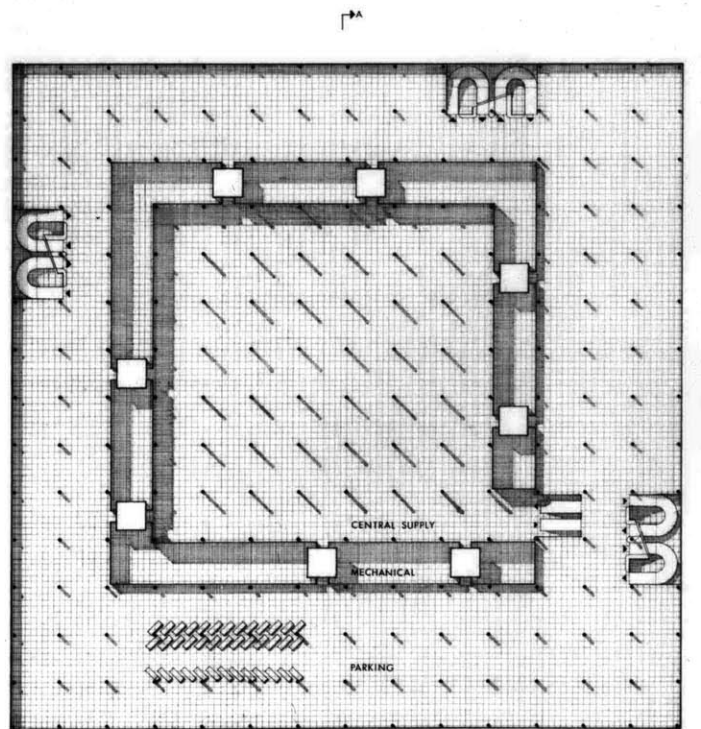
NINTH FLOOR



FIFTH FLOOR



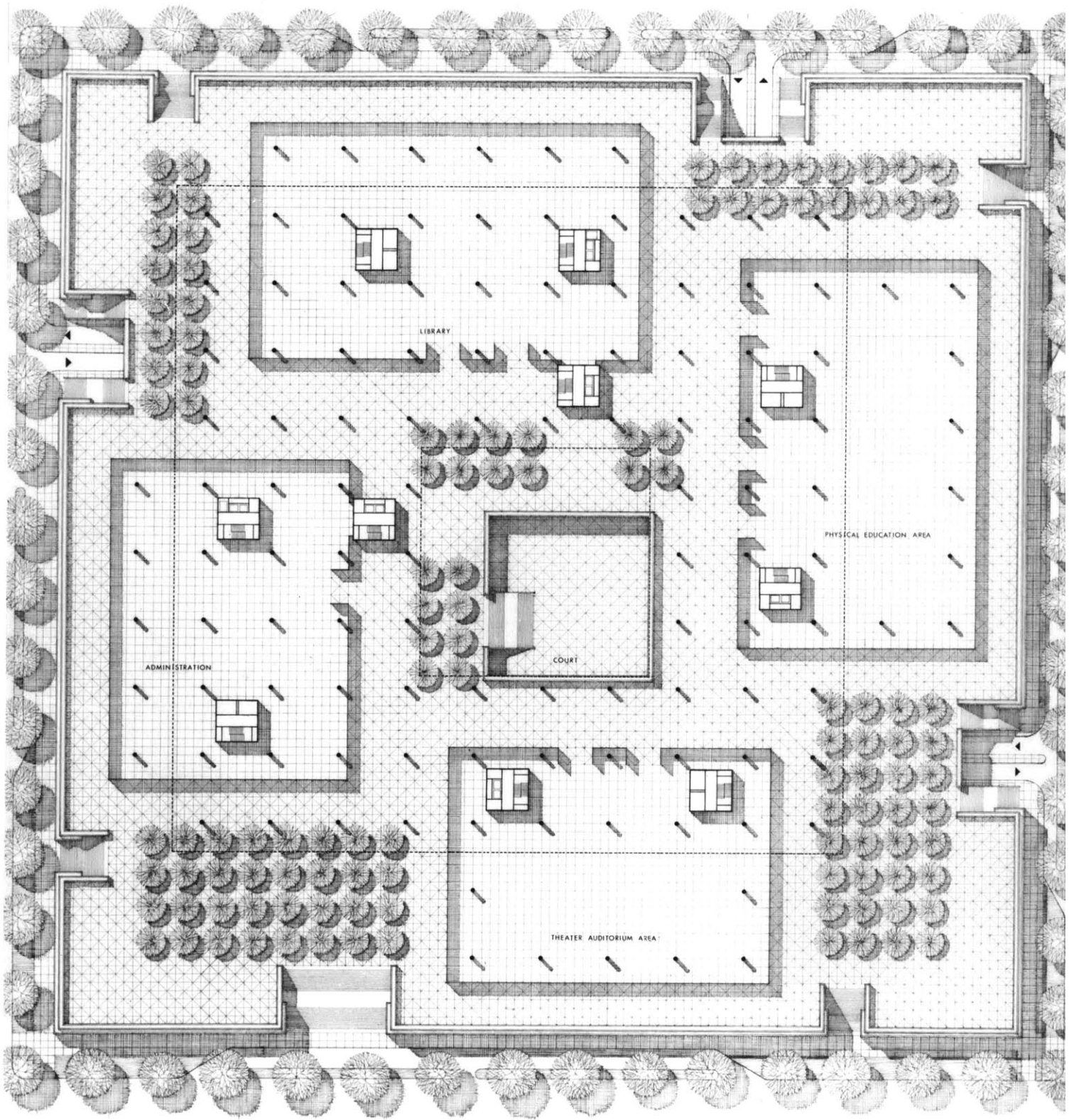
FIRST BASEMENT



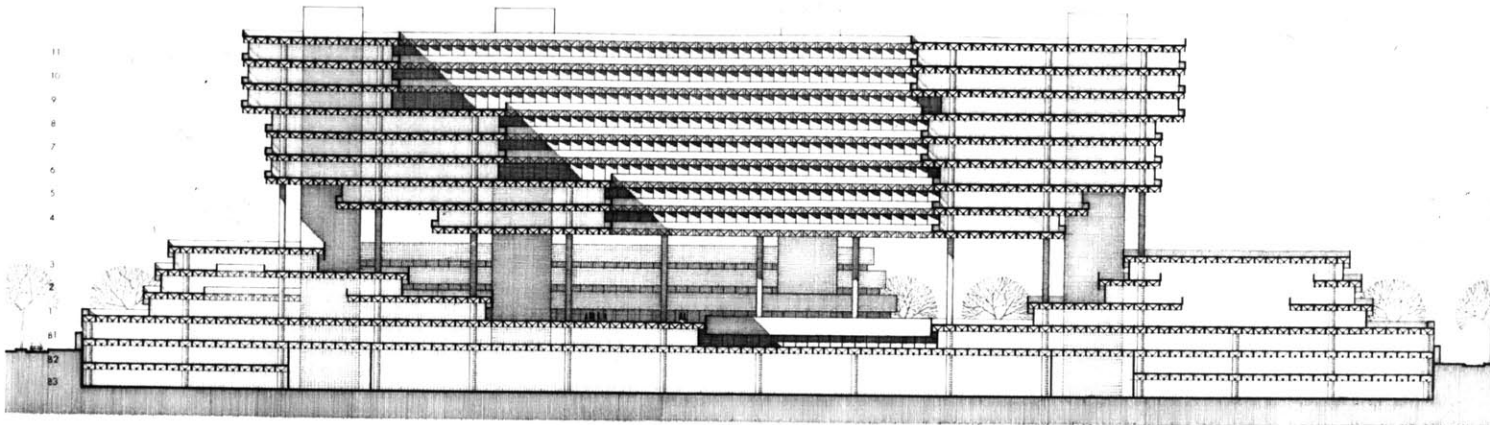
SECOND BASEMENT



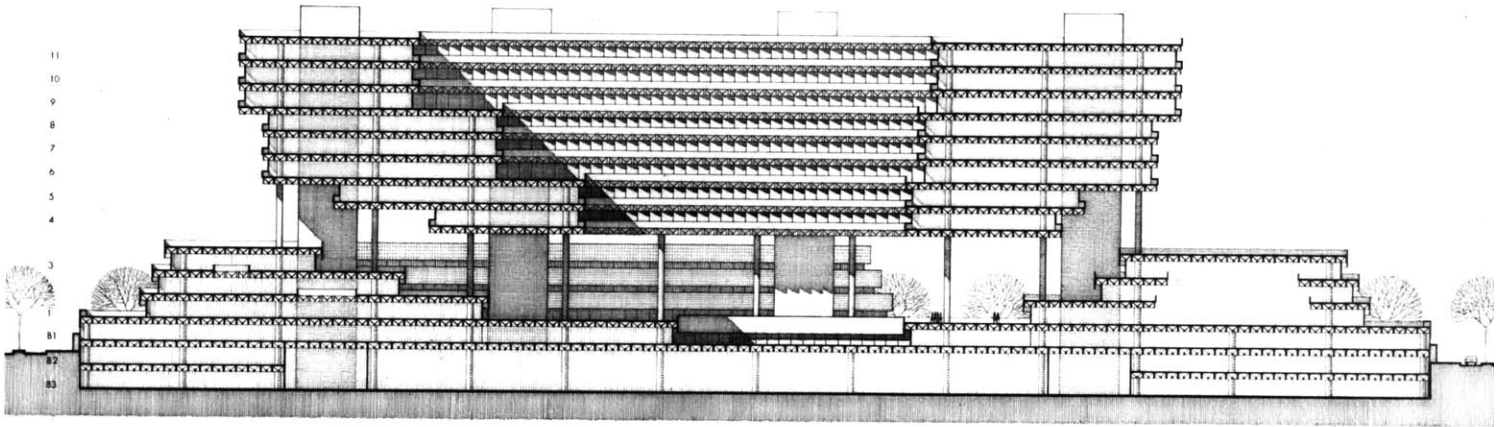
FLOOR PLANS



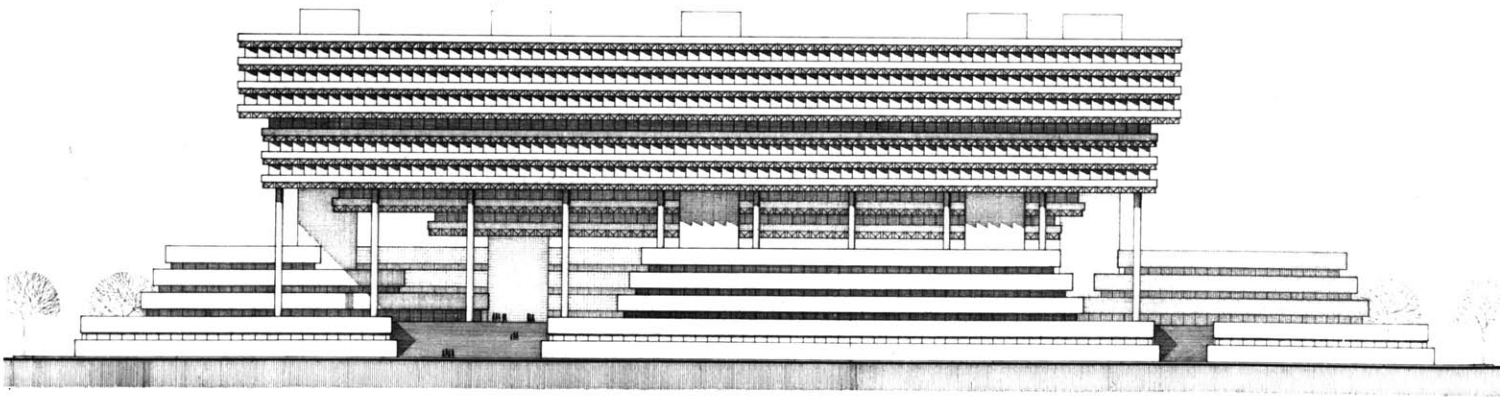
MAIN FLOOR PLAN



SECTION A



SECTION B



NORTH ELEVATION

SECTIONS ELEVATION

