

BUILDINGS AS SYSTEMS

by

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SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF ARCHITECTURE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

July, 1966

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July 1966

Lawrence B. Anderson, Dean
School of Architecture and Planning
Massachusetts Institute of Technology

Dear Dean Anderson:

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

Respectfully,

Gloria Lozano Barcala

THE AUTHOR WISHES TO EXPRESS HER
THANKS TO PROFESSOR EDUARDO F.
CATALANO, WHO AIDED GREATLY IN
THE DEVELOPMENT OF THIS THESIS.

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I. INTRODUCTION

In the last 150 years, the Occidental society has changed completely the speed of its technological development. While in the past, these changes were followed by the majority of the people and adjustments were made between demand and offerings; as well as recognition of the techniques used; nowadays the speed of the change is so fast that there is a complete divorce in the relations of: demand and its satisfaction; techniques used and potential techniques, and most important of all in the new role that art as well as industry must play. The effects of the Industrial Revolution as well as its adjustments were not yet made when today's new revolution began to take place. Only a few people are aware of the implications that this new revolution is going to produce; but all are going to receive the impact of it. In a brief summary, the effects that these two consecutive and interrelated processes are producing in the occidental world can be pointed out to be:

1. Development of the cities of more than 100,000 inhabitants up to metropolitan size.
2. Increase of population, caused by migration and by the extension of the average lifetime.
3. Cities offering more and more specialized services, attracting more of the population.
4. Dynamism and speed of progress in each field making it necessary for each service or activity to change its requirements faster thus making

flexibility one of the most important criteria because it provides the adequate environment for each changing necessity.

The consequence of the facts pointed out in this overall view is that the demand in the cities for structures capable of allocating the increasing number of the population, as well as providing them with the necessary services is increasing sharply. On the other hand, these structures must face an unstable group of requirements, since, as a result of the technological development, some of these requirements will be changing in quality or quantity. Therefore, the consideration of the time factor, not only in terms of speed in the provision of these facilities but also as a determinant of the cost of the structures is essential.

Architecture can no longer be isolated from the social, economic, and technological environment in which it takes place. The actual situation provides its origin. Therefore, architecture must solve the problems of its present situation; it must be the expression of the balance and equilibrium between technology serving human purposes and sensibility, providing the environment for an effective community and individual life, assimilating and incorporating in its overall structure the everchanging materialization of technological advances, and always serving human needs.

In conclusion, integrated structures that will have different cycles of life so as to solve temporary and permanent functions in harmonic

ensembles must:

1. Reach the equilibrium between the market demand and the market offers.
2. Express technological advances in an inspiring human environment.
3. Recognize the social-economic-technological factors.
4. Promote initiative in the industries to reach an integrated industrialized process of construction consistent with the actual demands and technological advances vs. the craftsmanship of the actual methods used.

II. AIM OF THE PROJECT

Buildings for services, administration, education, offices, laboratories, industries, etc., must offer a strong "Structure" providing shelter and mechanical facilities. In such a frame or skeleton allowance must be made for the allocation of structures of short life cycles, and for the specific and everchanging requirements of each function, so that they can expand, contract, or radically change without affecting the basic functions of the major "Skeleton".

For this, it is necessary to study each one of the different components of the so called "Skeleton", its exclusive possibilities and limitations, its interrelation and influence, and its assembly in an organic system based upon certain criterias.

Realistically, criterias are set by the program, limited funds, or technical boundaries; but in abstract terms, in order to be consistent with the result obtained, to be able to check it in the light that it has been brought up in; a designer should set certain criterias.

In this case, the criteria is: an economic (economic meaning with a long term usefulness) building using prefabricated elements, achieving a certain degree of flexibility. Up to that point, can we design a system that is 100% efficient? Human mind cannot, because of its own limits, deal with absolutes, but achieve them up to a certain degree by means of parameters, in this case of design, by criterias.

III. DESCRIPTION OF THE SYSTEM

Based upon the criterias mentioned in Chapter 2, a one way system offers economy in each one of its parts as well as simplicity of construction. It can have, large spans in one direction, and intermediate in the other, having as an average, large areas (in this case of 2100 sq.f.) which allow enough flexibility in terms of space requirements.

High velocity, two ducts, saves space in its vertical and horizontal distribution, allows flexibility in the control of temperature in different zones, and though more expensive to install it is more economical to run when the building is in operation.

The structural bay is 60 feet by 36 feet, dimensions based on the internal bay-module, it covers a major space of 2100 sq. feet that is sufficient for auditoriums, and halls of assembly considered as major space requirements, and the space can easily be subdivided.

Edge conditions allow the possibility of working with or without cantilevers of 20 feet in the direction of the 60 foot span; in the direction of the 36 foot span, a cantilever of 12 feet is constant. (Plate 1)

The mechanical system is carried inside the columns; thus, using the constructional depth required for structural reasons, the air can be allocated within the horizontal structure, avoiding the expensive increment of depth, and presenting a uniform, completely flexible ceiling grid.

A. STRUCTURE

Columns: are concrete poured in place because it allows maximum flexibility in the height of each floor and because this procedure does not work against the economy and simplicity of the system. The formwork is not complicated and the operation for each floor is not time consuming.

To assure the maximum section of concrete required on the basement (8 sq. ft.), to avoid the mass of a monolithic column, and to integrate the mechanical in its vertical and horizontal high velocity, the columns are split in two, each one with the shape of a U. At each floor the columns reduce the amount of concrete from the inside, so as to obtain the same visual appearance for all floors, and to compensate for the increment in size in the shafts, the mechanical room being on top. (See Plate 4-5).

Girders: a system of precast double girders that lies each one on a column with bottom cord also precast, assures the continuity in the compression zone spanning the 36 feet. These major girders of 2 1/2 , and 1 foot deep sitting on top of the column have a cantilever on both sides of 9 feet. Repeating the system, every other bay has a filling girder of 18 feet simply resting on horizontal supports provided in the girders, (See Plate 6). The double girders present slots on the top at a double interval, where the connections with the channels are assured.

In order to provide the continuity of the mechanical from the major horizontal circulation in between the girders to the negative spaces in between the channels, the girders are perforated at every other bay corresponding alternately to supply and return line. (See Plate 6-7)

Channels: Spanning the 60', channels of precast concrete are used. The geometry of these channels is dictated by the same basic criterias: Treat them as kind of membranes, saving in the minimum construction depth as well as in its width, the span of 6 feet which is the inside bay module. Structurally it can be described as a slab supported on two lateral inclined beams, which because of its slope, reduces the span of the slab.

The bottom cords are precast and prestressed. This operation can take place at the same time for all the units in the factory, and later on, by tightening the mesh of the lateral beams and slabs to some of the stirrups coming from the cords, the continuity is assured. At a length of 8 feet in each one of the "beams" and in both sides metal angles of equal flanges are inserted in the concrete, and come out 2 and 1/2 feet, sitting on the slots of the girders. To assure the continuity in the tension part, these metal angles are tightened one to another by means of welded bars.

The negative space between two adjacent channels is wide enough to let it run the mechanical services (low velocity) as well as the drainage zone and pipes.

As coverage is a function that is always needed, but the provision

of air conditioning can be integrated later on, the system allows the possibility of fixing the ducts and diffusers from the top, (during building construction an easier, more economic procedure) or from the bottom once the whole structure is finished, thus requiring low scaffolding at certain points.

Filling slabs of 2 feet simply rest on top of the structure closing the negative spaces in between the channels and girders.

Continuity is assured by means of 3" topping; the mesh of which is tightened to stirrups left for this purpose in the girders and channels. Two concrete diaphragms are precast within the channels, at 12' from both ends.

Inside the channels slots are made; each 4 feet to allow the insertion of acoustical removable panels. Being removable, the amount of absorption can be regulated according to the function and in large spaces when these panels are not necessary, the whole shell of concrete can be seen.

Cantilever: For edge conditions as well as for interior, special channels, with the same geometry and system of prefabrication of the large ones, are designed. The dimensions are: for edge conditions 20', allowing the location of offices with or without circulation included, with natural light in the 20' dimension, and the smallest one of 12'.

The major cantilever, because of its proportions, is postressed by means of cables placed on the top of the two lateral "beams". The diaphragms are placed at both ends.

Procedure of erection:	First step:	Columns pored in place.
	Second step:	Main girders are placed.
	Third step:	Filling girders are placed.
	Fourth step:	Channels are placed.
	Fifth step:	Filling slabs are placed.

B. MECHANICAL SYSTEM

As it was said before, the system is based on two high-velocity ducts, coming from the mechanical room on the top of the building and distributing the air in the two ducts, cold and hot, inside the columns, from the columns, and still at a high velocity, transferring the air to the horizontal inside the two girders.

Every 12' there is a supply line between the channels and at the same distance there is a return line. The two ducts transfer to a mixing box every 12 feet and then, at low velocity, enter both ways of the channels thus achieving a flexibility of temperature control each 12 feet.

The speeds used are:	for high velocity:	4000 fpm.
	low velocity:	1200 fpm.
	return:	700 fpm.

Horizontal diffusers were used for supply on the lateral beams of the channels as well as for return on the filling slats for the floor above. (See plate 2-4)

In the periphery, the provision of air is by the same method but in both cases with cantilever or without, coils are located in the sill of

the windows with four pipes, cold and hot water, supply and return. The air reaches the coil still at high velocity, and there is conditioned to the desired temperature, plus a percentage of the air taken from the same room by means of a grill.

Also in the periphery system, horizontal diffusers are used.

(See Plate 2-5)

The provision of air in the inside, except for the periphery zone, is regulated by the inside-bay module, let us say 6 feet by 4 feet. Each 4 feet there is a diffuser; or each increment of the room in the 4 foot direction corresponds with a new diffuser. The same happens in the 6 feet dimension; since the supply lines are located within a distance of 12 feet, but each of them feeds in both sides, each increment of the room in another bay corresponds with a new supply line. Return works exactly the same way.

An even distribution of air and return contributes to the homogenous quality of the overall area and increases the flexibility of the partitioning of the space. (See Plate 2-5).

C. PLUMBING

The pipes are located inside the columns, in controlled compartments that can be easily inspected. They run horizontally inside the girders of the supply line, and from there feed both adjacent bays running in the lower portions of the negative spaces in between the channels. As they run horizontally only 30 feet, the problem of slope is minimized. In the 60 foot dimension, the proportion of free space is increased, thus slope does not cause any problem. Any leak is going to be immediately detected

and is going to be repaired from underneath with no need of breaking the structure or even the finishes. (See Plate 2)

D. LIGHTING

The inside-bay module governs the distribution of lighting also. In each module, a connection is provided, but the lighting fixtures that are 4 by 1, can be ordered in different arrangements according to the requirements and needs of each space. Not only is the flexibility related to the amount of light but also to the disposition of the lighting fixtures in the space, as it is able to emphasize a certain direction according to the proportions of the room and its use. (See Plate 2)

E. ACOUSTICAL

Basically, the removable acoustical panels will take care of the transmission of sound from room to room as well as the excess of reflection and reverberation in each room. The absorbing material used will depend upon the critical frequencies to be absorbed in each case, (computers, typewriters, workshops, classrooms) and whenever they are not necessary, they can be removed partially or totally.

The ducts and pipes will be wrapped in fiberglass so as to avoid the transmission of the sound of the air or the water.

Sound absorbing insulation is placed inside the ducts next to each diffuser within the duct to avoid the travel of sound from one room to the other. (See Plate 2)

F. SPATIAL FLEXIBILITY

Partitioning, inter-bay module.

The basic bay of 60 feet by 36 feet is subdivided into internal bays of 6 feet by 4 feet, the 6 feet being constantly determined by the width of the channels, and the 4 feet by the removable acoustical pannels, allowing, in this case, the increase of the module by doubling or tripling it and so on.

The criteria for the selection of this internal module is based on the same criteria as that of the whole system: to achieve enough flexibility to enclose a minimum space, a room of 12 feet by 8 feet with a proportioned structure, that can also occupy the whole bay, giving the structure a different character and scale. In this case, the panels can be removed and the whole ceiling can be read as six vaults of concrete spanning 60 feet. The major circulation shall run parallel to the main girders, let us say, to the 36 feet span. The module of 6 feet orders the entrances at periods of 3 feet voids and 3 feet partitions; the rooms can grow flexible inside the bay, each 4 feet giving an increment of 24 sq. feet per module and maintaining orderly an orderly face to the circulation. When the proportions of a room reach the ration of 1:2, it justifies "jumping" to another bay of 6 feet, and so on. Internal circulations can vary between the limits of 20 feet and 8 feet (20', 16', 12', 8',) allowing a hierarchy and flexibility in the dimensions of it. The entrance to the rooms will

be stressed by the directionality of the vaults.

If circulation were to be parallel to the 60' span:

- 1) the smallest rooms would increase more abruptly, "jumping" to 6 feet next bay.
- 2) Columns and girders would frequently be included in the rooms creating an interruption in the ceiling grid.
- 3) The entrance to the rooms would be perpendicular to the direction of the channels.
- 4) The face of the circulation would be broken into a double rhythm of 3 feet solid, 1 feet partition.
- 5) Circulation would be only of 18', 12', 6'.
- 6) Circulation would follow the direction of the channels and in the case of long ones, could be obsessive. (See Plate 3)

G. GROWTH, EXPANSION, REMOVAL OF PARTS

Because of the reasons pointed out in Chapter 1, the system should allow very easily for the growth, the expansion, and the removal of parts without any interruption of the parts already working. The last row of columns has a double girder, no matter what edge condition is used. If needed, the horizontal growth is simply determined by:

- 1) adding a cantilever, (20')
- 2) adding a whole bay (60')

In the direction of the 36 foot span. The growth, because of the system of major and filling girders must be of 72 feet.

Thus the minimum increment of growth is, for cantilever: 1440 sq. ft.
for a bay : 4220 sq. ft.

Vertically, the growth is dictated by the structural resistance of the columns in the ground floor.

In terms of removing parts, each one of the channels can be removed. There is a possibility of increasing the void each 6 feet.

In the direction of the 60 foot span, the voids can be determined by:

Two cantilevers of 20'	Void of 20'
One cantilever of 20', one of 12'	Void of 28'
Two cantilevers of 12'	Void of 36'
One cantilever of 20'	Void of 40'
One cantilever of 12'	Void of 48'
Without cantilever	Void of 60'

H. CORES, FLEXIBILITY, HIERARCHY, MINIMUM, MAXIMUM, GROWTH, ADDITION

The cores are self sufficient structures, that gather in a complex the vertical circulations, (stairs, elevators, freight elevators), rest rooms, telephones, and maintenance rooms, and storage rooms such as janitor's rooms, electrical rooms, etc.

The requirements of each core will be dictated by the program and its location. Within the module grid (coordinator of the whole), cores will satisfy these different requirements, not by the assemblage of basic units, but by thorough study and design of its parts according to a certain hierarchy dictated by the program. For example: cores given to major public spaces). Each core is going to serve a certain area, determined by its spacing, the maximum being 105' radius dictated

by the Code (120' as maximum travel line). From this maximum, and arranging the cores diagonally or in straight lines, and reducing the radius of service, a maximum and a minimum (full lines in Plate 8) as well as internal growth (dotted lines in Plate 8) are set by the structure.

IV. CONCLUSIONS

It must be stated that this system means more as a process of study, a way of personal research; as the framing of a system of personal decisions and criterias; as an intent to gather all the parts of a building in a consistant and integrated relation, and in the recognition of the necessity of such an integration, rather than as a final product.

The advantages have already been pointed out; but to briefly review them:

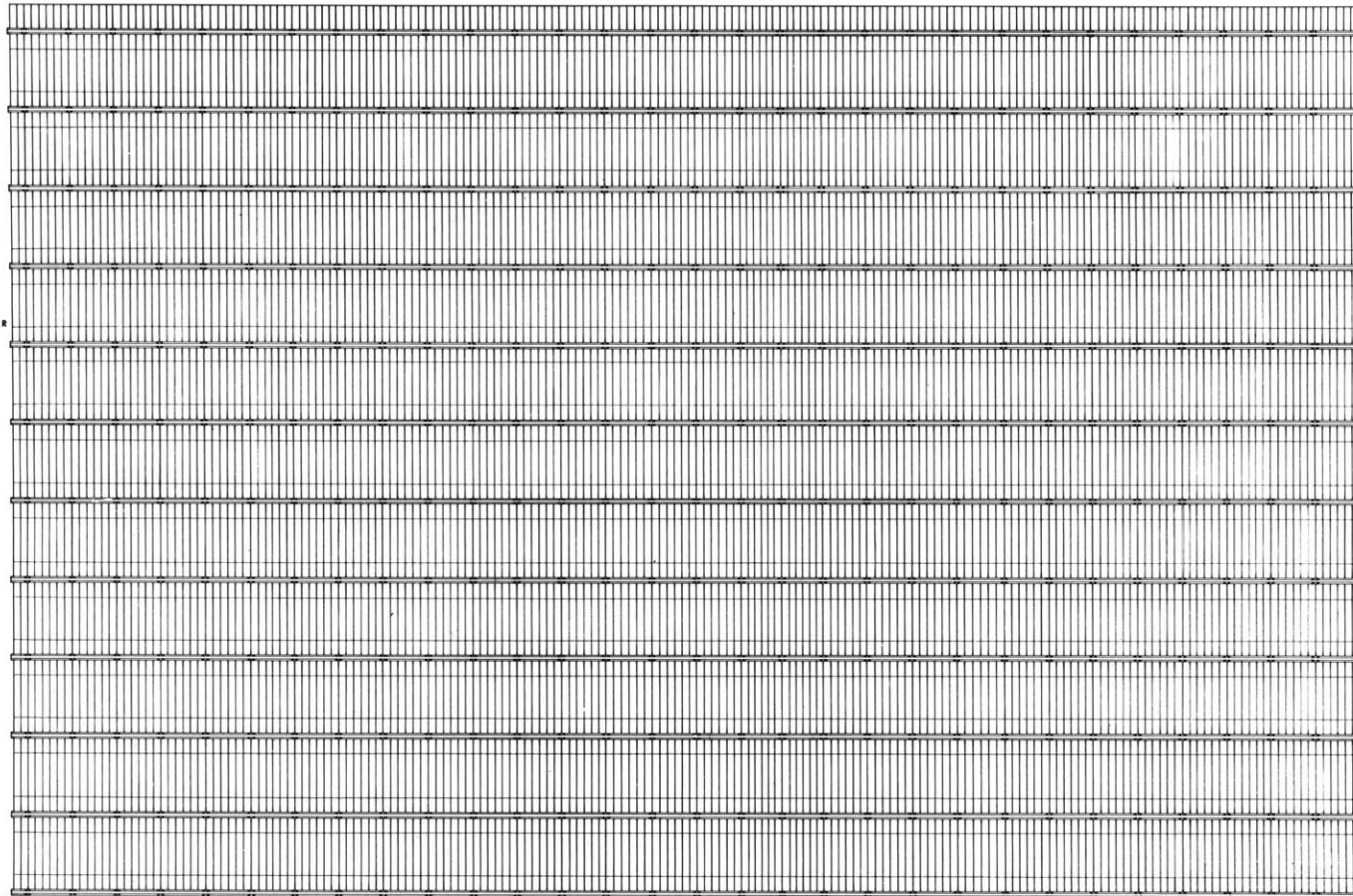
- a) an economic and simple building construction.
- b) flexible enough to allow different functions with different requirements.
- c) use of simple forms and parts.
- d) simplicity in the precast process in the plant.
- e) no need of scaffolding.
- f) no need of postension.
- g) integration of mechanical, acoustical, plumbing, within the structure.
- h) easy growth with no alteration of the mechanical and structural components.
- i) details of perimeter and its expression can be subjected to changes; then the basic system can be used in buildings of completely different appearances.

The disadvantages:

- a) flexibility in the mechanical is reduced to almost a line, each 12' but running 120' with the same air temperature, Mixing boxes could have been placed along the bay, in the negative spaces, so as to enable temperature control by zones, instead of by a long line.
- b) 10 double girders are not a structural necessity, a single girder on top of a column, with the mechanical running both sides, would be more economic as each girder would span (30' each side) instead of 30' one side and only 2 and 1/2' on the other.
- c) The connection between the channels and girders should have been of concrete. Take the metal angles. Though completely covered by concrete, they would have a weak point: if the concrete, by expansion cracks, leaks of oxide or rust would appear in the concrete, and these would be bad points in case of fire.
- d) narrow dimensions in the space between the channels would make it hard for a worker to place the mechanical.

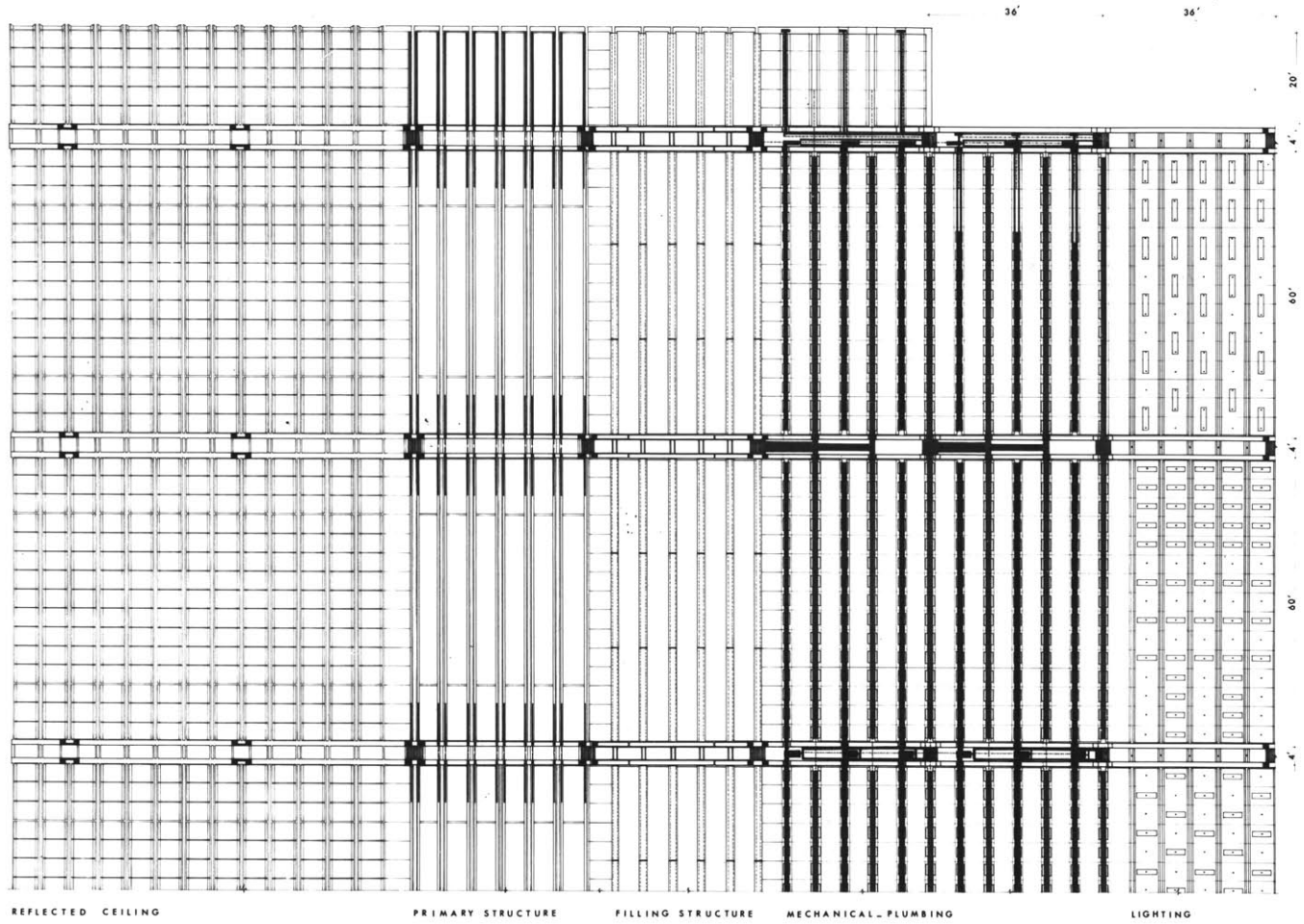
WITH CANTILEVER

CANTILEVER



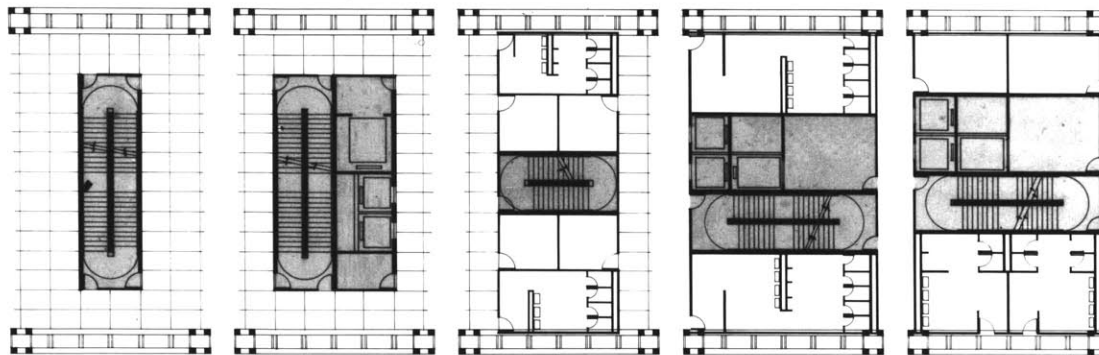
WITHOUT CANTILEVER

BASIC GRID SYSTEM COLUMN SPACING
EDGE CONDITIONS

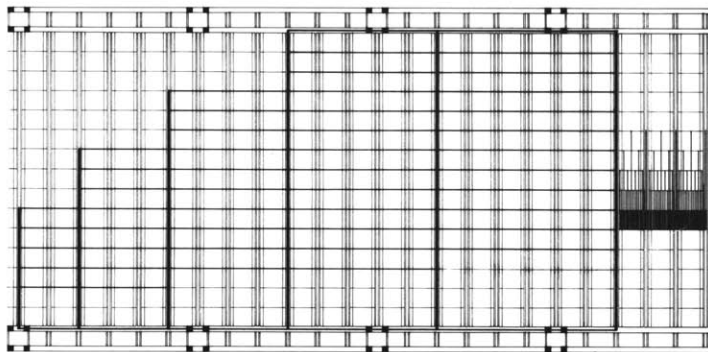


FOOTPRINT

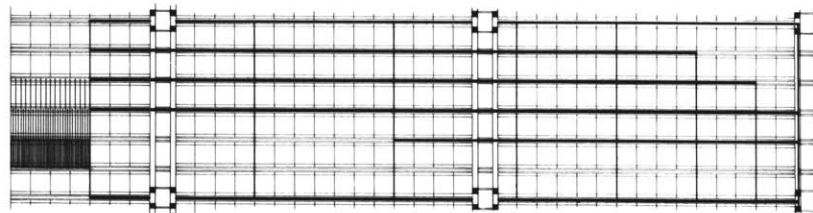




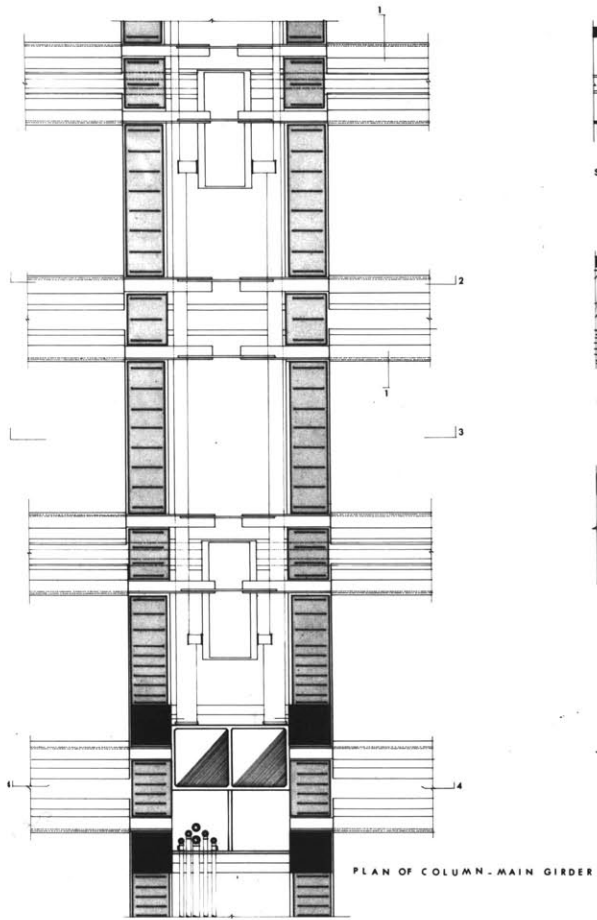
C O R E S



S T U D Y O F P A R T I T I O N S



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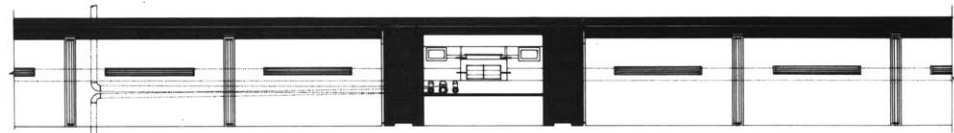
STRUCTURAL-MECHANICAL SYSTEM IN INTERIOR ZONE



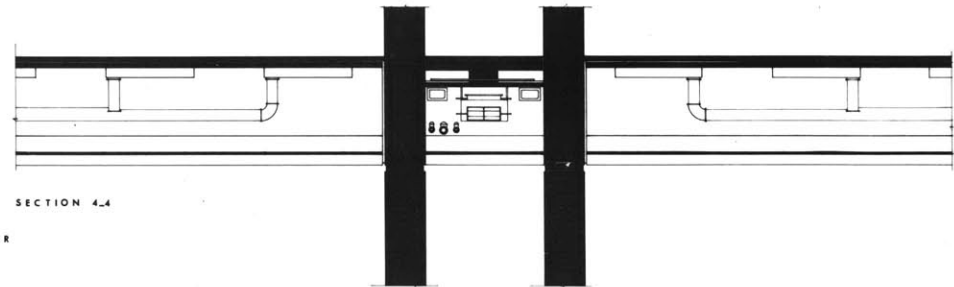
SECTION 1_1



SECTION 2_2

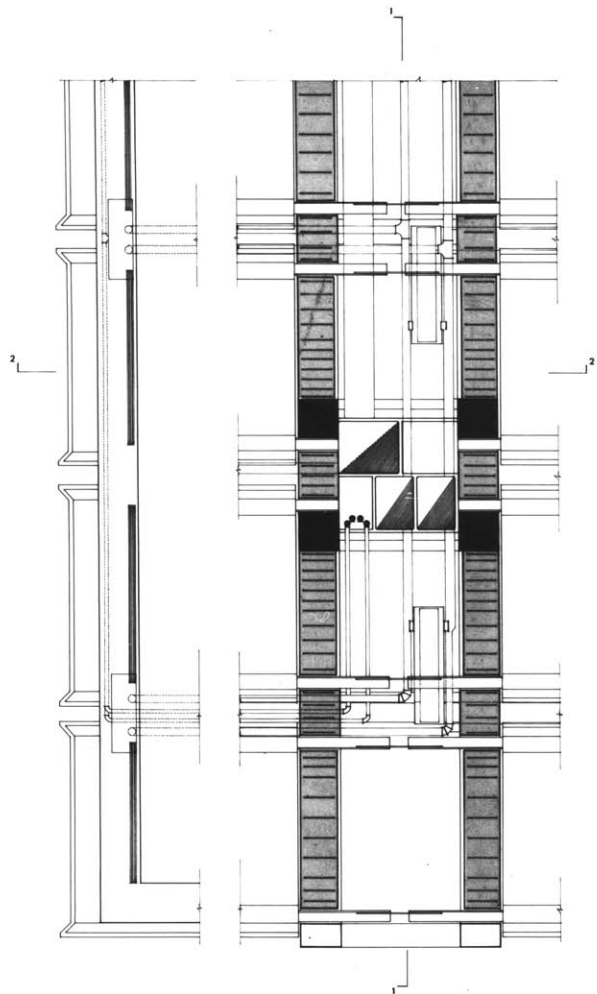


SECTION 3_3

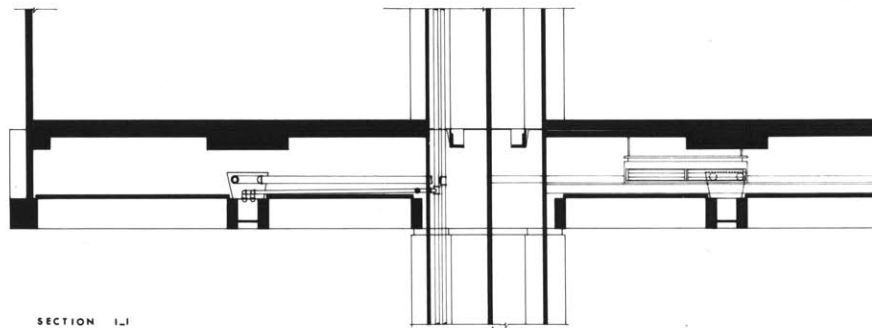


SECTION 4_4

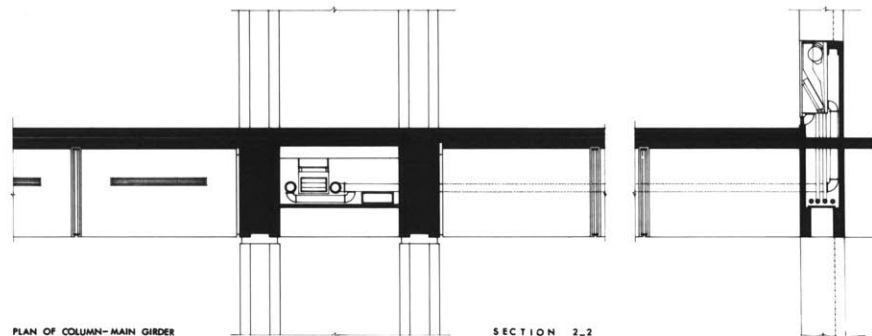
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STRUCTURAL - MECHANICAL SYSTEM IN PERIPHERY



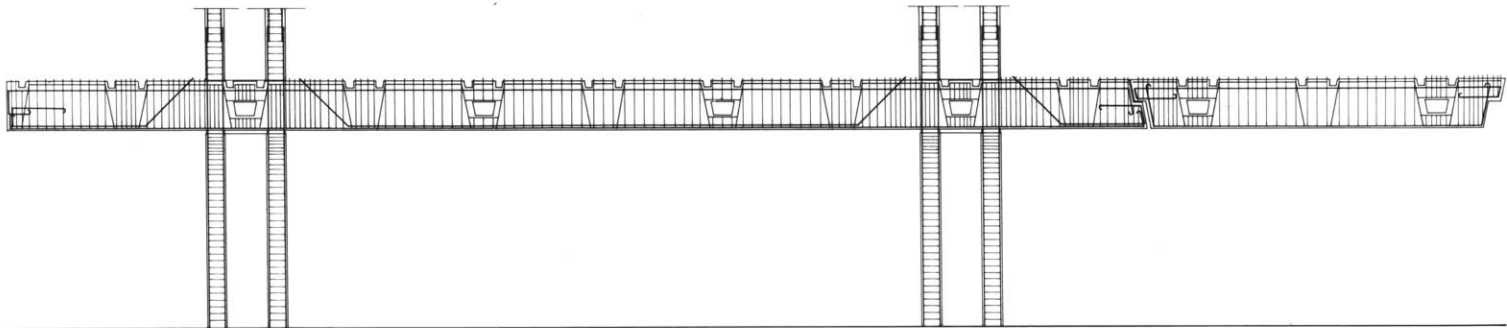
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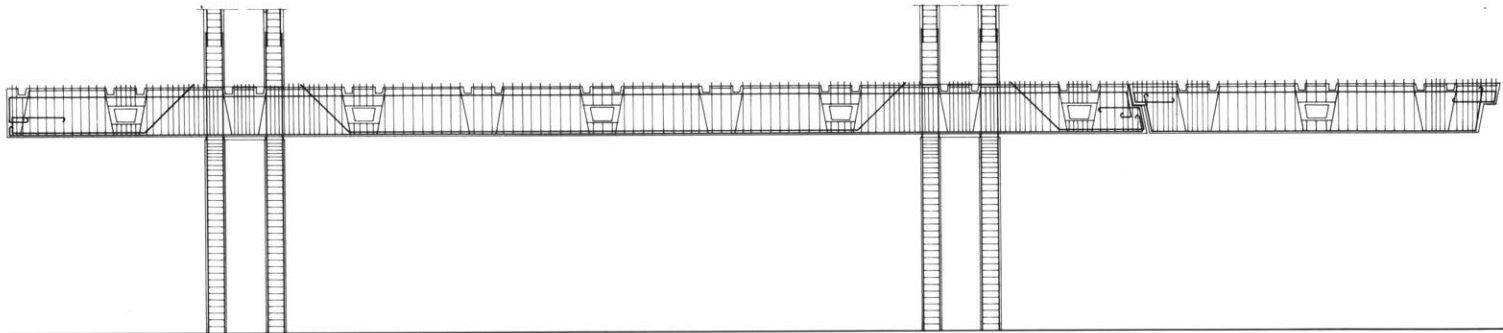
PLAN OF COLUMN-MAIN GIRDER

SECTION 2-2

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REINFORCEMENT IN RETURN LINE



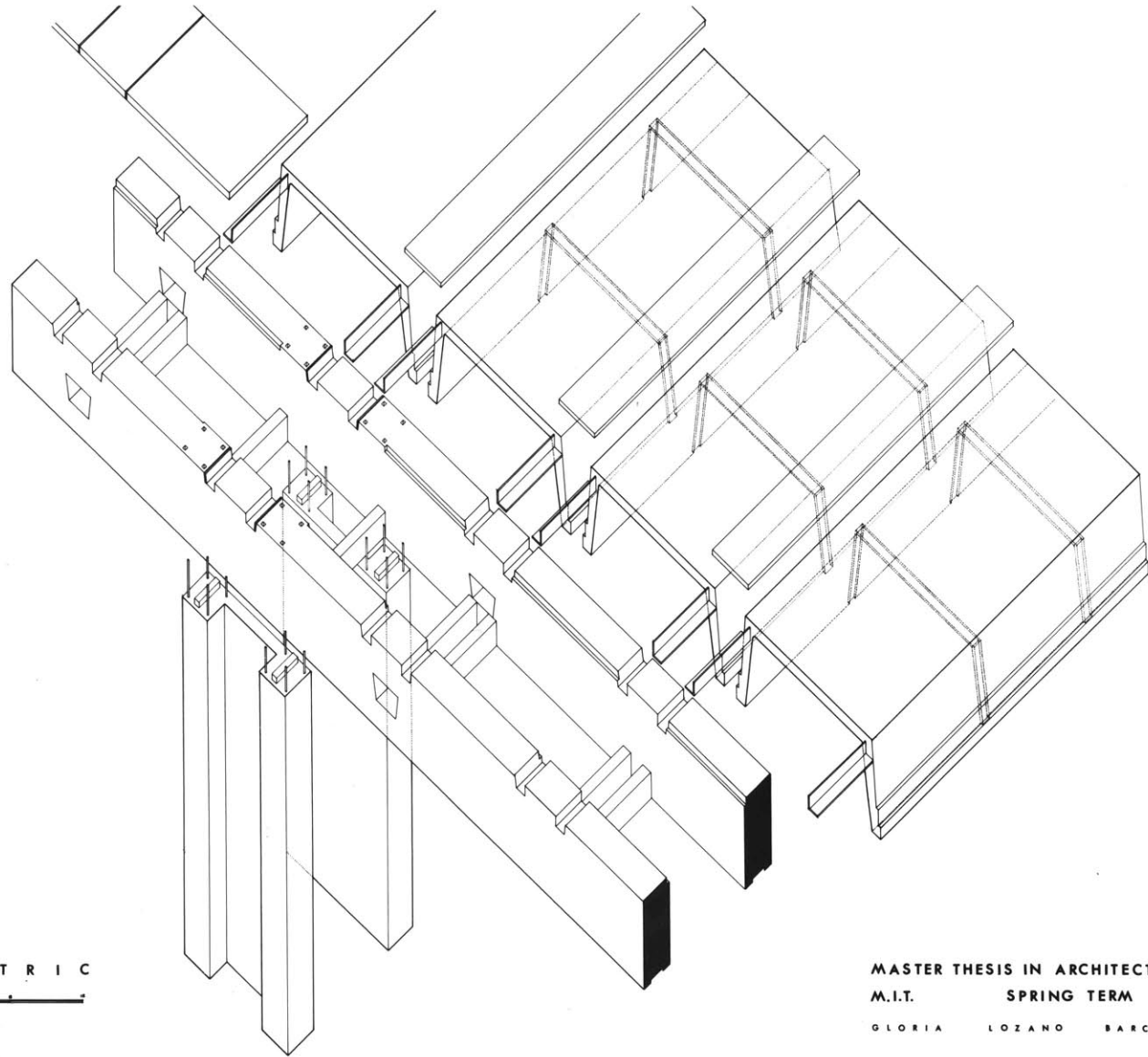
REINFORCEMENT IN SUPPLY LINE



REINFORCEMENT IN CHANNEL

REINFORCEMENT





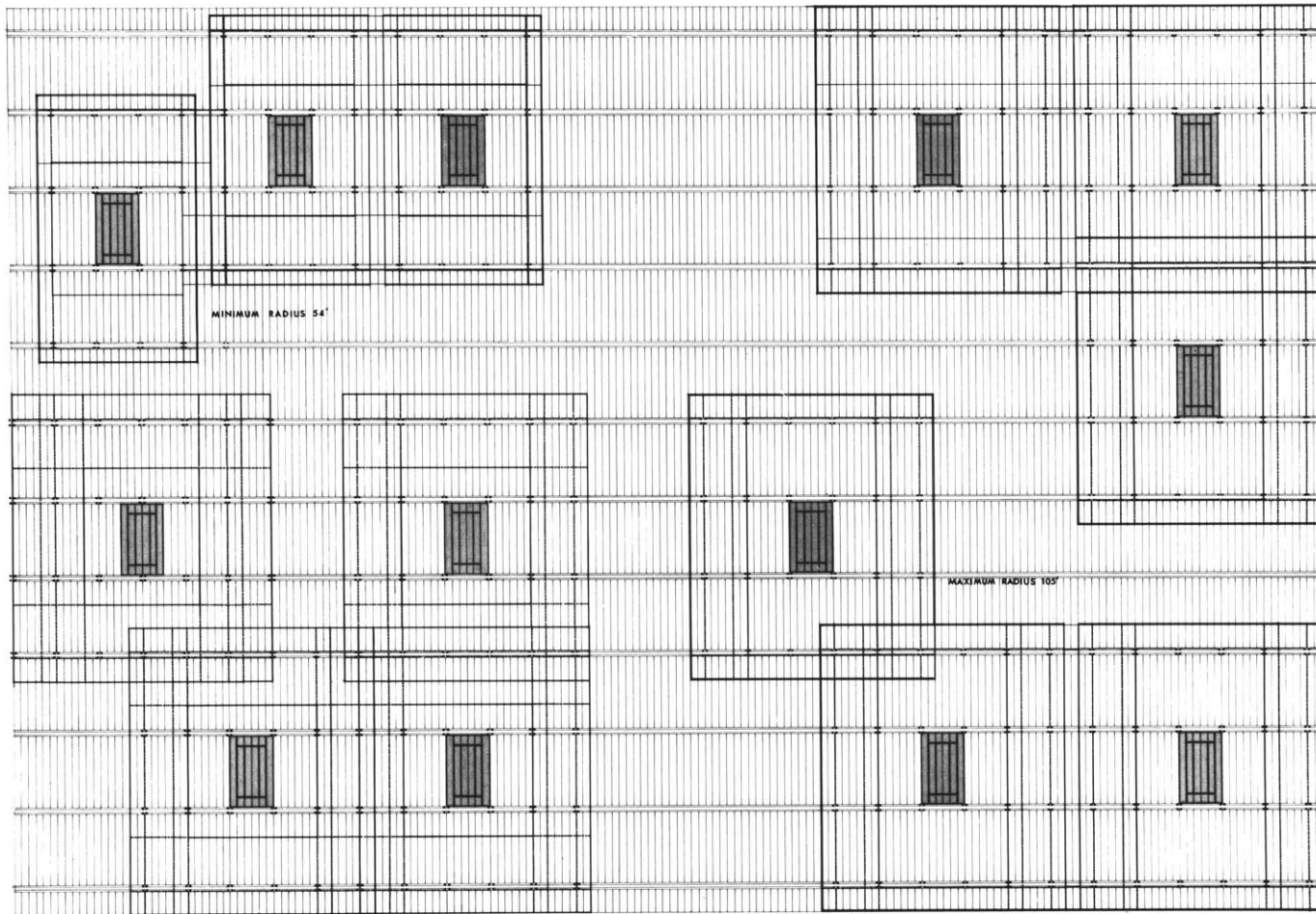
I S O M E T R I C



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CORE SPACING - BASIC BUILDING UNITS

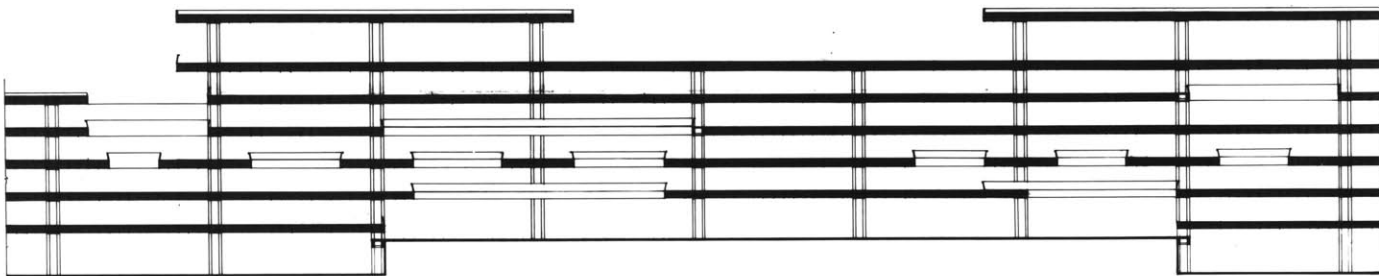


MINIMUM - MAXIMUM
GROWTH - ADDITION

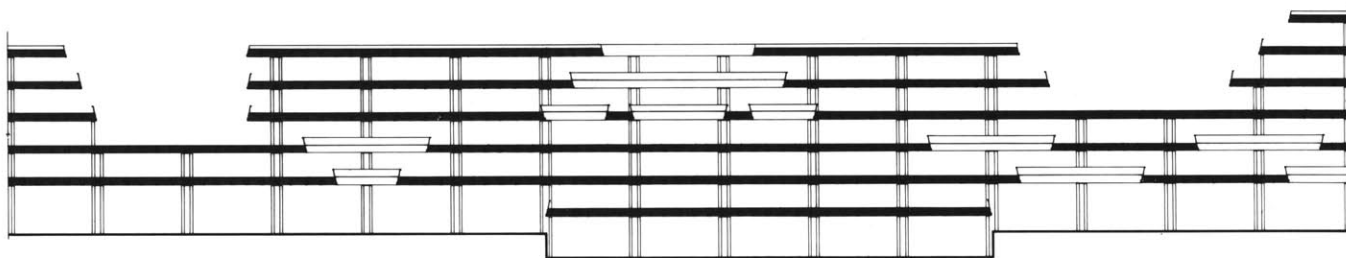
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SECTION THROUGH MAIN GIRDERS



SECTION THROUGH CHANNELS

POSSIBILITIES IN VERTICAL SPACES



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