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BUILDINGS AS SYSTEMS

by Ary M. Pedju,

Ir. Ars., Institut Teknologi Bandung,
Bandung, Indonesia, 1963

Submitted in partial fulfillment of the requirements for the degree of Master in Architecture at the Massachusetts Institute of Technology, June 1965.

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June 15, 1965

Dean Pietro Belluschi
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Dear Dean Belluschi:

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

Respectfully,

Ary M. Pedju

AMP:mam

A C K N O W L E D G E M E N T

The author wishes to thank the following whose assistance and advice contributed substantially to this thesis project: Professors William A. Litle and Peter Pahl of the M.I.T. Department of Civil Engineering; Professors Waclaw Zalewski, visiting professor, and Eduardo Catalano, thesis advisor, and Mr. Leon Groisser, instructor, of the Department of Architecture.

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I N T R O D U C T I O N

The architect, in the ancient as well as recent past, could be at once an artist and a technologist, a designer and a builder. During the last half century, however, specialization of knowledge has so developed that various functions once performed by the same man are now done by different men. The rapid development in technology, the increasing needs of the multiplied number of humans (more housing, schools, factories, offices, theaters, laboratories, transportation depots, etc.), and the changes in the civilization, the technological direction of our culture --all these tremendous forces are challenging the architects of today and tomorrow. "The mass media allow, compel, large numbers of people to gather under the same roof for all the gregarious activities so typical of our era. Large stations, large stadia, large churches, large theatres, large arenas appear in increasing numbers. Urban agglomerations require the sprouting of taller

buildings. The large structure has become a symbol of our culture and a monument to its groups, be they governments, churches, or corporations."[1]

There is a tendency for the gap between architecture and various branches of knowledge in refined modern technology to become larger and larger, since, according to tradition, the architect is trained primarily as an artist. In his article, "The Architect Within our Industrial Society," Gropius says that the architect is in a very real danger of losing his grip in competition with the engineer, the scientist, and the builder, unless he adjusts his attitude and aims to meet the new situation.

Nevertheless, engineer Mario Salvadori responds: "The influence of structure on modern architecture is so prevalent that some architects wonder whether the engineer may not eventually take over the field of architectural design. The growing importance of technical services and of

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1. Mario Salvadori, Structure in Architecture, page 6.

structure suggests such a danger. And a grave danger it would be, since the engineer, as a technician, is not trained to solve the all-encompassing problems of architectural design. But these fears may, after all, be unjustified: the engineer, while participating creatively in the design process, knows that in a group society like ours his role is limited to a collaboration with the leader of the group. This leader is and will always be the architect."[2]

Little thought is thus required to answer the question of whether the architect should become more of an engineer or the engineer more of an architect. Obviously, it is morally mainly up to the architect to bridge the gap.

From earliest times, a sense of beauty has been innate in man. It is questionable whether architecture which is deeply concerned with engineering unavoidably leads to beauty. But it is undeniable that a correct technological approach satisfies the eyes of even the most unknowledge-

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2. Ibid., page 73.

able layman, and that a wrong approach is often offensively ugly.

Architectural beauty may be born healthy through the architect's capability of, in Nervi's words, "making formulas alive, more human and understanding, and of lessening their impersonal technical brittleness."[3]

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3. In Salvadori, foreword.

O B J E C T I V E

The project objective was to design an integrated building system of space, structure, and services. This system is applied to a prototype building providing facilities for space research and development. Emphasis is placed on developing a very flexible system which will accommodate various changes in program. A great deal of emphasis is placed upon evolving a system which will permit expansion and growth of the building as needs require.

S T R U C T U R A L S Y S T E M

Structure is the only permanent system in the building. The systems which are not permanent, but are subject to change as required, are the mechanical and circulation systems and the system of growth. The structure should accommodate all the dynamic systems and allow freedom for future changes in these systems within the building. It is obvious that a correct structural system based on logic and simplicity of construction will allow fulfillment of the above-mentioned criteria.

Reinforced concrete was decided to be the basis of construction, conceived as a prefabricated system of components with total standardization of its formwork.

One-way and two-way load dispersal systems have been considered as alternatives, and it is concluded that the latter is the one which is able to meet the architectural and structural needs.

For flexibility of interior space, beams and girders should have equal depth. The logical way to have equal beams and girders is to use a two-way load dispersal structural system. The arrangement of one-dimensional resisting elements is usually impractical and inefficient.

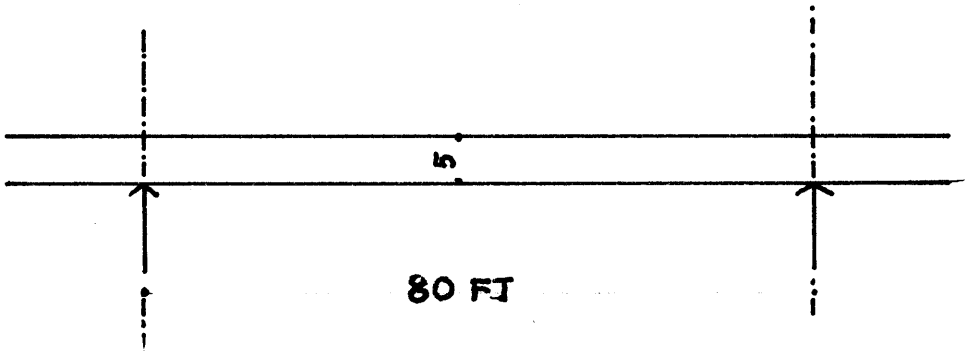
Prefabricated and prestressed techniques are used to take advantage of the new advances in industrialized construction. Also, since the building is of large dimensions and employs numerous repetitive structural elements, precasting would be very practical.

The structural system chosen is a two-way Vierendeel beam grid, with a span 80 feet long, 5 feet deep, and cantilevered at the ends. The beam grid is a 5-foot module, supported on hollow columns. Cores which are part of the structural system are systematically located at the distance of every 160 feet.

The 5-foot beam depth is chosen to satisfy the mechanical needs, that is, to allow perforations

in the beams for air ducts and pipes, to serve a reasonable floor area. Perforations of about 3' x 3.5' can be provided by this depth.

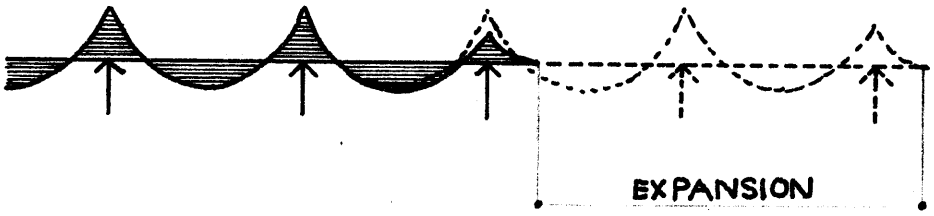
The 80-foot span is assumed to be reasonable with the 5-foot beam depth, which gives a depth-to-span ratio of 1:16.



The 5-foot beam grid is a convenient module for flexibility in room sizes, and is also indicated in the use of 4-foot long lighting fixtures.

Bays on the perimeter have a 20-foot cantilever all around the typical floor. A 1:4 cantilever-to-span ratio is used to obtain a good distribution of stresses along the beams, and also to

accommodate the change of beam behavior encountered in structural growth (expansion). The increased negative moment can be controlled within this area.



Hollow columns, 5' x 5', are provided to allocate 6" drain pipes, 4" hot water, 2" cold water, and 2" ventilation pipes, and extra room for additional pipes and room to repair them.

Cores 40' x 40' function as stabilizing structural elements, and within them are permanent, fixed elements such as fire stairs, vertical shafts, toilets, elevators, electrical rooms, and janitors' closets.

Constant distances between columns and between

cores provide simple structural behavior throughout the building, adapted to the system of growth.

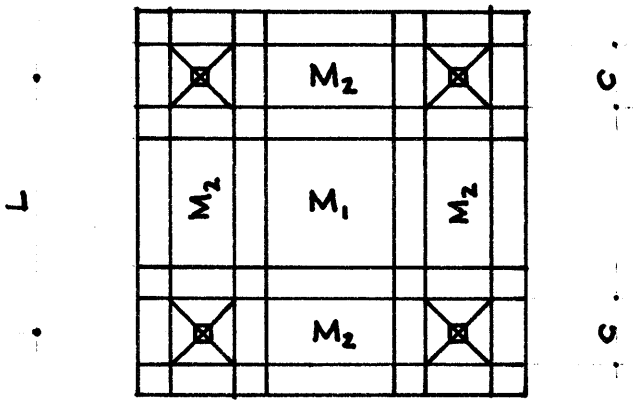
Details of the Structural Elements

Precise joinging of column to floor system is facilitated by casting in place a 20' x 20' column head integrally with the column. In addition to crossing ribs, diagonal ribs are provided at the corners of the column head, in the direction of the principal stress line. These ribs are formed by permanent fillers, with the usual concrete reinforcement, as indicated in the detail drawings. Negative prestressing cables are located at the upper part of the ribs, at right angles to them. Special openings are provided in the floor system to give access for installation and repair to the pipes located in the column.

The dimensions of beams are based upon the approximate analysis of mushroom slabs. It is estimated that statics require a total positive and negative moment of:

$$M_o = 1/8\ WL\ (1 - 2/3\ \frac{c}{L})^2$$

where W is the total uniform panel load, L is the span, and c is the diameter of the column capital.



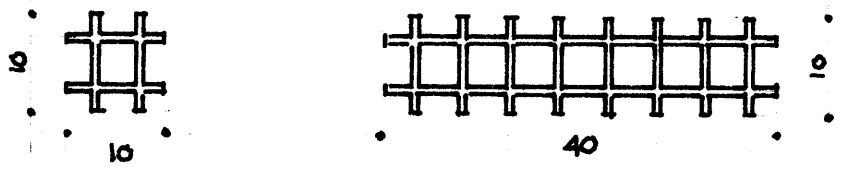
$$M_1 = 1/3\ M_o$$

$$M_2 = 2/3\ M_o$$

A straight strand prestressing method is considered to be more practical, due to the perforations in the beams. Two stages of post-tensioning are proposed; the second stage takes place after the floor system has been completed. The straight strand prestress method is not structurally economical compared with the draped strand method, but the flexibility and the practical way of

prestressing that it offers may outweigh the disadvantage.

Two typical sub-units are the 40-foot and the 10-foot long beams.



PLAN

Groups of units are post-tensioned at 5-foot centers in the direction of right angles, resulting in a slab which is continuous over spans of 80 feet and cantilevered 20 feet long.

Floor panels are of 5' x 5' precast concrete components covering the whole area.

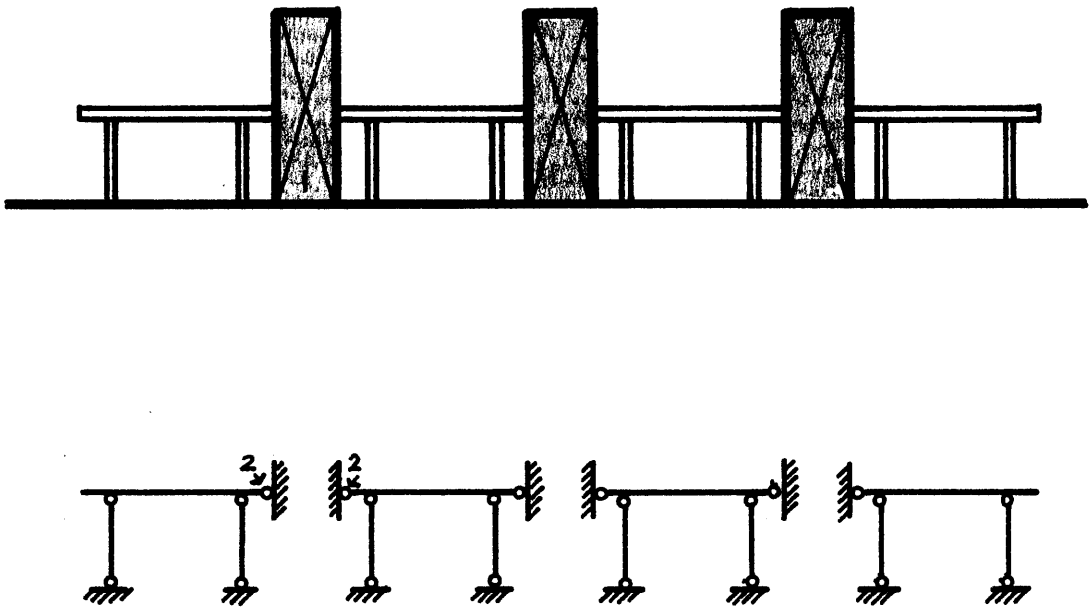
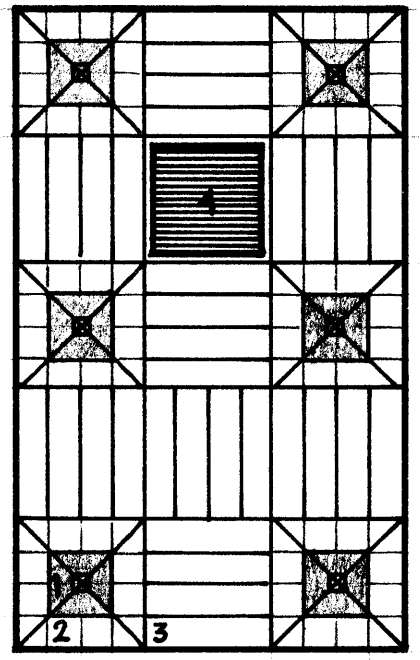


Diagram showing theoretical stability.

1 - Core, functioning as stabilizer in horizontal direction

2 - Hinge



1 - Poured-in-place column and column head

2 - Precast Unit A, 10' x 10'

3 - Precast Unit B, 10' x 40'

4 - Core

M E C H A N I C A L S Y S T E M

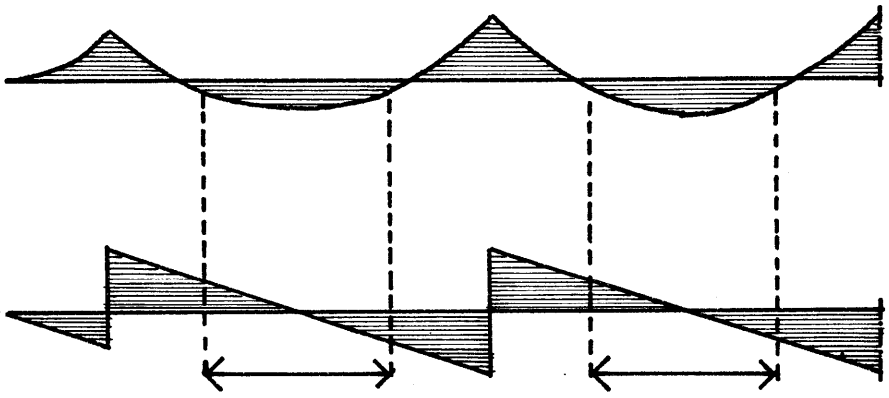
Air Conditioning

The basic unit which is served mechanically is the 120' x 200' basic unit of the building. Each unit has a core with mechanical shafts, and is served independently.

The building is divided into two different zones, that is, interior, and critical (exterior). Two separate systems of air conditioning are provided for these zones. The exterior zone extends from the outside wall of the building to a point 15 feet inside, along the periphery. It is assumed that rooms placed next to an outside wall would not be less than 15 feet deep.

An induction unit system is used for the critical area. It is serviced from the mechanical floor through the core by a high velocity air duct. The interior zone is controlled by an all-air two duct system, for supply and return. The main supply and return air branches are located in the areas

provided in the structural system where shear forces are minimum.



Mechanical rooms are located in the basement and on the roof. Main air risers and returns are located in the cores, and supply each floor from the mechanical rooms.

Air is supplied and returned on a 10-foot module. Duct space is figured at the rate of one square foot per 1,000 square feet of total floor area for the interior zone, and .25 square feet per 1,000 square feet for the induction unit system. Only about 75% of the air will be sent back to the air handling units.

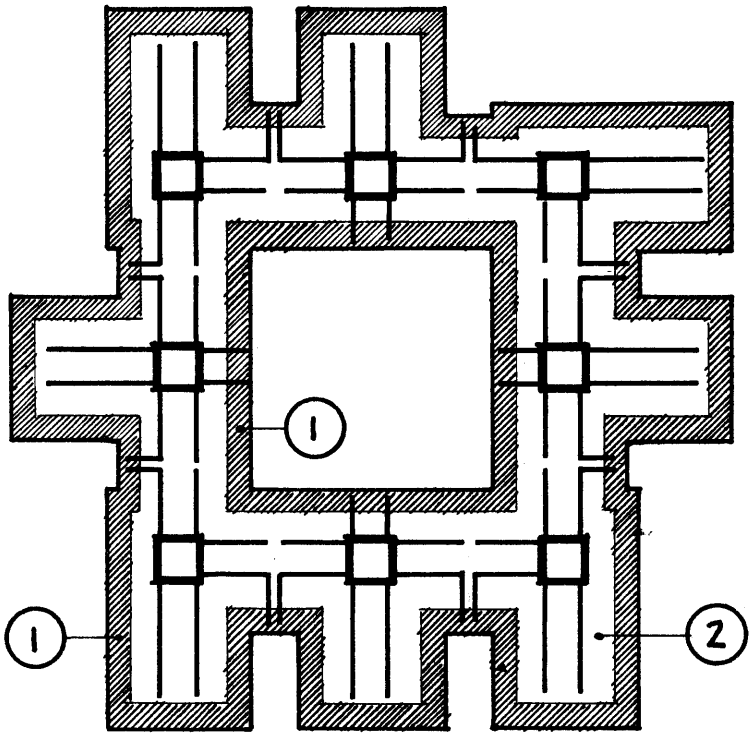


Diagram of air conditioning main lines.

1 - Exterior (critical) area

2 - Interior

Each unit requires a total of ± 3500 square feet of cooling tower area, based on the calculation of 5% of gross area. The cooling towers will be evenly distributed on top of the building.

Refrigeration units and boilers are on the mechanical floor in the basement.

Piping

Wet mechanical services are located in the hollow columns. They originate and terminate in the mechanical floor. Fume hood exhausts are carried in the columns to fans on the roof.

C I R C U L A T I O N

The circulation system is part of the building's system. The location of structural elements such as columns and cores makes possible a clear and easy access to the building.

The circulation system lines run between cores in two directions, perpendicular to each other. Roads and ramps for cars, as well as entrances for pedestrians, are located on these lines.

Parking and service areas for cars and trucks are located on the ground floor and in the basement.

Lineal circulation within the building itself is mainly from core to core, around the open space.

Future circulation will follow the same system lines as the building grows.

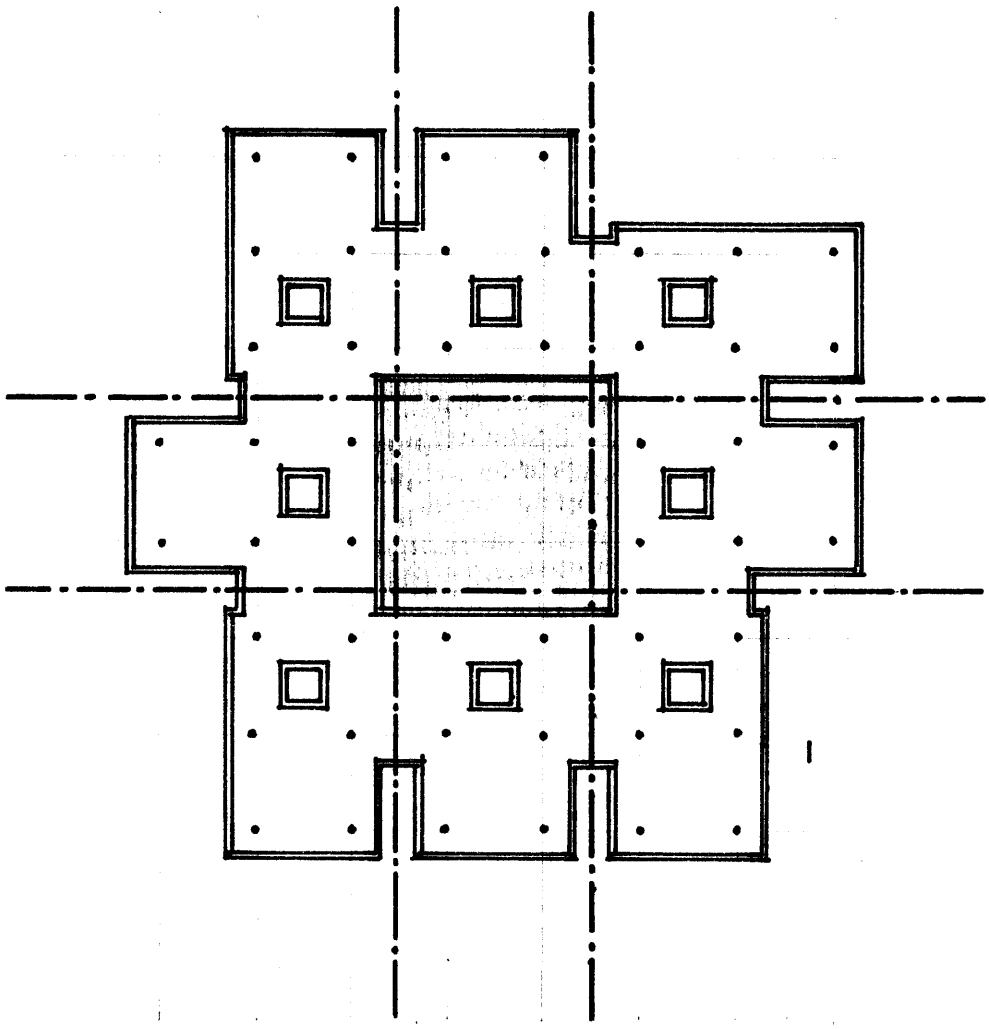


Diagram showing circulation lines.

G R O W T H

Orderly future changes and growth of the building depend on a growth system integrated with the structural, mechanical, and circulation systems. While the provision of the growth system has been the most decisive factor in designing the total system of this building, the growth system depends on a successful structural system: one which, as the strong backbone, is both the permanent element and is capable of growth. The design of mechanical and circulation systems has also been based on this dual principle of permitting, and providing the order for, future growth.

The growth system is based on the 120' x 200' basic unit of the building, with its independent mechanical system. It follows the order of the structural, column and core, lines, and the circulation lines.

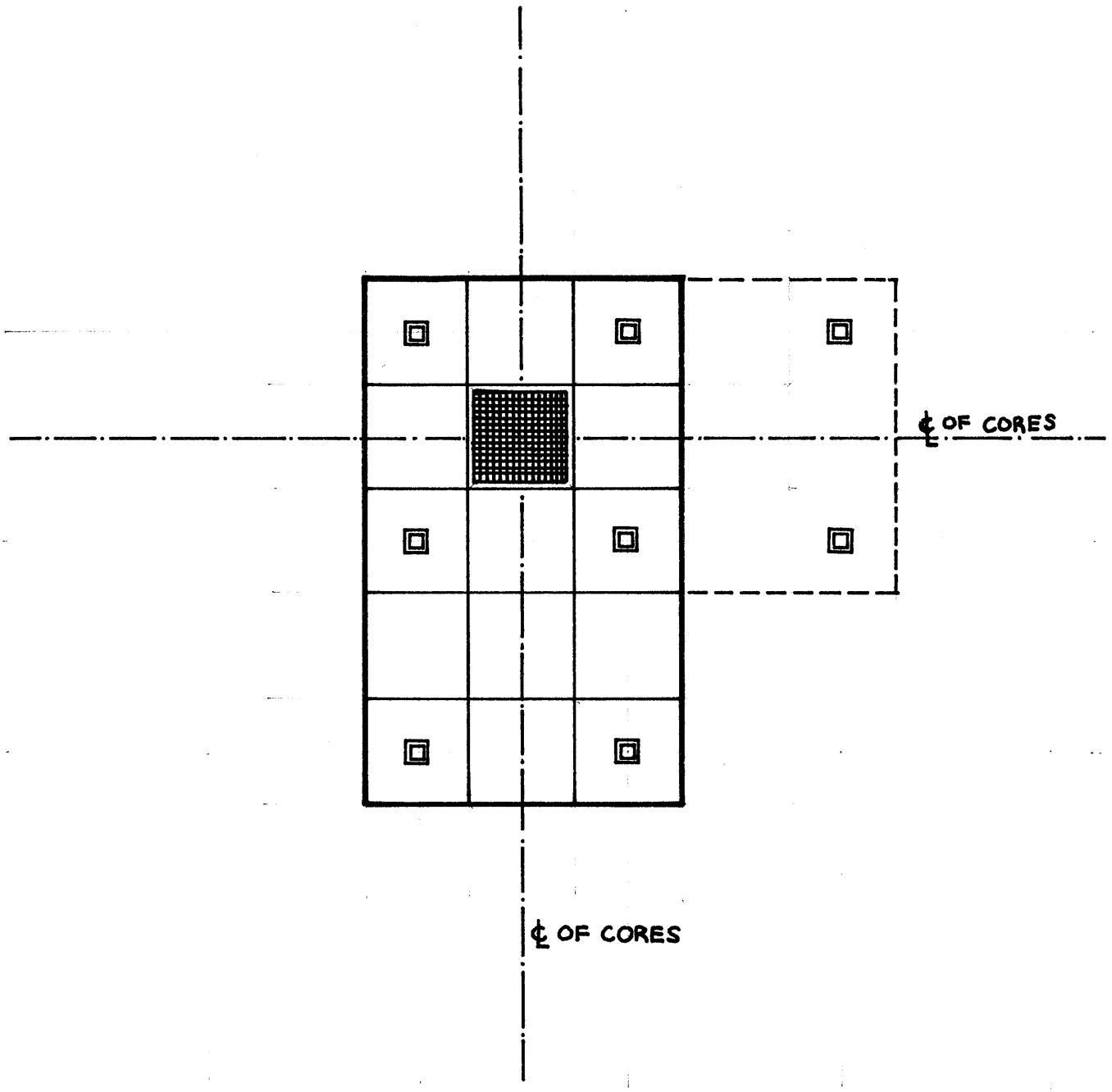
To add one bay to the building, the cast-in-place columns with their column heads would be first

constructed, and then the infilling floor system would be placed between the columns and existing structure and joined by post-tensioning. If more than one bay is to be added, all the additional columns would be constructed and floor system joined to them, but would not be joined to the previous building until the entire flooring system is completed, so that the removal of the partitions and walls in the old building need not take place until the last moments of the construction period.

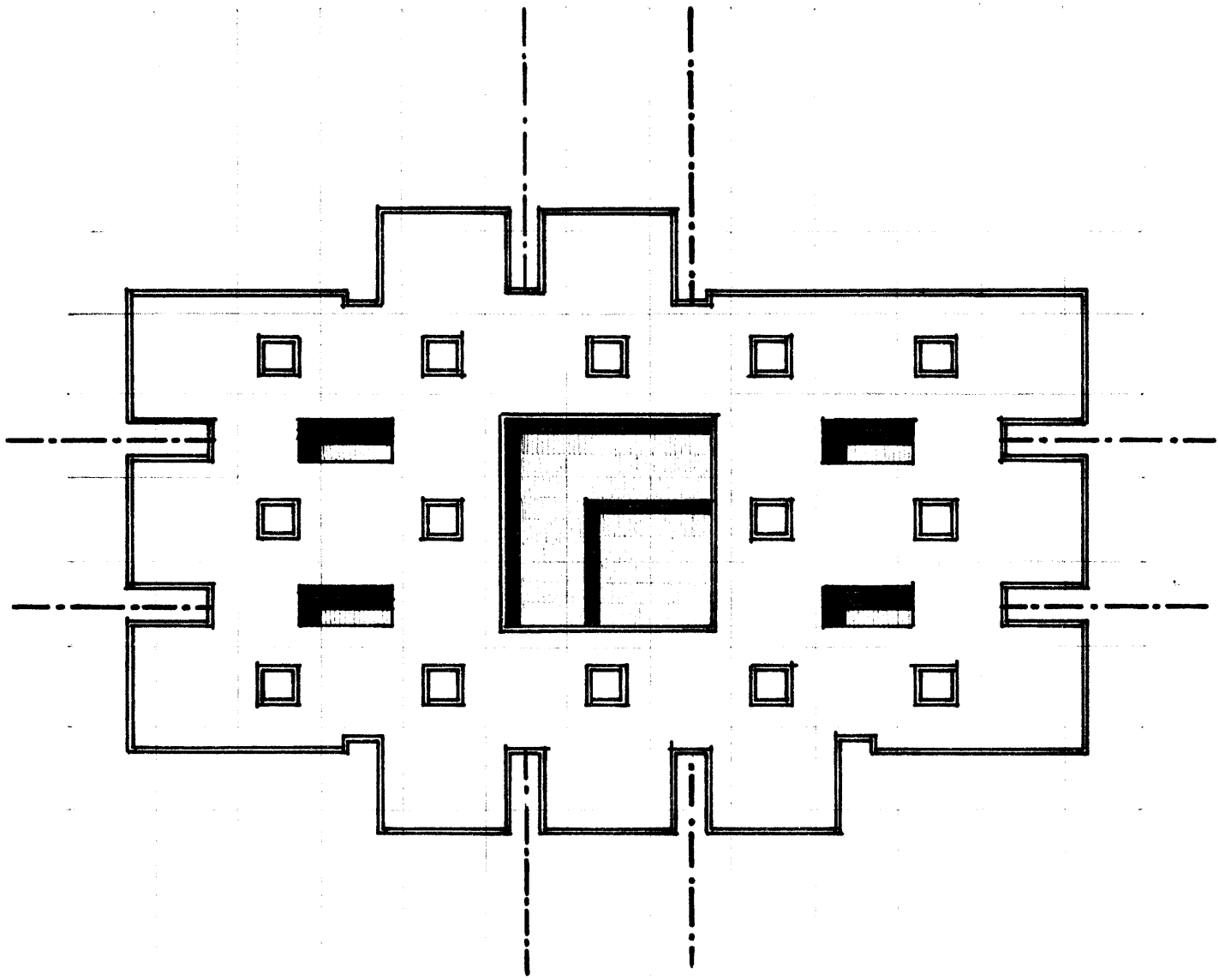
The spacing of columns and cores in future expansion would always follow their system lines, that is, 80 feet for columns and 160 feet for cores, to maintain the uniformity of structure and the order of circulation.

The advantages of structural continuity are gained with this growth system. The structural system is designed to withstand the changes in structural behavior that result from the addition of one or more bays.

The "direction", that is, the long axis of the individual unit, may be perpendicular or parallel to that of other units, giving richness to the elevation and permitting growth adapted to an irregularly shaped site. This is made possible by the off-center location of the cores. The system also makes provision in future expansion for the fully- or partially-enclosed exterior open spaces which give the building "life".



Variation of "direction" of the basic unit.



A possible growth scheme.

E R E C T I O N P R O C E D U R E

Footings, basements, retaining walls, etc.

Cast-in-place column and column head.

Temporary supports around the column to place the small unit, Unit A, around the column head.

Placement of Units B.

Post-tensioning, stage 1.

Placement of precast floor slabs.

Post-tensioning, stage 2.

Repeat procedure.

Finishing.

Topping is poured after the floor system is completed; with the slab units it works structurally as a shear plate.

Mechanical system is installed after each floor is completed.

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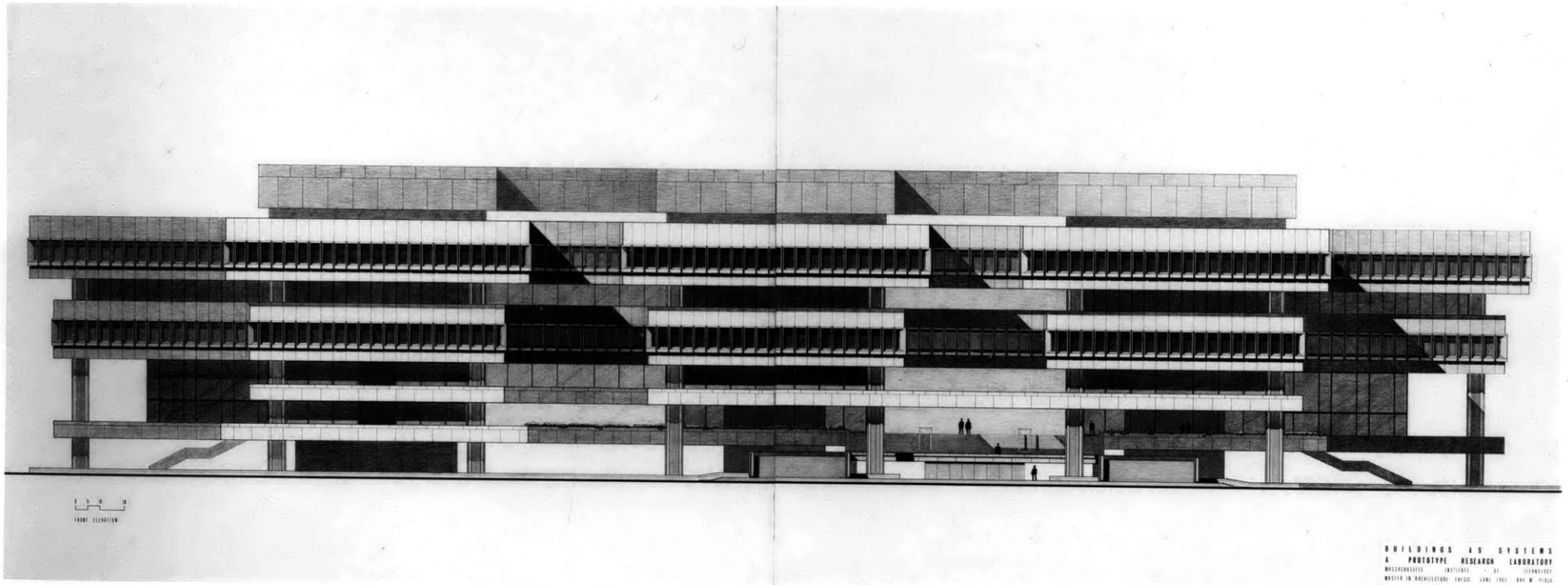

FRONT ELEVATION

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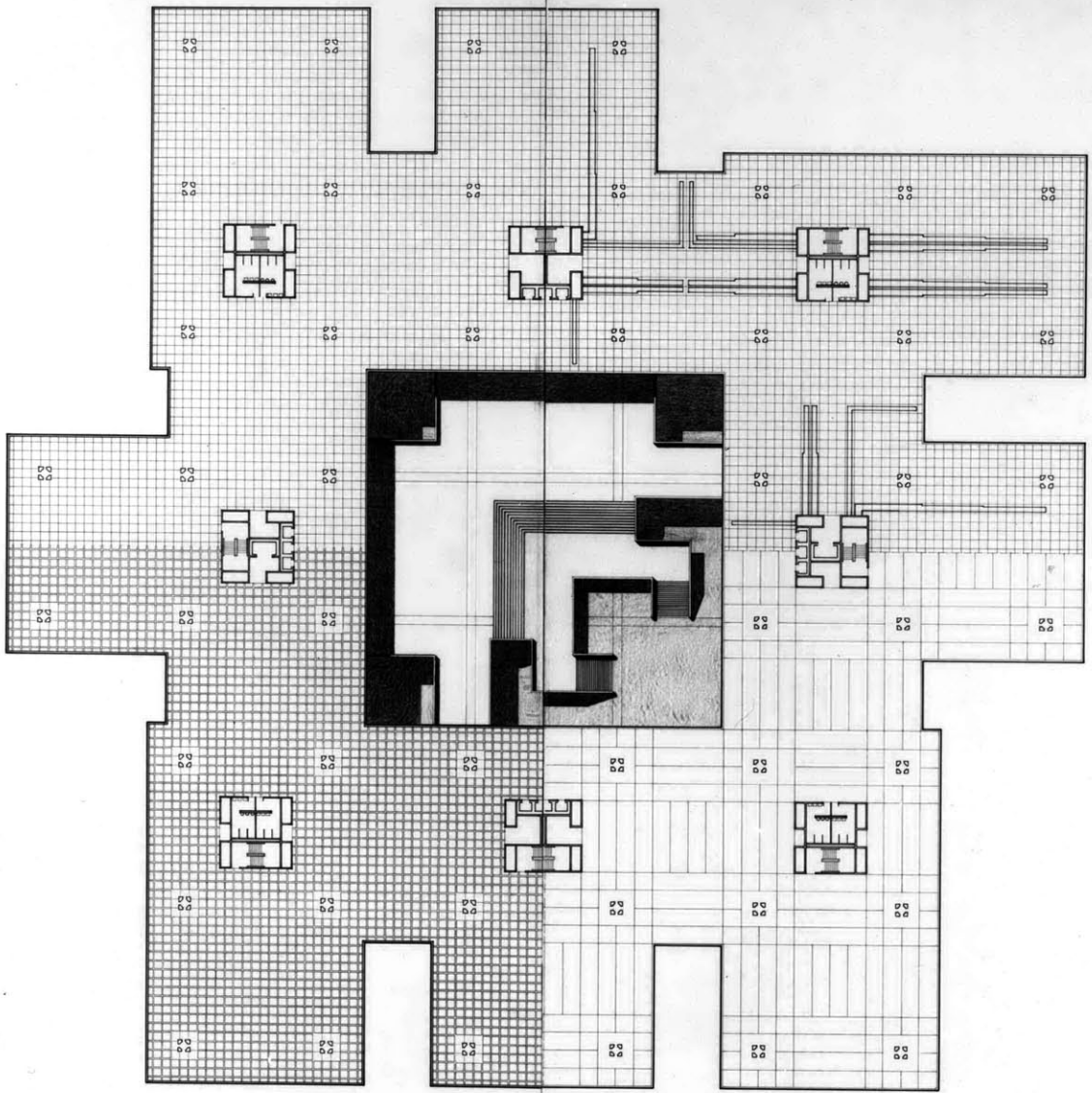

0 5 10 20 40 80

REFLECTED CEILING
PLACEMENT OF STRUCTURAL ELEMENTS
AIR CONDITIONING MAIN DUCTS

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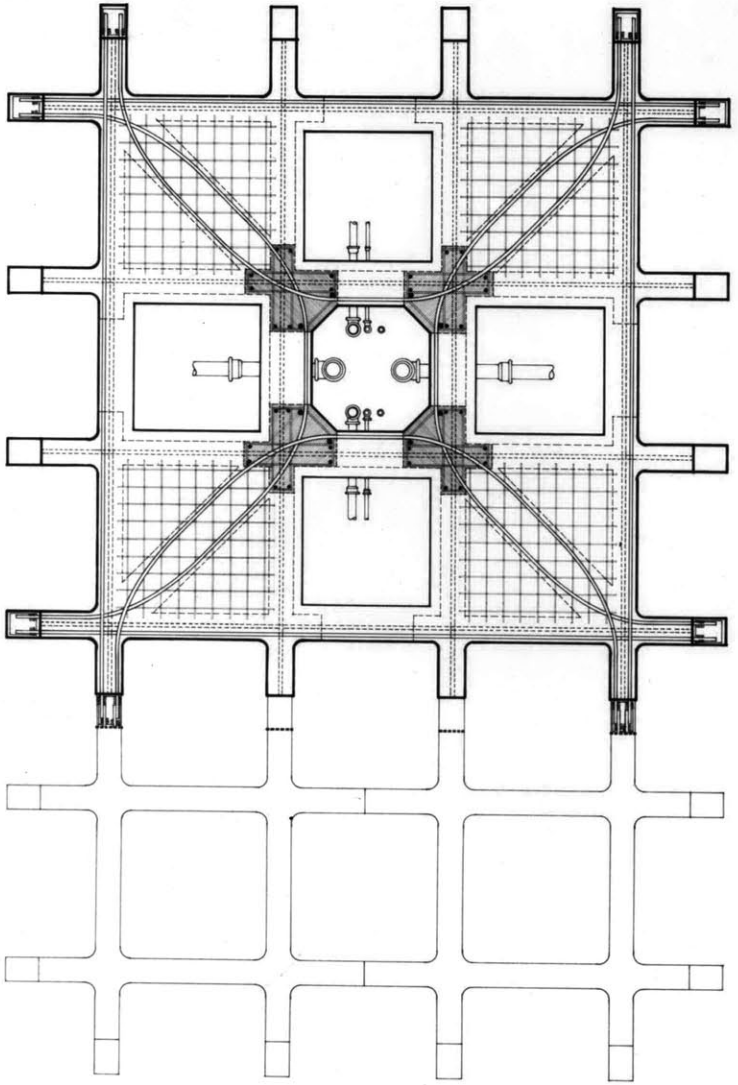
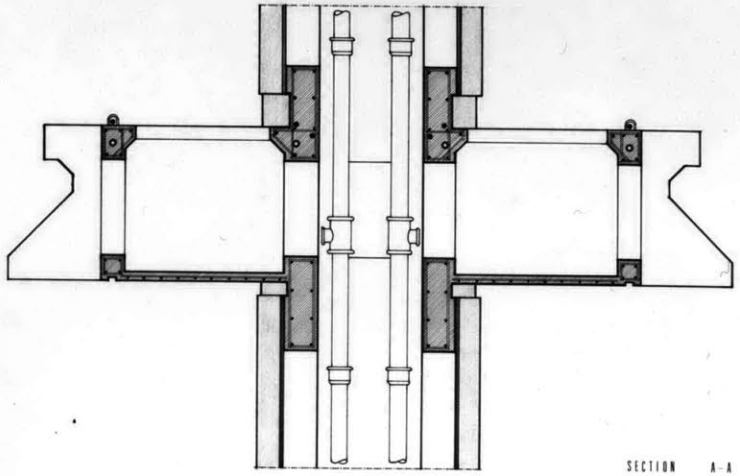
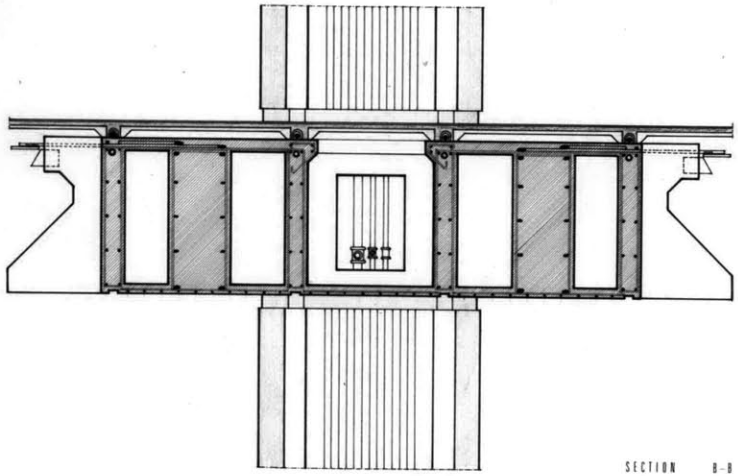




SECTION A-A



SECTION B-B

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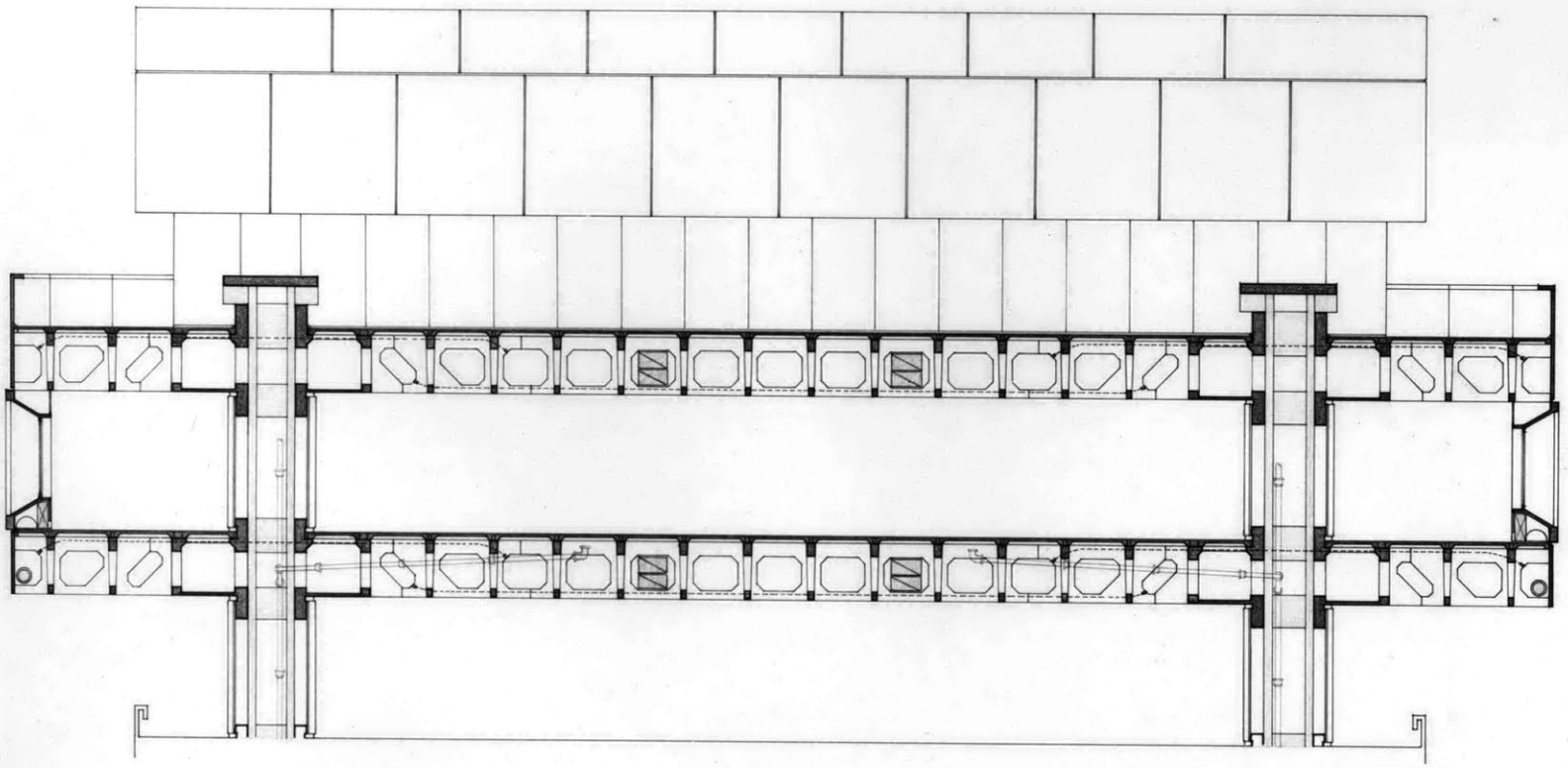
CAST IN PLACE COLUMN



0 1 2 3 4 5 10

SECTION OF TYPICAL BAY

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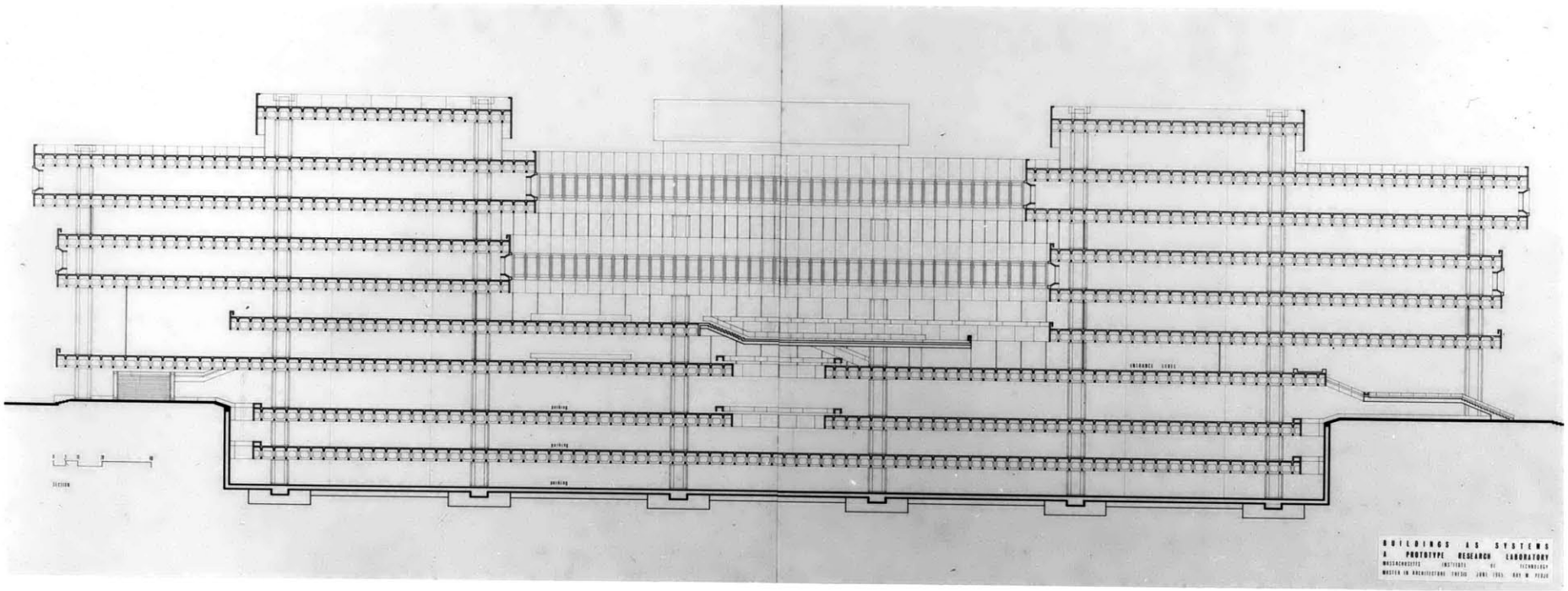
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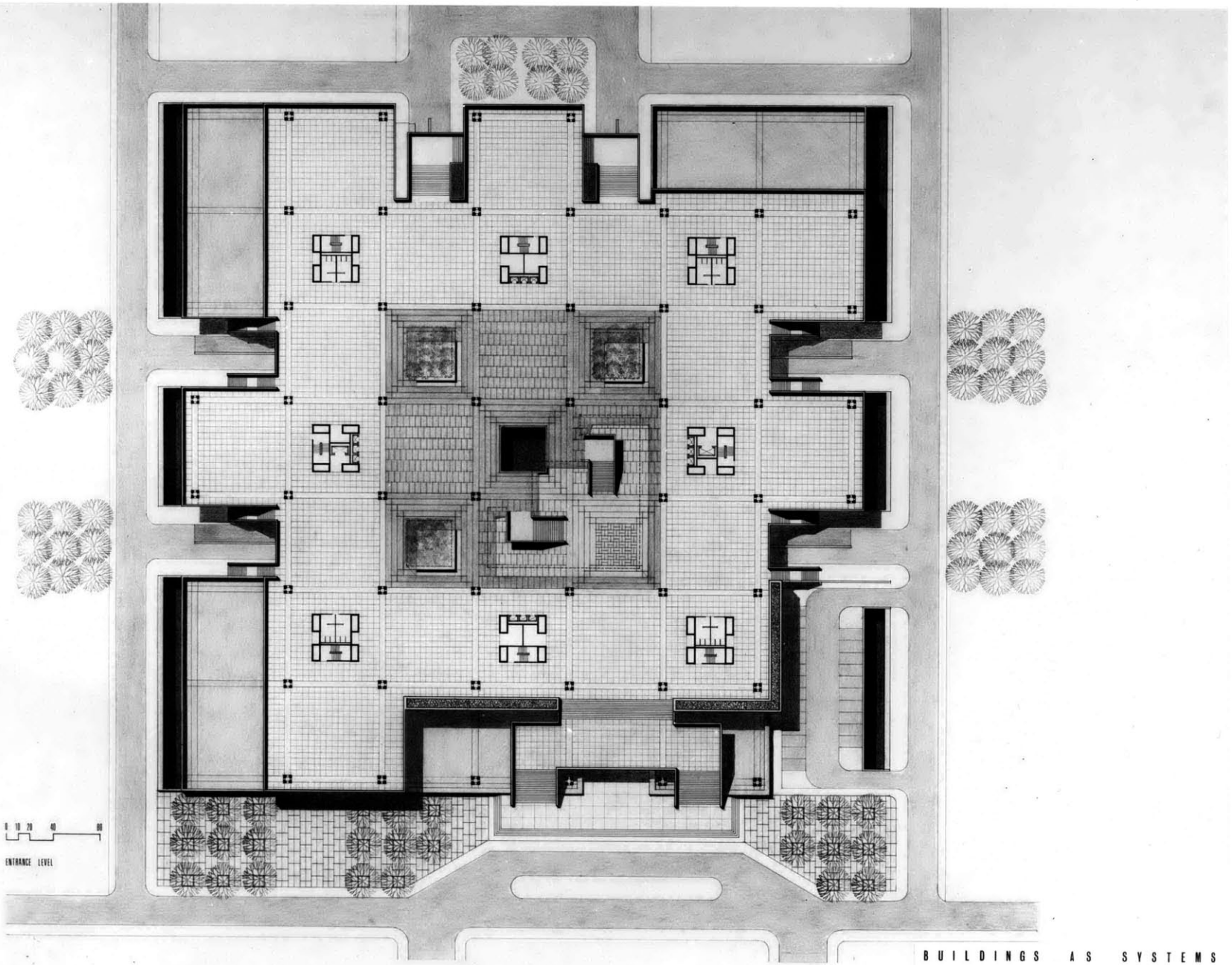

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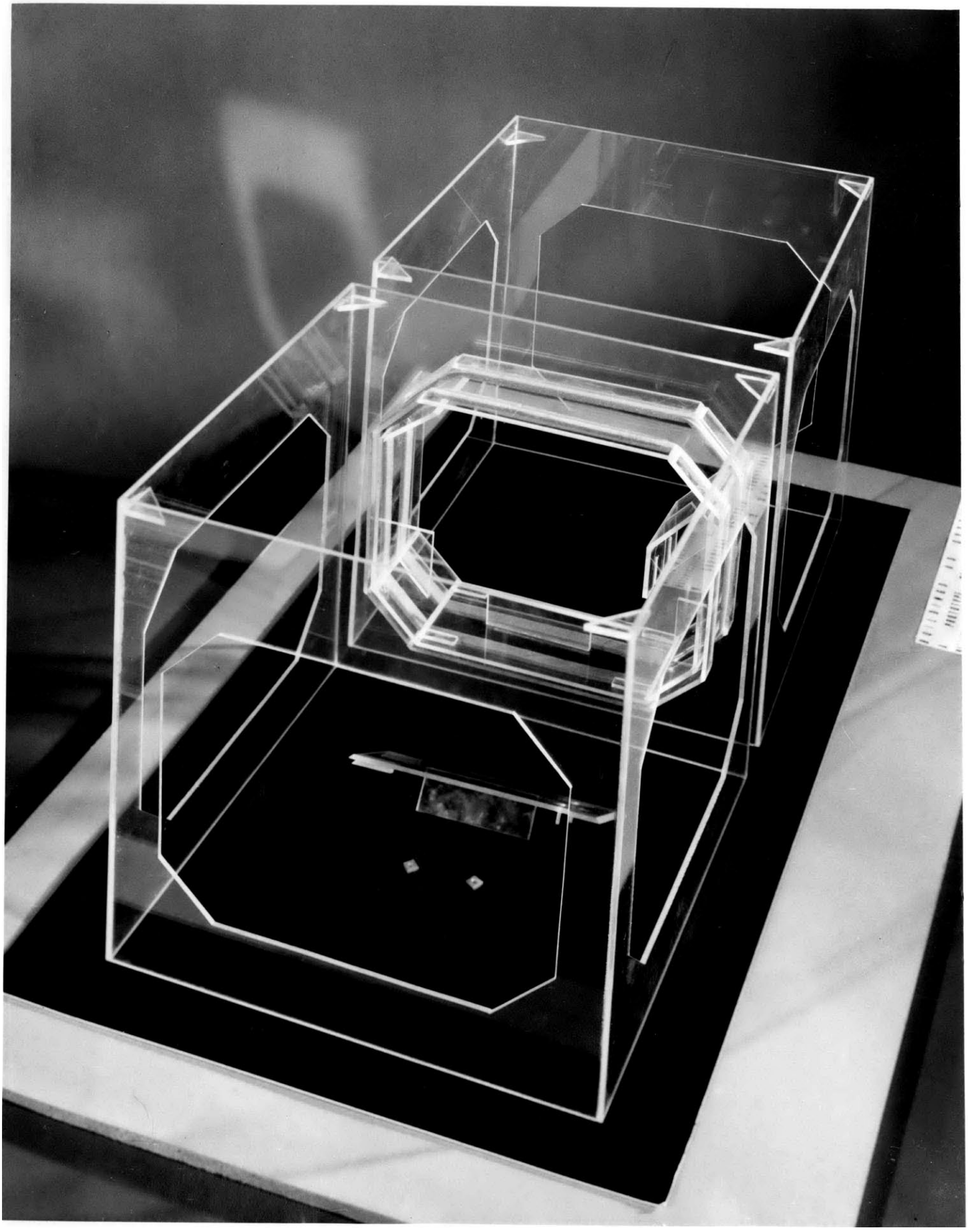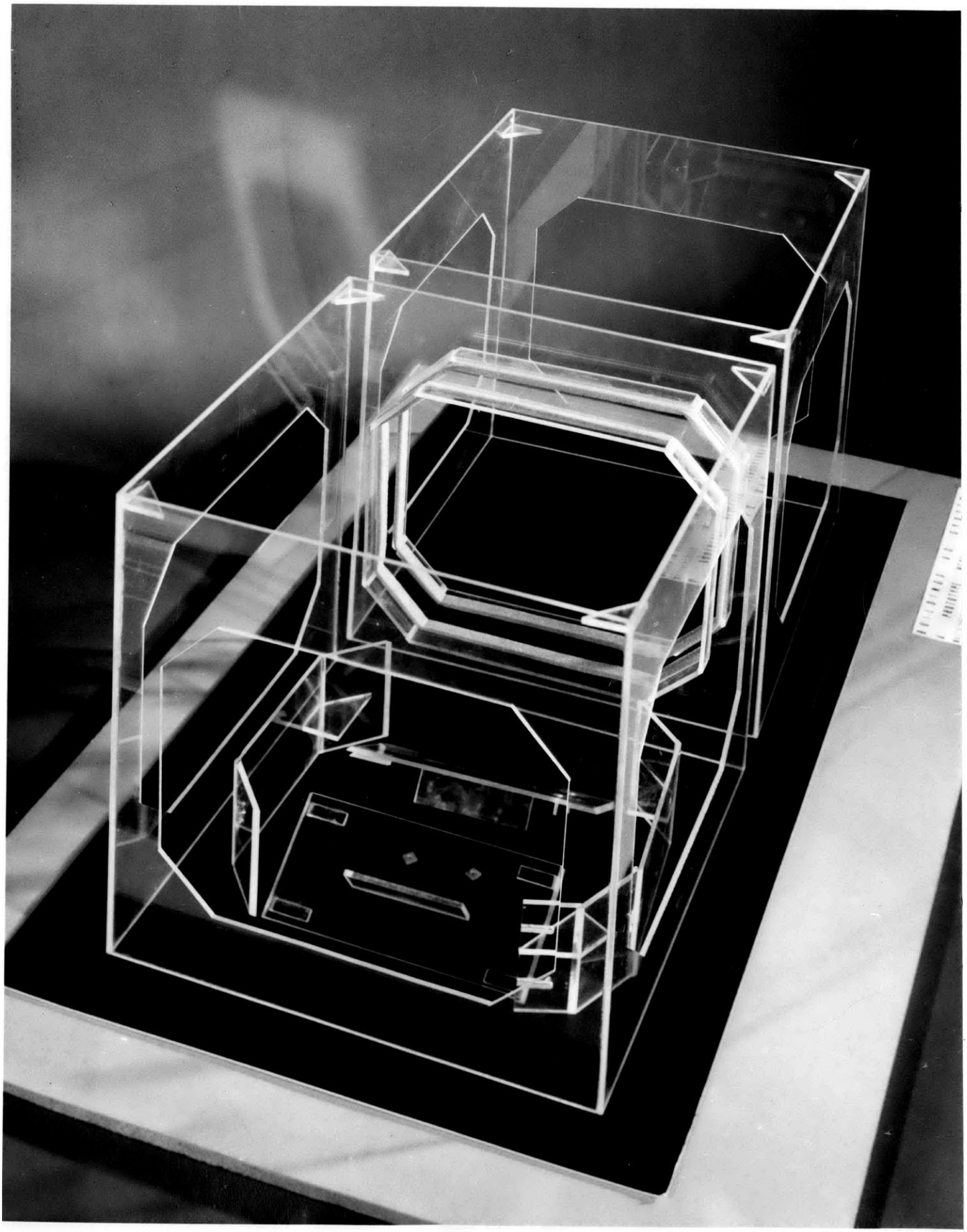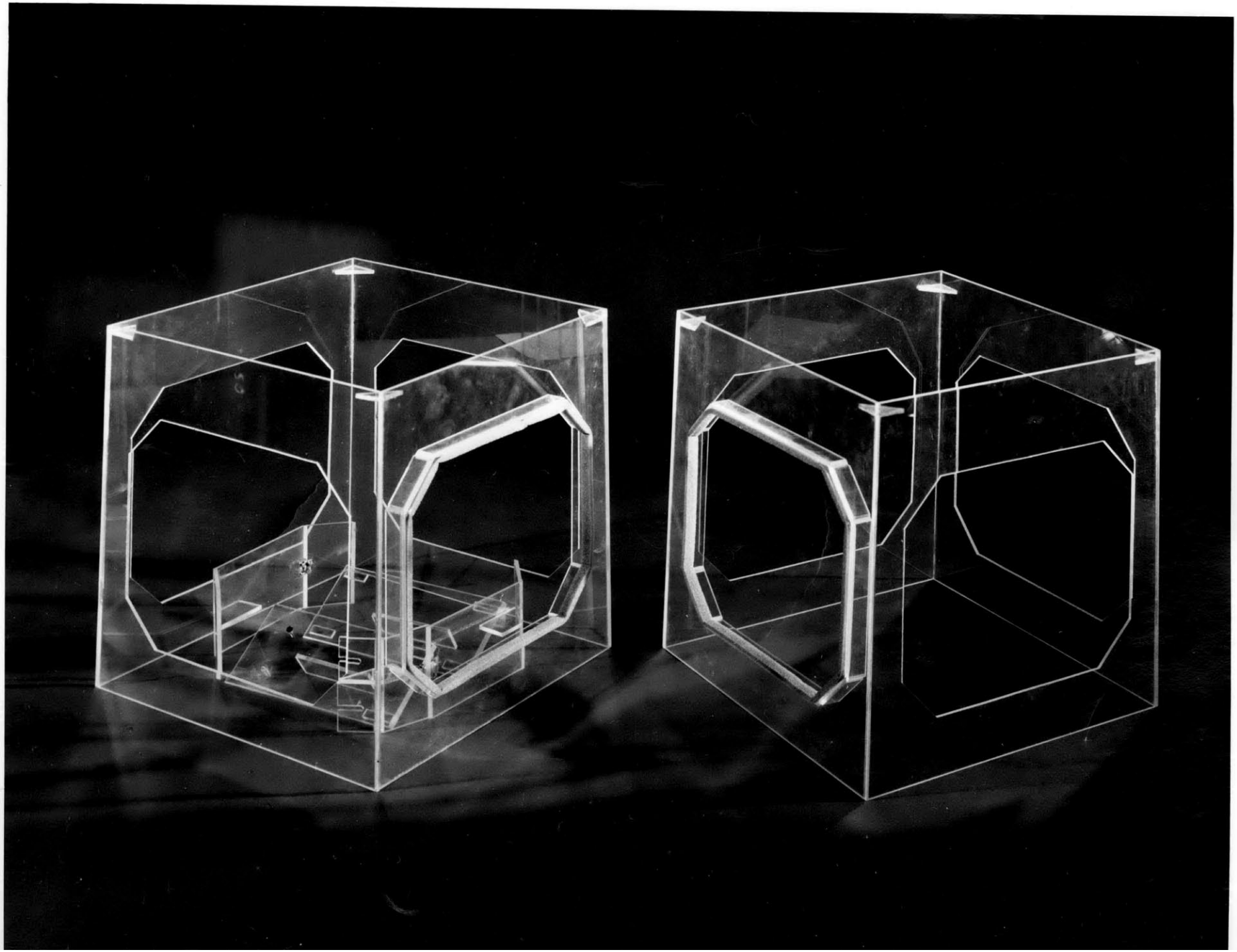
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