

AN INTEGRATED BUILDING SYSTEM

by

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Signature of Author.....
Department of Architecture June 17, 1968

Certified by.....
Thesis Supervisor

Accepted by.....
Chairman, Departmental Committee on
Graduate Students



ABSTRACT

An Integrated Building System

Gus Michael Pelias, Jr.

Submitted to the Department of Architecture on June 17, 1968, in partial fulfillment of the requirements for the degree of Master of Architecture.

The purpose of this thesis was to investigate and develop the potentials of unified, integrated building components. These components, including structural, mechanical, electrical, acoustical, and functional elements, were studied in relation to each other with the aim of defining their inherent interactions and conflicts. The objective of the project was to create a system in which all components would exist in harmony. The completed building system allows for maximum flexibility and change, which are the practical advantages of this type of development. Since an architectural expression of the components was not prerequisite to the finished system, the project was concerned primarily with the basic physical realities and interactions of the building components. Because subjective aesthetic considerations were minimized, the system was adaptable to complete computer analysis. The resulting system is to be considered an exercise in architectural component integration, rather than an expression of total architecture.

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Dear Dean Anderson:

In partial fulfillment of the requirements
for the degree of Master of Architecture,
I hereby submit this thesis entitled, "An
Integrated Building System", as envisaged
for an urban environment.

Respectfully,

Gus M. Pelias, Jr.

ACKNOWLEDGMENTS

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Eduardo F. Catalano, M. Arch.
Professor of Architecture

Yusing Yiu-Sing Jung, M. Arch.
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Professor of Structures

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I. PROBLEM

The problem is the development of an integrated building system for an urban environment. The similarity of most urban space affords the possibility of creating an ordered system of growth and change.

II. WORKING ASSUMPTIONS

- A. Generating factors in determining the final geometric pattern and physical form will be structure, planning, air distribution, lighting, mechanical and communication utilities, acoustics, and horizontal and vertical circulation.
- B. Economy of means and materials will be of major importance.
- C. Precast concrete will be used for the major structure. Other materials will not be investigated.
- D. The building system will be limited between five and ten floors. Below five floors land use efficiency in an urban area can be questioned. Above ten floors building systems change radically.

III. DESIGN OBJECTIVES

- A. How can a building system maximize potentials for realistic flexibility and change?

One of the main purposes of building systems is to allow for change of function and use. Most buildings being done today are tailored structures. This is not only economically impractical but is creating chaos in urban environments. The need for flexible, ordered systems is obvious.

Frequency of change is reducing the life expectancy of buildings drastically.

Tailored space is mono-functional, and any change is either impractical or impossible. There will always be a need, however, for some specialized, dominant, tailored monuments. In the Palace of the Assembly in Chandigarh, Corbusier was able, by contrast, to relate the ordered structure of the office space with the tailored structure of the Assembly Hall. Here Corbusier showed how these two conflicting structures can exist in harmony with each other. With the

understanding that both tailored and multifunctional spaces are desirable in their appropriate places, a further investigation of the implications of change is necessary. In order to have change within a system, its elements must be non-permanent and flexible.

An element of the system can be considered temporary only if it can be changed practically and economically. Conversely, a permanent element is fixed and cannot be changed practically or economically. What is economically practical can only be determined by the user, but the degree of economically practical change can be extended to its realistic limits by the architect. In order for any system to have maximum realistic changeability, it must have temporary components for changing the three dimensional space, the movement of people and utilities, and the method of creating habitable space. The limits of realistic changeability are difficult to define, but at some point the initial cost will not

justify the degree of flexibility. A completely demountable structure would be flexible, but the cost would be prohibitive and probably not desirable. Permanent elements give any system continuity and order with little sacrifice in changeability. The system should therefore maximize the potentials of the temporary elements without destroying the continuity and order of the permanent elements. In terms of changeability, a major permanent system supplying basic requirements and a variety of temporary sub-systems are required.

- B. How can a building system maximize potentials for realistic, flexible, and ordered growth?

Within a growing system, dynamic equilibrium must be maintained. The self-contained entity of a tailored structure is always in static equilibrium. Dynamic equilibrium of a building system can be achieved if the building always presents a finished face while expressing the dynamic

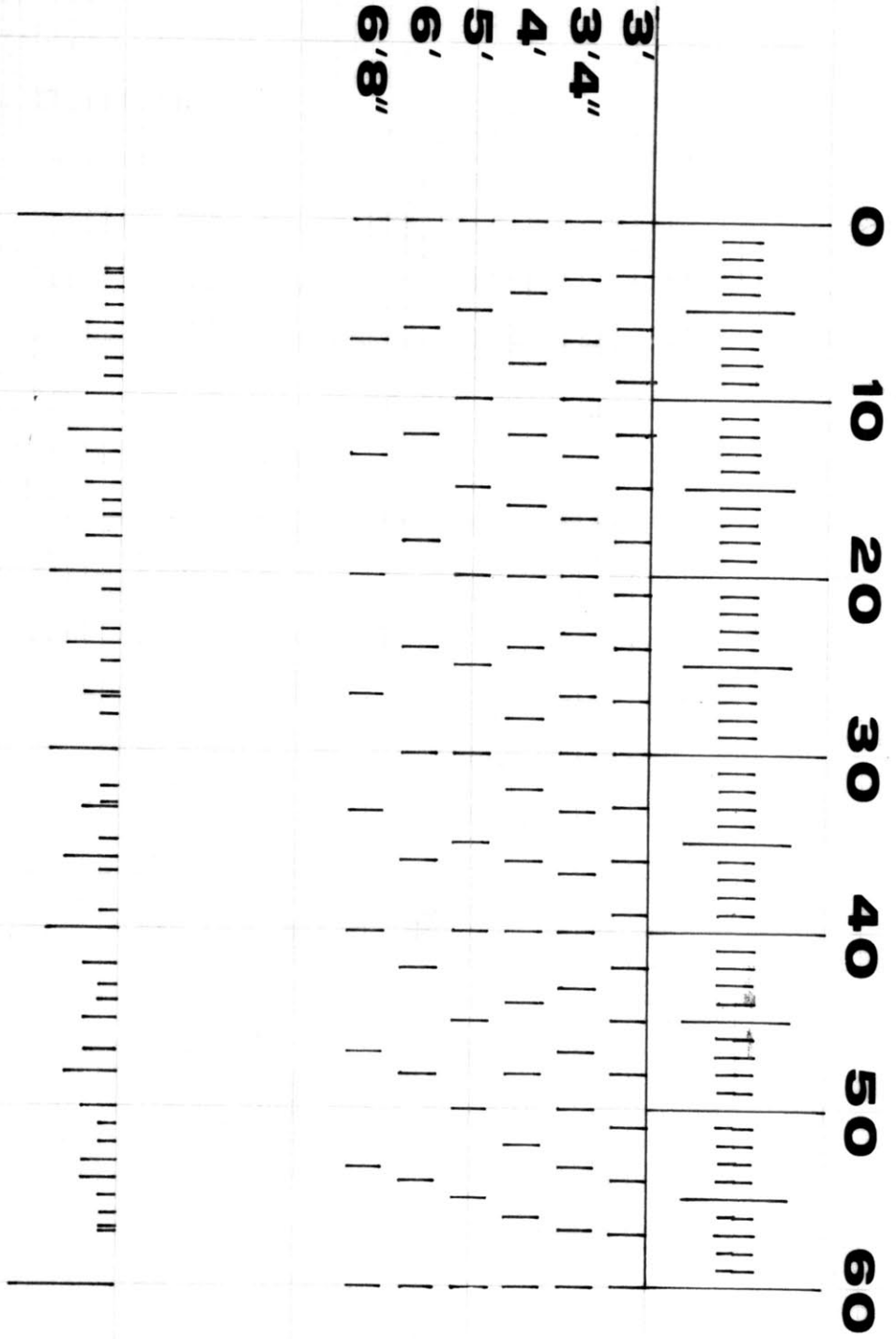
quality of the system. One of the finest examples of this is Habitat 67. The building is always complete, yet always open-ended. The use of a clear-cut structural element as a growth unit gives the complex dynamic equilibrium. Predetermined size and direction of growth is difficult; so the structural element must have the ability to be different sizes through multiples of elements and be structurally multi-directional.

At any stage in growth the new system should have the ability to deviate from existing permanent elements. This deviation, which gives a design flexibility, must still be related to the existing system. Without some basic relationships, dynamic equilibrium cannot be maintained. Through these basic relationships growth can take place with minimal disturbance to the existing system. In terms of growth, a variety of inter-related permanent elements is desirable.

IV. DESIGN OBJECTIVES (GENERAL)

In building systems the two major considerations are change and growth. In order to maximize the potentials of both, a variety of inter-related temporary and permanent elements is necessary. This suggests that the final system be a multitude of related possibilities because any single solution will not have the ability to outlive the tailored structure.

Figure 1. Module Evaluation



V. DIAGRAMATIC DEVELOPMENT

A. Structure (Fig. 1)

1. Plan (Fig. 2)

The basic structure is a continuous two-way truss system spanning 60' with a 20' strip between each bay (Fig. 2a). The structure forming the ceiling grid is on a 10' module.

The bay size was chosen because an efficient depth-to-span ratio at 60' gives adequate space within the structural depth for mechanical distribution. The 20' strip gives an efficient area for articulating horizontal movement of major mechanical, pedestrian circulation, and, when not being used for circulation, is large enough to allow efficient planning within the strip. The splitting of the columns into four spreads the column to a greater area of the slab, eliminating any high concentration of stress, allowing for smaller member sizes, and an efficient edge condition with the same size column. By using a 60' column

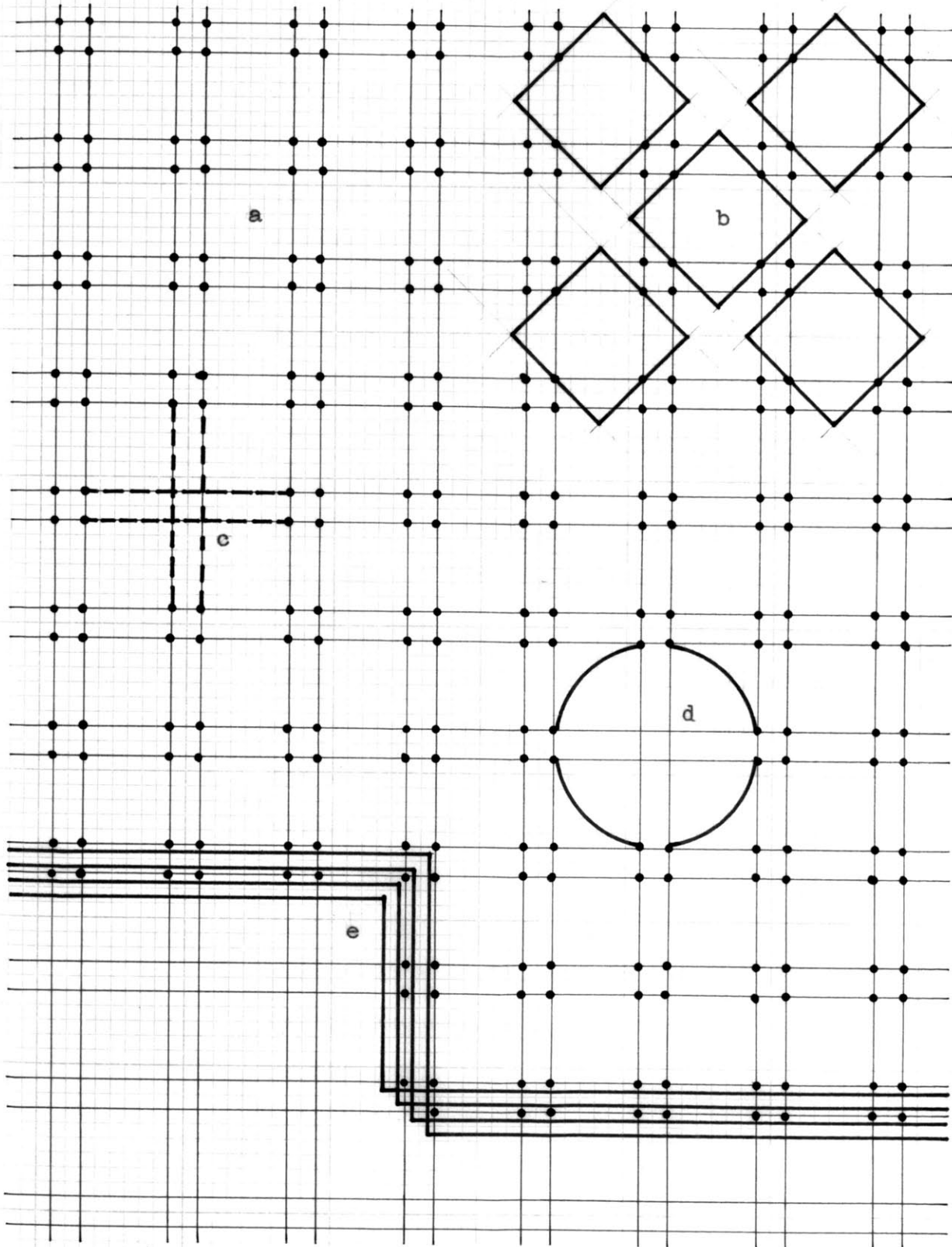
spacing and 20' structural grid, the greatest degree of lighting, diffuser, and partitioning flexibility was obtained. The scale of most urban space demands large areas of clear span. Sixty feet is an efficient planning module for urban space because this span will accommodate all major urban functions within a reasonably manageable structural system. With the major structure being a permanent element of the system, related deviation can facilitate growth flexibility. In Fig. 2b the structure has been rotated 45°. This gives a new growth axis and a larger bay size with the same structural depth. There are certain planning problems with this deviation, but it could be a valuable tool in accommodating growth flexibility. Often in urban space we are confronted with the need for large, column-free space. This could be accomplished by a special element (Fig. 2c). This could not be done within the structural depth, but partitioning would not be

used in this type space.

The third deviation could be of either the temporary or permanent nature. By stopping the system, a tailored structure of permanent quality can be interjected into the system (Fig. 2d). This should be independent, allowing both elements to be self-sufficient. The tailored structure could be in the form of a high-rise building, an auditorium, or any specialized dominant monument. The temporary deviation can be dependent on the basic system. The temporary system would be in the form of a light-weight demountable type, such as library stacks, acoustical enclosures, or mezzanine-type structures.

Figure 2e indicates the basic edge conditions of the system. The edges could be a 10' or 20' cantilever off either column line.

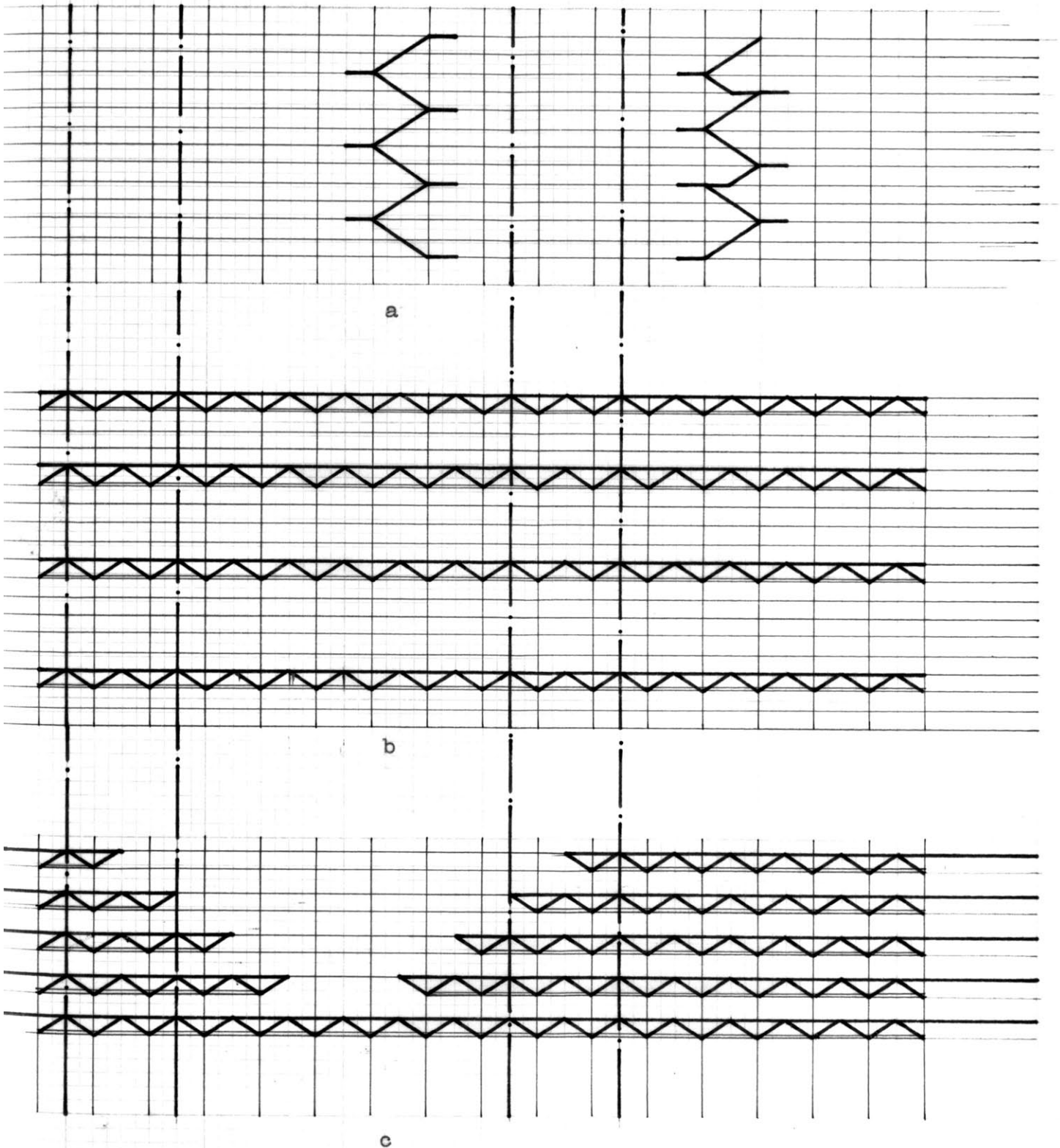
Figure 2



2. Section (Fig. 3)

In order to establish some uniform vertical dimension, a module of 6'8", related to the stair landings, was established. In order to gain maximum vertical flexibility, an intermediate 3'4" module was established. This creates two basic stair components, one of which rises 6'8" between landings and the other of which rises 3'4" (Fig. 3a). This system gives the possibility for any multiple of 3'4" to be the ceiling height, such as 10', 13'4", or 16'8" (Fig. 3b). Permanent sectional variations are infinite because any multiples of the 10' square unit can be removed except the ones adjacent to the column (Fig. 3c). As discussed in the paragraphs on plan deviations, special temporary or permanent elements can supplement the basic system to satisfy sectional requirements.

Figure 3



B. Circulation (Figures 4 and 5)

In any pedestrian circulation pattern, scale of movement is the size-determining factor. In an urban environment the complete range of scale exists. The scales have been divided into three basic categories. These are major public, intermediate semi-public, and minor private. Of the three categories, only major public should be of a permanent nature. By linking the system with a permanent system of major public circulation, orientation and order can be maintained. This is not always possible within a dynamic system. Thus all three categories of circulation must have the ability to change. The diagrams in Fig. 4 indicate intermediate semi-public and minor private circulation within and outside the 20' strips.

The diagrams in Fig. 5 indicate both temporary and permanent major public circulation. Circulation diagonally through the system could only be a

permanent element, but diagonal movement can reduce distances traveled by about 30% and could be the link between the basic structural system and the 45° rotated system.

Figure 4

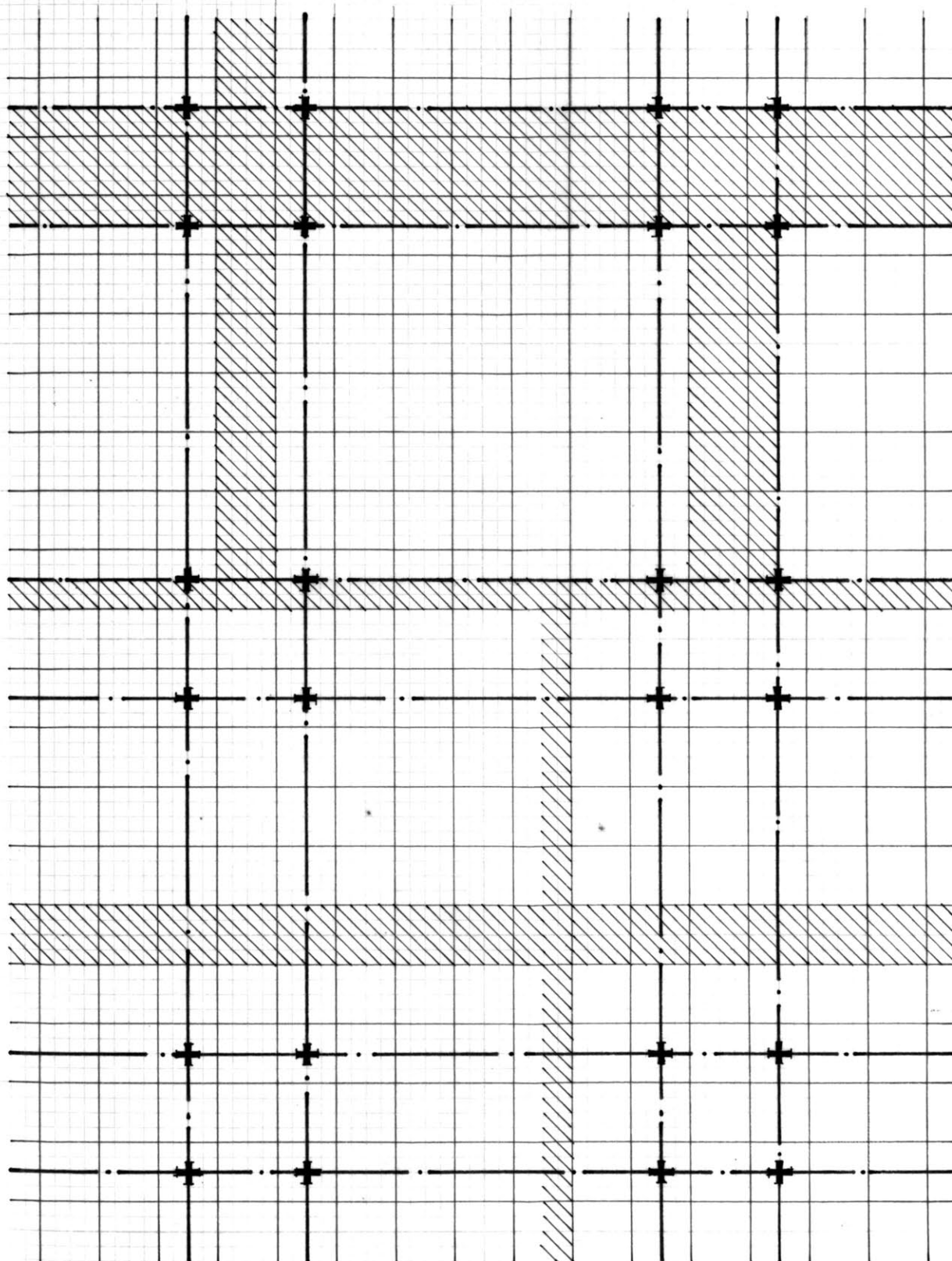
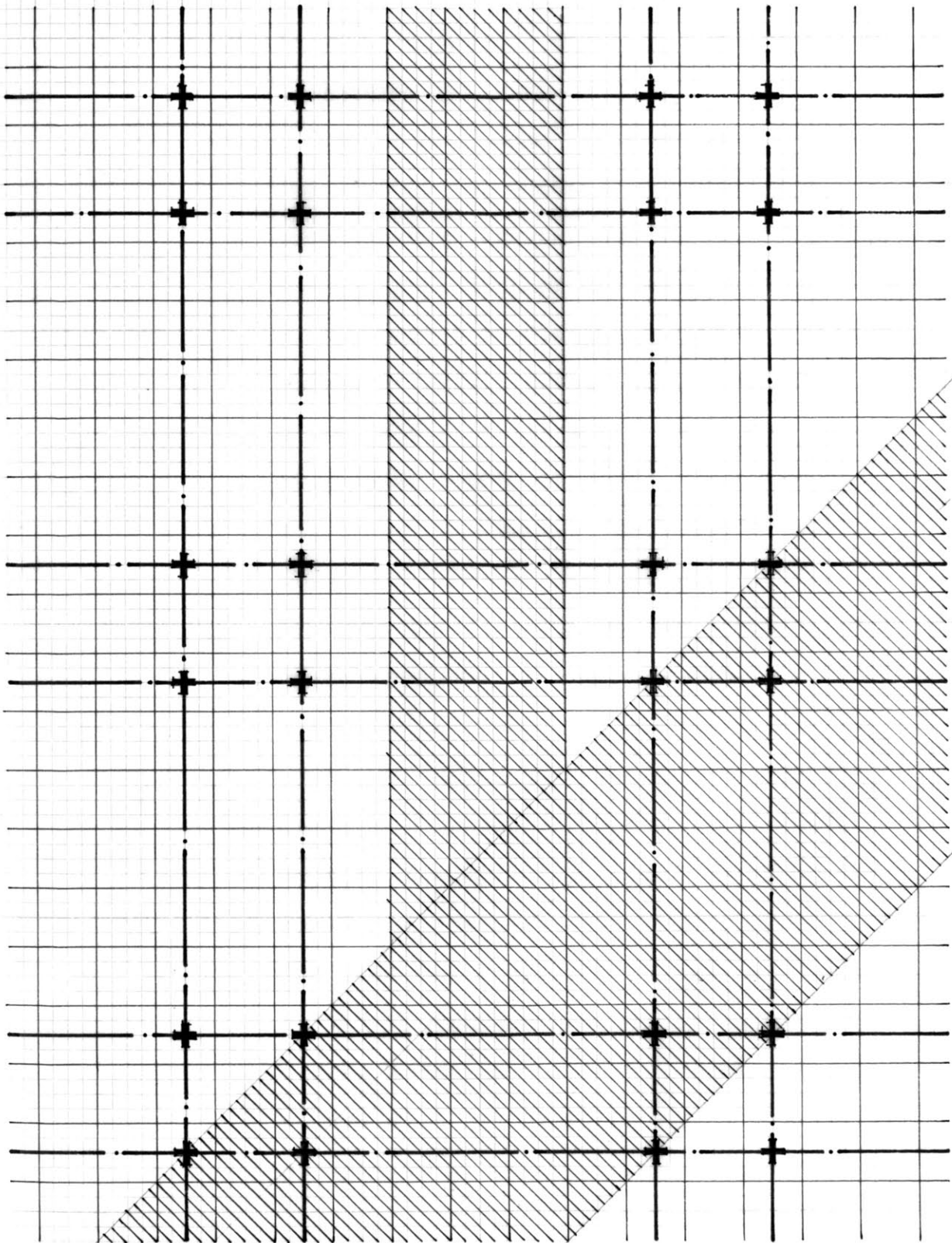


Figure 5



C. Vertical Movement: cores

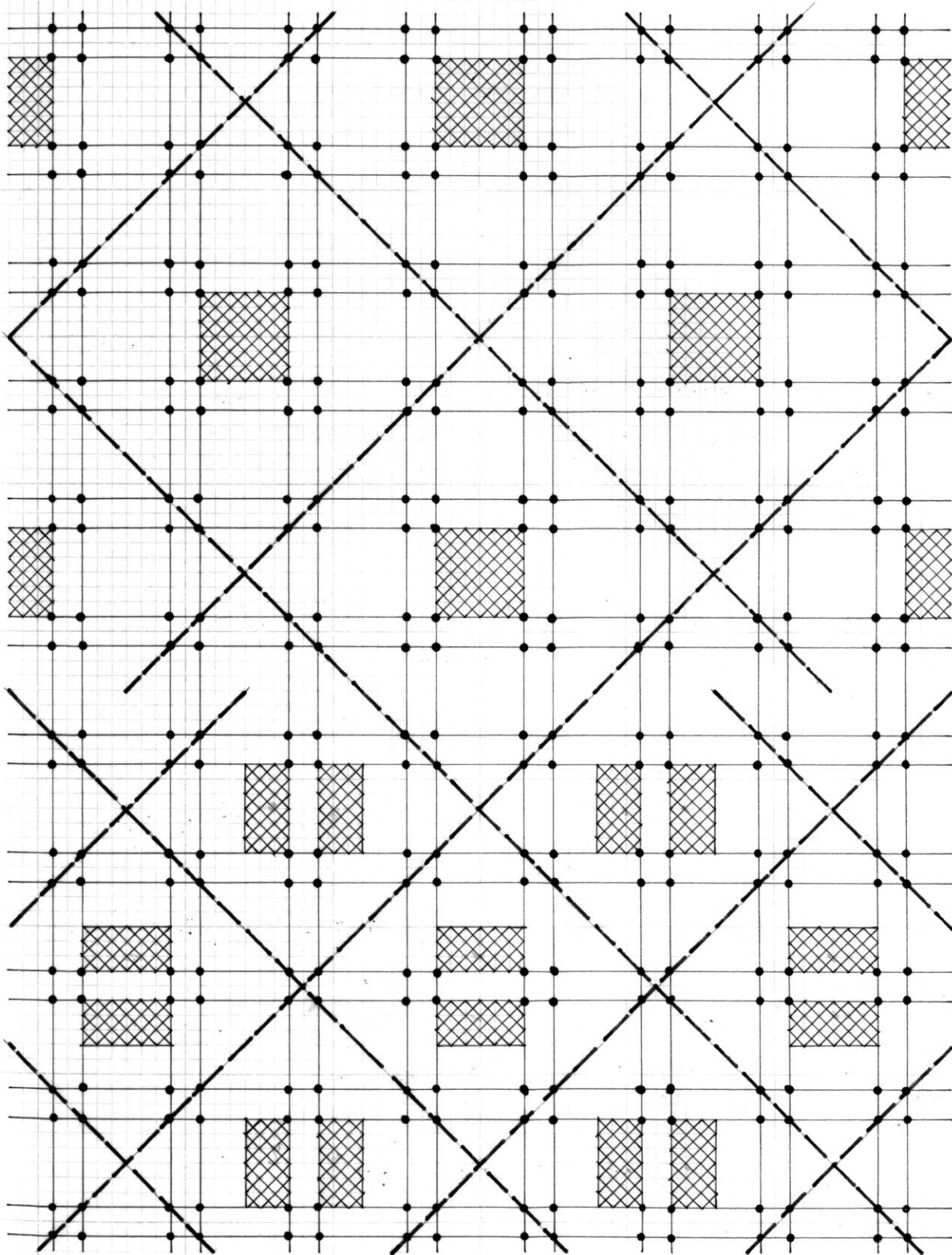
1. Spacing (Fig. 6)

The largest area for planning is obtained if all vertical services are consolidated with maximum distance between cores. Maximum distance between cores is determined by distance between stairs, number of people being served, capacity of air distribution within an efficient structural depth, and type of occupancy. Because of the varied functions of an urban environment, maximum spacing of minimum core requirements will vary within units. The size of the core elements varies only slightly because when the cores are required to be closer, the density of people is usually increased, so that the number of people being served remains approximately the same.

The need for more than minimal requirements should be accommodated by single element cores. These should be of a temporary nature with the capacity of being added or subtracted as required. This system avoids

the problem of all cores having to satisfy maximum requirements and allows for standardization of core elements. Indicated in Fig. 6 are maximum and minimum core separations for efficient core use.

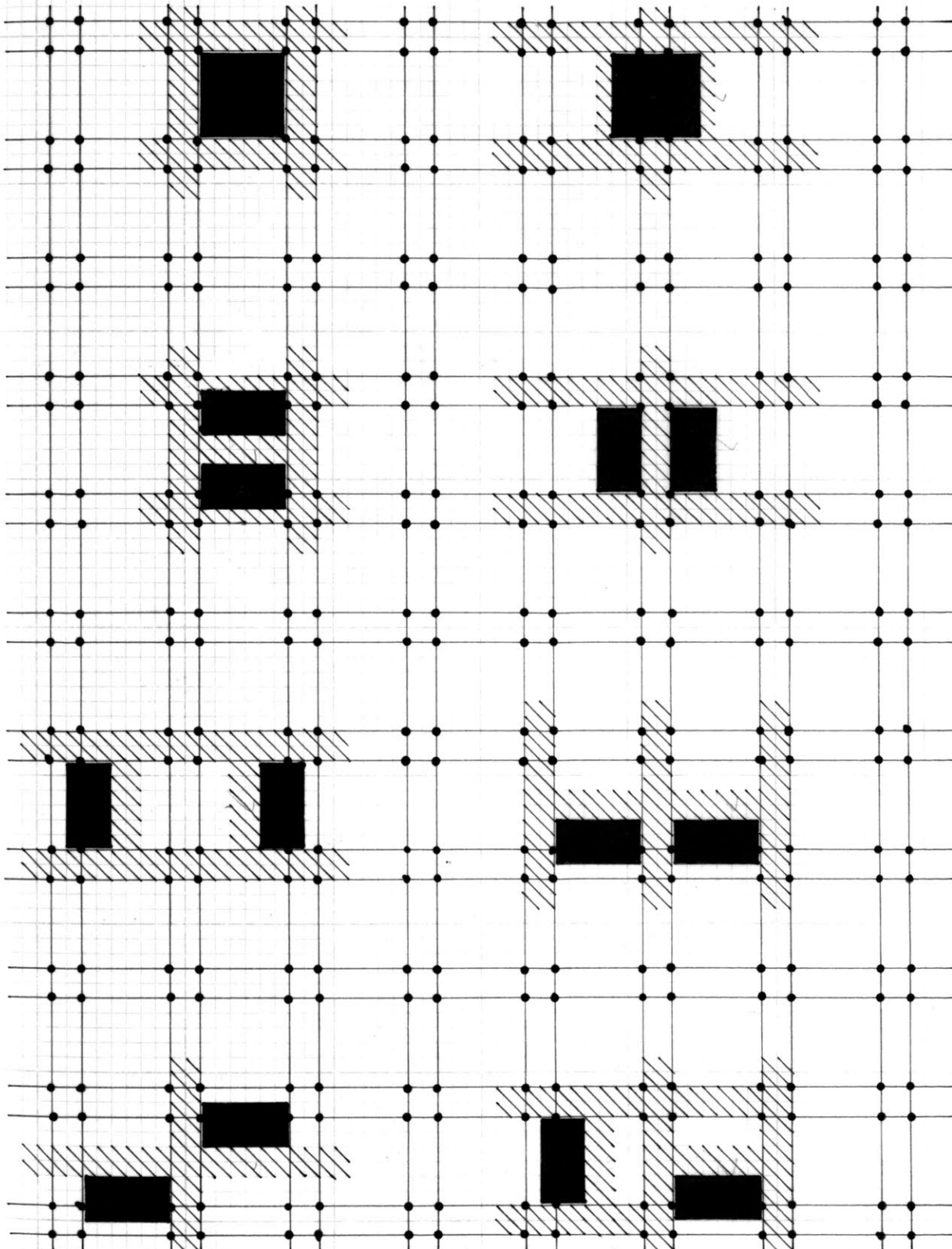
Figure 6



2. Core configuration (Fig. 7)

The basic core element consists of two similar parts. This was done to facilitate growth and flexibility and to give a variety of core configurations. With each configuration certain implications about the type circulation will result. The eight diagrams in Fig. 7 show basic core configurations and related circulation.

Figure 7



3. Core element: permanent (Fig. 8 and 9)

The basic minimal core element consists of stairs, elevators, and air, electrical, plumbing, and communication utilities distribution. In Fig. 8 the basic arrangement is shown related to the structural system.

When the space is not air conditioned, or when air handling is facilitated elsewhere, or when there is a reduction in vertical requirements, the basic arrangement is modified as indicated in Fig. 9.

Figure 8

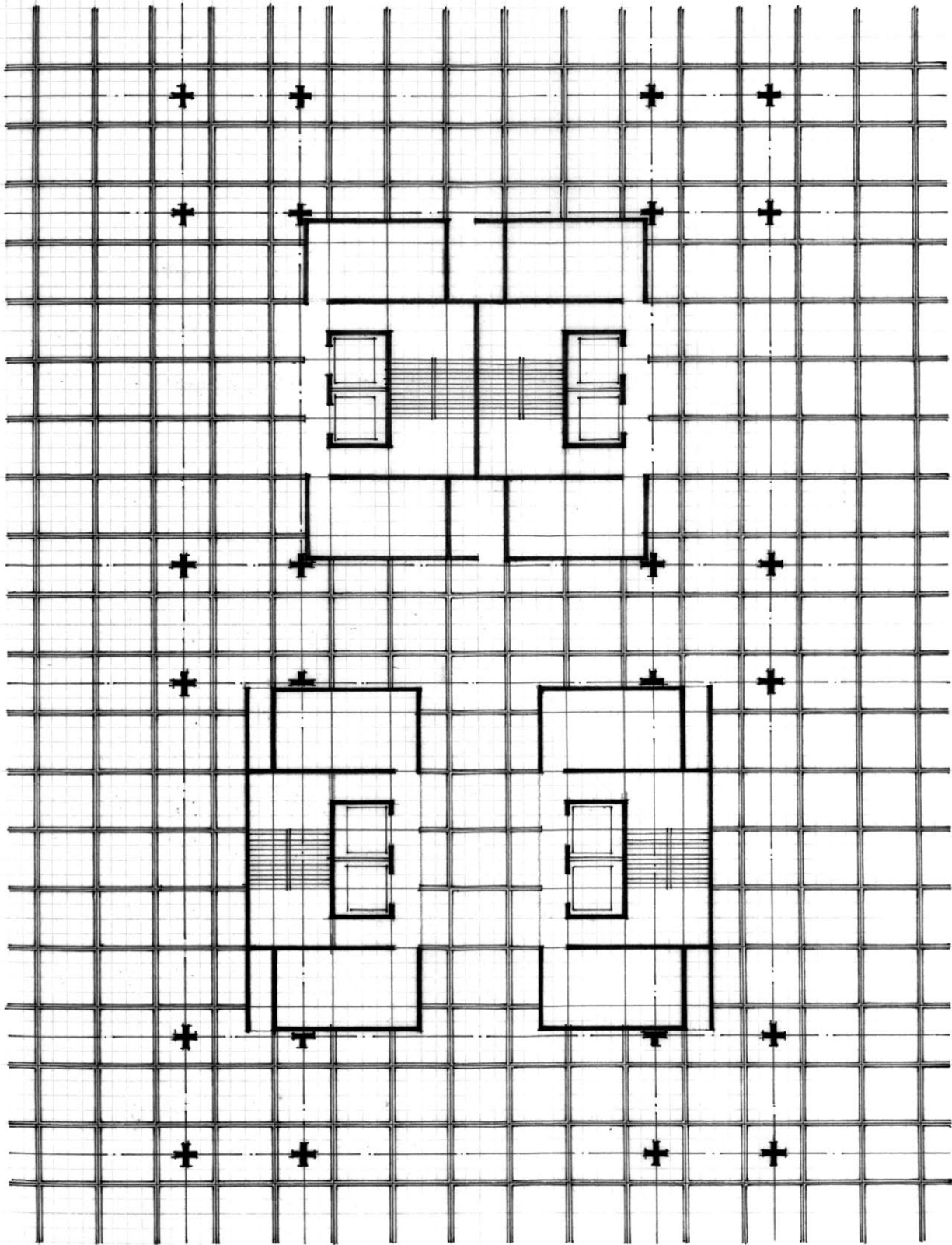
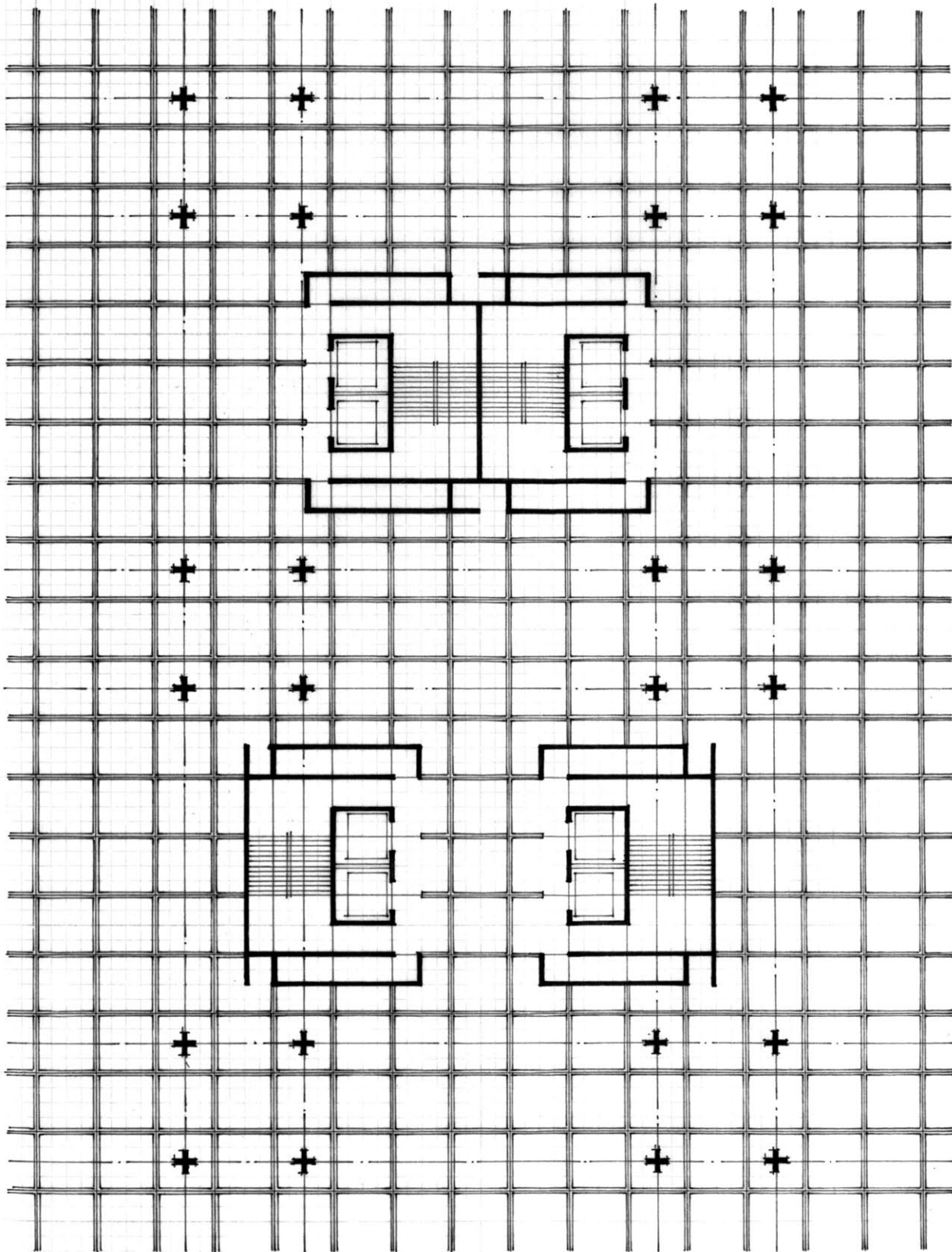


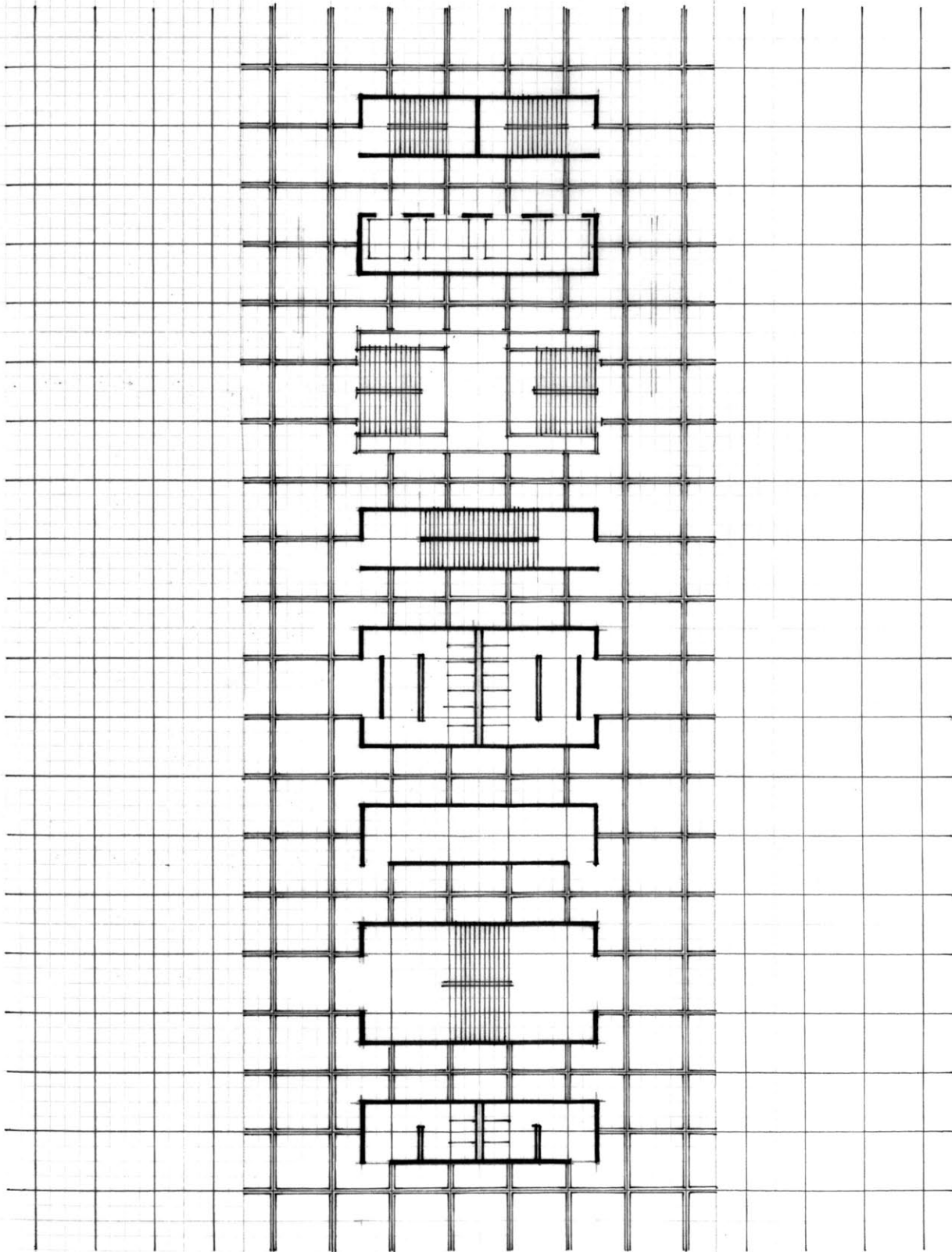
Figure 9



4. Core element: temporary (Fig. 10)

Single element temporary cores are indicated with relation to the structure in Fig. 10. These elements offer the greatest potential for realizing special requirements, thereby adding greatly to the flexibility of the system.

Figure 10



D. Air Handling

1. Major distribution (Fig. 11 and 12)

Core distribution was chosen because the square foot area of chase space used for column distribution would be 625 sq. ft., as opposed to 400 sq. ft. for a chase at the core. Furthermore, the column chase would have created planning problems and structural complications. The type of major distribution system used is determined by desired growth pattern and degree of individual control and flexibility. In office space a dual-duct high-velocity system with mixing and attenuation boxes located along the 20' strips is planned, so that almost total individual control could be obtained. In commercial spaces with uniform air distribution a single duct system would be more practical. Distribution patterns will determine the degree of flexibility and type of growth. In Fig. 11 and 12 major distribution patterns are indicated.

Figure 11

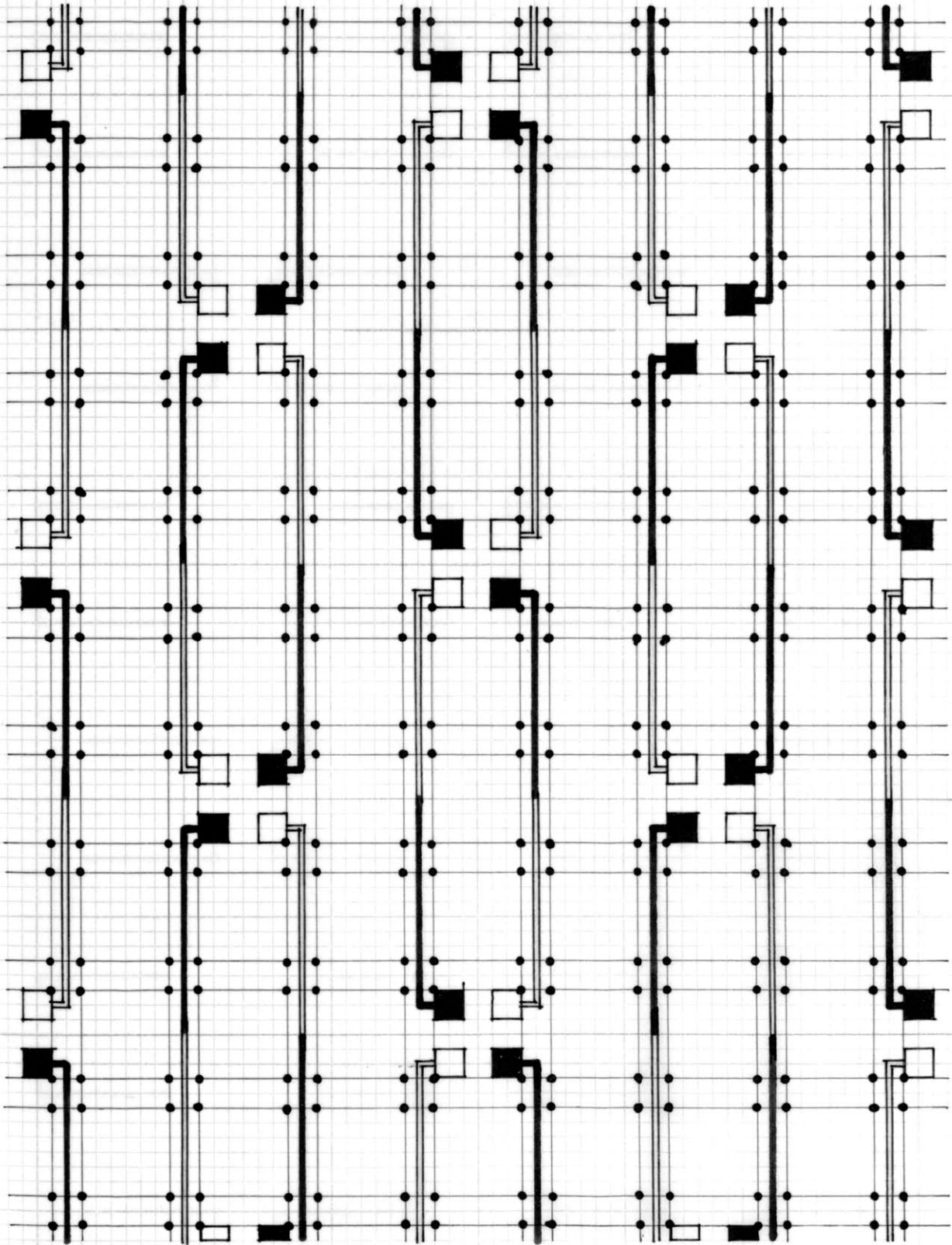
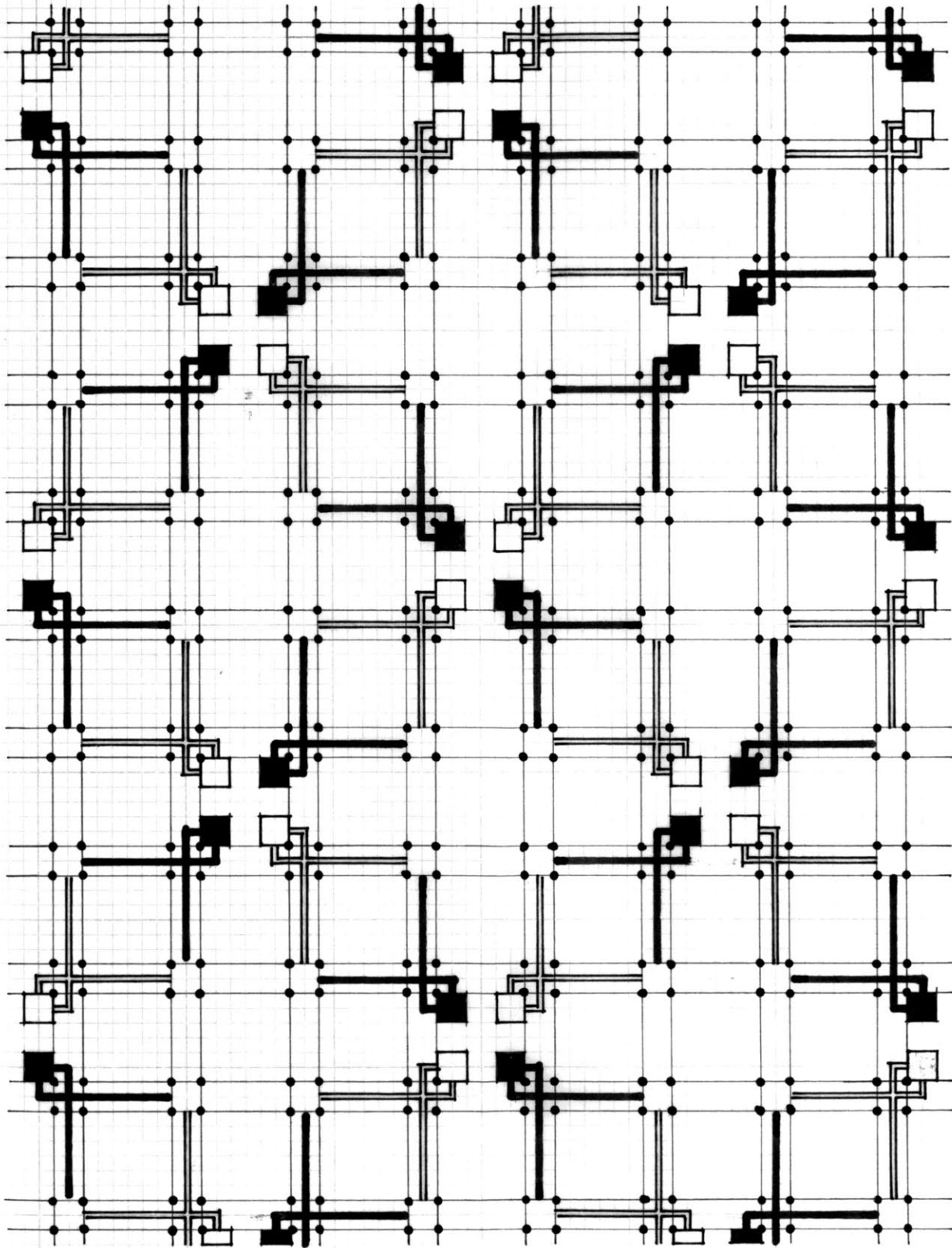


Figure 12



2. Minor distribution (Fig. 18)

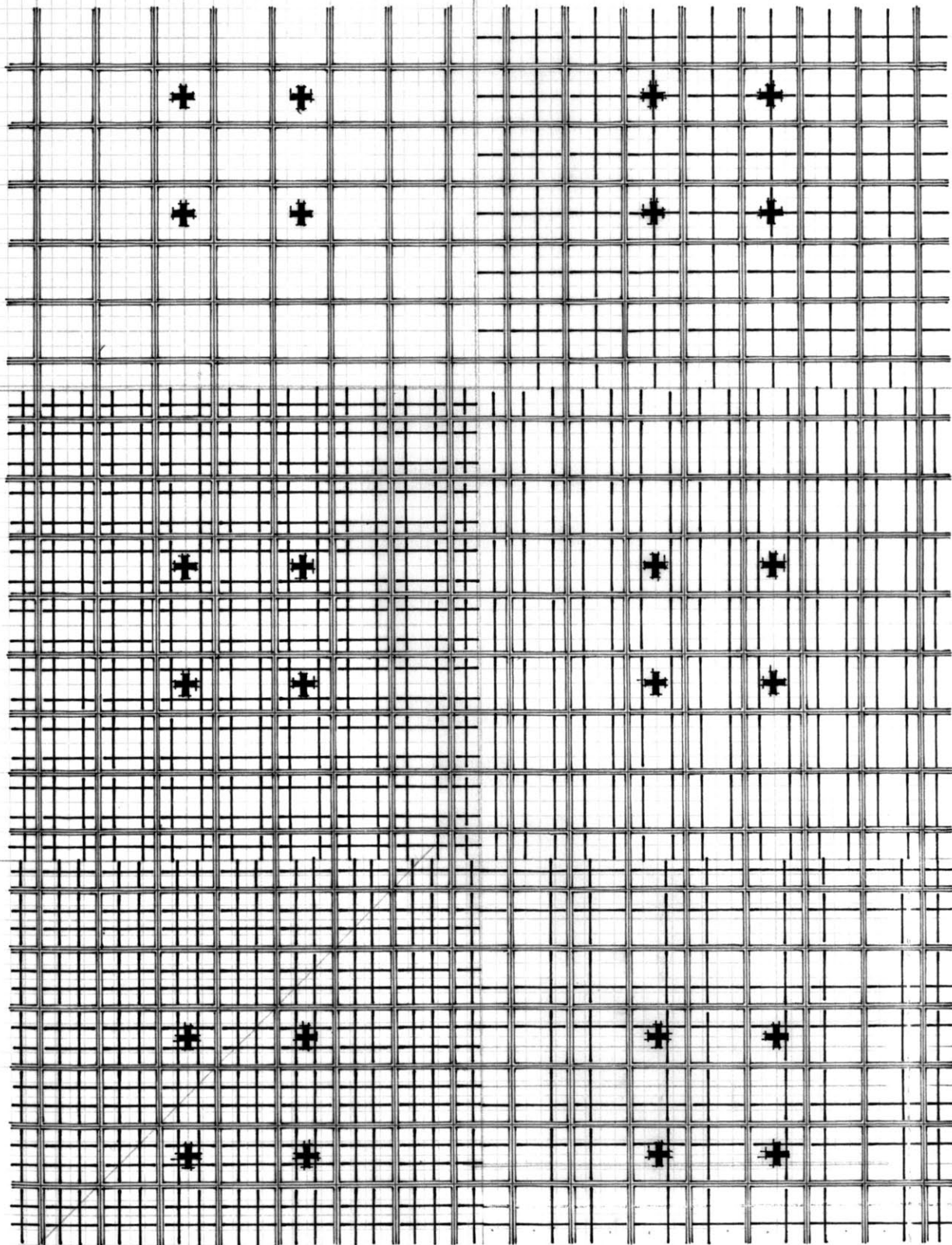
Within the minor or individual bay distribution pattern, it is possible to have air delivery every 10' in the structure. This allows for maximum individual control and flexibility. Every 30 feet would be economically practical for large areas with uniform air distribution. The type of function will largely determine the distribution pattern. By running the ducts in a uniform geometric pattern, it is possible to leave the minor system exposed and to use infill panels beneath major distribution ducts, attenuation boxes, and pipes within the 20' strip. This is not only an aesthetic consideration but also an economic one. By running the duct in the center of each 10' structural module, it is possible to use four types of diffusers, namely, air distribution above the ceiling panels, integrated diffuser and lighting fixture, through a ceiling diffuser, and at the top of a partition. The minor distribution patterns are

determined by the type of major distribution, desired flexibility, and desired control.

E. Partition Planning (Fig. 13)

As discussed above, the 10' structural grid gives the most flexibility in planning modules. The non-structural temporary grid should be determined by the type planning being done, the desired lighting and diffuser pattern, and the function of the space. Figure 13 indicates some basic planning modules.

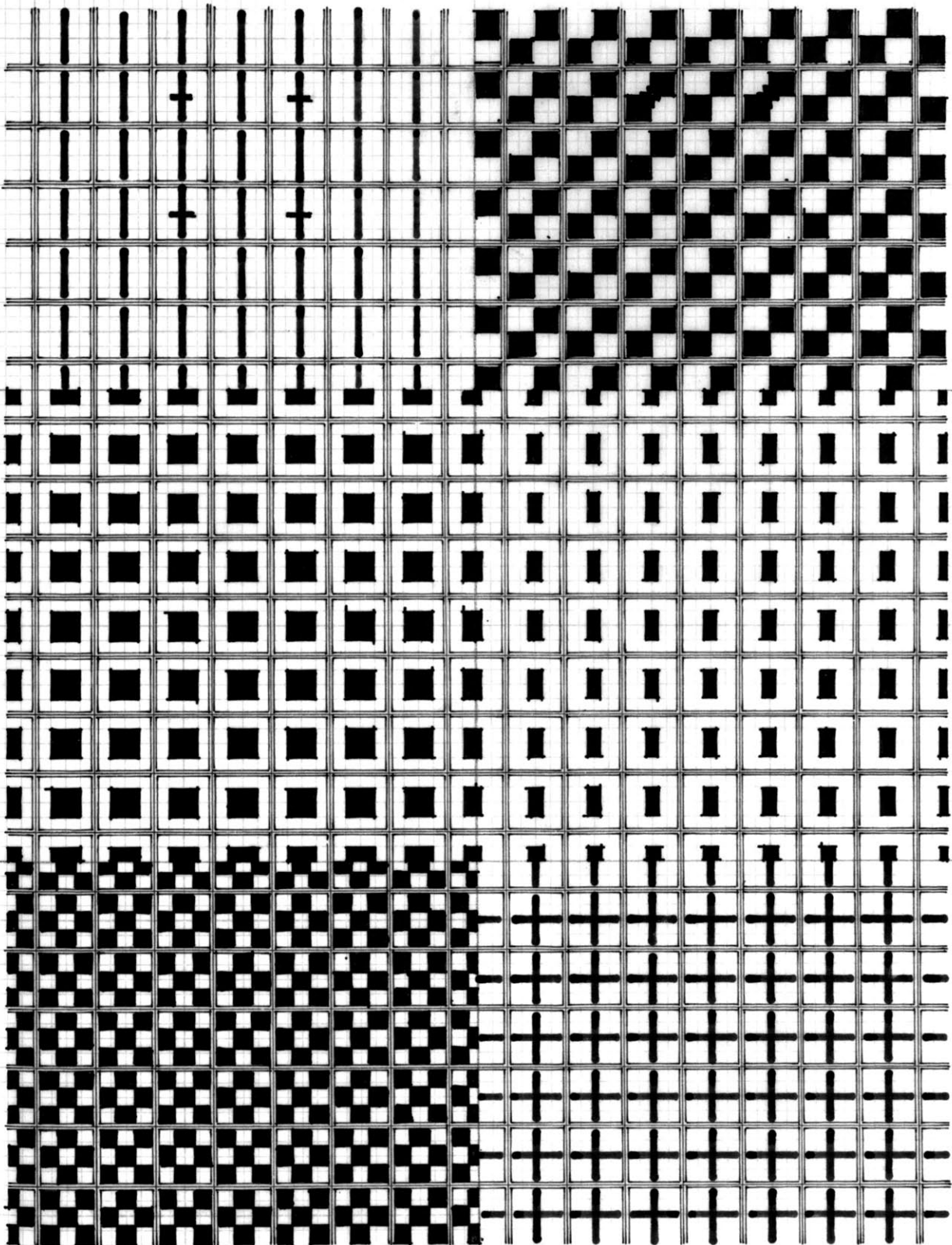
Figure 13



F. Lighting (Fig. 14)

Lighting systems are determined by function of the space, partitioning module, and number of foot candles required. In Fig. 14 a few lighting patterns are indicated.

Figure 14



VI. DIAGRAMATIC DEVELOPMENT: CONCLUSIONS

From the preceding diagramatic development it becomes apparent that flexibility and total integration of individual components do not necessarily evolve in harmony.

Flexibility implies use-change, including mechanical, lighting, and planning elements. Total integration implies that the components facilitate each other so that they are dependent on each other, thus giving them a permanent, unchangeable quality.

The designer must now decide which characteristic to emphasize. The total integration of components can produce a more enriching system, but flexibility must be sacrificed according to the degree of component integration. However, the potentials of flexibility were pursued in detail in order to define the maximum practical advantages of building systems.

VII. DETAILED DESCRIPTION

A. Structure

1. Details

The column center line spacing repeats at 60'-20'-60'20' intervals. The structure consists of two precast components: the top pyramidal unit forms the diagonal web members and part of the compression cord, while the bottom unit is a 10'x10' square unit with an L-shape in section. When two bottom units are placed together, they form a U-shape for housing post-tensioning cables. When top and bottom units are erected, they form a two-way truss system 3'4" deep. The maximum positive moment is in the center of the 60'x60' bay, with moments of equal intensity along the column lines. Since the two-way truss acts as a slab, the moment along the column lines does not act as a girder and thereby equalizes the intensity throughout the structure. This allows for the same size precast units to be used efficiently throughout the structure. The stress in the web

members becomes greatest closest to the column. In order to minimize the stress on any one unit, the columns are split into four and spaced 20' apart. The number of diagonal web members is increased from 8 to 32, creating $\frac{1}{4}$ the original stress in any single web member. These diagonal web members transfer the load directly into 4 girders along each column line instead of 2 girders, thereby reducing the stress along the girders by 50%. The perimeter girder projects 10' into the 60' bay, thereby reducing the effective span to 40' and minimizing the stress in the bay center. With this configuration, all stresses in the members are about equal to a 35' or 40' bay size.

2. Construction sequence

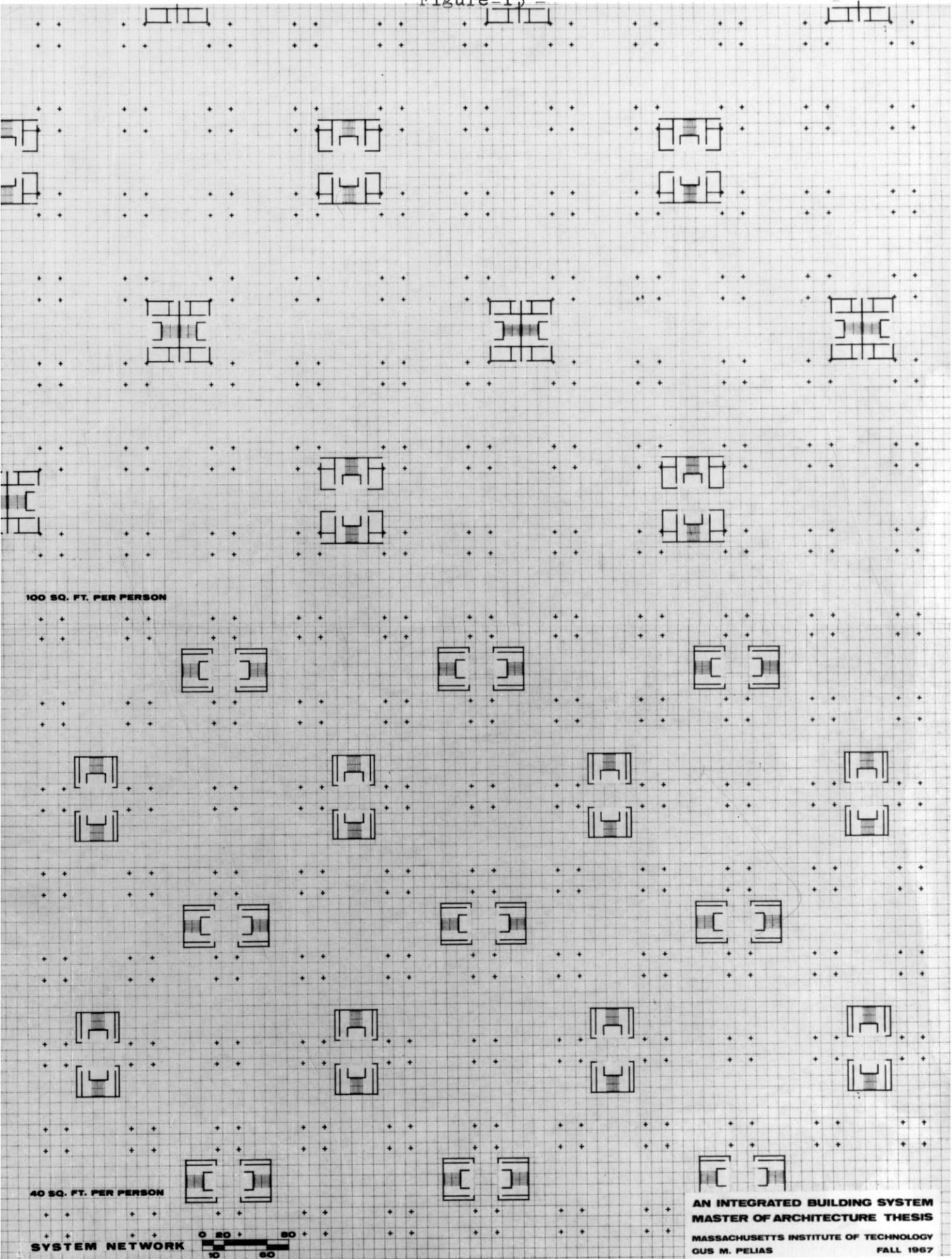
- a. Construct forms for poured-in-place columns and erect scaffolding on 10' grid. Pour column.
- b. Place 10' square precast bottom cord on scaffolding and level.
- c. Place precast column capitals and pyramidal units at the intersection of the four bottom cord members.
- d. Thread post-tensioning cables and post-tension 15% of maximum stress. Grout all joints.
- e. Place form board or precast floor panels on top of pyramidal unit.
- f. Position all reinforcing bars.
- g. Pour topping. Fill U-shaped pocket in lower cord and column capital with concrete.
- h. Post-tension cables 100%.
- i. Repeat for each floor.

B. Cores: permanent and temporary

The permanent or fixed core will be slip-form concrete. Permanent cores could be used for supporting cranes during construction. They would have the additional duty of resisting wind loads in the finished building. The temporary cores will be constructed of demountable materials, such as steel with plaster fireproofing or concrete block. They could be added or eliminated depending on the functional requirements. Any resulting voids in the floor slab could be filled in and joined to the remaining structure by coupling to the existing post-tensioning cables. This would be a major but feasible alteration job.

VIII. PRESENTATION DRAWINGS

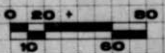
Figure 15 -



100 SQ. FT. PER PERSON

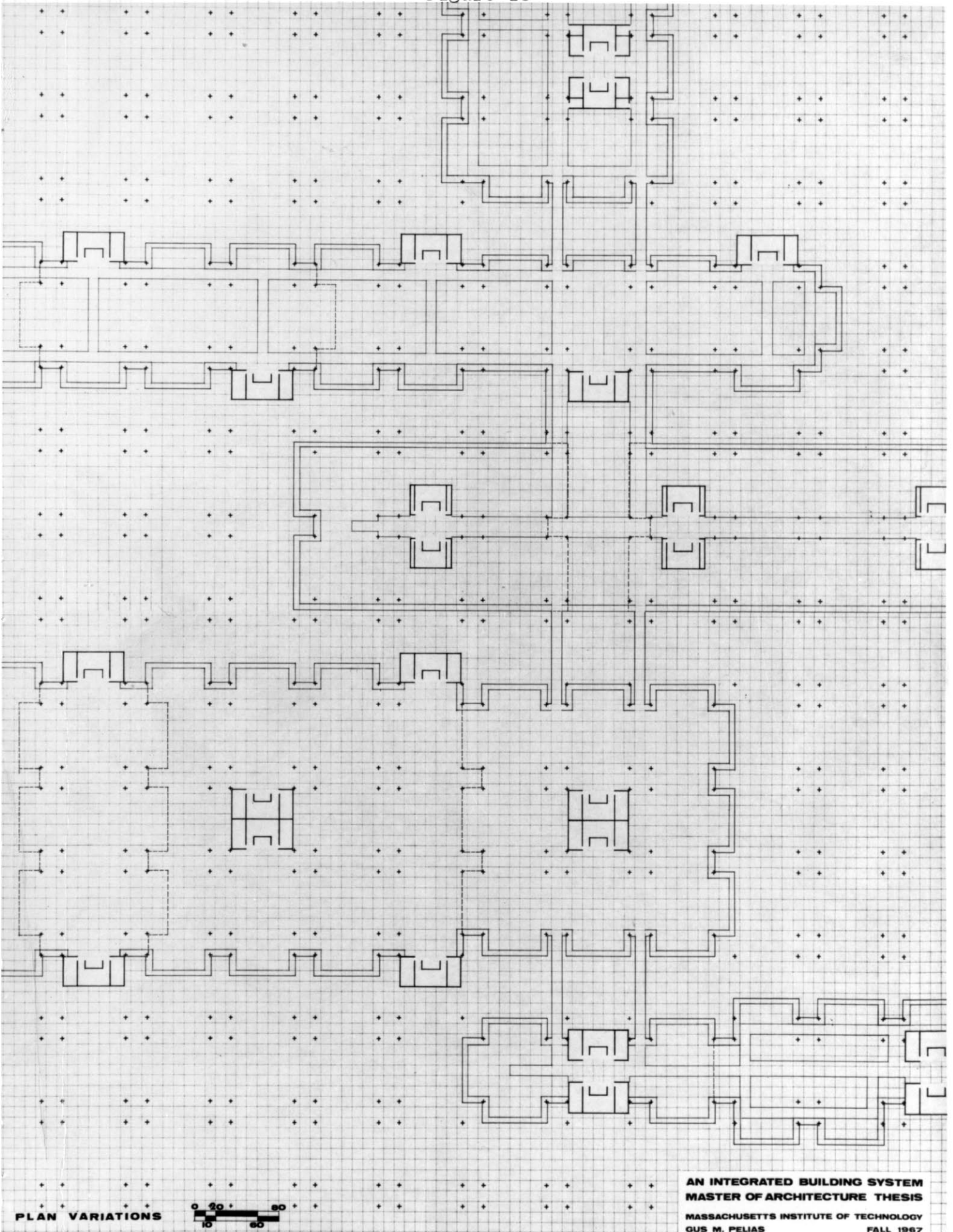
40 SQ. FT. PER PERSON

SYSTEM NETWORK

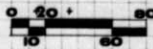


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Figure 16

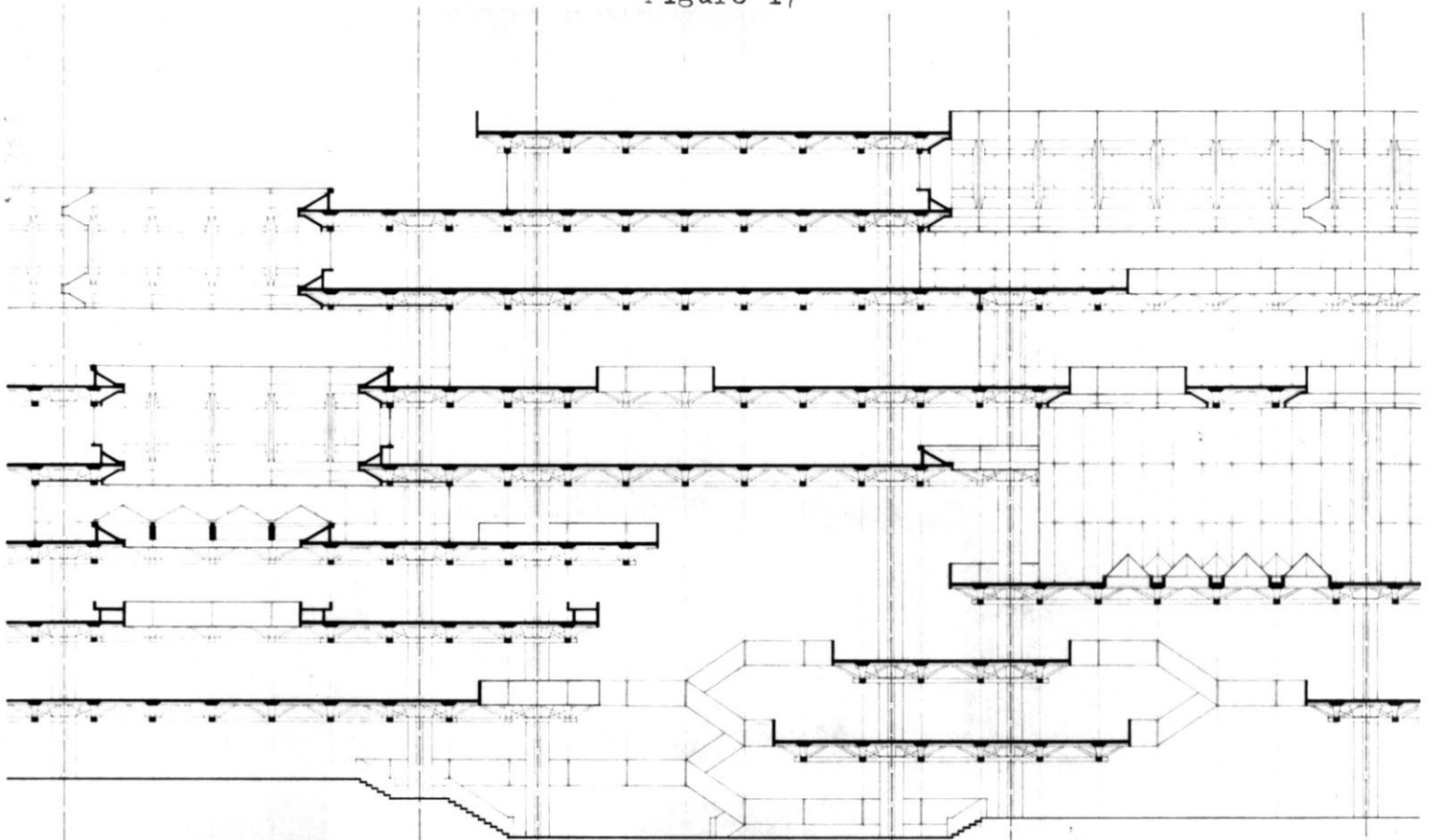


PLAN VARIATIONS



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Figure 17



SECTION VARIATIONS

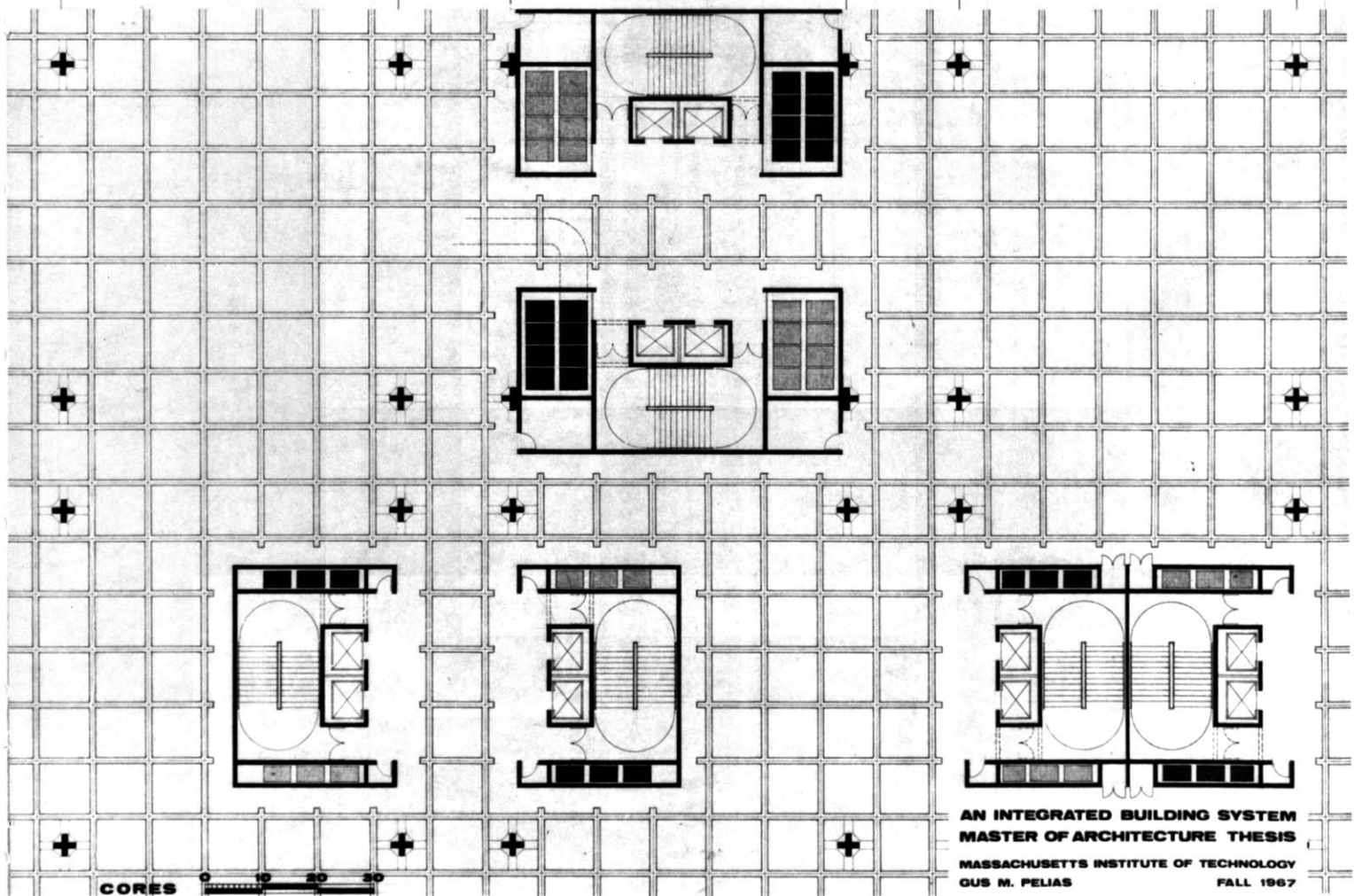
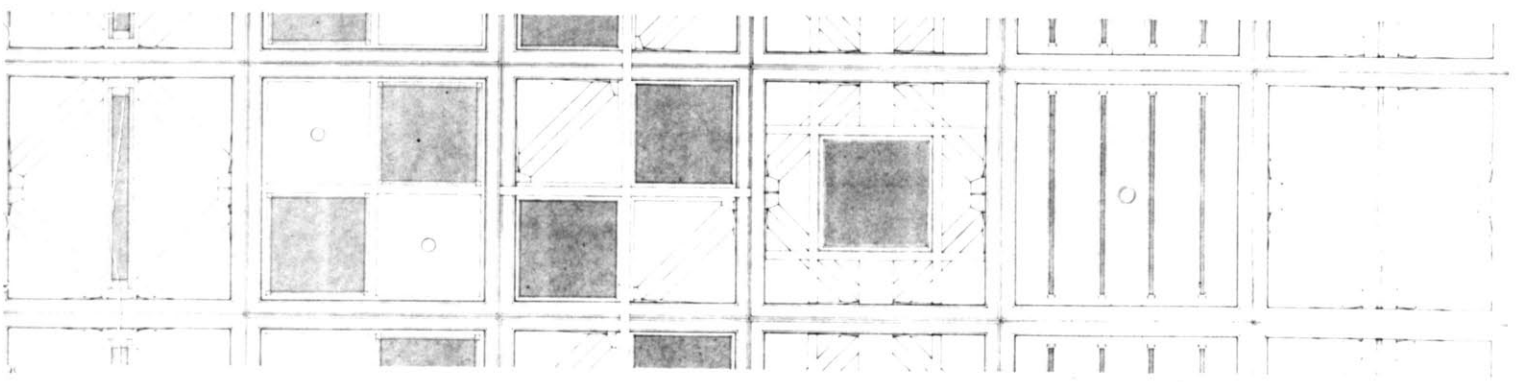
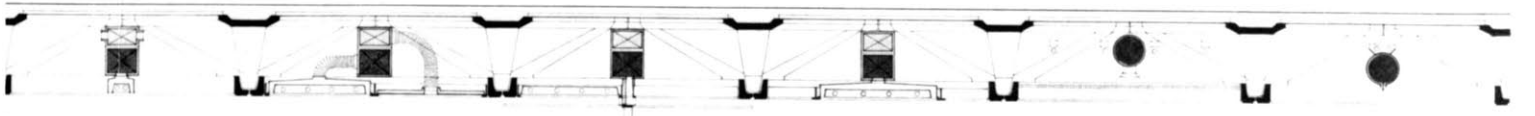
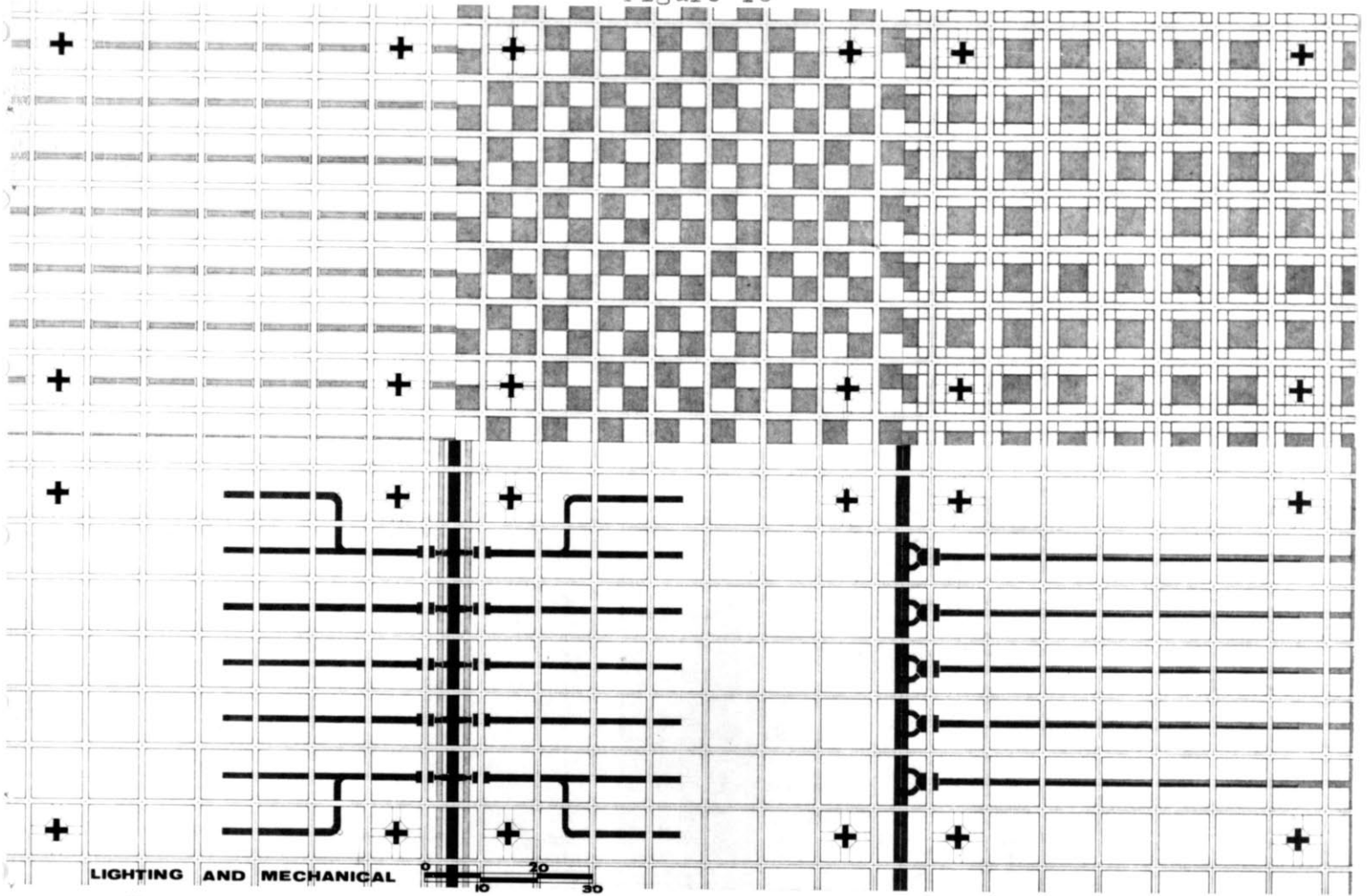


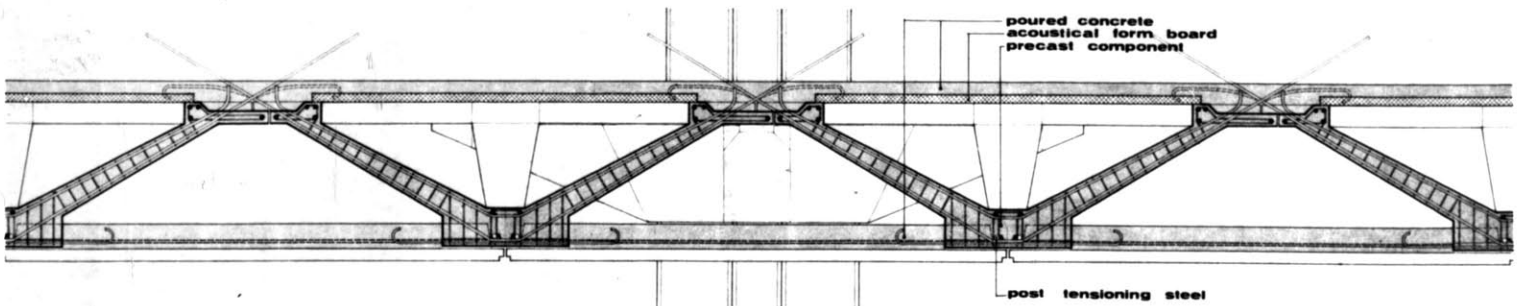
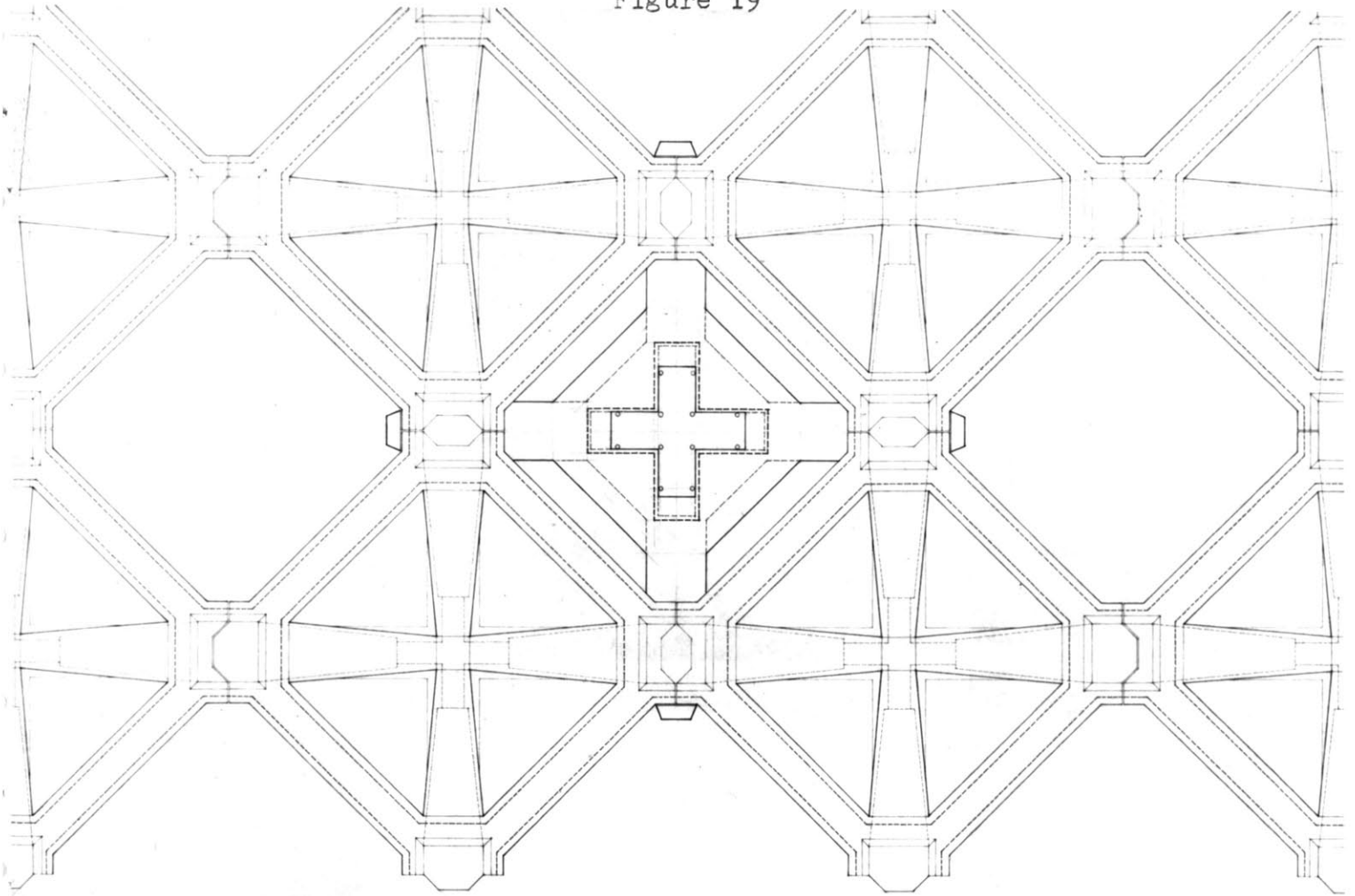
Figure 18



LIGHTING AND DIFFUSER VARIATIONS



Figure 19



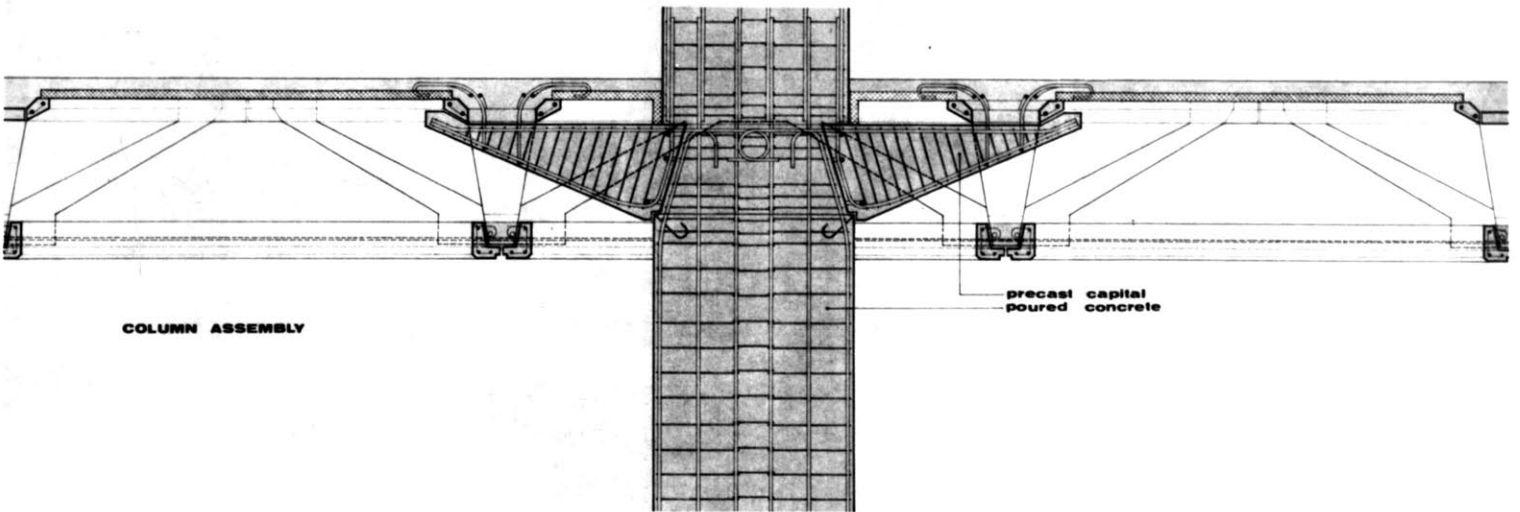
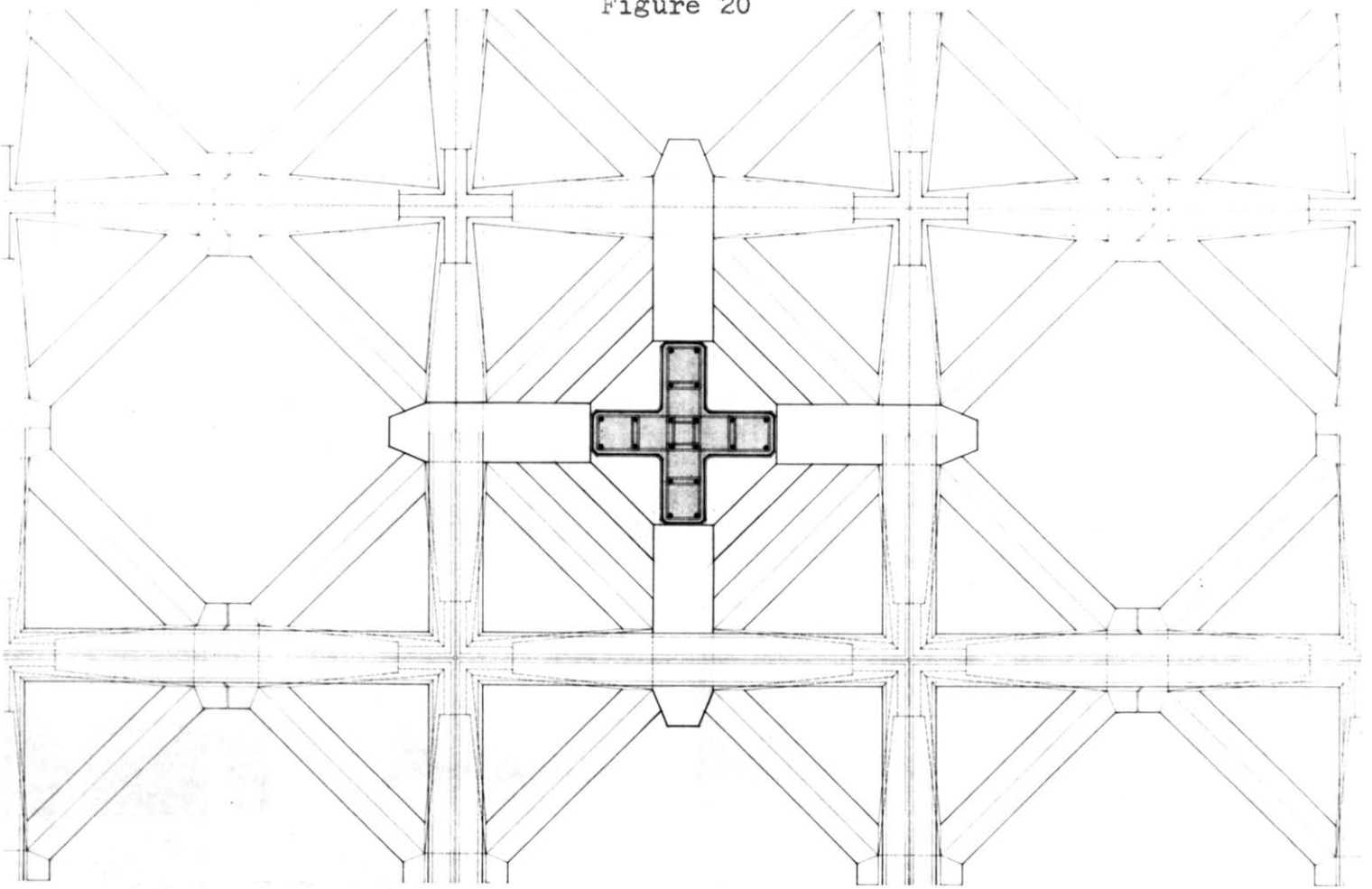
COMPONENT ASSEMBLY

STRUCTURAL DETAILS

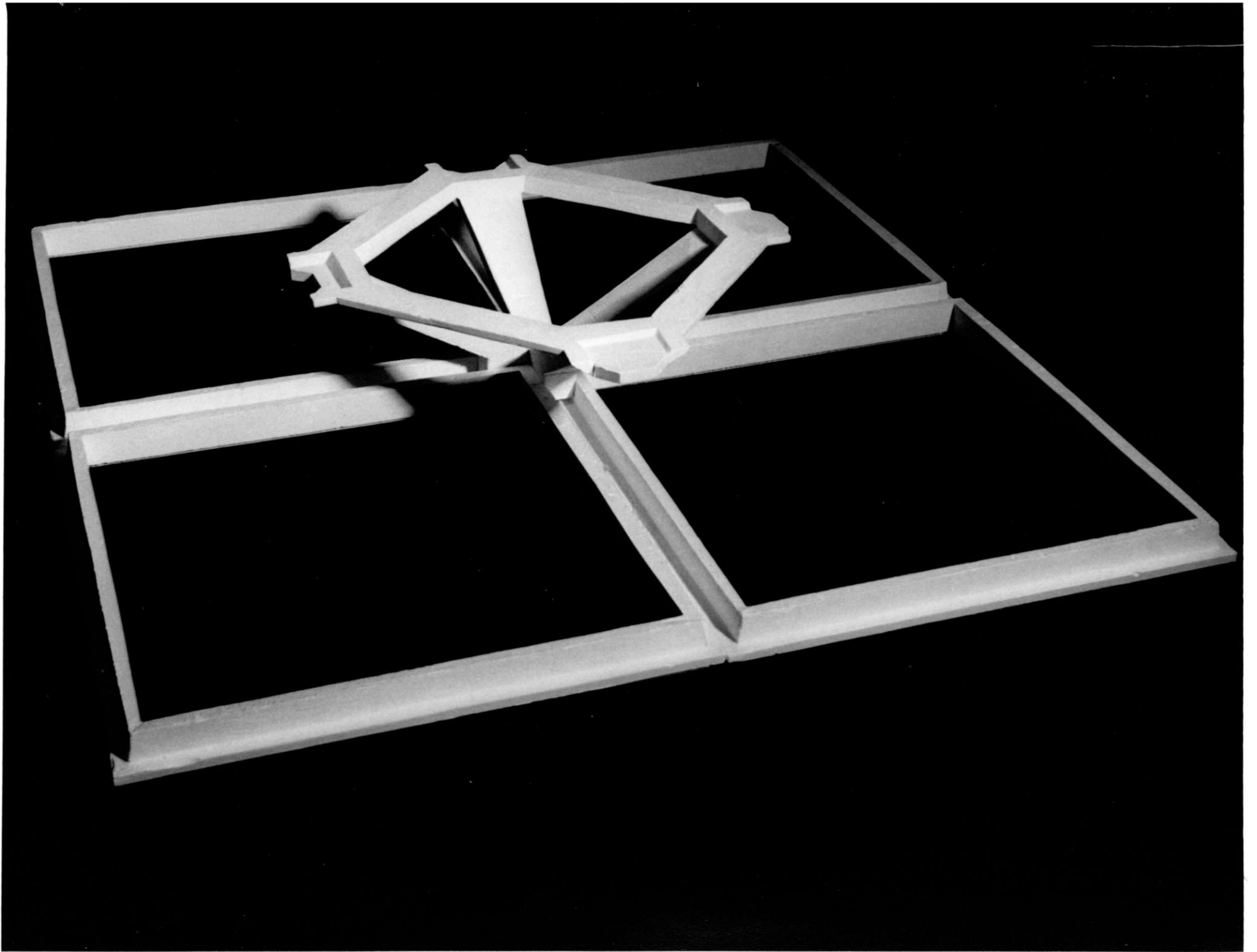


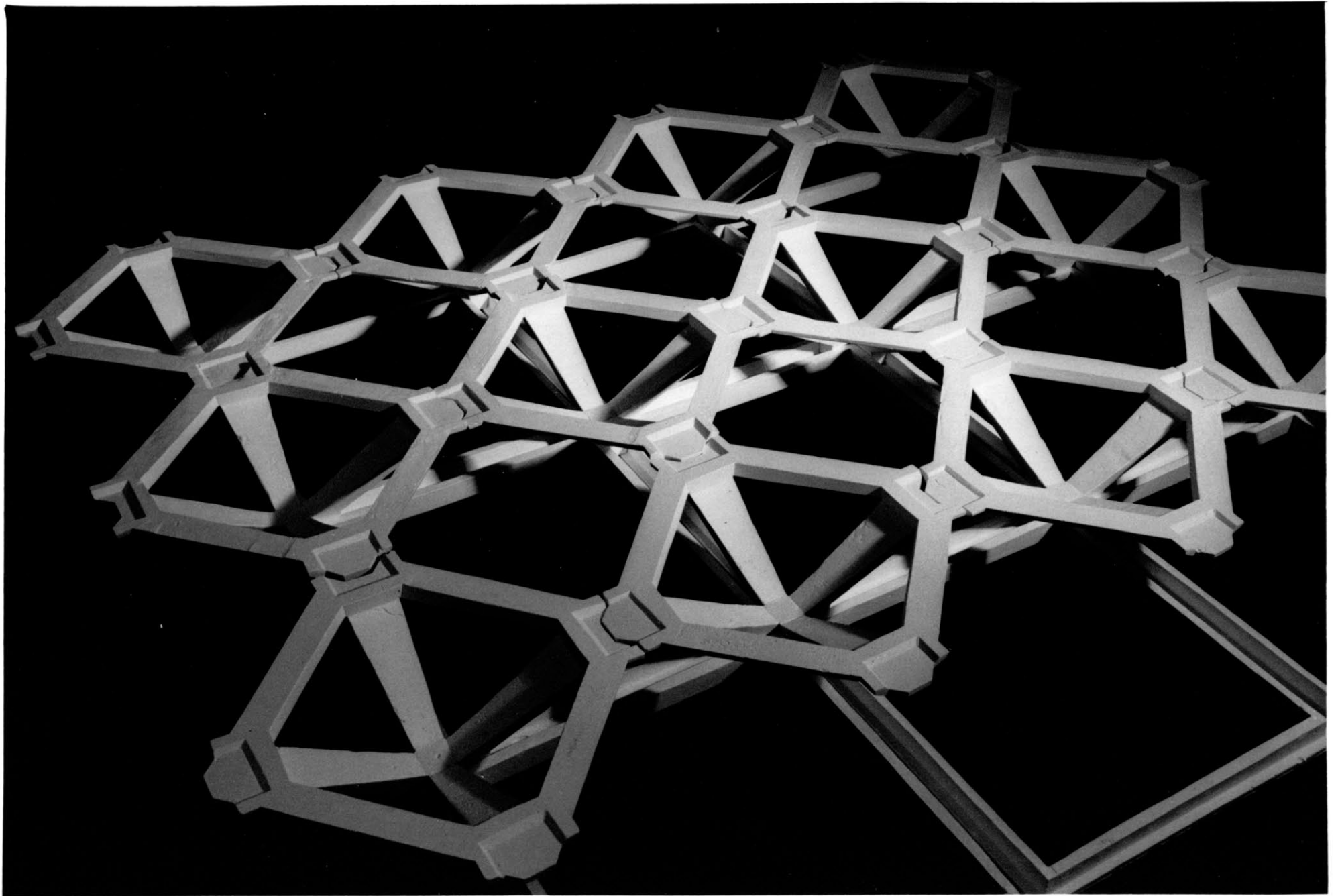
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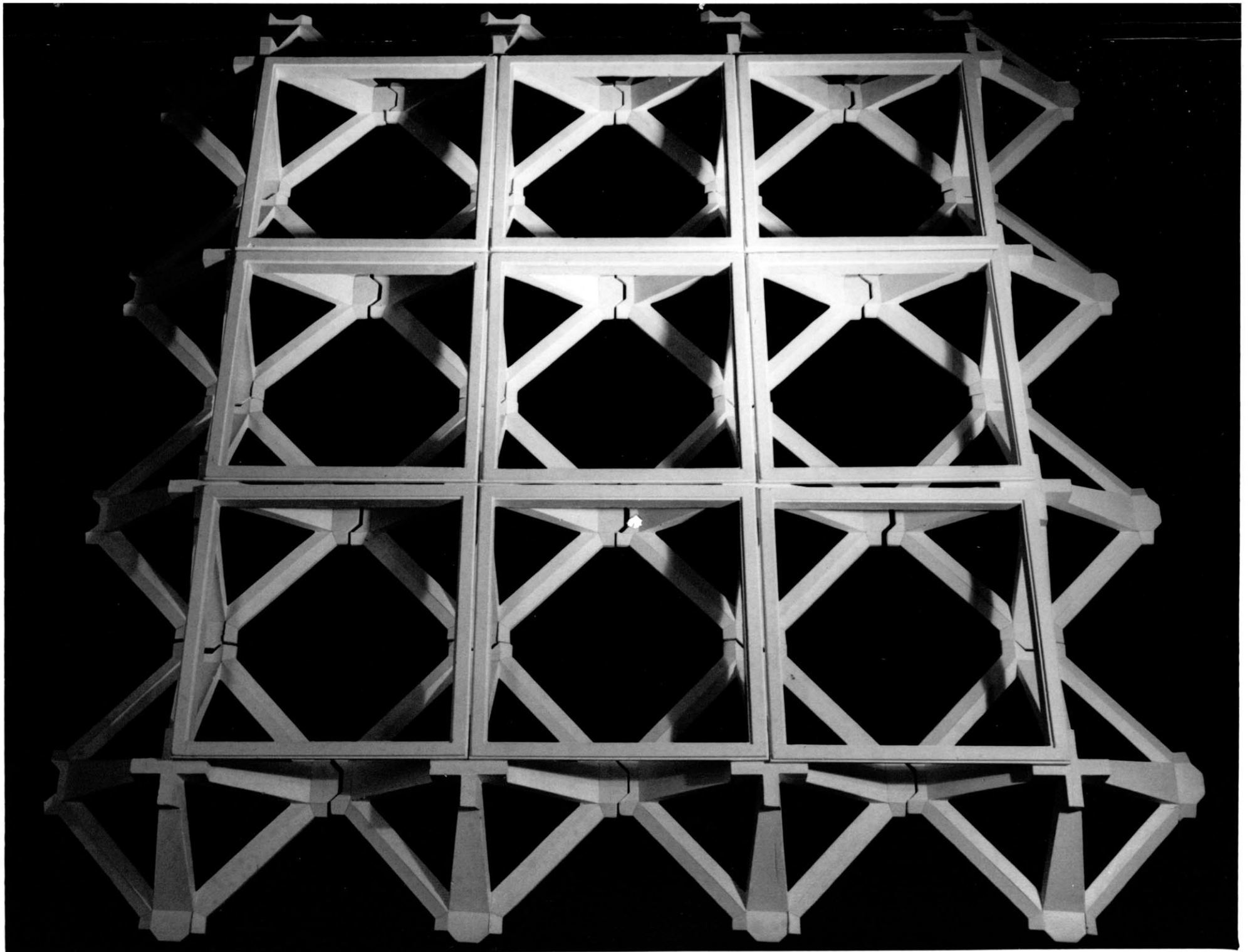
Figure 20

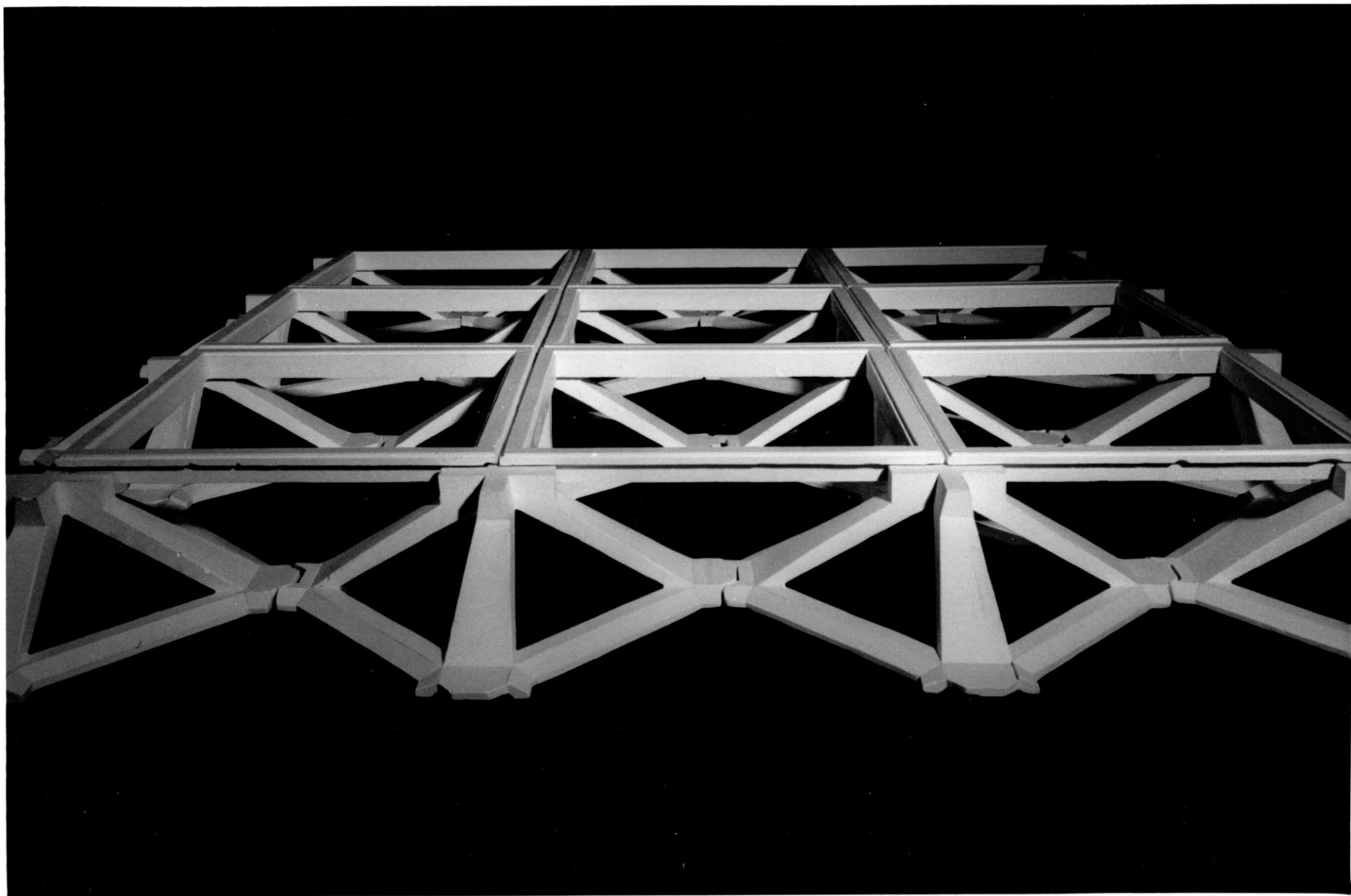


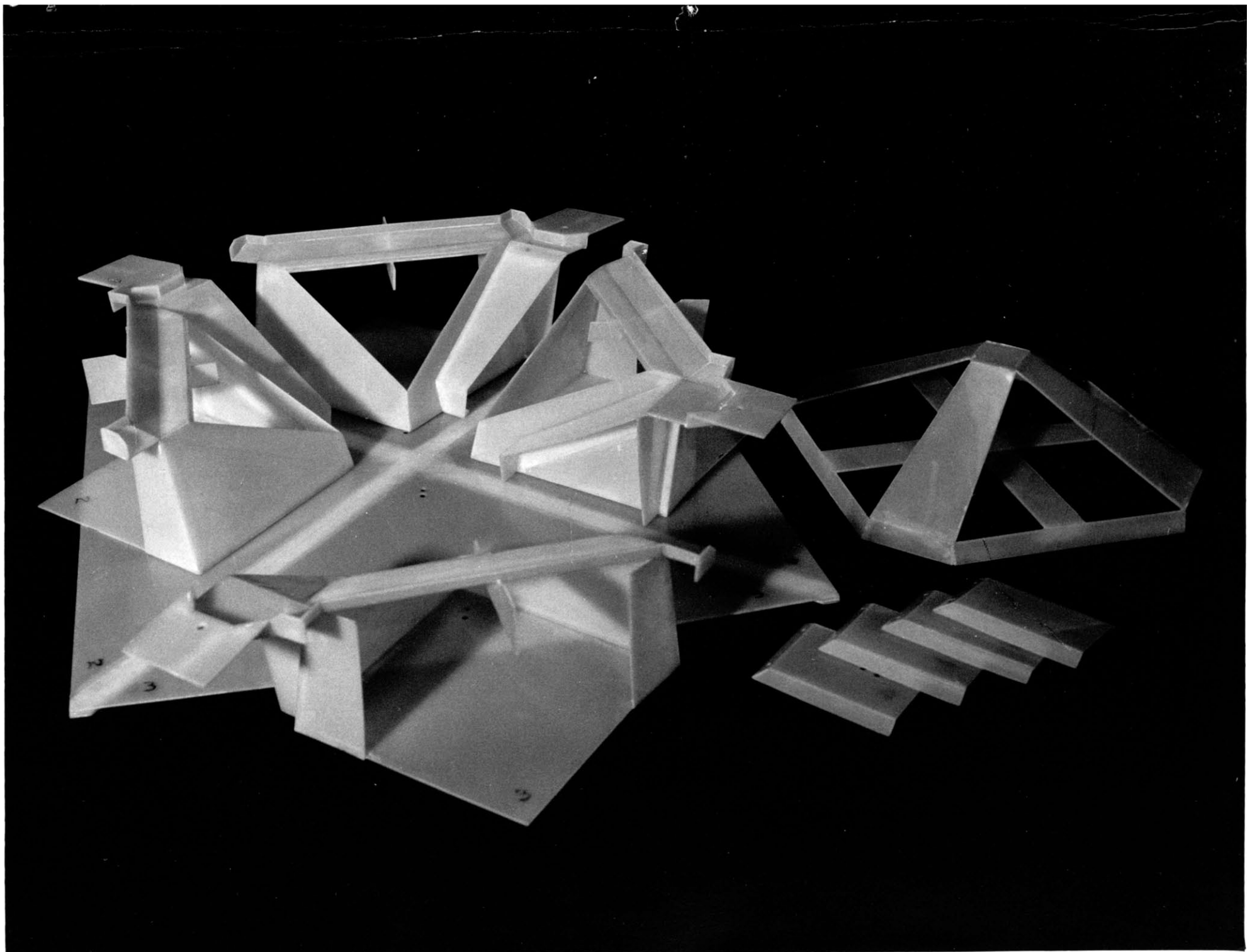
IX. MODEL PHOTOGRAPHS

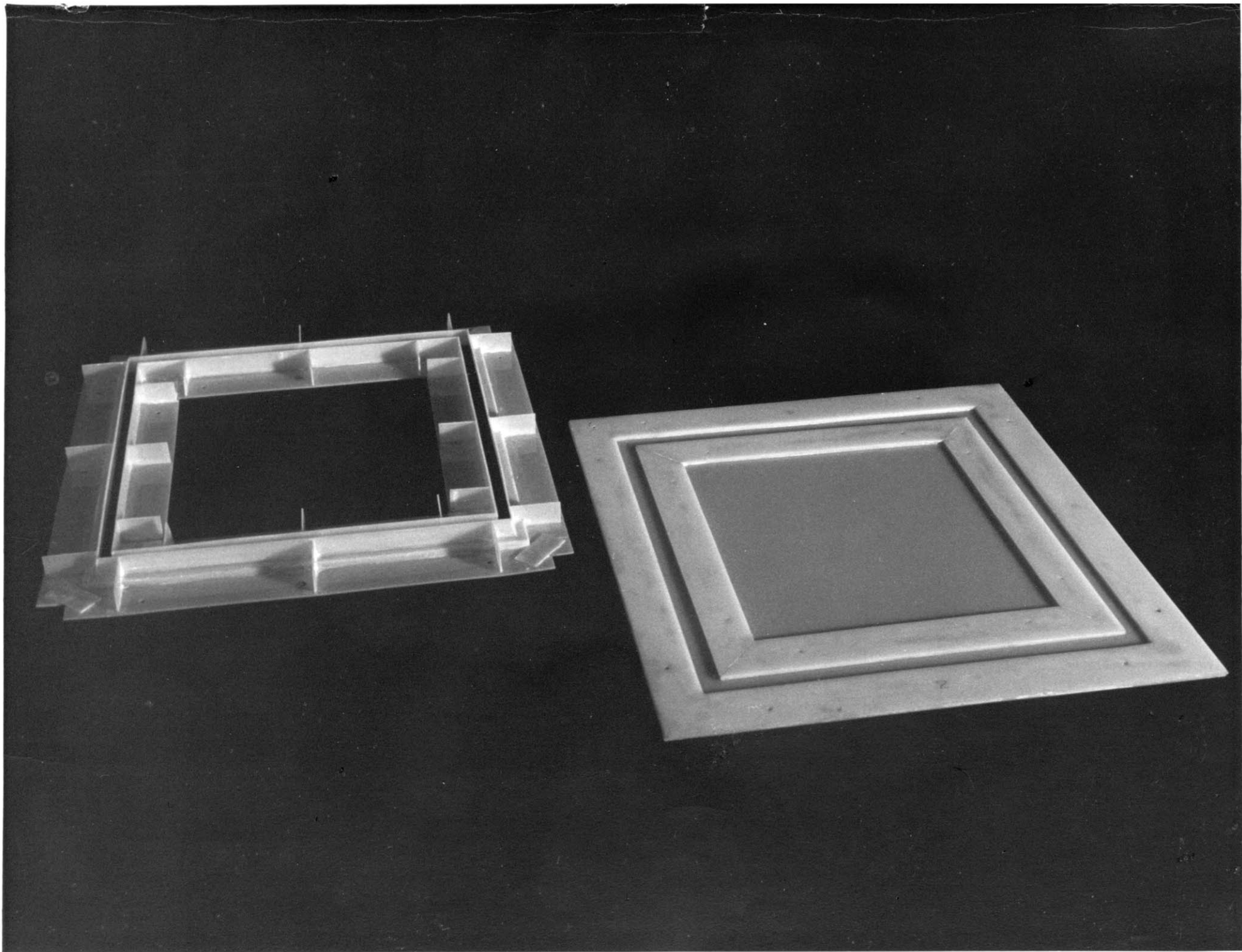












X. APPENDIX: COMPUTER ANALYSIS