TO MORROW'S MANUFACTURING FACILITIES:
THE DESIGN OF A CAR ASSEMBLY PLANT FOR THE 21st CENTURY

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UPA2
Paris, France
1980

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
MASTER OF SCIENCE IN ARCHITECTURE STUDIES AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June, 1987

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ABSTRACT

Spatial reorganization of production conditions (resulting from technical progress in the field of fabrication), on both, a large and a small scale, implies that an important effort from industrial companies has been made to develop new concepts for the working environment. Many companies, such as IBM, Renault or Olivetti, have already invested large amount of money and research time in the definition of their future factories, involving architects, sociologists, economists, etc..

As a consequence, new and different requirements have been formulated that have to be considered by architects and engineers in charge of the design. Flexibility, and a deep concern about protecting future design possibilities, in order to make the best adaptation to the market, lead these thoughts.
Because a car assembly plant involves a wide range of different techniques, in the production area, and allows the definition of building and design criteria for the construction industry, it has been chosen as a case study.

The present thesis analyzes the existing models and their problems, determines a direction for solutions, and explores a new structural modular system, as a step towards new approaches for design and construction. The design proposal shows an example of a displaceable building, with the same duration cycle as the manufactured product, and minimum damaging consequences for the site.

Thesis supervisor: Waclaw Zalewski
Professor of Structures

ACKNOWLEDGEMENTS

I am very grateful to Professor Waclaw Zalewski for what he has brought me during my stay at M.I.T. and especially during the completion of the present thesis. I will remember his broad-mindedness and the richness of his guidance.

I would like to thank Carlos H. Hernandez for his kindness and his advice.

I would also like to thank all my friends and professors at M.I.T. who showed understanding, interest, and friendship.

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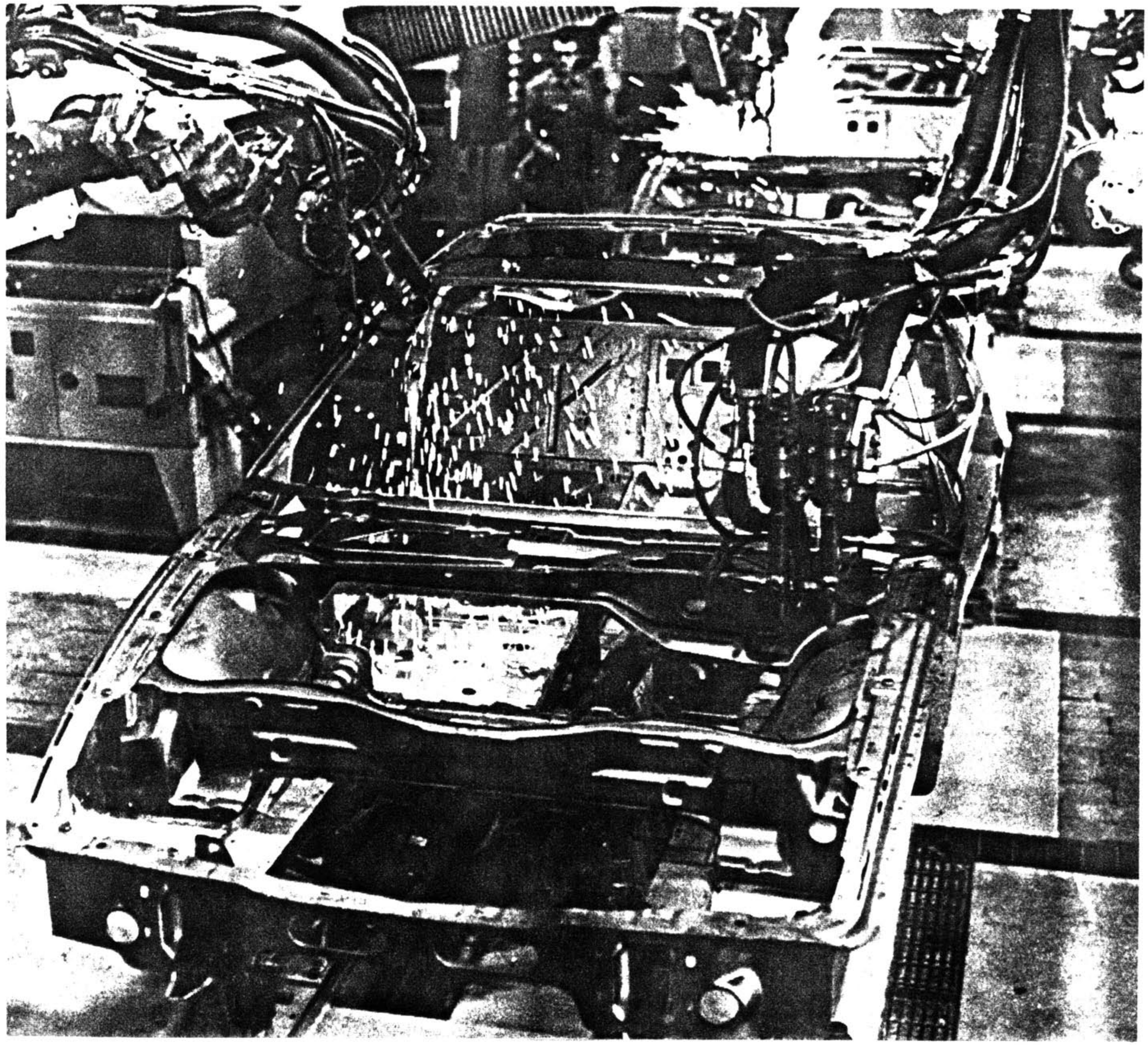


INTRODUCTION

Artificial separation between " noble " and ordinary types of buildings led in the past to a damaging abandonment of the idea of architectural quality in industry.

Today, the on-going research efforts of various companies are deeply concerned with architectural quality and innovation.

Manufacturers are facing adaptibility and profitability problems. The geographic localization remains important for state regulations, social relations and laws, salaries, and proximities of subcontractors for just-in-time deliveries. The environment of an industrial production is subject to rapid modifications, which can force the industry owners to improve their mobility in order to find the most favourable conditions for production. Since the technology duration, the market, and the clients' desires are difficult to predict in the long term, manufacturers are reluctant to commitments over long periods of time. The idea of an adaptable building that can be quickly dismantled and displaced (or easily disassembled and stored) according to immediate needs, then has come up as an alternative to the traditional manufacturing facility design.

The reasons for this move towards more satisfying buildings are mainly as follows:

-- The manufacturing technology evolution now requires an environment adapted to its progress. Computers, robots, new communication networks within plants, and new intensive use of material have created the need for special spaces and fittings which can hardly be added to existing buildings. Rather, these buildings must be completely redesigned.

-- The recent economic challenge in manufacturing which has shown that many production organizations are out of date, both in research facilities and in industrial installations. Improved ability to answer rapidly to new market demands is imperative.

-- Personnel qualifications are now higher, insuring the efficient functioning of the manufacturing facility while increasing the pressure for better working conditions.

-- It is necessary to improve land utilization in industrial countries, where land is more and more rare and expensive, especially in industrial zones. Land is a resource which has to be managed relative to the needs of the moment, and in many cases, it can no longer be continuously occupied for decades without serious justification.

-- There have been improvement and breakthroughs in design and in building technology, allowing for new and more satisfying solutions to various problems (structure, HVAC, waterproofing, clean rooms,etc.).

This thesis aims to develop skills and knowledge related to manufacturing facility design within the framework of a case study : a 21st century car assembly plant project.

Most of the issues relative to this case study have been developed in a design research program by GM (General Motors) and ACSA (Association of Collegiate School of Architecture), who together launched a competition in Fall 1986 under the title :
"A 21st Century Manufacturing Facility".

The design program for the above competition will be used as a guideline in this study.
The thesis will be composed of five main parts subdivided into subparts.
The first part will detail the major necessary changes in facility design.
The analysis of the existing building types will constitute the second part.

In the third part, I will formulate the requirements for a new building type and suggest new approaches to the design.

The fourth part explains the design choices.

The fifth part presents the design proposal.

"No single building type exists in a greater profusion of scales, styles, shapes, materials and other variables than industrial structures.

This nearly limitless variation is due to the equally limitless nature of industry itself, which ranges from the infinitely delicate to massive, amorphously styled mills (not to mention 'public industrial buildings' such as railroad stations and others, which process mainly people.)"

Roger M.Vogel

"Industrial structures."

in Built in the USA

1 THE NEED FOR MAJOR CHANGES IN MANUFACTURING DESIGN

1-1 The Manufacturing Technology Evolution

We have observed the end of the steel hegemony in the automobile manufacturing field. New materials are now widely used in order to save weight and to increase corrosion protection. The number of types of plastics is infinite, but their existence is contingent upon their use. For an equal resistance, plastics can save up to 50% of the weight. Although they are more expensive than steel, their lightness and ability to simplify the manufacturing process compensate for that expense. High-strength steel and aluminium compete with composite materials. All of these materials lighten vehicles and improve their safety. Ceramic and electronic components will be highly involved, in the near future, in engine and car production. In terms of materials, major changes will affect and modify production habits and will require new professions and competencies on behalf of the manufacturers.

Other recent developments affecting manufacturing technology includes robots and CAM.

Robots (capable of environment apprehension and adaptation) are present in most phases of the manufacturing process, and their use is only limited by the comparative cost of manpower. CAM (Computer Aided Manufacturing) is one important aspect of computer application and allows flexibility on the assembly line

1-2 The Economic Competition

The highly competitive economic environment forces industry owners to react very quickly to any move of the market. They cannot rely anymore on any area remainig protected from competitors,. The life span of a product is shorter and shorter and requires the ability of a manufacturer to shift rapidly to a new fabrication. The manufacturing tool and plant must make these changes possible.

1-3 The Personnel Qualification Evolution

Altough less numerous than in the past, modern employees need more qualifications and higher salaries. The development of new production processes has created new disciplines with a shortage of know-how. The high rate of unemployment allows for a more selective choice, in terms of personnel, but these new workers require better working conditions. The necessity of a full time production process leads companies towards a policy of avoiding strikes and social disturbances. Creating a high-quality environment including all types of facilities is an important part of that new policy.

1-4 The Increasing Price of the Land

In industrialized countries, the suburb has been the traditional location for industry, due to various factors, of which the most important was the proximity of both the labor market and the clients. With on-going urbanization, the price of the land has increased and no longer allows the implantation of huge horizontally spread manufacturing facilities for long periods of time. Even if moving to less populated places, plants need access roads, electricity, etc., and have to settle in industrial zones where the use of land is planned and organized. The cost of a given piece of land will become prohibitive if quick profitability and return are not considered. If the plant's duration is much longer than the duration of a certain technology or product, the manufacturers have to face, in addition to property taxes, expenses for the maintenance of obsolete buildings. Moreover, nobody then takes advantage of that available space. " How to get rid of building" becomes an issue. Ease of dismantling, or convertibility of industrial buildings should be taken into account at the decision and design stage. That reflection may include the building process, the materials, the components' size and the sharp definition of each program element.

1-5 The Building Industry

Improvements in the field of building construction have made it possible to find new architectural answers to manufacturers' problems. Such improvements include the invention of high-resistance bolts, automatic welding, development of standard components, pre-stressed concrete, corrugated sheeting for roofing, high-quality reinforced fabric (which may be insulated and fireproofed), inflatable structures, new possibilities in design and construction of huge spaceframes and space structures fostered by the development of methods of analysis. These improvements have resulted in important transformations which are due more to technological progress than to the evolution of architectural or manufacturing concepts. These new technical possibilities are no longer only experimental prototypes but can now satisfy many real requirements.

2 THE CURRENT MANUFACTURING FACILITY BUILDING TYPE

Most current manufacturing facilities have been designed and built during periods of economic expansion. Confident in the future , and in coherence with existing building techniques, manufacturers have erected facilities for the long term (about 50 years). All their efforts have been directed towards the organization and the profitability of the production process, and until recently, maintenance or improvement of buildings and attached working conditions were not a priority.

2-1 History and References

1945 - 1957 The North-American pattern:

After the second World War, and until about 1955, industry buildings were characterized by a good average architectural quality and by a style often considered monumental. Steel was the most popular material in the United States (45'- span steel trusses, partitions and exterior walls made with concrete blocks or bricks), while concrete was mainly used in Europe. Essentially, the production spaces were constituted by large halls, which were the subject of important studies in the field of daylighting, electric lighting, and light diffusion. Sheds were occasionally used in roofing. The notion of typical units for storage purposes only appeared in that period. Facades were well designed and widely opened. In general, industrial buildings were designed as public buildings. The industrial space also included various social amenities (toilets, recreation halls, cultural areas, etc.).

1958 - 1970 The standardization of industrial buildings:

Important developments in technology accompanied a progressive standardization of construction components. When the nature of the production allowed for it, the building became independent of the fabrication process. There was a total separation between the envelope and the industrial tool, in order to provide maximum internal flexibility. Capacity augmentation and technological changes lead to increases in building size. The outside aspect became trivial and was reduced more and more to a blind envelope. These transformations, characterized by a loss in design quality, can be explained by the concern for maximum financial profitability. Therefore, the use of a cheap and quickly erected envelope spread, especially with the development of new building systems (e.g., the development of metallic light prefabricated walls). An exception can be made for some high-technology industries, which assimilated the particular quality of their product with the architectural quality. As a general rule, no athletic or social facilities were added to industrial installations during that period. The building defined an impermeable envelope, and the employees, while working in the plant became deprived of many basic human convenicnces.

1970 - 1979

In the United States, many assembly plants were built for industries or private groups, most of the time in a suburban or rural environment. Most of them were made with standardized elements, and developed the notions of autonomous workshops and flexibility. The public image of corporations were subject to studies considering architecture as a means of communication.

2-2 Profile of Today's Typical 50-Year Life Cycle Factories

The following description is extracted from the General Motors competition program (Fall 86):

"Functional organization

The Administration Building component is typically joined to a common abutment on one side of the larger scaled Manufacturing Building.

Roof system

The roof is a flat and is designed for water drainage through the use of roof sumps. The roof system is typically made up of a 1 1/2" or 3" metal roof deck, vapor barrier, insulation (thermal conductive C=.24) and a mopped-on 4 ply composition roofing. The flat roof landscape supports and contains air supply houses, exhaust fans and electrical substation equipment. The composition roofs are warranteed for 20 years but often leak before that time. Leak is often the result of damage caused during maintenance of roof mounted equipment.

The use of skylights monitors was eliminated due to high initial cost, maintenance and leakage problems and the belief that skylights are not functional and cost effective. There is also the question of their usefulness in maintaining appropriate general light levels in the work areas throughout "all" work shifts.

Provisions for emergency exhaust of smoke and hot gases by the use of ventilators on the roof and the containment of smoke and hot gases inside the building by Draft Curtains has been effective in limiting damage to buildings, its contents and loss of life. The ratio of vent-to-floor area for normal hazard is 1 sq. ft of Ventilator for 100 sq. ft. of floor area. Draft Curtains, which act as a vertical shield run from the roof to the bottom chord of the truss. They are located between areas of fire hazard containing 70,000 to 100,000 sq. ft. each.

Structural system

The typical Manufacturing Facility System is a 45'x45' grid with the following members:

-- *Steel purlins parallel to the general flow of the manufacturing process (...).*

-- *Steel trusses perpendicular to the general flow of the manufacturing process (...).*

-- *Steel Jack trusses parallel to the general flow of the manufacturing process (...).*

-- *Wide flange steel columns at 45' spacing in each direction supporting trusses.*

-- *Spread footings, drilled caissons, or piles with pile caps, depending on the soil conditions, supportig the columns.*

-- *Concrete slabs on grade reinforced top and bottom.*

-- *(...)*

Structural loads

The typical loads used in design are as follows:

-- *Snow or rain loads with adequate provision made for water ponding or snow drifting around roof projections.*

-- *Mechanical and Electrical equipment loads as required.*

-- *Miscellaneous manufacturing process hanging loads of 1000 pounds at midspan of roof purlins and 4000 pounds at each carrying truss bottom chord panel point.*

-- *(...)*

Manufacturing exterior wall system

The exterior wall is typically composed of a hard "sill" wall from ground level to 8'-0" with metal siding above. The metal siding is insulated, comprised of exterior sheets, sub girts, and interior metal sheets, factory fabricated with a baked on protective finish on both interior and exterior surfaces. Overall thickness of the metal siding is 3 1/2" with an insulating factor of U= .07. When metal siding is used continuous (without a sill wall) from the roof to ground floor level in the Manufacturing areas steel guard rails are necessary to protect the wall from vehicle traffic such as fork lift trucks. Theses guard rails are located away from the interior surface of the exterior metal siding wall. From the outside the use of metal siding from the roof to ground floor level gives the manufacturing building an appearance of a single volume .

Exterior walls alternatives are:

-- *full height precast concrete panels*

-- *long span insulated prefabricated metal siding*

Sill wall alternatives have been:

-- *brick*

-- *concrete block*

-- precast sill concrete panels

(...)

Typical interior partitions are:

-- Concrete block partitions in Manufacturing Areas, Toilet Areas, and Fire Separation walls required.

-- Insulated metal panel with glass openings where required in Ovens and Paint Booths.

-- Metal stud and dry wall, movable partitions, systems furniture type partitions in Office Building Areas.

Truck docks

Truck docks are typically used for the Receiving and Shipping operations for most Manufacturing production operations. The Truck Docks are served by mechanically activated levelers designed to sustain a 60,000 pounds load with safety devices to hold the truck trailer from moving. Fork lift trucks service these truck docks by loading/unloading outside deliveries at the perimeter of the Manufacturing Building and within the facility when there is no interior Automated Guided Vehicle System. Historically the Receiving and Shipping locations were either in adjacent open parking areas or totally enclosed truck areas with levelers arranged side by side. New production concepts such as "Just in Time" delivery and "Point of Use" have changed *the receiving and shipping requirements. Receiving areas are now being located around theperimeter of the building so that they are closed to the "Point of Use" on the production line.*

Automated Guided Vehicles (AGV's) and automated overhead cranes are being used as replacements for manned fork lifted trucks.

Manufacturing process impacts:

Typically, Mechanical and Electrical systems are layered above the bottom chord of the trussses. There have been many Mechanical and Electrical systems components developed and used in existing facilities. (...). Typically, process conveyors are hung from the bottom chord of the trusses at the panel points. The radiating web of steel angles that supports the conveyor are clamped to the truss. When the manufacturing process changes, these web panels of supports are removed and the new conveyors installed. In some recent plants, AGV's have replaced most overhead conveyors.

The ground floor slab in the Manufacturing areas are designed for heavy loading of equipment and fork lift trucks. Certain areas along the production line require utility trenches and drain trenches for process fuid (oil and anti-freeze) spills. When there are manufacturing process changes, heavy machinery may be placed in new locations. Existing utility trenches and drain trenches are filled in and new ones installed. Other services are also rerouted to these new machine locations.

Note: One of the most important consideration in the Manufacturing process is to have a continuous flow of the product with a minimum of turns or other disruptions which may cause product damage, slow down the manufacturing, and make the manufacture of the product more costly or make the process more labor intensive. Any disruption caused by unnecessary turns, interruption by a structural column or service component,and reduce the ease of servicing and maintenance should be minimized.

(...)

Management facilities

The Administration Building provides an area for interface with vendors, manufacturing representatives, and the public. Personnel in this area generally are not directly involved with the manufacturing process. Those support functions directly involved in the manufacturing operations and administration are located in the manufacturing facility itself. Manufacturing offices for foreman, general foremen,etc. are located in the production areas adjacent to the production lines.

In some current facilities, major components of the Manufacturing process are organized as separate Business Units, responsible for their product.

Conclusion

(...) Obviously, the present 50 year life cycle of manufacturing facilities with its related technology would not necessary apply, be relevant or appropriate to a ten year life cycle .Manufacturing Facility. (...).

In this careful search for the 21st Century Automotive Manufacturing Facility Model it will require the consideration of future trends that shape and impact all systems of the facility. (...)."

3 REQUIREMENTS FOR A NEW BUILDING TYPE

3-1 The General Motors Analysis

The following requirements are extracted from the General Motors competition program (Fall 86):

"The manufacturing facility should meet the following goals:

-- Protect the environment and enhance the landscape setting the facility finds itself in.

-- Become an asset to the local community.

-- Be:

a. Functional

b. Appropriately innovative

c. An environment that promotes teamwork, quality productivity, and communication.

d. Cost effective

e. Convey the image and Corporate identity of the Owner"

Industry owners are not satisfied with the contractor's and engineer's design which doesn't answer to their demand for quality and innovation. According to them, quality, flexibility, and maintenance criterias are now more important than some traditional economic issues, as building longevity. The industrial building is more and more considered as part of the production instrumentation, not just like the production process shell.

"It is desireable to maintain "optimal" adaptability and flexibility within and about enclosed space for product process and functional adjustments, due to operational product and/or managements needs. Demounting, disassembly, rework, and reassembly must be considered, not just moving equipment inside the facility footprint. (...) . Minor functional additions may be added over the 10 year life. (...). The effective life of the sitedevelopment and manufacturing is 10 years. This is the projected life cycle ot the product. At the end of 10 years, adjacent areas of the site might be developed to make a new product. The existing facility may be renewed to make a new product, recycled to a new use, moved away,or disassembled."

(Extracted from the General Motors competition program, Fall 86)

It appears that both, the product and the building evolution are narrowly interrelated.

Designed as a generic tool, the building should be able to become specific at the demand.

3-2 Consequences for the Design Process

"Therefore, the 21st Century Manufacturing Facilities will need :
Professionals with skills in problems definition, strategic decision planning and systems performance optimization. They will need to be innovative in integrating all aspects of Architecture and Engineering while weighing the cost impact of manufacturing facilities to optimally meet competitive needs without becoming obsolete and irrelevant. Tomorrow's manufacturing facilities will have to be efficient and competitive. They need to be able to respond quickly to the requirements, changing desires and directions of the market place."
(Extracted from the General Motors competition program, Fall86)

According to Peter Rice, from Arup and Partners:
"The solution of a problem comes not from waiting until it arises, but from systematically anticipating it." Industrial demands in terms of weigh, prices, durability, aspect, will improve designers knowledge. Several studies showed that the current conception does not resort to a process comparing a wide range of construction possibilities, but tends to repeat well known formulas, and to avoid in general the introduction of new processes and materials. Site and facility should be designed and engineered from the identification of issues in the problem and

through alternatives evaluation.

As a result the design team needs to operate more like a research unit in industry. *"What's actually called industrial design"*, argues R.Piano, *"is better than what's called architecture, because there is a unity of process, a better interconnection between conception and material and processes. The designer has to invent the process, not just the finished product, and he has to design the tools too."*

According to the opinion of Brian Taggart and Nick Grimshaw (British architects), the tendancy toward neoprenes, aluminium, polyester shells, and metallic panels, comes from an approach where facade panels can easily be replaced or removed by unskilled manpower.
As structures get more sophisticated and their details ever more refined, individual buildings become comparable with the design prototypes of a perfectly finished product from the industry.

4 THE DESIGN PROPOSAL

4-1 The Manufacturing Process

The following product definition is extracted from the General Motors competition program (Fall 86):

"The product to be produced is a "Family of Cars" in which four body styles on four wheel bases result in eight models (...) using a driveable chassis (space frame/structural panels) and plastic (composite) non-structural outer panels (skin). The body concept is that of a steel lattice space frame, welded from stamped and roll formed components into a roof frame and lower frame which are joined after a substantial amount of component installation, in a top drop operation by mean of rivets and adhesives. Structural shear panels, compression molded from Sheet Molding Compound (SMC) in a common neutral pigmented color, are bonded to the space frame by means of adhesives cured in room temperature. Body surface panels are compression molded from SMC with the exception of fenders, which are Reinforced Reaction Injection Molded (RRIM). All body surface panels are attached by either fixture adhesive bonding, conventional bolts or simple fasteners to qualified mount pads situated on both the space frame and the structural panels.

The steel space frame is composed of beam and joints components organized into a platform that retains a common engine compartment and underbody cross-car components and utilizes specific passenger and luggage compartment components. (...). The tooling program for specific components of this linked space frame is de-proliferated by use of common forms with specific piercing, cut-off length, sweep forming or fabrication. (...).

The Family of Cars is to be produced at a single site at a rate of 358,000 vehicles annually. Operation rates - on a two shifts basis - are thus 90 units/hour, 249 days/year. Composite molding operates on 3 shift basis to meet vehicle requirements.

In contrast to classic assembly plant flow of body shop -- paint shop -- chassis shop -- trim shop -- final line, the envisioned assembly flow (...) utilizes revised body structure configuration , materials and joining methods to enhance use of modular assembly concepts, split line processing and reduction of "non-workable" job lengths to allow effective use of flexible automation and facility space.

For purposes of this study, all linear processes - i.e, body shop, paint shop, general assembly and final assembly should be considered to be 45' wide. This 45' consists of the work-in-process, room for workers and/or equipment, and stock. Linear processes are separated by twelwe foot aisle for people and stock movement."

4-2 The Program

A detailed program is given in **figure 1** (extracted from the Fall 86 General Motors competition program).

"Maintainability" and relatively dust free environment is essential to many Process Operations. Floor must exhibit resistance to chemicals, grease/oils utilized in Process Operations.

Process vertical clear area is required as follows:

-- *Die Repair Area: 25' clear to structure.*

-- *Press Area: 36' clear to top of lifted load plus space for crane and structure."*

-- Miscellaneous elements:

Component Mfg.

Body Shop

Paint Shop

Assembly Areas *All average 25' clear to structure*

Maintenance

Storage Etc.

-- *Office and People: 9' to 10' clear to ceiling*

Support Areas

The following reproductions come from the General Motors competition program (Fall 86):

PROCESS DEFINITION

The Family of Cars is to be produced at a single site at a rate of 358,000 vehicles annually. Operating rates - on a two shift basis - are thus 90 units/hour, 249 days/year. Composite molding operates on 3 shift basis to meet vehicle requirements.

In contrast to classic assembly plant flow of body shop--paint shop--chassis shop--trim shop--final line, the envisioned assembly flow indicated on the next pages utilizes revised body structure configuration, materials, and joining methods to enhance use of modular assembly concepts, split line processing and reduction of "non-workable" job lengths to allow effective use of flexible automation and facility space.

For purposes of this study, all linear processes - i.e., body shop, paint shop, general assembly and final assembly should be considered to be forty-five feet wide. This forty-five feet consists of the work-in-process, room for workers and/or equipment, and stock. Linear processes are separated by twelve foot aisle for people and stock movement.

PROCESS DESCRIPTION - COMPONENTS

PRESS PLANT (Area Breakdown Item "A")

The Space Frame sub-components will be formed and fabricated from mild steel material requiring various methods of stamping, roll forming and fabrication welding.

Press plant function include receiving and storage of rolls and sheets of steel; forming and welding of components, die storage, maintenance and repair; finished parts storage; and shipment to the body shop.

Press plant machines and equipment will include:
A blanking machine, a high speed press, several transfer presses, roll stands with presses for sweep or stretch bending and approximately 30 fabrication weld presses.

COMPOSITE MANUFACTURING (Area Breakdown Item "B")

Composites materials are to be used for structural panels and exterior panels. All panels except front fenders are to be manufactured from Sheet Molding Compound (SMC). Fenders will be manufactured by Reinforced Reaction Injection Molding (RRIM).

SMC resins will be stored in four 15,000 gallon and four 3,000 gallon tanks. Calcium carbide filler will be stored in two 20,000 gallon silos. These quantities represent one week bulk storage. The SMC will be molded into sheets and stored in a maturation room, Later the material will be slit, as required, molded into panel form, deflashed and drilled, and -in some cases- component panels will be assembled together. Structural SMC panels will have received a molded-in pigment and will not require painting. SMC exterior panels will also receive a molded-in coating, but require a primer surfacer coating and a color coat.

RRIM materials - isocyanate and polyol - will be stored in bulk tanks and used at a rate of 12,000 gallons each per week. These materials are metered and pumped directly to machines, molded, deflashed, drilled and washed. RRIM fenders will receive a barrier primer coating prior to color coating.

PROCESS DESCRIPTION - ASSEMBLY

BODY SHOP (Area Breakdown Item "C")

Lattice Space Frame - comprised of mild steel sections - is assembled into two major subassemblies (i.e., top frame portion, bottom frame portion). The frame will be joined into major subassemblies by means of automated weld process. Frames will receive corrosion protection in the form of a 500 foot long phosphate spray/dip, a 300 foot Elpo (electro-deposition/immersion), a 800 foot curing oven, and 90 feet of cooling. After corrosion processing and some hard/soft trim installation, the top frame portion is joined to the bottom frame portion by means of rivets and structural adhesives.

Eight major model types affect space frame configuration. The eight frame models are derived from common motor compartment and mid and lower crossmembers. In conjunction with two basic luggage compartments, the full variation is achieved by exchange, relocation, and/or elimination of pillars, rockers, and rails defining the length and silhouette of the passenger compartment.

Body structural panels are attached to the space frame to add structural integrity to the total vehicle.

PAINT SHOP (Area Breakdown Item "D")

Body structural panels require no painting.

Surface panels are to be painted with a primer surfacer immediately after molding to identify defects. The primer surfacer process involves five modules, as follows:

- 3 stage washer - wash, rinse, de-ioned water rinse (25 feet)
- Blow-off (5 feet)
- Spray booths with robots and other automatic spray equipment (20 feet).
- Flash zone (20 feet)
- Curing oven (80 feet)

After primer surfacer, the surface panels are to be color coated - off the vehicle - with base coat/clear coat (BC/CC) paint. Eight modules, similar to the above primer surfacer moduals, will be required.

After cure, surface panels will be stored until needed.

Soft fascia (front bumper/grill and rear bumper) will be out-sourced and will be received painted body color.

Small parts will be phosphate and elpo dipped with the space frames and then color coated (if required) along with surface panels.

Note: Because the painting process is energy intense and requires "clean room" quality, curing ovens are often grouped together. Paint modules are often similarly grouped.

GENERAL ASSEMBLY (Area Breakdown Item "E")

General assembly is usually a linear process. It includes (but is not limited to) installation of interior and exterior trim, seats, doors, stationary glass, drivetrain, trailing axle, chassis items, tires and wheels, fuel system and exhaust system.

FINAL ASSEMBLY (Area Breakdown Item "E")

Final assembly is also usually linear and includes addition of literature, labels, fluid fills, test, repair, conditioning, final inspection and drive away.

SCHEDULING BANKS (Area Breakdown Item "F")

Scheduling banks are computer controlled marshalling areas - in the paint shop and assembly - that are used to store or sequence vehicles.

FUNCTION DESCRIPTION - SUPPORT

MAINTENANCE (Area Breakdown Item "G1")

This function may be centralized or may be distributed to the Components and Assembly areas per the Functional Area Program.

OPERATIONS SUPPORT (Area Breakdown Item "G2")

Operations Support involves those administrative functions that are involved in the day-to-day operation of the plant. The obviously include direct supervision of plant personnel. In the concept of semi-autonomous business units within the plant, they also may involve satellite personnel from financial, engineering, training, etc.

This function may be centralized within the plant or may be distributed per the Functional Area Program.

RECEIVING AND STORAGE (Area Breakdown Item "H")

In the classical sense the Body Shop and paint shop do not require a receiving function. Nor do they require a storage area as their "product" is immediately passed the next Business Unit.

Press operations and composite manufacturing require receiving (for raw material) and storage (for holding of batch run lots).

Assembly operations have both receiving and storage. The balance between these functions shown on the Functional Area Program is typical of existing plants. If just-in-time deliveries and point-of-use distribution is used, the same total area would be required, but a greater percentage would be allocated to receiving.

OFFICES (Area Breakdown Item "J")

These are administrative in nature (financial, personnel, engineering, etc.) with limited need for direct interaction with the plant floor. Operational offices are located in the plant, within the designated Area Breakdowns.

AREA BREAKDOWN

Net useable process areas*, as shown here, total 3.3 million sq.ft. The specific areas maybe in non-traditional locations, but have been listed here in standard groups.

COMPONENTS		
PRESS PLANT (Item "A")	100,000 SQ.FT.	
COMPOSITE MFG. (Item "B")	450,000 SQ.FT.	
		550,000 SQ.FT.
ASSEMBLY		
"BODY SHOP" (Item "C")	100,000 SQ.FT.	
"PAINT SHOP" (Item "D")	800,000 SQ.FT.	
GENERAL ASSEMBLY (Item "E")	700,000 SQ.FT.	
FINAL ASSEMBLY (Item "E")	225,000 SQ.FT.	
SCHEDULING (Item "F")	250,000 SQ.FT.	
		2,075,000 SQ.FT.
SUPPORT		
MAINTENANCE & SUPPORT (Item "G")	240,000 SQ.FT.	
RECEIVING & STORAGE (Item "H")	450,000 SQ.FT.	
ADMINISTRATIVE OFFICES (Item "J")	25,000 SQ.FT.	
		715,000 SQ.FT.
		3,340,000 SQ.FT.

*All circulation systems are excluded.

4-3 The Process Flow

Figure 2 (simplified process flow) shows the general manufacturing process through the plant.

4-4 The Process Diagram

Figure 3 (process diagram) gives the details of the working process, shows the subassemblies areas, and delivery stations of externally supplied material.

4-5 The Preliminary Functioning Study

Figure 4 shows the necessary connections between rooms determined after the program analysis.

4-6 The Site Plan

Figure 5 shows the site plan. The manufacturing facility is implanted in the site with a T-shape. Two main accesses to the plant and miscellaneous facilities are provided. The first entrance is reserved to employees, visitors and public transit. It leads to the adminstration buiding and goes along the shipping area. Visitors have their own parking close to the administration building. The plant employees can park all along the facade in order to get a direct access to their work station.

The other entrance is provided for service vehicles, material deliveries, maintenance, refuse, etc.. A road goes all along the building in order to allow just-in-time deliveries, and eventually ship vehicles from the shipping area. That road never crosses the public or employees circulation.

A rail access insures the shipping of achieved cars from the shipping area at the end of the assembly line. Considering the short life duration of the plant and the "zero defect" objective of the manufacturers, an automobile test track has not been estimated necessary.

4-7 The Layout of the Designed Manufacturing Facility

Figure 6 shows a schematic layout of the manufacturing facility, respecting the requirements of the process flow, of the process diagram, and of the preliminary analysis. After the analysis of the requirements for a new building type, it appeared that for economical reasons, the number of building should be very limited, in order to avoid the increasing of facade surfaces, of the heating expenses, and of expensive conveyors. Nevertheless the different functions of the manufacturing facility building have been shared in two parts according to the technologies used and to the number of persons working in each area.

In the horizontal bar of the T-shaped building are gathered the following functions, highly automated and robotized requiring many dust free rooms and just a few employees : Press Plant, Body Shop, Component Mfg., Paint Shop. Considering the small amount of people working in these areas, the assumption is made that the building doesn't need natural light or a particular facade treatment, except in some very localized rooms as Composite Manufacturing Administration (10,000nsf, 300p). The width of the building is about 650 feet.

At the opposite, the General Assembly building requires a lot of personnel and is less automated. The required good quality of the working environment commands natural light as possible, and views on the exterior or on interior patios. Split line processing are connected perpendicularly from the Seat Assembly and the General Assembly to the Final Assembly line. The finished car goes to the shipping area after the quality assurance room. The width is about 650 feet. Turns are minimized in the process.

4-8 The Structural Choices

The gathering of the different requirements exposed in part 3 led to the idea of a modular kit-of-parts building, easy to erect and dismount, with minimum damageable consequences for the site or remaining important parts in or on the ground. So any roof system should be light enough to be mounted rapidly. Such systems usually don't allow the hanging of heavy technical devices as mechanical or electrical equipment or miscellaneous manufacturing processes. The majority of the distribution systems will find place in the first floor depth and will come back up to the working level when needed. They should be able to be removed or maintained easily, which means that the first floor should allow accesses and possibilities of working conditions to employees. They can also become overhead distribution systems through the use of light structures, supported by the first floor, removable, and independant of the main building structure. A deep, stiff and strong first floor is necessary to answer to these requirements. If that one is stiff enough, it can act as a load distribution structure spread over the ground. Thus the building needs no expensive foundations, which saves money and time during the erecting process, and respects the requirement of site preservation. In addition, in case of removability, this solution offers the building settlement the opportunity to be independent of the soil quality.

All the connections for both, the first floor space frame and the structures are made through the mean of bolts , in order to allow dismantling.

After equalization and cleaning of the site (that one should be quite flat), a thin concrete layer (a few inches) including the water proofing is poured inside the plant perimeter. A drainage surrounds the building whose base is a continuous space frame settled on the ground, and constituting a service basement supporting all the working areas and processes. That first floor space frame receives the columns sustaining the roof structure and a light overhead grid including equipment like artificial lighting, sprinklers and catwalks. The roof made of fabric insures the water proofing of the building. Penetrations through the roof are concentrated to areas above and between columns, (for air exhaust and supply), thus reducing the possibilities for the water leakages. We can even consider that in certain cases, air exhaust and supply can be made through the depth of the first floor space frame, in direction of the facade with exterior prefabricated chimneys.

Figure 7 shows the plan of the basic structural unit. Three assembly lines can be installed from column to column. Parallel to the assembly lines, and between the columns are the air exhaust and supply systems. They can be removed or displaced. A patio is possible in the center of this basic structural unit (through the mean of a partial roof removal) according to the need of the production process. The basic floor element is square and size of the side is 11'6". There are 16 of them between each line of columns spanning 184' in each direction. An assembly line lays on 4 floor units (46') and is separated from the next one by 1 floor unit (11'6") for people and material circulation.

Figure 8 shows the roof plan with the air exhaust/supply system and the ring suspended from the top of the columns and sustaining a teflon covered fiber glass fabric. It is fire proofed, and includes thermic insulation . The fabric can be removed in the center of the ring in order to allow the creation of a patio.

Figure 9 shows the plan of all the overhead structures. The ring is hanged to the columns. The ring and the columns support overhead catwalks allowing for circulation over the whole plant, and a continuous overhead grid receiving artificial lighting and sprinklers. That grid, which corresponds to the floor grid, also allows the creation of enclosed rooms. It can receive the top of vertical panels and light ceiling panels.

Figure 10 shows a general section throughout the building with various possible organizations.

Figure 11 shows a section through the building edge and a structural solution to bring the roof tensions in the first floor space frame in order to balance tensions around the column.

Figure 12 shows a section through the press plant. Considering the exceptional load being supported by the first floor in this area (30000 pounds capacity die truck, 80 ton lifting capacity), some elements like very heavy presses and some overhead cranes will have separate foundations. The space frame itself will be doubled for the first floor in order to respond to the load bearing requirements concerning die truck. The vertical clear area required is 36' to top of lifted load plus space for crane and structure (24' in the rest of the plant). The kit-of-parts columns and the roof system with the grid are thus higher than in the other part of the manufacturing facility.

Figure 13 shows a partial facade of the paint shop building with a cladding made of inflatable cushions, and a facade of the whole assembly plant.

Figure 14 shows a partial facade of the assembly building and another facade of the whole assembly plant. The cladding of the assembly building is made of dismantable panels including wide garage doors for just-in-time deliveries to subassembly lines, or split in lines and to the main assembly line. This cladding allows the insertion of transparent elements allowing employees views on the exterior.

Figure 15 shows the end of the paint shop building.

Figure 16 shows the end of the assembly operations building.

Figure 17 shows an alternative for cladding with vertical cylindrical inflatable cushions.

Figure 18 shows the building's erection process:

1) The concrete layer is poured on the leveled ground, including the water proofing layer.

2) Loads repartition square steel grids and sliding rails for the space frame deployment are laid on the concrete.

3) Deployment of the first floor space frame.

4) Erection of the columns.

5) Erection of the roof and of the overhead grid.

6) Installation of the cladding and of miscellaneous equipments.

All the construction elements (first floor space frame, columns, suspended ring, overhead grid,etc.) are made of parts bolted together. This connection type allows for dismantling and reuse of elements. In case of dismantling and relocation, a new fabric should probably be made and provided, for the old one can hardly be folded and unfolded again without any damage.

The dismantling process should be as follows:

1) Dismantling of the equipments and of the cladding

2) Dismantling of the overhead grid

3) Dismantling of the roof

4) Dismantling of the columns

5) Fold of the first floor space frame

6) Cleaning of the upper layer of the soil through the mean of bulldozers

The land can be reused for other building settlements.

The building construction elements are checked for security reasons, painted or fixed if needed, stored or reused in an other site with a new plan configuration.

Figure 19 shows an axonometric view of the space frame type. It is based on a square grid. Each square has a 11'6" side and is free of structural element in its center. Such a configuration allows the installation of all fluids ducts and pipes, the easy circulation of maintenance teams, a good repartition of permanent and temporary loads through the space frame and the installation of devices at various depths or altitudes in the plant. Removable trenches for process fluid spills can also be put in place.

Figure 20 shows the deployment process of the first floor space frame. Its members are made of steel pipes. The basic transportable unit is made of rigid trusses (which length are 57'6") connected together with perpendicular foldable elements and hinges reconstituting a truss when unfolded. These two perpendicular sets of trusses form the space frame. The basic transportable parts of space frame are about 3500 nsf.

They are connected together by bolts in order to make a strong stiff platform. Then the floor elements are settled and recovered with the adequate resistant flooring. (according to the needs of the plant area). The expansion joints are about every 180'. They are made by the mean of tolerance in the bolts connections.

Figure 21 shows the rigid truss of the first floor space frame.

Figure 22 shows the view of the elements perpendicular to the rigid trusss and the unfolded elements with the hinges.

Figure 23 shows a plan and section of the first floor space frame hinges at the junction point between the trusses and the foldable elements.

Figure 24 shows the base of the kit-of-parts column built with 4 steel pipes. This base is strongly attached to the first space frame by means of bolts going through the top level of the space frame at the bars junction points, in order to insure the loads repartition through all the space frame. The calculation will say whether or not some bars reinforcements will be necessary on the space frame depth at that place.

Figure 25 shows a plan and a section of the column at the level of the junction with the roof fabric. Air exhaut and supply chimneys are going through the fabric between columns and inside the columns.

Figure 26 shows the top of the column and its connection with the supporting roof cables. It also shows the way parts of the column (about 25' each) are connected together with the mean of plates and bolts. Considering that the buiding edge column should be identical to the other columns, in that particular case, tension directions are kept the same at the top of the column by the means of a steel bar perpendicular to cables, allowing the redirection of the tensions.

Figure 27 shows the ring sustained to the columns and tensioning the fabric roof. It is made of steel trusses and allows the removability of the central part of the fabric roof. The light overhead grid is hanged to that ring.

Figure 28 shows schematic sections of the cladding made of inflatable cushions. A light steel joist with a strong connection to the first floor space frame supports the cushions and gives transversal stiffness.

5 FIGURES 1TO 28

FUNCTIONAL AREA PROGRAM

Extracted from the General Motors Competition Program (Fall 86)

FUNCTIONAL AREA PROGRAM 9/29/86 / 1

		FUNCTION/ BUSINESS UNIT	NET AREA (NSF) (SEE NOTE 1)	TOT NET AREA (NSF)	TOTAL POPUL (PERSONS)	SHIFT
BUSINESS UNITS (PROCESS FUNCTIONS)	A	PRESS OPERATIONS:		100,000 NSF	150 P	1, 2
	A1	STAMPING/PRESS AREA	100,000 NSF			
	B	COMPOSITE MANUF'G:		450,000 NSF	570 P	1, 2, 3
	B1	COMPOSITE MANUF	310,000 NSF			
	B2	COMPOSITE ASSEMBLY	40,000 NSF			
	B3	PRIMER SURFACE PAINT	90,000 NSF			
	B4	MATURATION ROOM	10,000 NSF			
	C	BODY SHOP OPERATIONS:		100,000 NSF	220 P	1, 2
	C1	SPACE FME ASSEMBLY	45,000 NSF			
	C2	PHOSPHATE/ELPO	55,000 NSF			
	D	PAINT SHOP OPERATIONS:		800,000 NSF	185 P	1, 2
	D1	PREPARE FOR PAINT	215,000 NSF			
	D2	PAINT MIX/STORAGE	25,000 NSF			
	D3	PAINT BOOTHS	70,000 NSF			
	D4	CURING OVENS	430,000 NSF			
	D5	TWO TONE AND REPAIR	60,000 NSF			
	E	ASSEMBLY OPERATIONS:		925,000 NSF	2,060 P	1, 2
	E1	GENERAL ASSEMBLY	585,000 NSF			
	E2	SEAT ASSEMBLY	115,000 NSF			
	E3	FINAL ASSEMBLY	185,000 NSF			
	E4	QUALITY ASSURANCE	40,000 NSF			
SUPPORTING FUNCTIONS	F	SCHEDULING BANKS:		250,000 NSF	25 P	1, 2
	F-A	PRESS PLT OPERATIONS	0 NSF			
	F-B	COMPOSITE MANUF'G	0 NSF			
	F-C	BODY SHOP OPERATIONS	0 NSF			
	F-D	PAINT SHOP OPERAT'NS	150,000 NSF		15 P	
	F-E	ASSEMBLY OPERATIONS	100,000 NSF		10 P	
	G1	MAINTENANCE OPERAT'NS:	(SEE NOTE 2)	130,000 NSF	400 P	1, 2, 3
	G1-A	DIE REPAIR/MAINT	5,000 NSF			
	G1-B	COMP MFG MAINT	10,000 NSF			
	G1-C	BODY SHOP MAINT	5,000 NSF			
	G1-C	EMPTY SKID REPAIR	20,000 NSF			
	G1-D	PAINT SHOP MAINT	10,000 NSF			
	G1-E	AGV REPAIR	30,000 NSF			
	G1-E	CENTRAL CRIB/MAINT	50,000 NSF			
	G2	ADM/OPERATIONS/SUPP:	(SEE NOTE 2)	110,000 NSF	1,630 P	1, 2
	G2-A	PRESS PLT OPERATIONS	6,000 NSF	(SEE NOTE 4)	70 P	
	G2-B	COMPOSITE MANUF'G	10,000 NSF		300 P	
	G2-C	BODY SHOP OPERATIONS	12,000 NSF		100 P	
	G2-D	PAINT SHOP OPERAT'NS	20,000 NSF		100 P	
	G2-E	CENTRAL OPERAT'NS AND TRAINING	62,000 NSF		1,060 P	

figure 1

FUNCTIONAL AREA PROGRAM 9/29/86 / 2

SUPPORTING FUNCTIONS	H1	RECEIVING OPERATIONS:	(SEE NOTE 2)	100,000 NSF	160 P	1,2
	H1-A	PRESS PLT OPERATIONS	15,000 NSF		(BOTH H1&H2)	
	H1-B	COMPOSITE MANUF'G	40,000 NSF			
	H1-C	BODY SHOP OPERATIONS	0 NSF			
	H1-D	PAINT SHOP OPERAT'NS	0 NSF			
	H1-E	ASSEMBLY OPERATIONS	45,000 NSF			
	H2	MATERIAL STORAGE:	(SEE NOTE 2)	350,000 NSF	(SEE H1 ABOVE)	1,2
	H2-A	PRESS PLT OPERATIONS	40,000 NSF			
	H2-B	COMPOSITE MANUF'G	60,000 NSF			
	H2-B	COMP MFG BULK STOR	EXTERIOR 40,000			
	H2-C	BODY SHOP OPERATIONS	0 NSF			
	H2-D	PAINT SHOP OPERAT'NS	0 NSF			
	H2-E	ASSEMBLY OPERATIONS	250,000 NSF			
PRIMARY SUPPORT	J	OFFICE/EMPL SUPPORT:		25,000 NSF	100 P	1,2
	J1	PLANT ADMINISTRATION	25,000 NSF			
	J2	EMPLOYE SERVICES	T B D			
SEPARATE BUSINESS UNIT	K	UTILITY COMPLEX:	(SEE NOTE 3)	T B D	T B D	1,2,3
	K1	CENTRAL PLANT	T B D			
	K2	TREATMENT FACILITIES	T B D			
	K3	MAINTENANCE	T B D			
	K4	RECEIVING/STORAGE	T B D			
	K5	ADM/OPERAT'NS/SUPP	T B D			
		TOTALS		3,340,000 NSF	5,500 P	

TBD: TO BE DETERMINED BY COMPETITION ENTRANT

NOTE 1: EACH FUNCTION/BUSINESS UNIT IS EXPRESSED IN NET SQ FT AREA INCLUDING ALL PRODUCT PROCESSES, OPERATIONS AND INTRA-FUNCTION CIRCULATION. INTER-FUNCTION CIRCULATION MUST BE ADDED TO PROGRAM REQUIREMENTS.

NOTE 2: MAINTENANCE, RECEIVING/STORAGE AND/OR ADMINISTRATION/SUPPORT FUNCTIONS AND OPERATIONS MAY BE COMBINED AND/OR CENTRALIZED IF DESIRED IN THE DESIGN CONCEPT.

NOTE 3: THE DESIGN AND OPERATIONAL REQUIREMENTS OF THE UTILITY COMPLEX WILL BE DETERMINED FROM THE DESIGN CONCEPT.

NOTE 4: THE NET AREA FOR ADMINISTRATION/OPERATIONS REPRESENTS OFFICE TYPE FUNCTIONAL SPACE REQUIREMENTS FOR 740 PERSONS. THE REMAINING 890 PERSONS FUNCTION IN THE PROCESS OPERATIONS AREA AND DO NOT REQUIRE PERMANENT OFFICE SPACE.

figure 1

SIMPLIFIED PROCESS FLOW
Extracted from the General Motors
Competition Program (Fall 86)

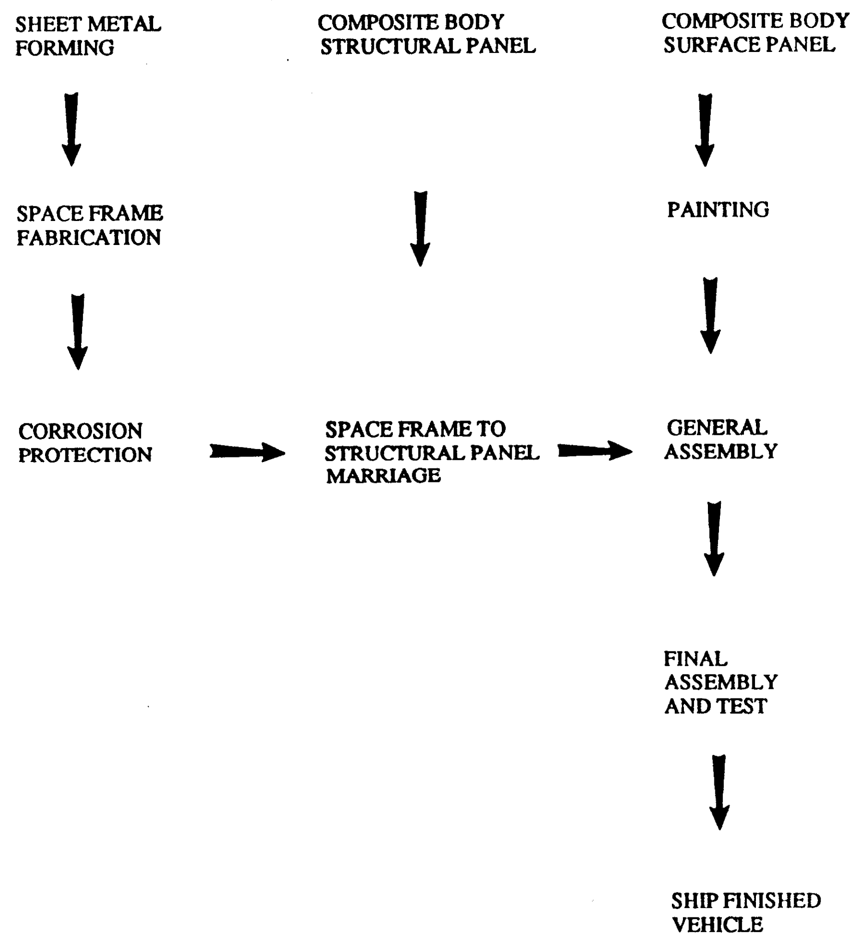
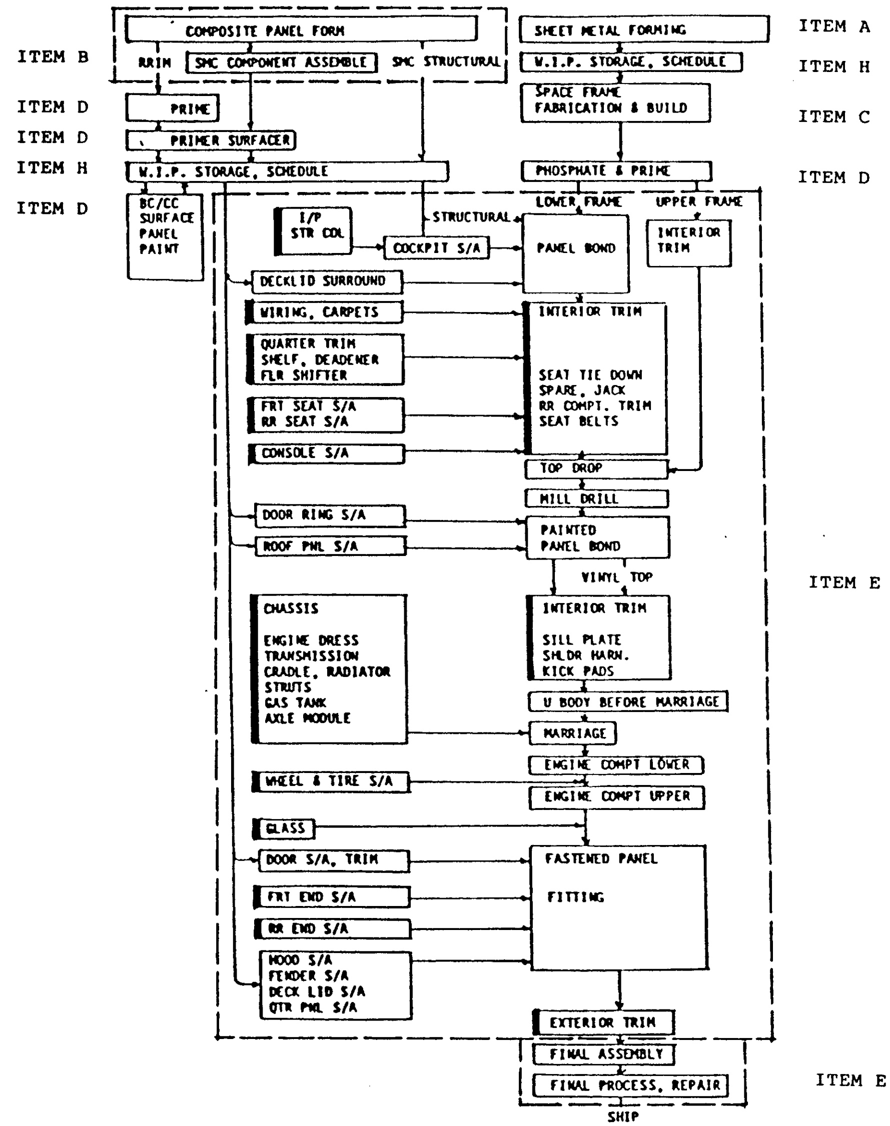


figure 2

PROCESS DIAGRAM

Extracted from the General Motors Competition Program (Fall 86)



S/A = SUBASSEMBLY
W.I.P. = WORK-IN-PROCESS
▌ = EXTERNALLY SUPPLIED MATERIAL

figure 3

PRELIMINARY
FUNCTIONING STUDY

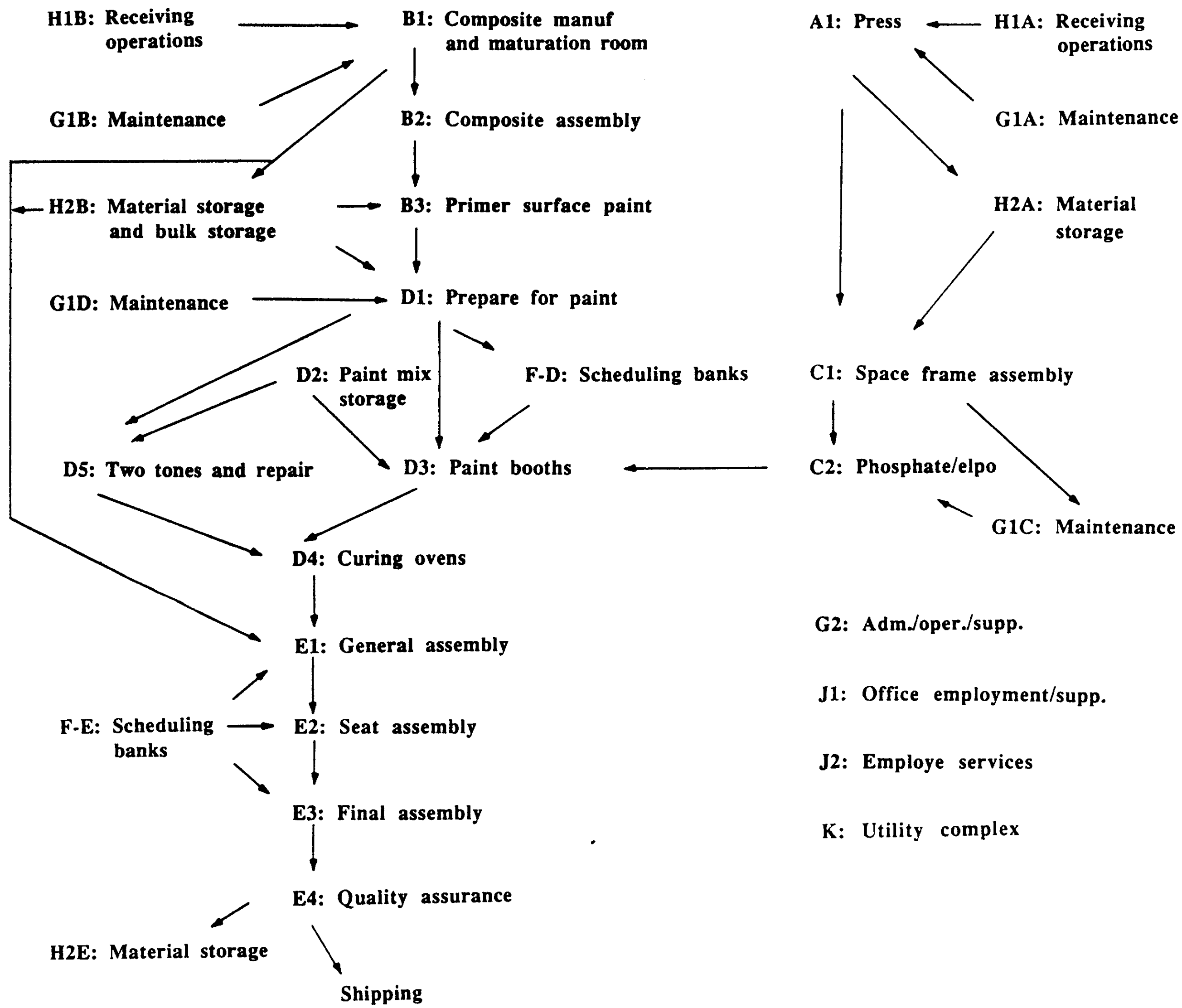


figure 4

SITE PLAN

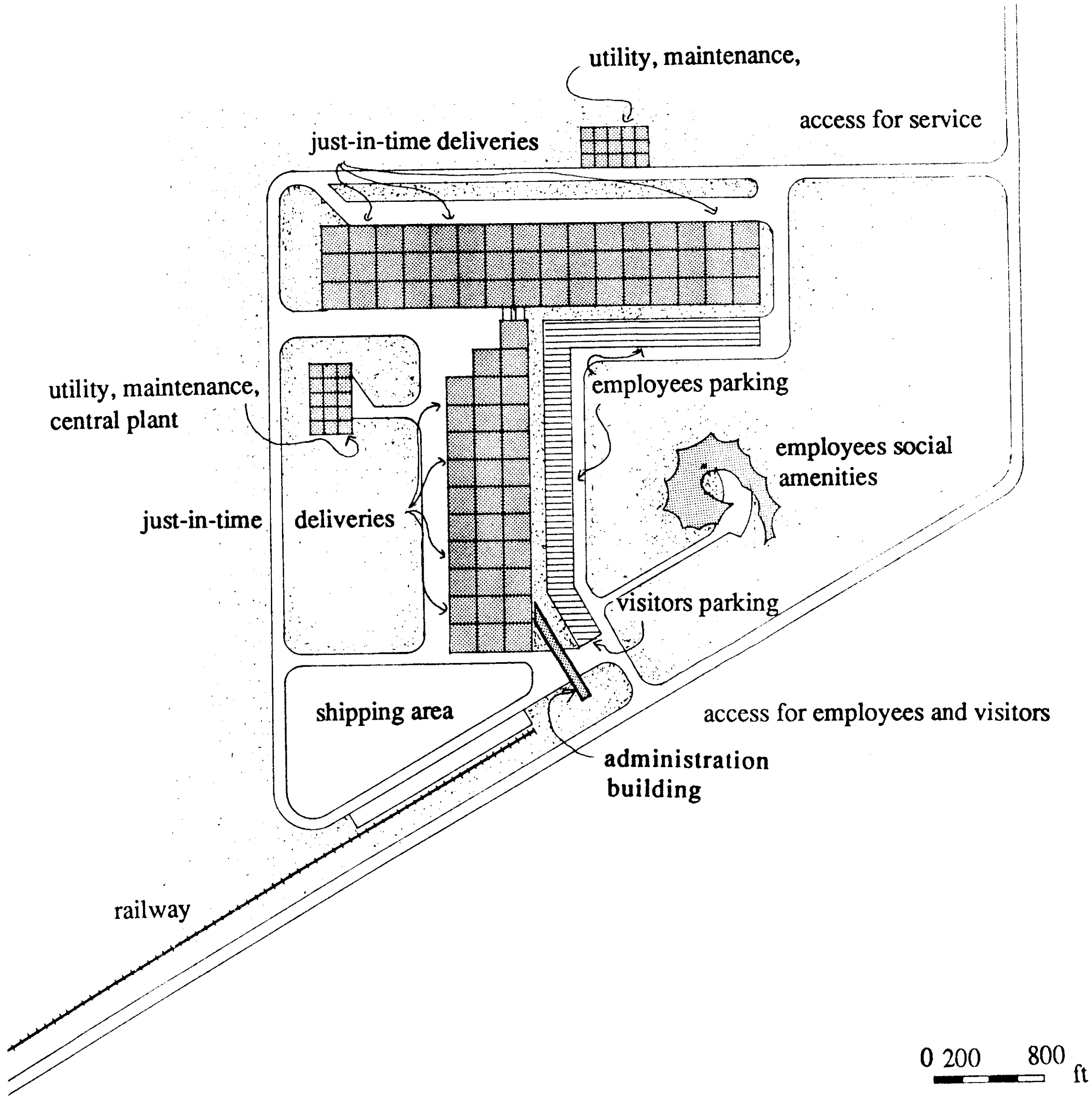


figure 5

SCHEMATIC LAYOUT

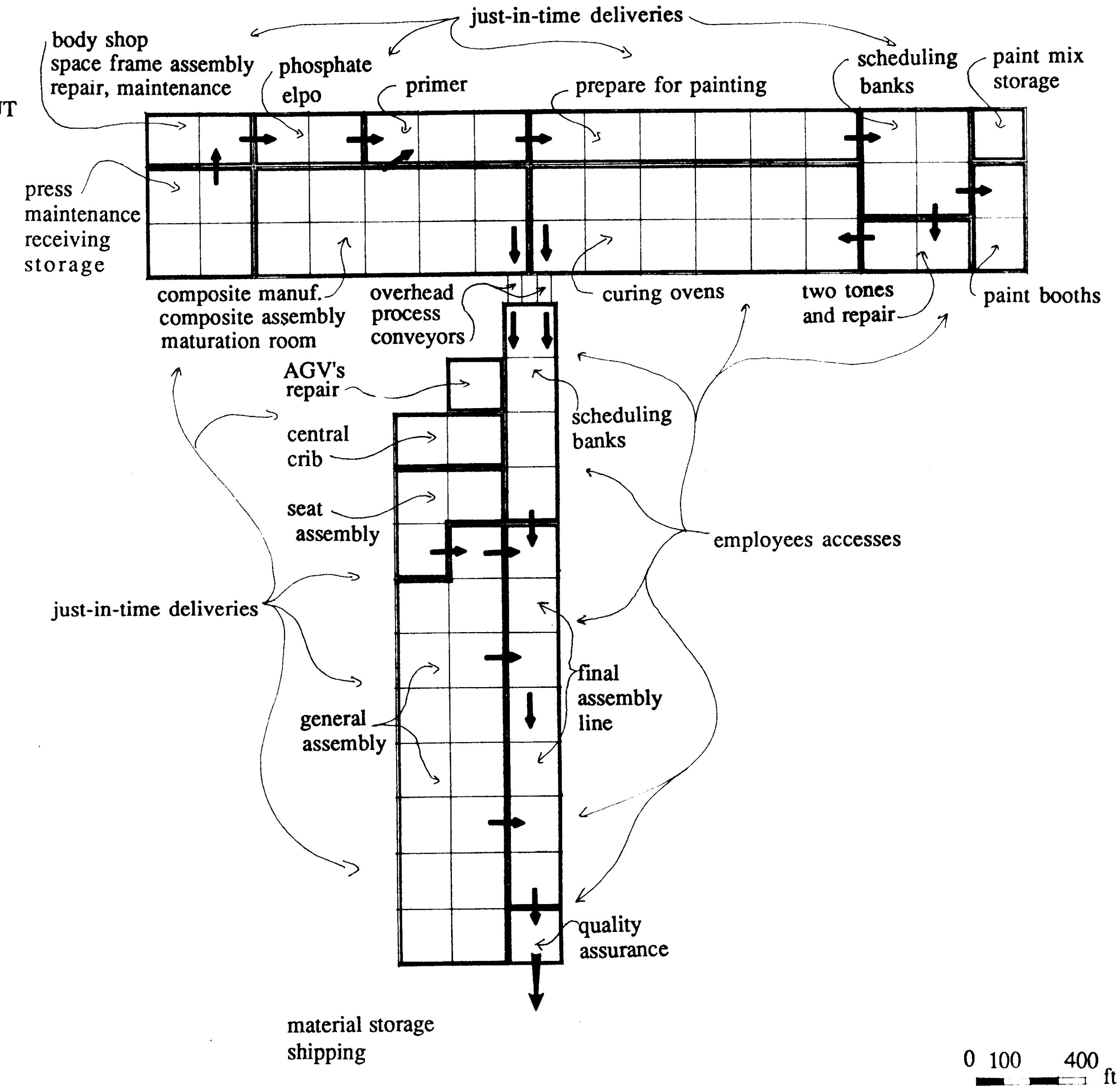


figure 6

PLAN OF THE BASIC
STRUCTURAL UNIT

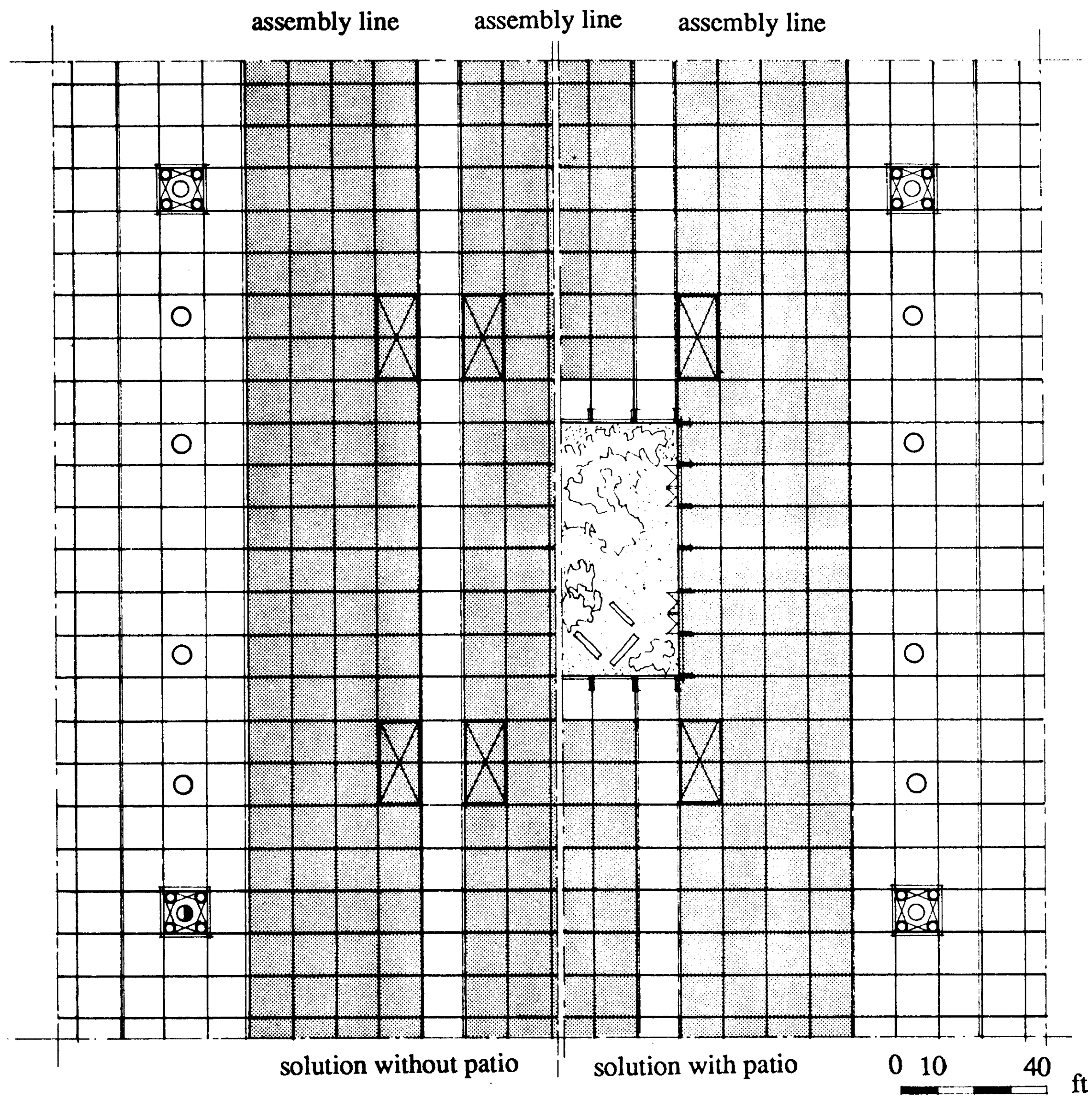


figure 7

ROOF PLAN

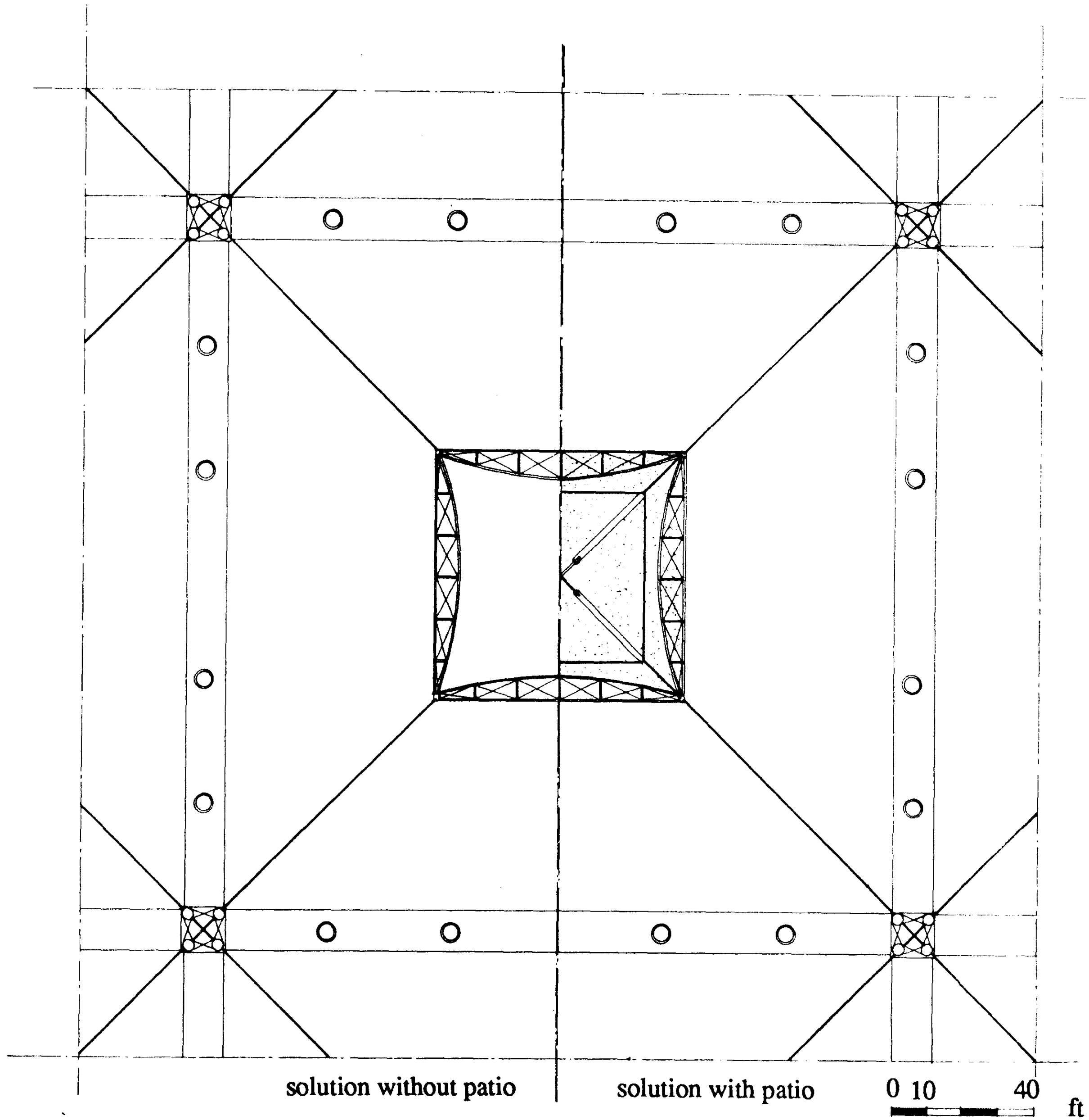


figure 8

OVERHEAD STRUCTURES PLAN

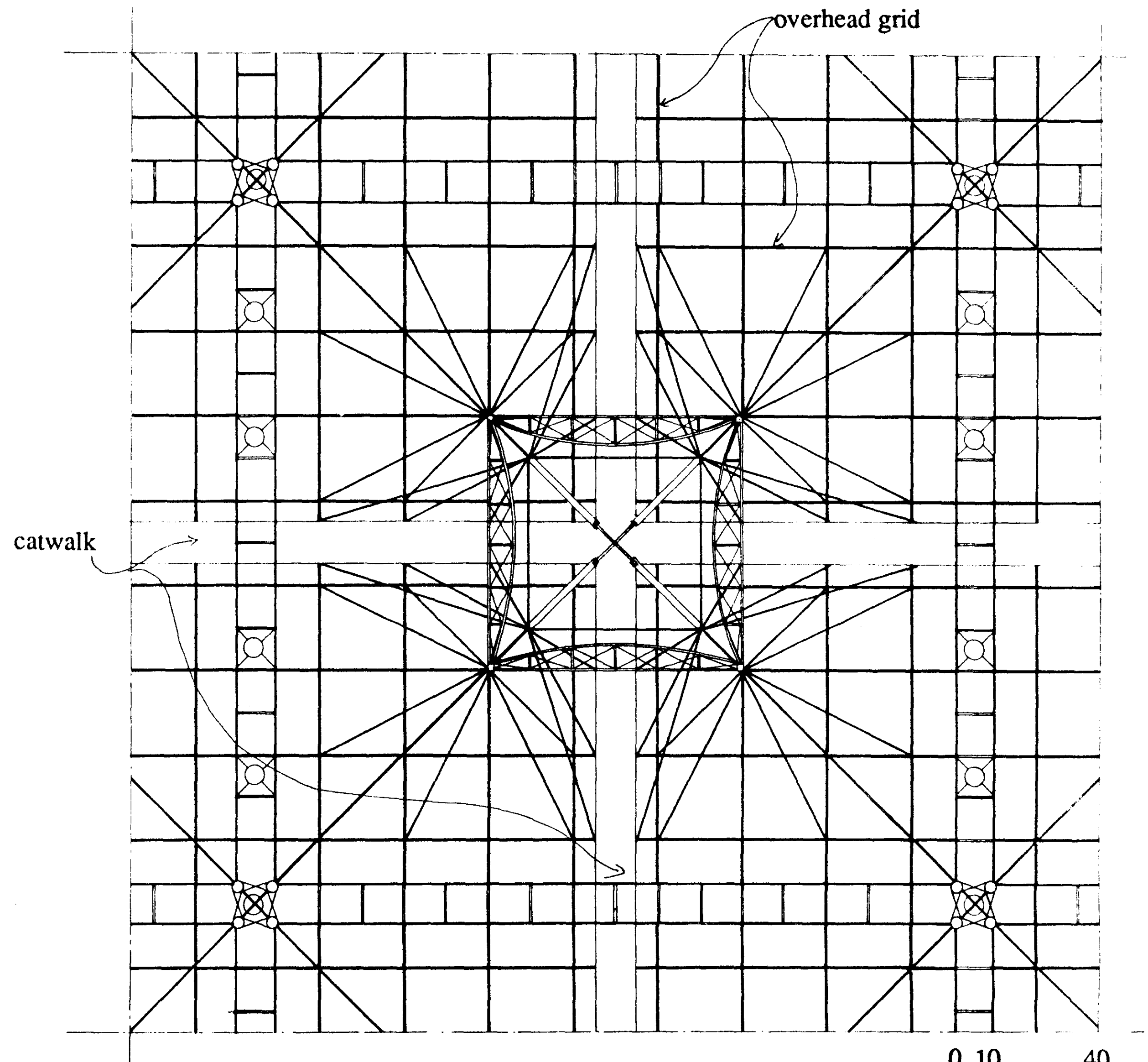


figure 9

GENERAL SECTION

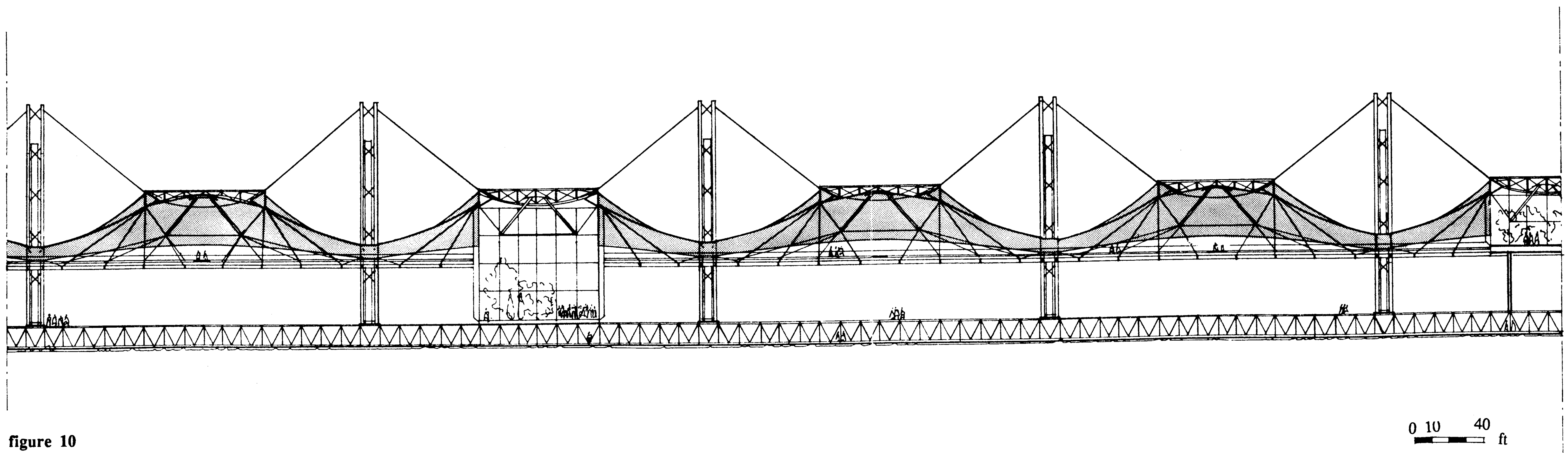


figure 10

VERTICAL SECTION
THROUGH THE FACADE

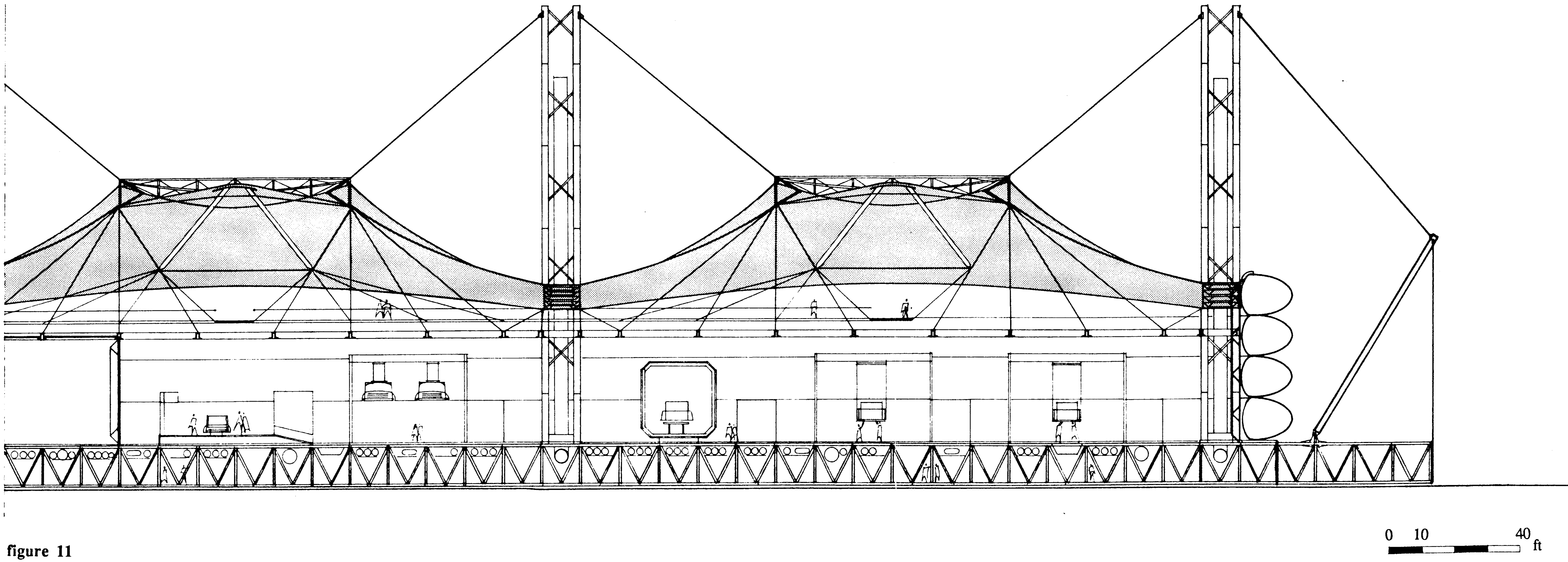


figure 11

SECTION THROUGH
THE PRESS PLANT

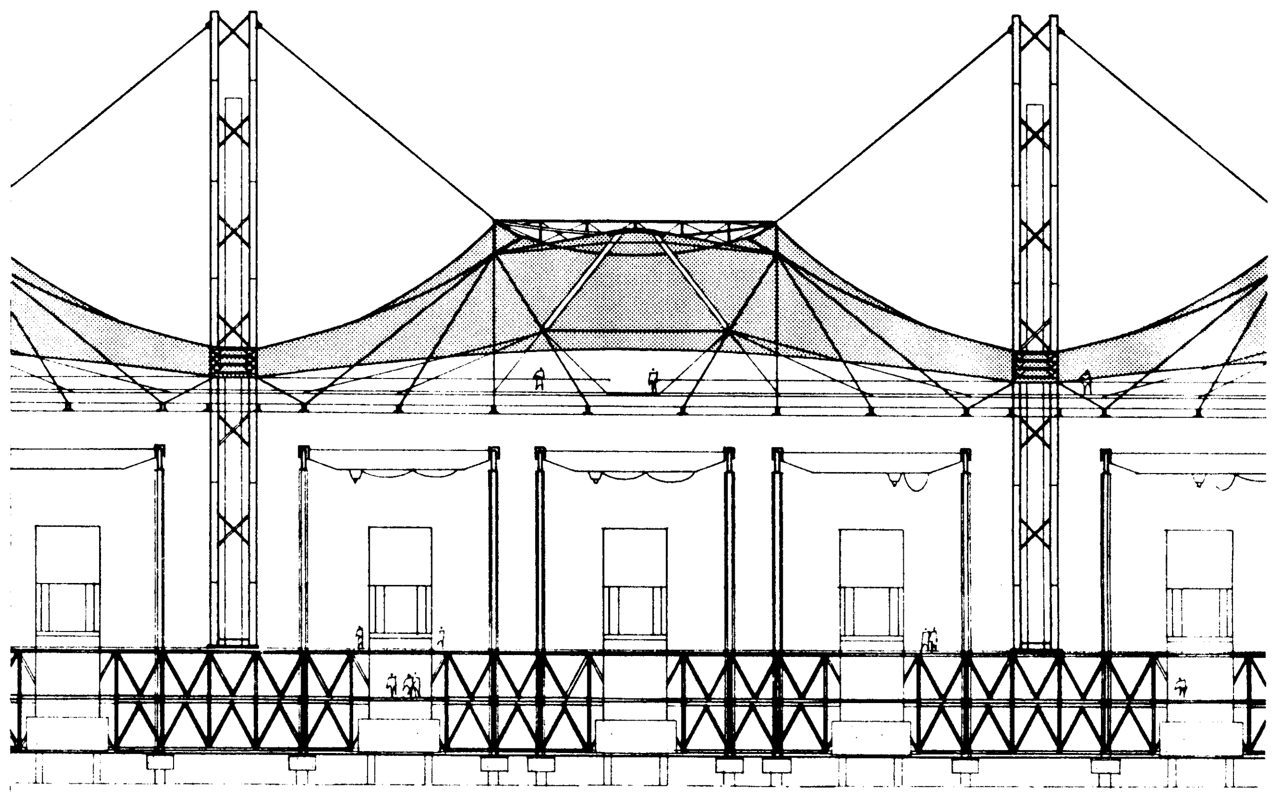
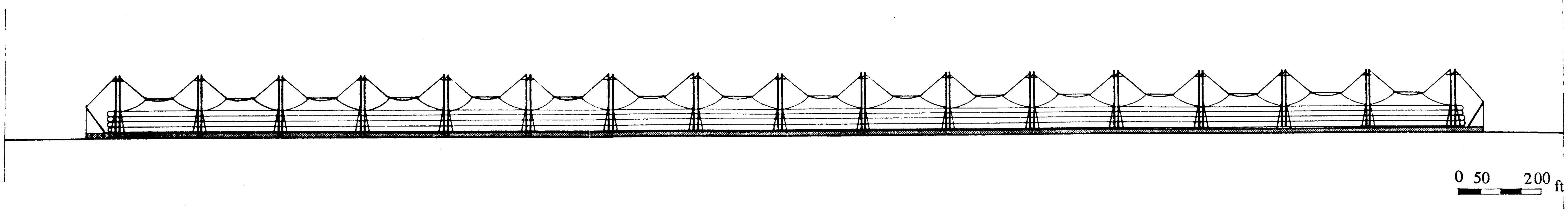


figure 12



PAINT SHOP BUILDING: FACADES

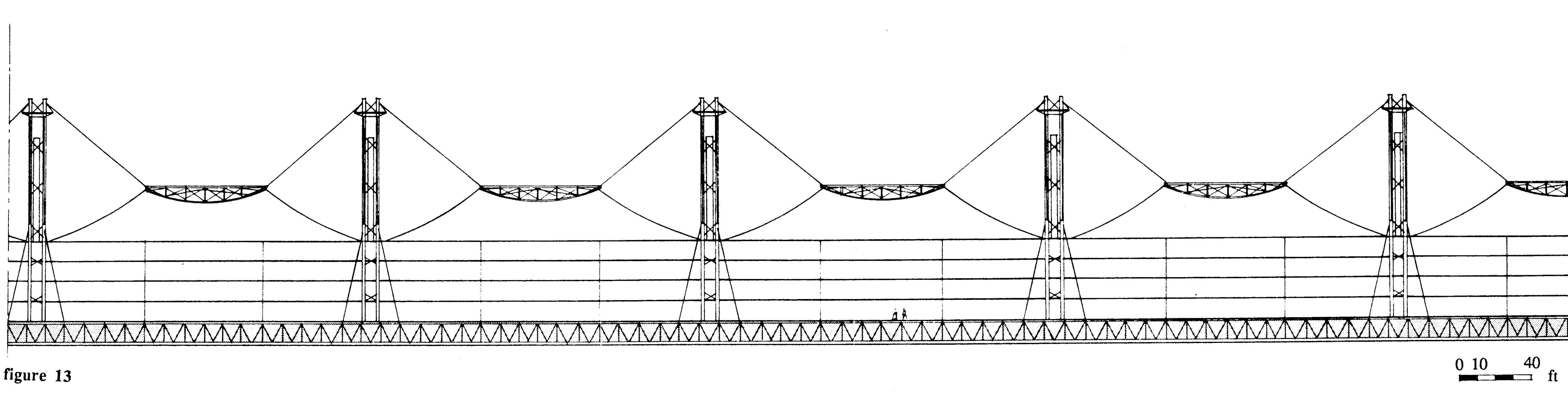
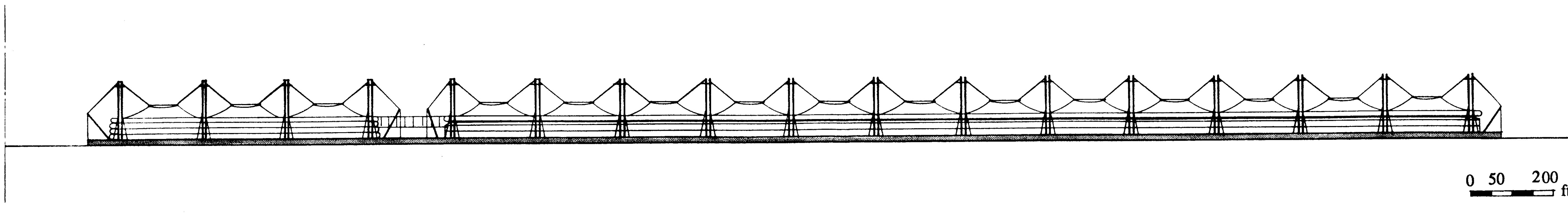


figure 13



ASSEMBLY BUILDING: FACADES

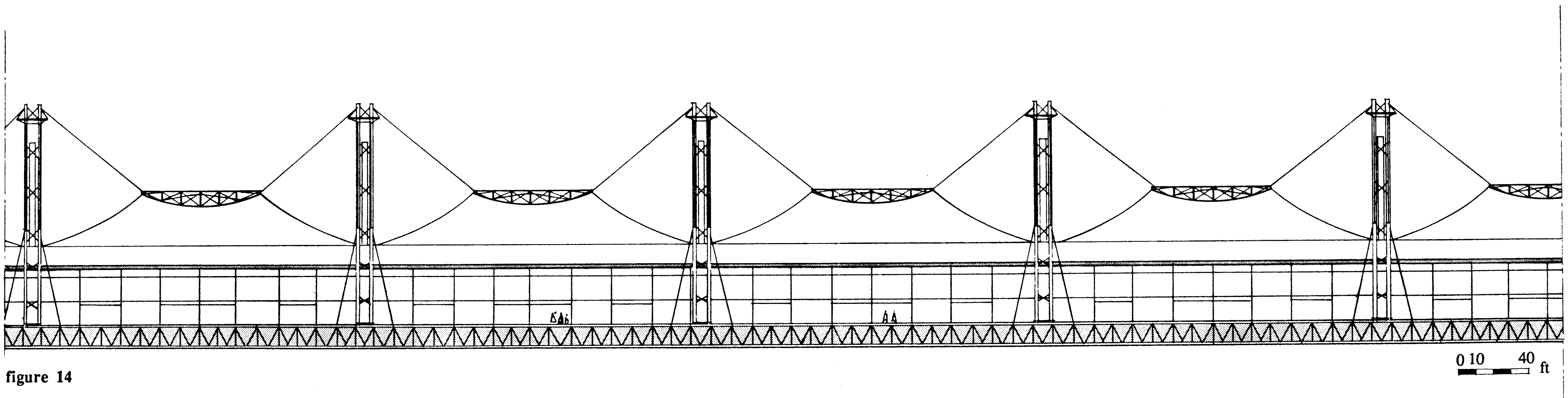


figure 14

EDGE OF THE PAINT SHOP BUILDING: FACADE

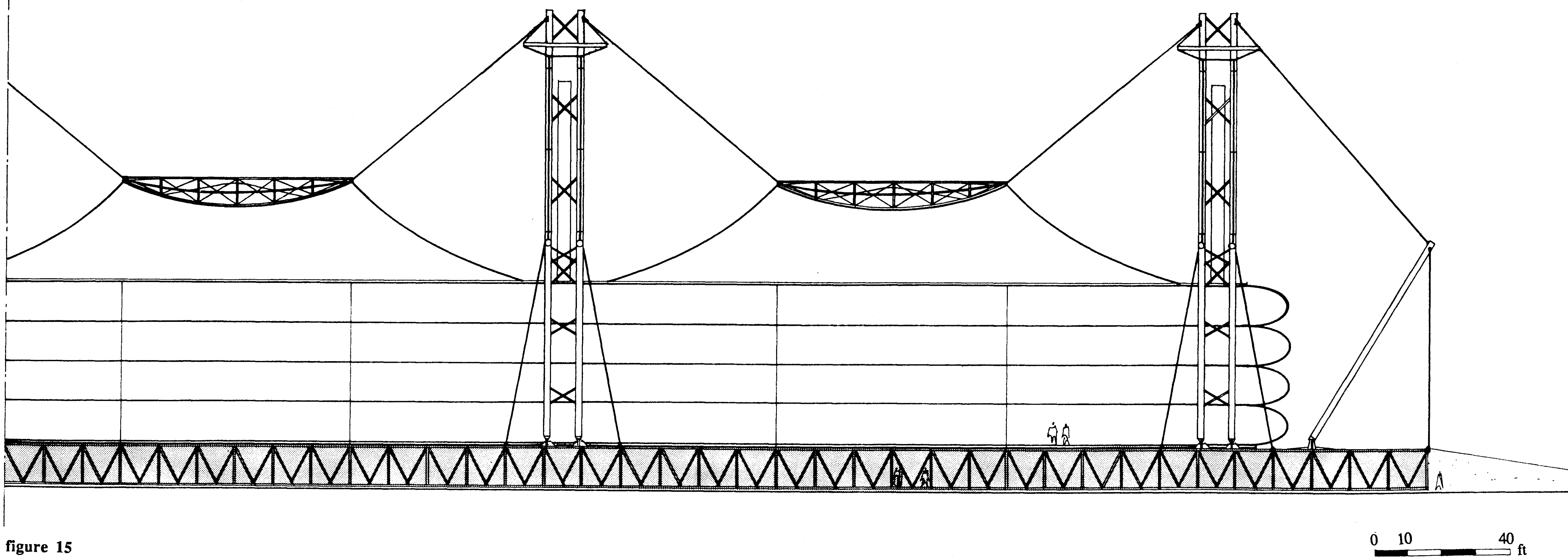


figure 15

EDGE OF THE ASSEMBLY BUILDING: FACADE

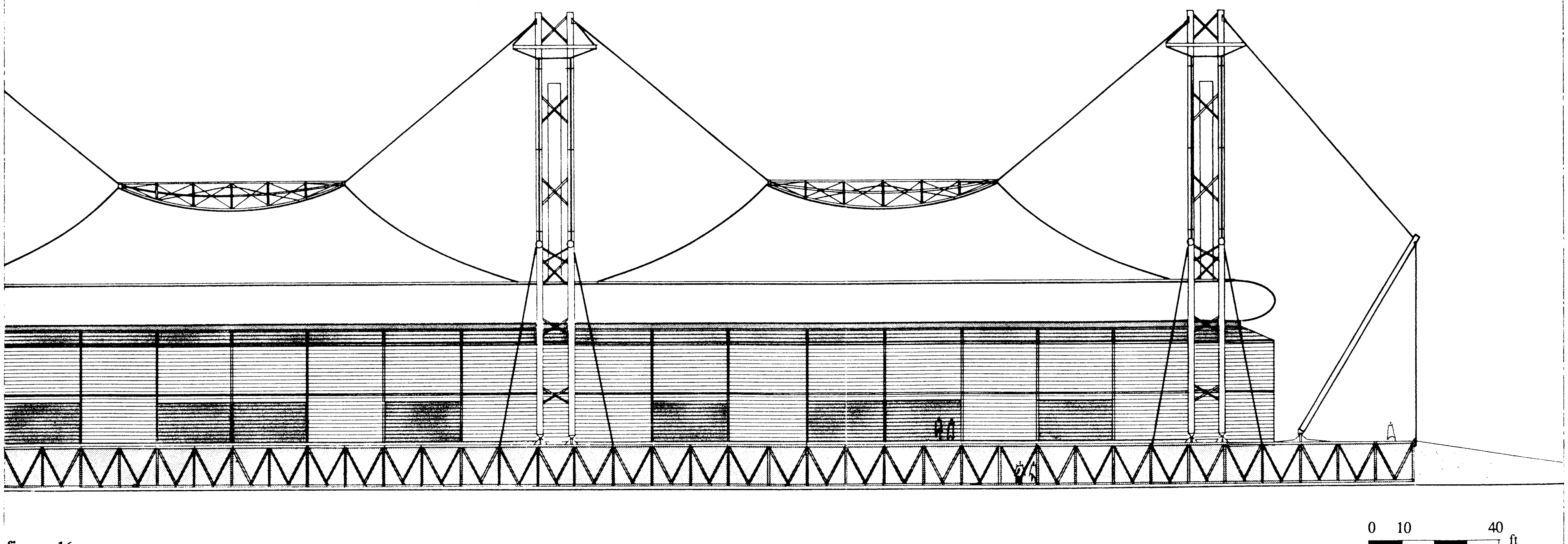


figure 16

CLADDING ALTERNATIVE

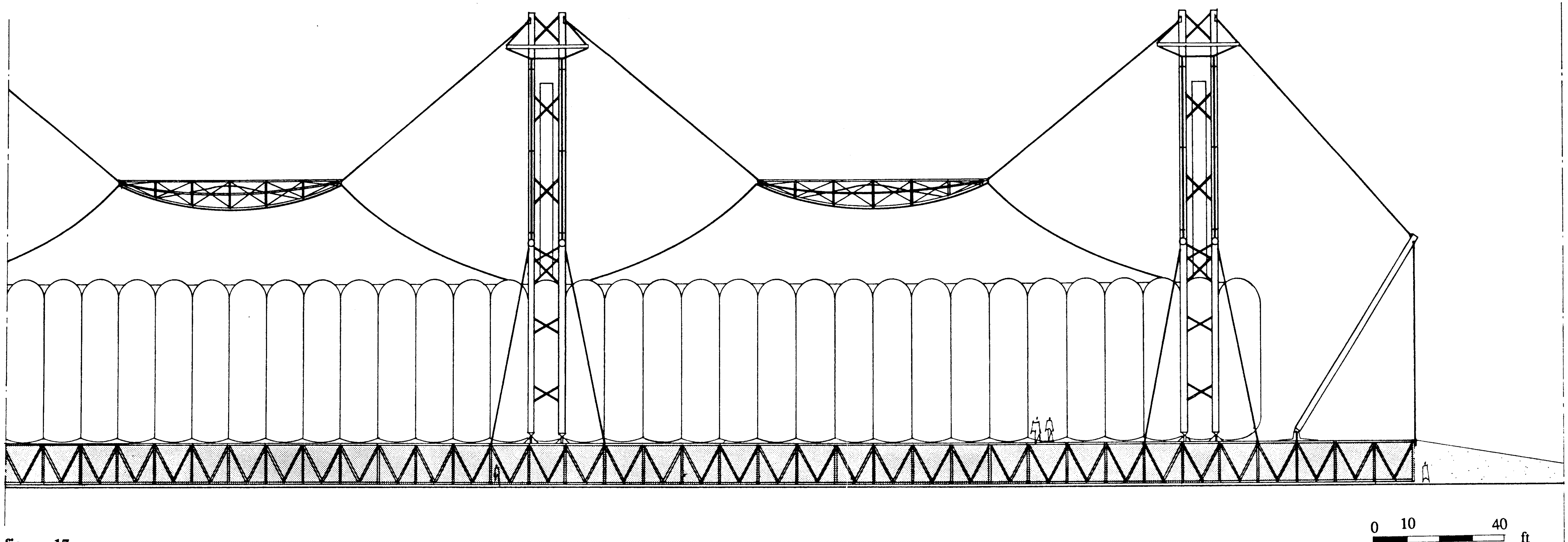


figure 17

ERECTION PROCESS

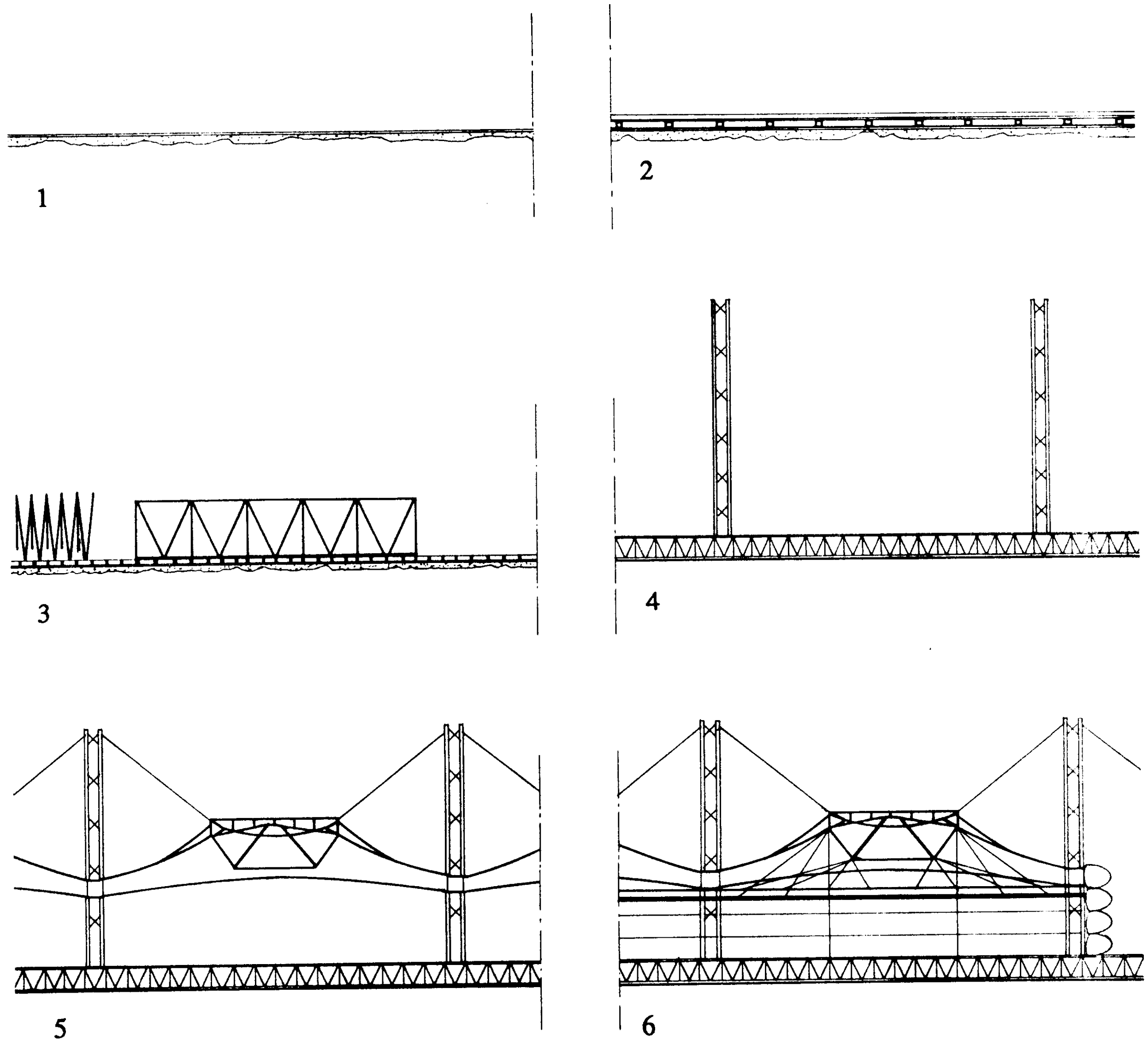


figure 18

FIRST FLOOR SPACE FRAME:

AXONOMETRIC VIEW

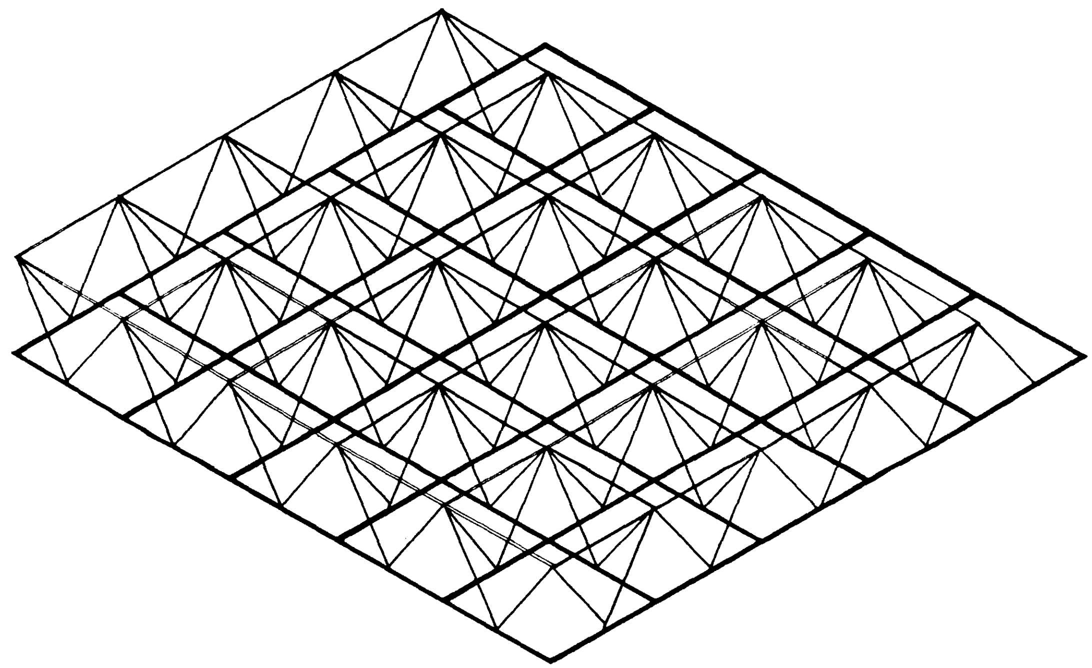


figure 19

FIRST FLOOR SPACE FRAME:
DEPLOYMENT PROCESS

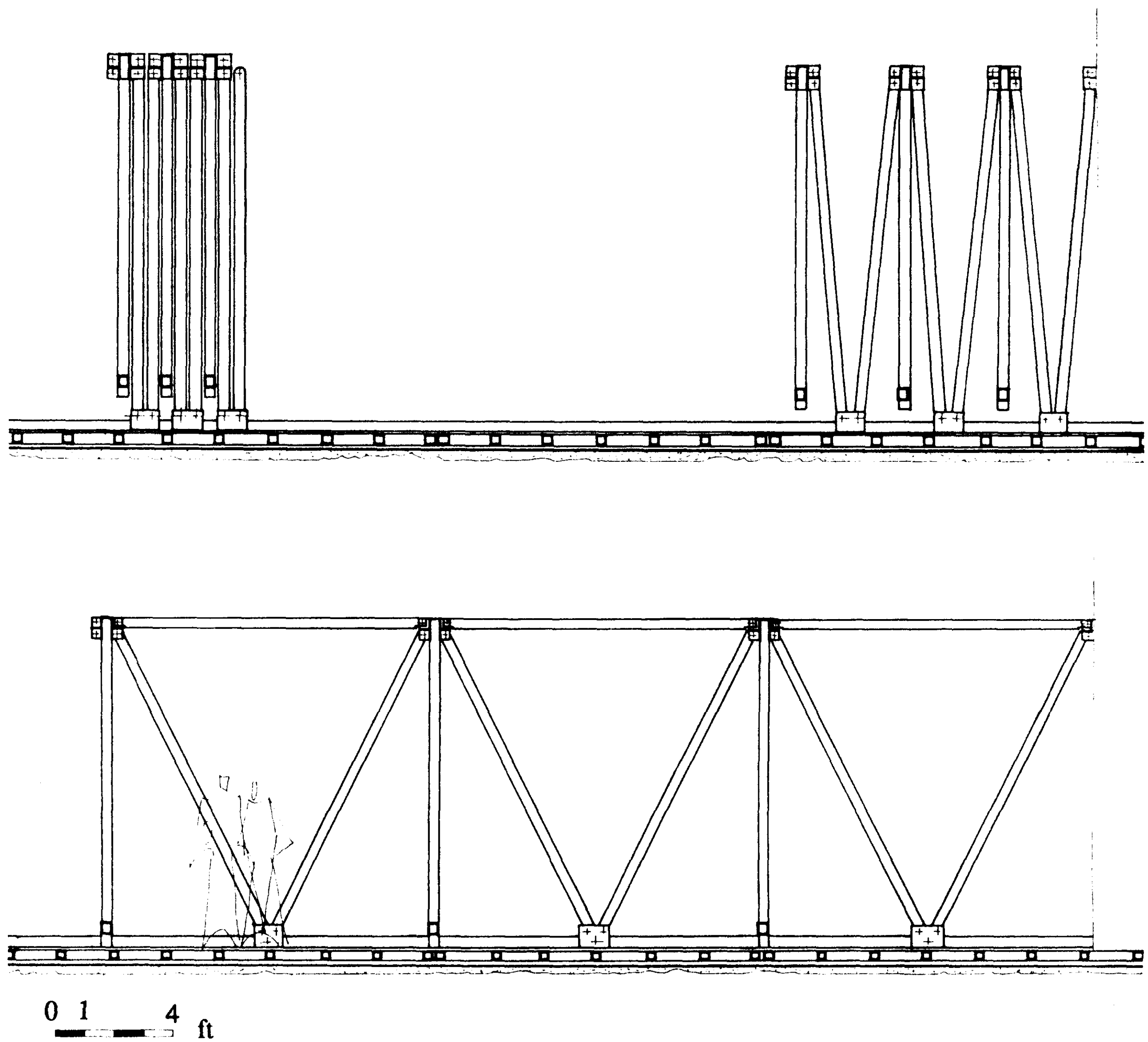


figure 20

FIRST FLOOR SPACE FRAME:
SECTION

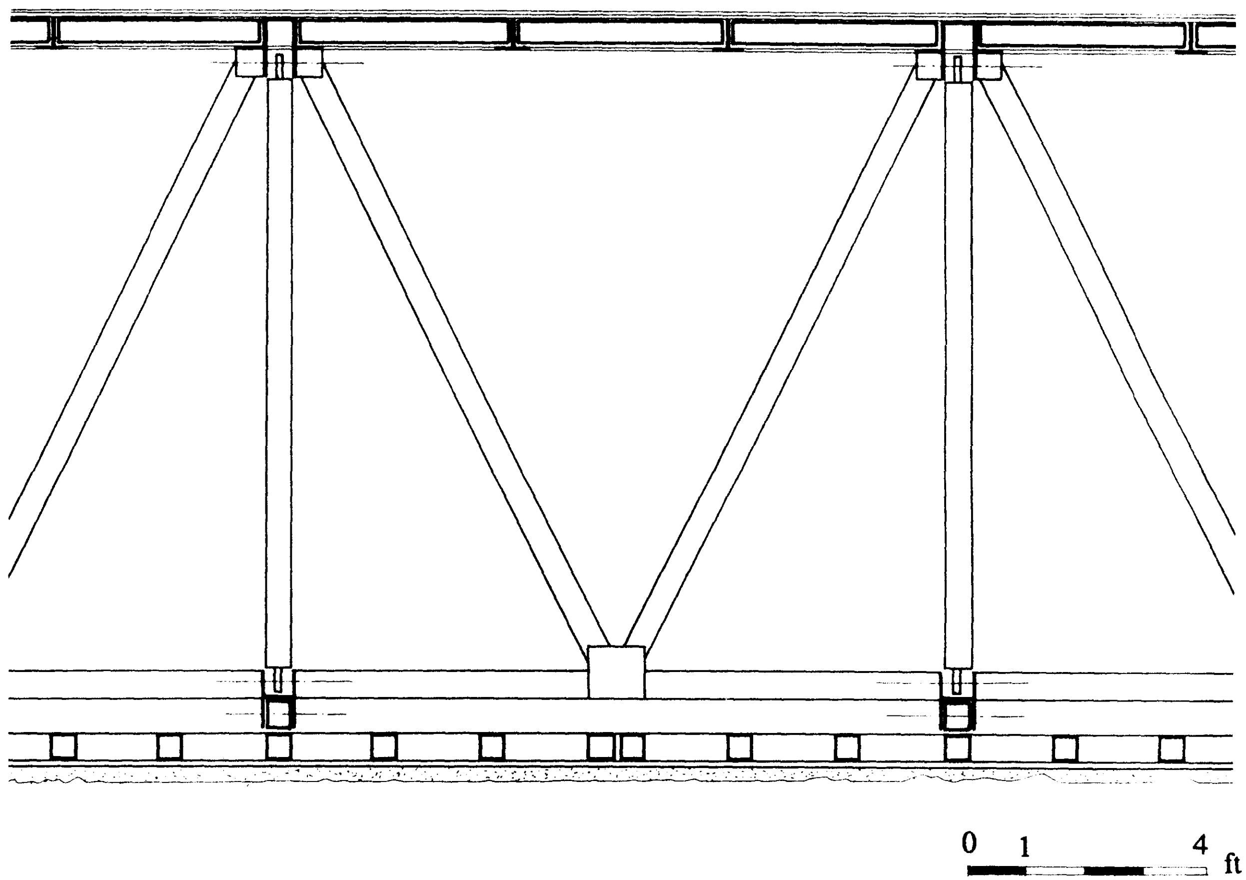


figure 21

FIRST FLOOR SPACE FRAME:
SECTION

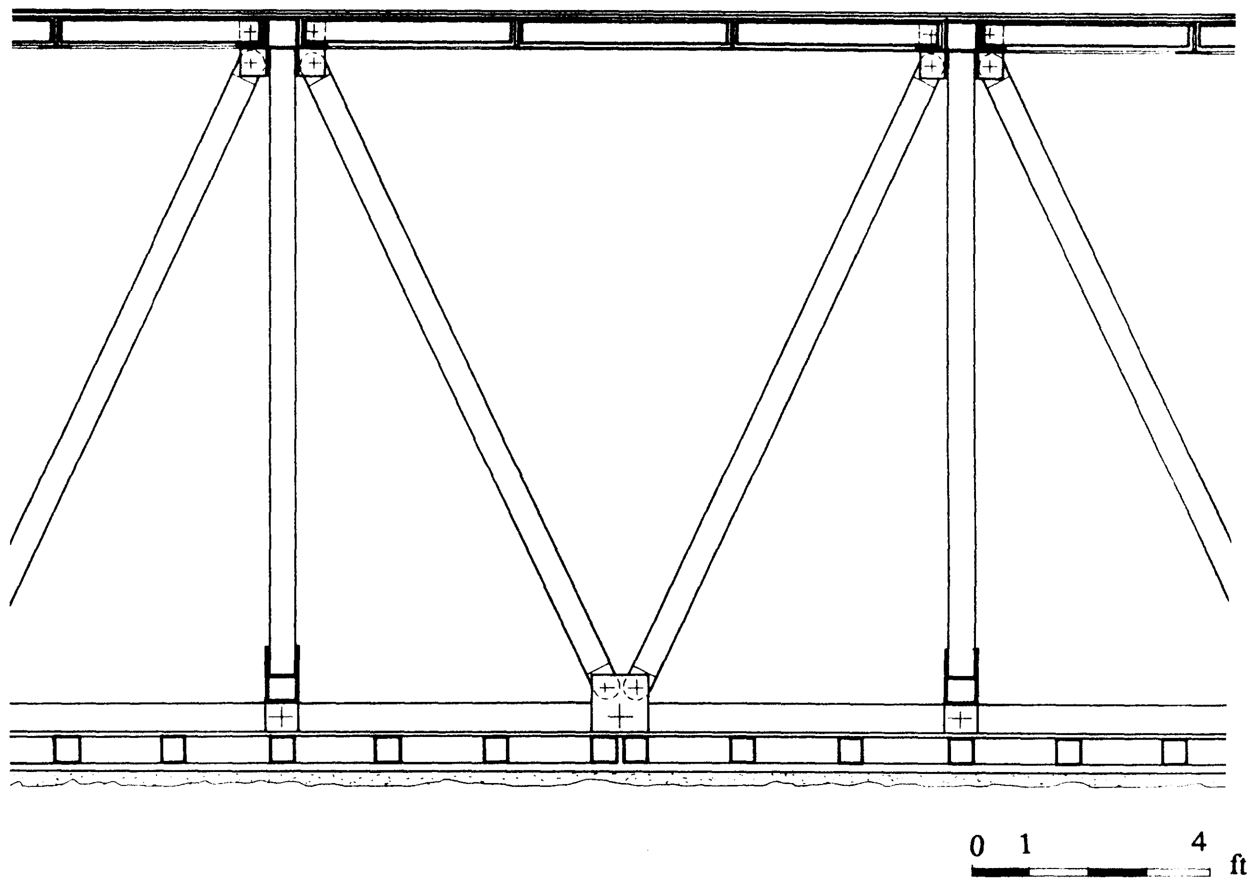


figure 22

FIRST FLOOR SPACE FRAME:
HINGE AND CONNECTION
DETAIL

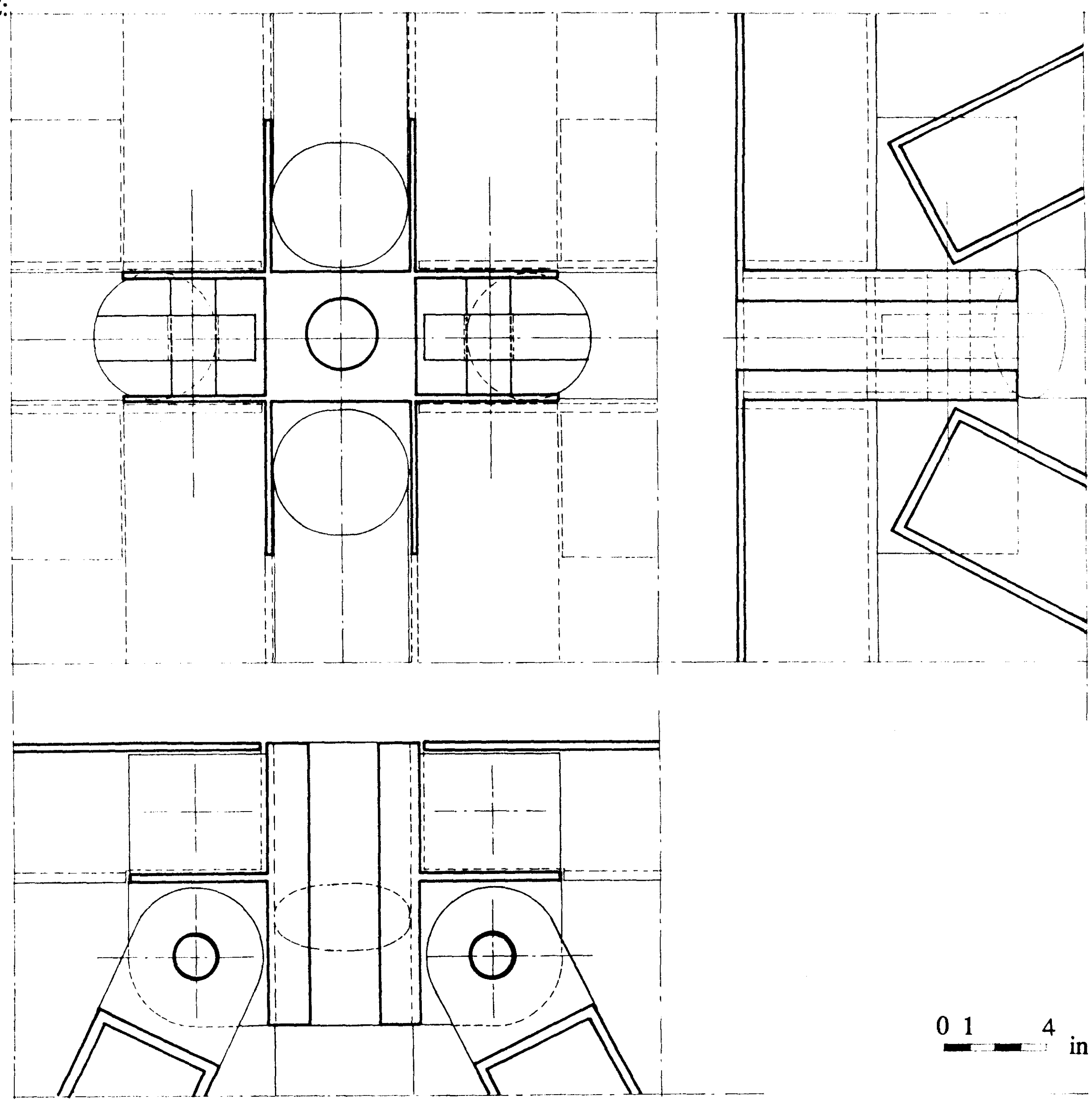


figure 23

COLUMN: BASE DETAIL

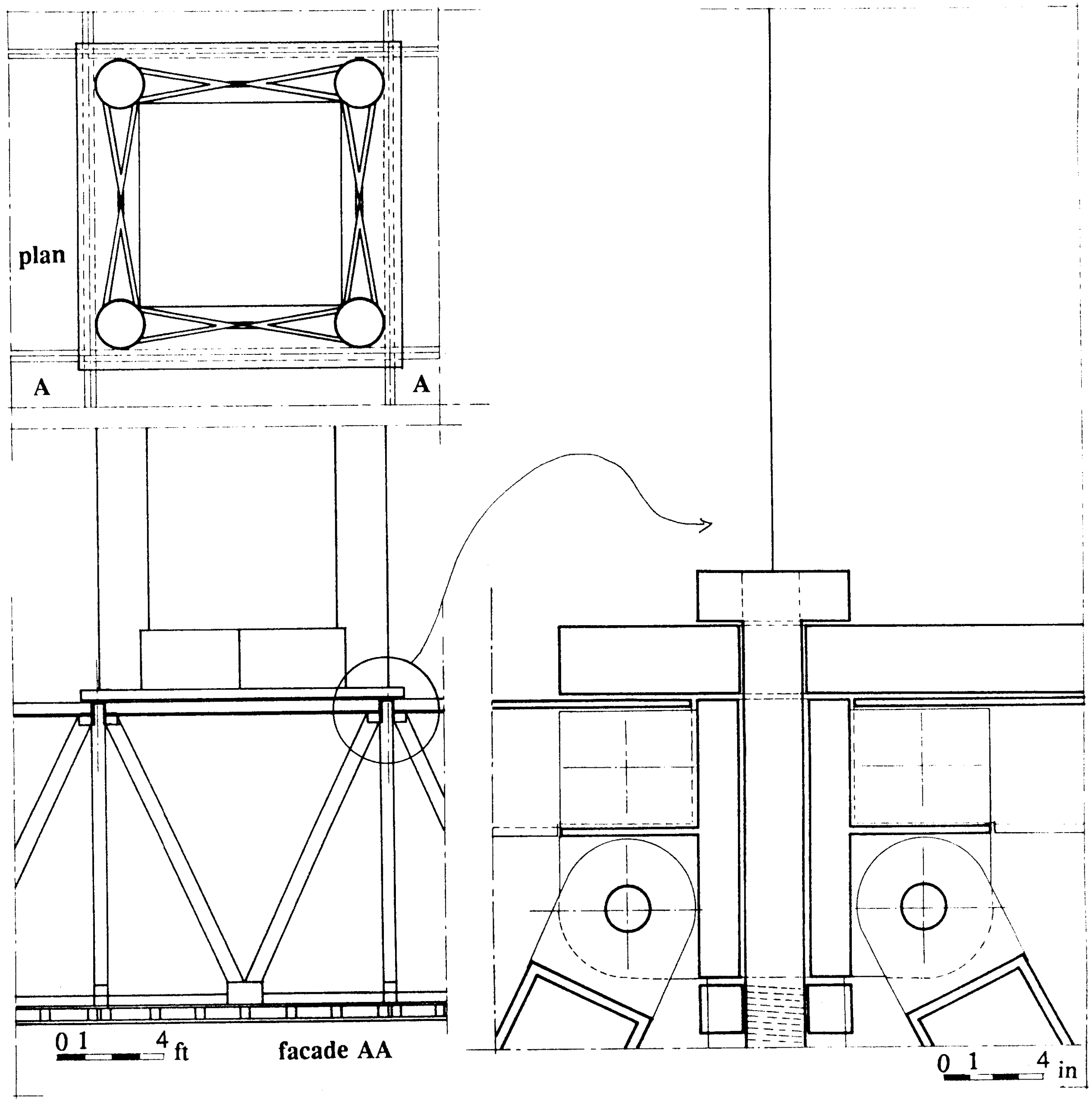


figure 24

COLUMN:
JUNCTION WITH FABRIC

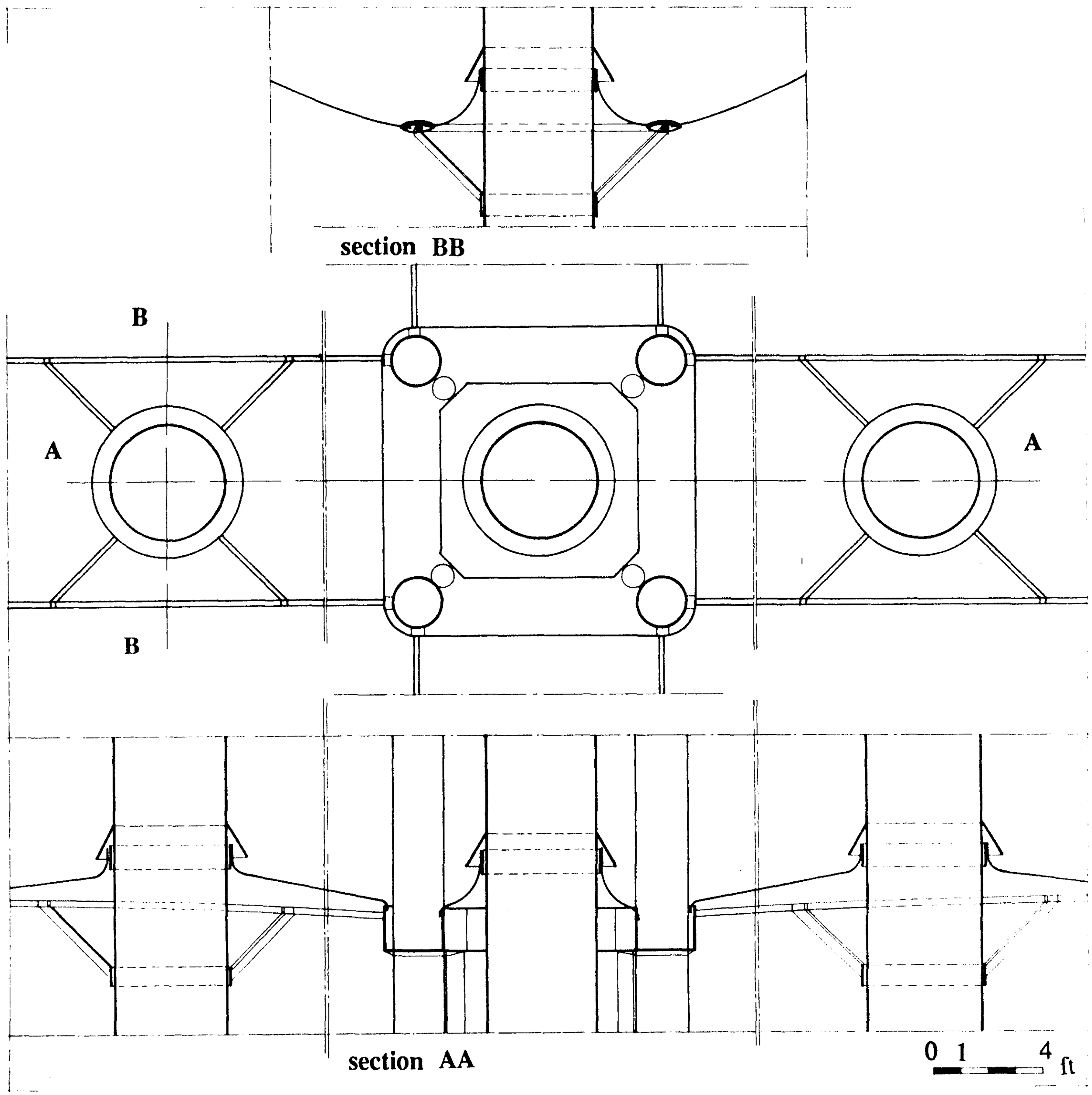


figure 25

COLUMN: TOP DETAIL

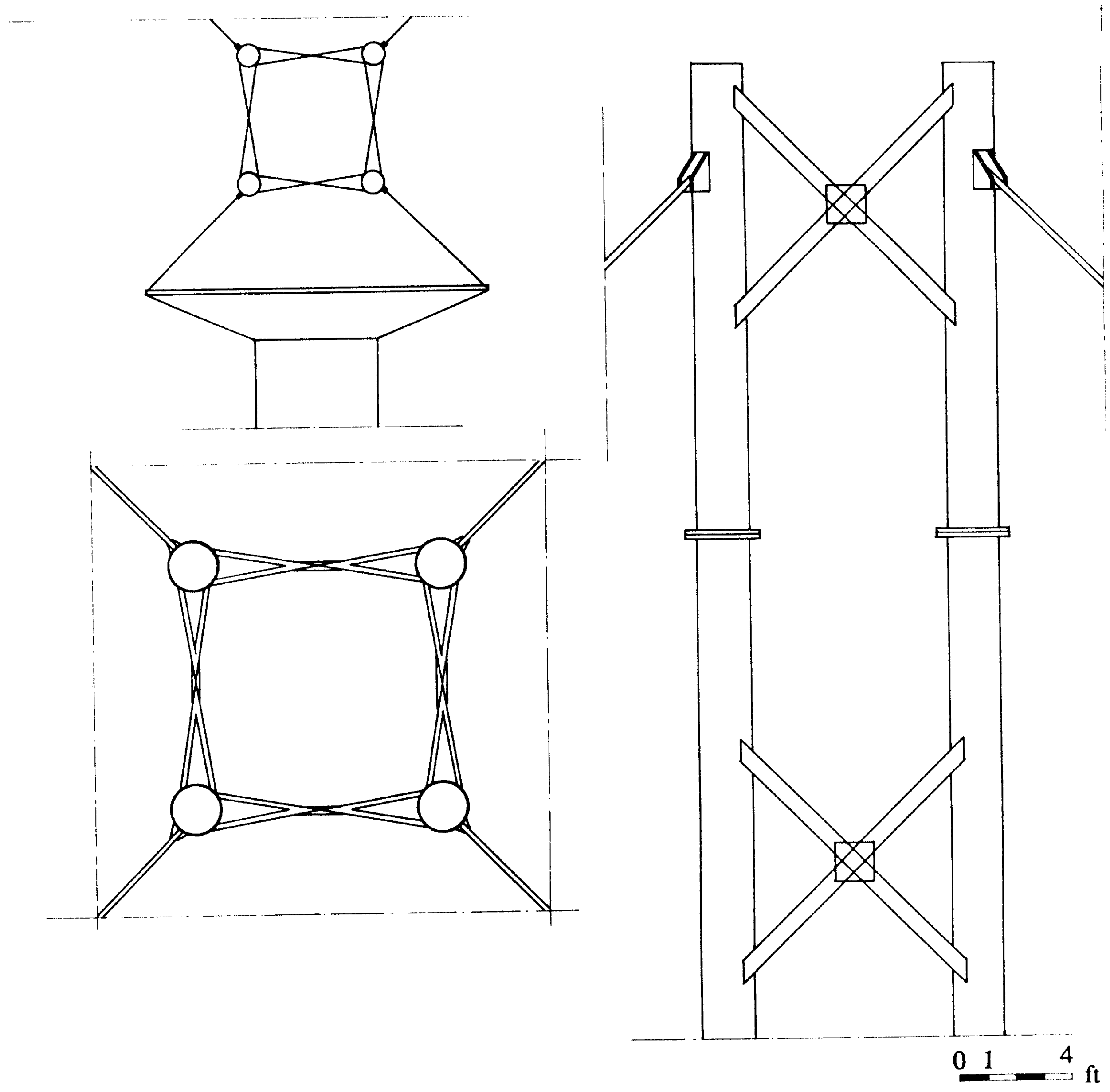


figure 26

SUSTAINING RING

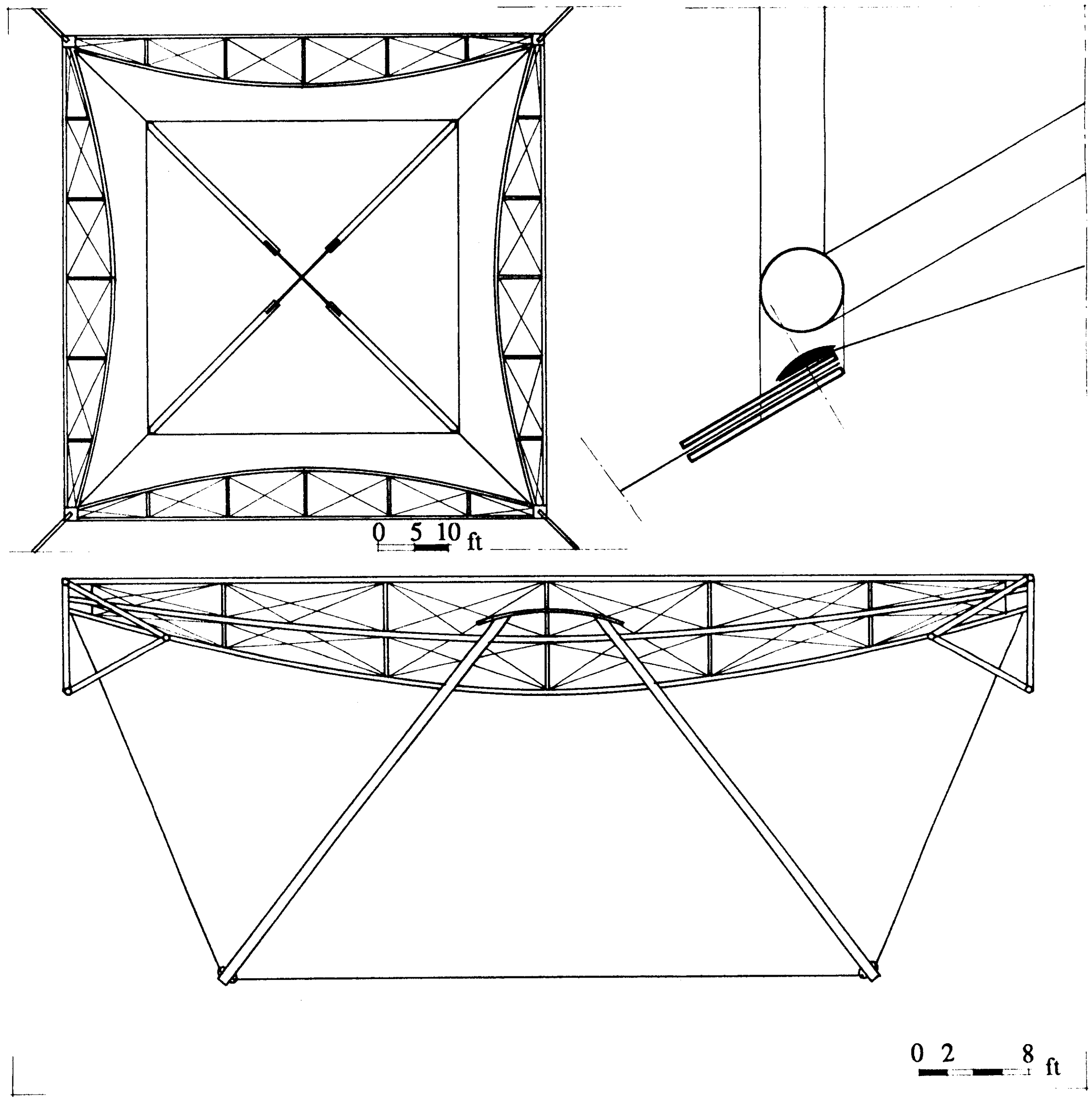


figure 27

CLADDING:
INFLATABLE CUSHIONS

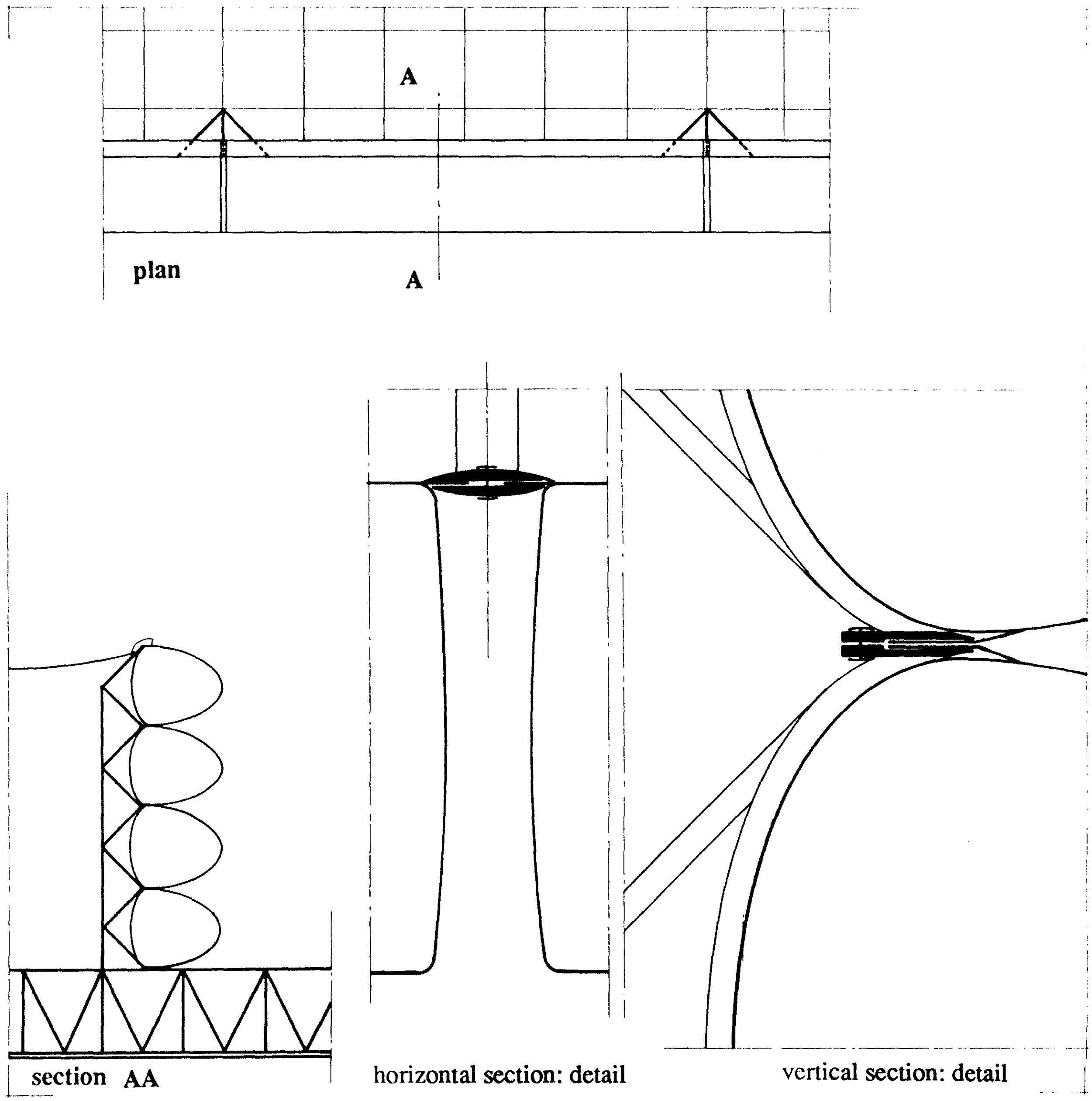


figure 28

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