SPACE STRUCTURES 4

EDITED BY G. A. R. PARKE
AND C. M. HOWARD

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Thomas Telford

186. Expandable structure for the Venezuelan Pavilion at Expo '92

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SYNOPSIS. Deployable structures are the structures of the future, offering tremendous potential for both engineers and architects. The paper describes the design and construction of the Venezuelan pavilion at the Exposition in Seville in 1992.

INTRODUCTION

1. The use of deployable structures began in ancient times when nomadic tribes moved from place to place. Their relatively light tents and tepees were made collapsible and transportable. The main advantages of deployable (transformable) structures are their re-usability, the small volume they occupy during storage and transportation, and the ease and speed of erection. The attractiveness of the idea of structural transformation and the expectations of its practical application to the new uses and demands in the contemporary technological and economical environment, brought recently new interest in the old idea; its revival was stimulated by the trend-setting works and concepts of E.P. Piñero and R. Buckminster Fuller.

2. Implicitly, the deployable structures of the future will have a far broader range of applications than ever before; in architecture, construction and aerospace industries.

3. They can serve either as once only deployed frameworks used as stationery objects or, more often, can be put to recurring uses, passing various cycles of deployment, collapsing and transportation.

4. The repetitive utilisations of deployable structures include emergency facilities (shelters, bridges, hangars etc.), funfair exposition pavilions, grandstands, sport facilities and various types of domed, vaulted and plane space trusses. In outer space the single, deployable only operations, are considered for the main framing support systems and manned stations and laboratories.

5. In these days, there exists already a multitude of contributions reflecting certain specialised interests in the theory of structural transformations. Unfortunately, in most cases these investigations are focused on the similar, relatively narrow studies, such as the mathematical formulation of geometrical and mechanical constraints and the kinematics of events associated with the evolution

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of structure from its compact to final form. Quite rare are however, realistic propositions and studies of the broader character, more directly related to the development, planning and erection of usable, easily buildable, economical structures, resisting the whole range of transportation and service loads.

6. In response to the professional and intellectual challenge of the idea of structural transformations and to involve the students of the Massachusetts Institute of Technology (MIT) in Cambridge -Mass and the researchers in the Instituto de Desarrollo Experimental de la Construccion (IDEC) in Caracas, in the new and very promising field of Architecture and Engineering; the investigations into deployable structures have been undertaken a few years ago with workshops and seminars conducted in both places. Their research and educatory efforts have been motivated by the firm belief in the rationality in the idea of structures adjusting their forms to the consecutive stages of construction and service, and also by the strong desire to see them built.

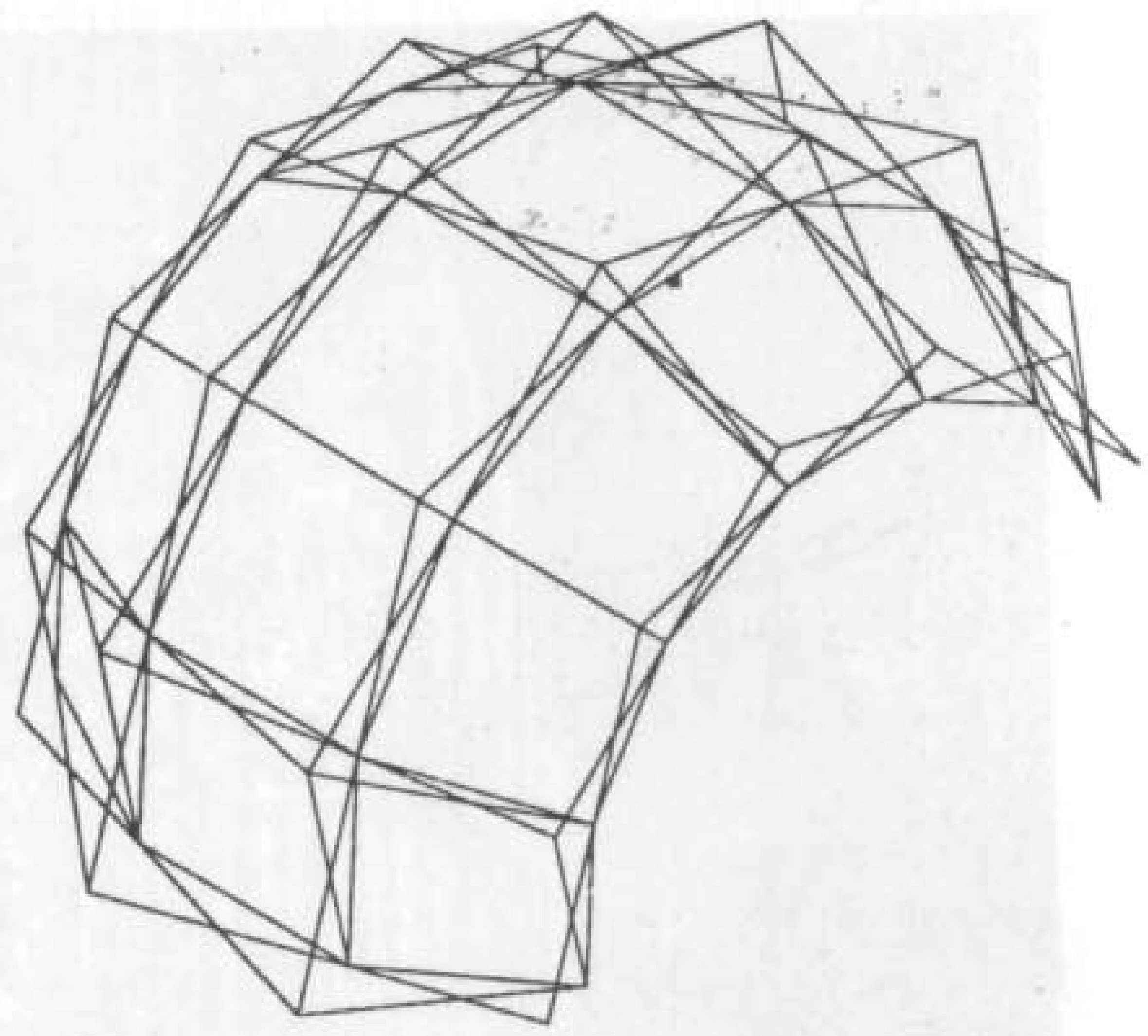

Fig. 1.

7. Until now the emphasis of our research was mainly related to under explored areas such as:

- Economical and functional feasibility of deployable structures.
- Classification and selection of their types and material.
- Design of joints and other hardware.
- Mechanics and management of the deployment and collapse operations.

The initial experience and understanding of technical problems pertinent to the implementation in practice of the concept of structural transfiguration have been developed through studies on models and large size prototypes as well as by the contacts with prospective clients, producers and contractors, resulting in a deeper involvement with various actual projects.

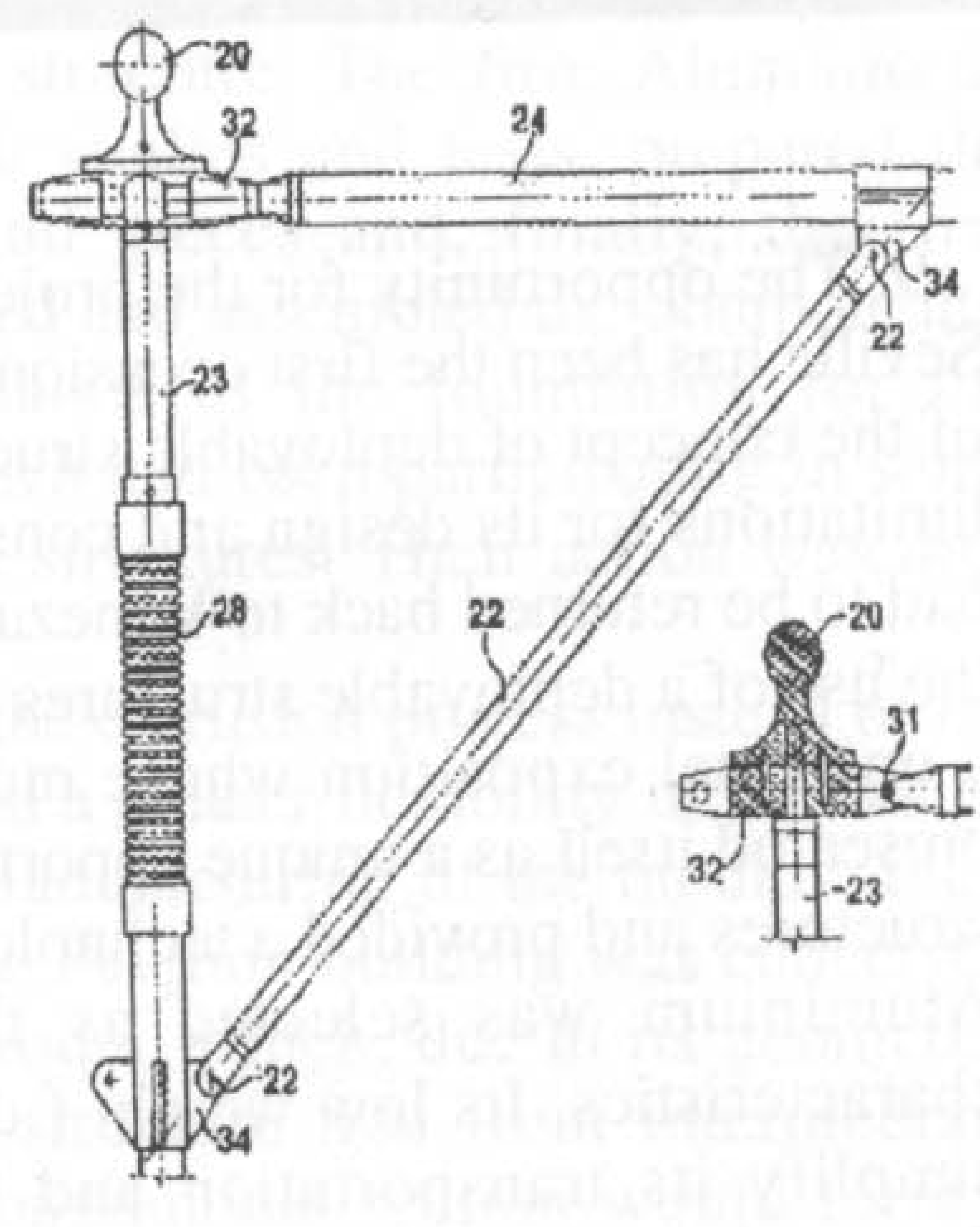

Fig. 2.

8. The largest of these projects, namely the pavilion of Venezuela for 1992 Exposition in Seville, has already passed the first stages of its realisation, offering a quite positive example of the team work in which the constituent, artistic, architectural and technical concerns and ideas were mutually interacting and incorporated into the final solution. It also inspired many conceptions for the broader uses of deployable structures in the future.

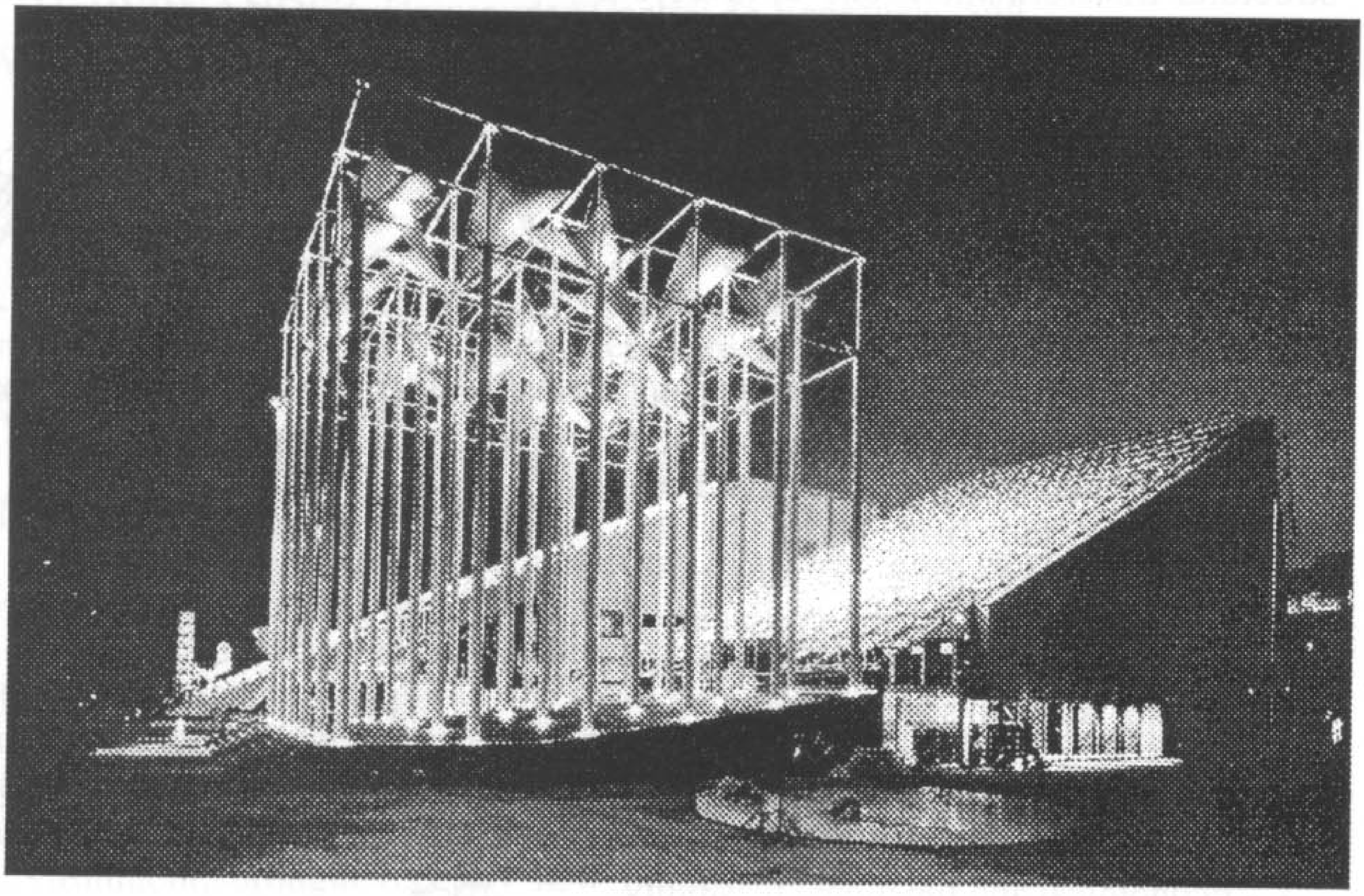

Fig. 3.

9. The opportunity for the project of the Venezuelan pavilion at the Expo'92 in Seville has been the first occasion to demonstrate, on a large scale, the application of the concept of deployable structures. The requirements of the project, the time limitations for its design and construction; the need of a temporary building, that had to be returned back to Venezuela and the high costs of building in Spain made the use of a deployable structures a convenient choice. On the other hand, to go to a universal exposition whose motto was THE ERA OF THE DISCOVERIES, presented itself as a unique opportunity to advance the development of deployable structures and provided a technological innovation in the Pavilion for Venezuela. Aluminium was selected as the building material due to its particular characteristics. Its low weight (density 2.71 kg/cm^3) allowed lighter pieces to simplify its transportation and handling. The use of this material was also favoured for its behaviour vis-a-vis the climatic agents, considering that its structure would be exposed to different conditions.

10. Its particular characteristics and production process made it possible to prepare the required alloy, thus obtaining the necessary resistance for each case

(Alloy N° 6261 with an ultimate strength of $3300kg/cm^2$), thus rationalising its use. Also, the possible finishes attainable were in accordance with the image of the Pavilion; a symbol that represented the level of technological capabilities of the Venezuelan industry. In this way close team work developed between the researchers and professionals from Idec and the engineers of the aluminium industry Alcanven and Albarca. This led to the successful design, detail engineering, production engineering and construction of this structure, between July 1990 and May 1991, when the structure was shipped to Spain.

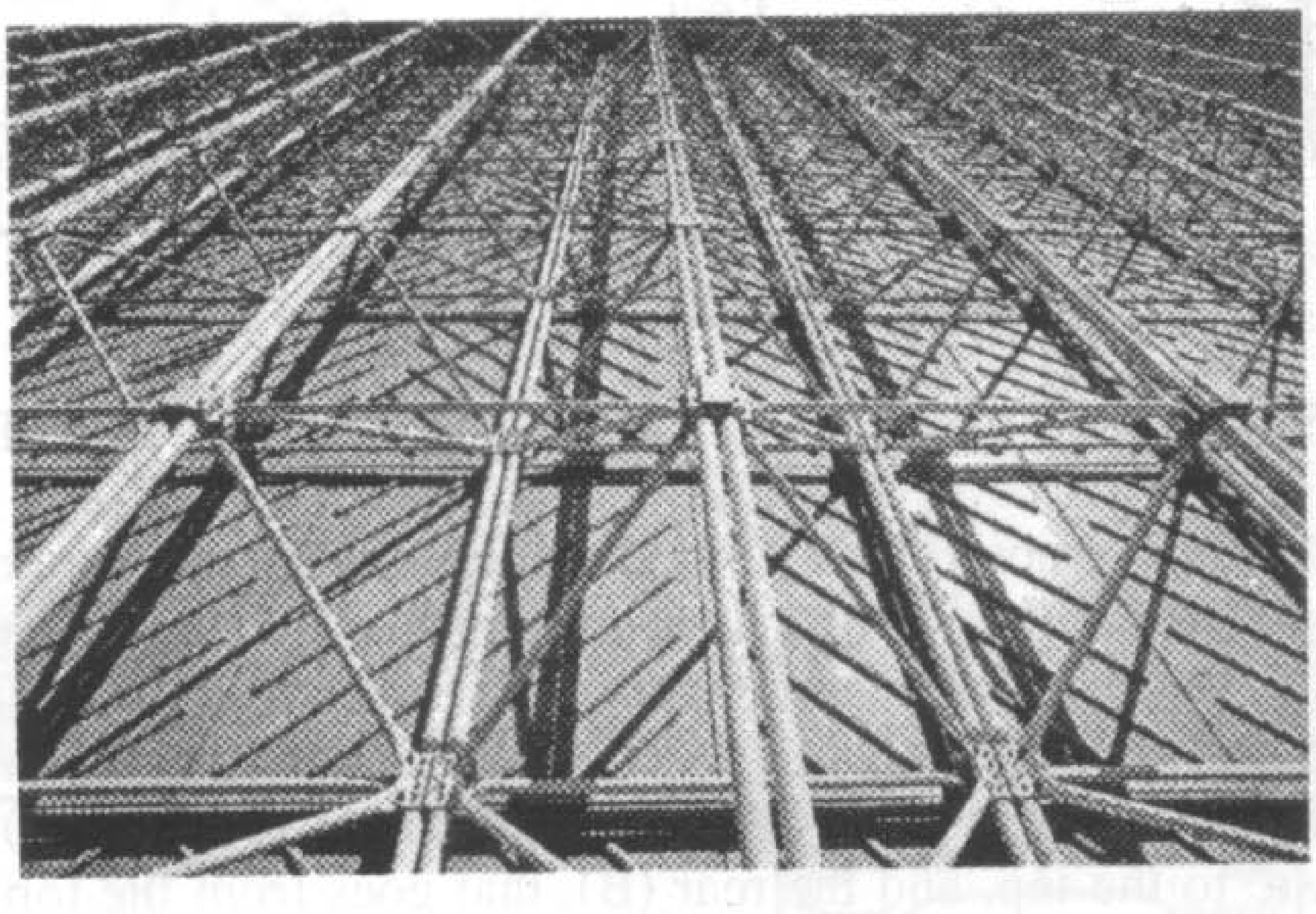

Fig. 4.

11. The raw material processing plants, VENALUM and ALCASA, donated the aluminium necessary for manufacturing the structure. The firm Aluminio de Venezuela, ALCANVEN, made the strength studies and tests, prepared the required alloy, manufactured the moulds and pieces and, finally, the firm Aluminio de Barquisimeto, ALBARCA, painted and assembled the components. All this process had the support and guidance of the foundation for the development of aluminium FUNDALUM, which had been participating in some of our investigation in the area of deployable structures. Their action was thus decisive for the development of this process.

12. For the manufacture of the components, the extrusion process instead of the injection process was used, because it permitted a greater flexibility in the design of the components and simplification in the manufacturing of the moulds; thus, considerably shortening construction time. The Pavilion building was conceived basically as the container of an audio-visual room, which, due to its geometric requirements, made it necessary to adopt a structure free from intermediate supports. The result was a building whose longitudinal section would form a triangular shape to orient the visual relations between spectator and screen (Fig. 5).

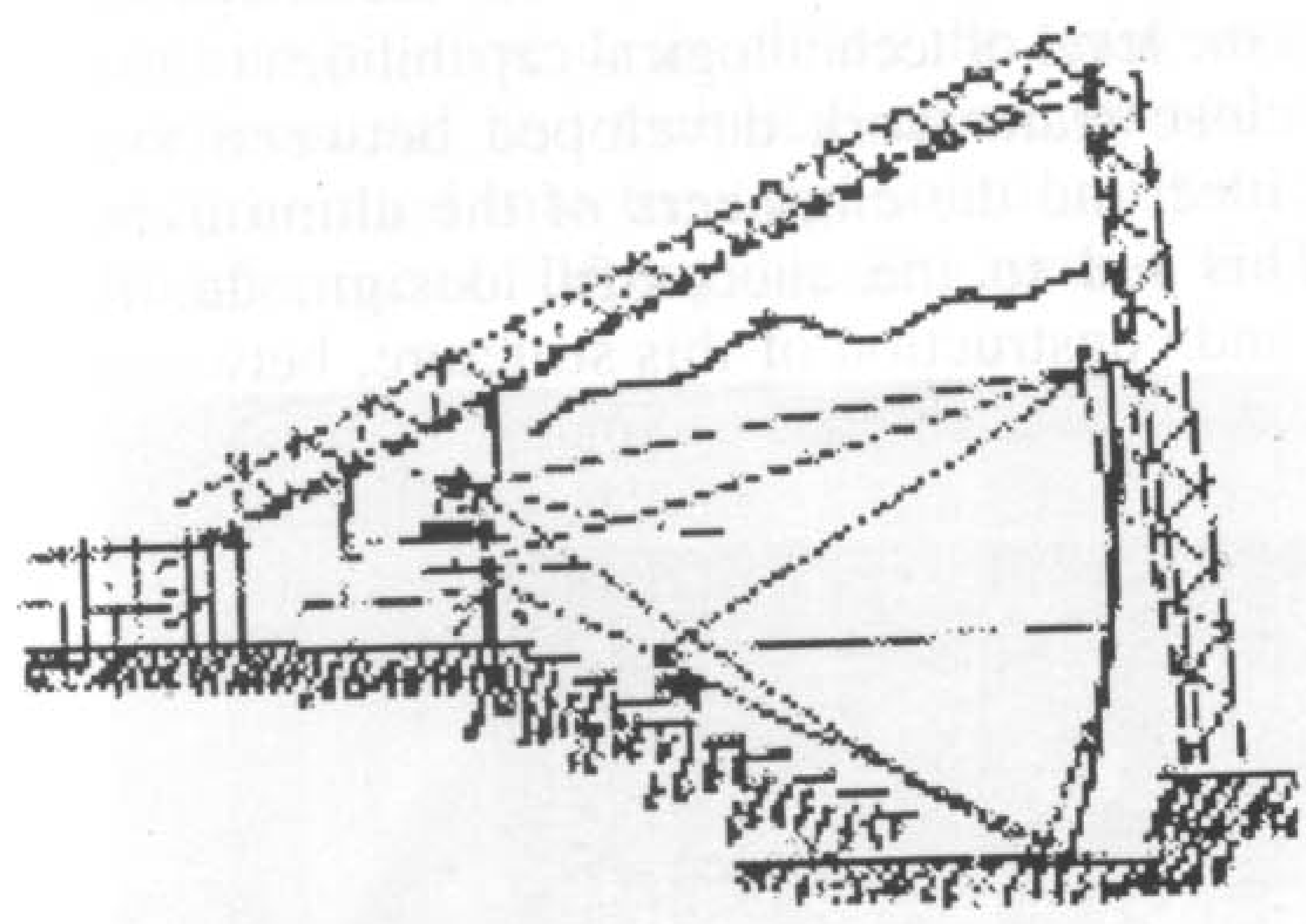

Fig. 5.

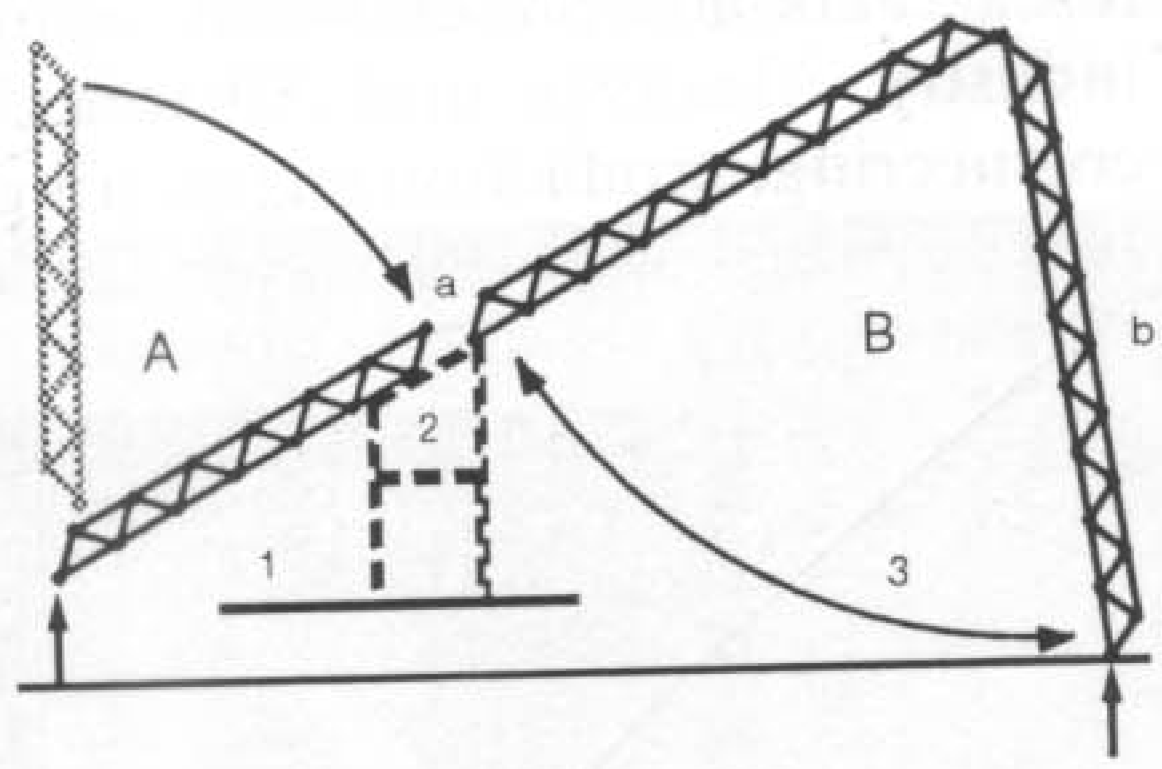

Fig. 6.

13. A deployable structure that folded in one direction, formed by parallel trusses hinged at its nodes to permit an accordion-like fold, was chosen due to its adaptation to the geometrical requirements of the Projection Room and because of the smaller number of pieces required together with simplification in the erection.

14. The structure, defined on two planes, (Fig. 6) the superior (A), which goes from the square to the top, and the rear (B), that goes from the top to the floor. The plane A has an intermediate support (the projection cabin) and it was divided into two groups of trusses, one with a span of 13m and the second with a span of 18m, plane B has trusses of 18m also. The side planes (C), that complete the ensemble and collaborate with the distribution of the side forces from the wind, are made up by variable size trusses, connected to the structural grid of the building.

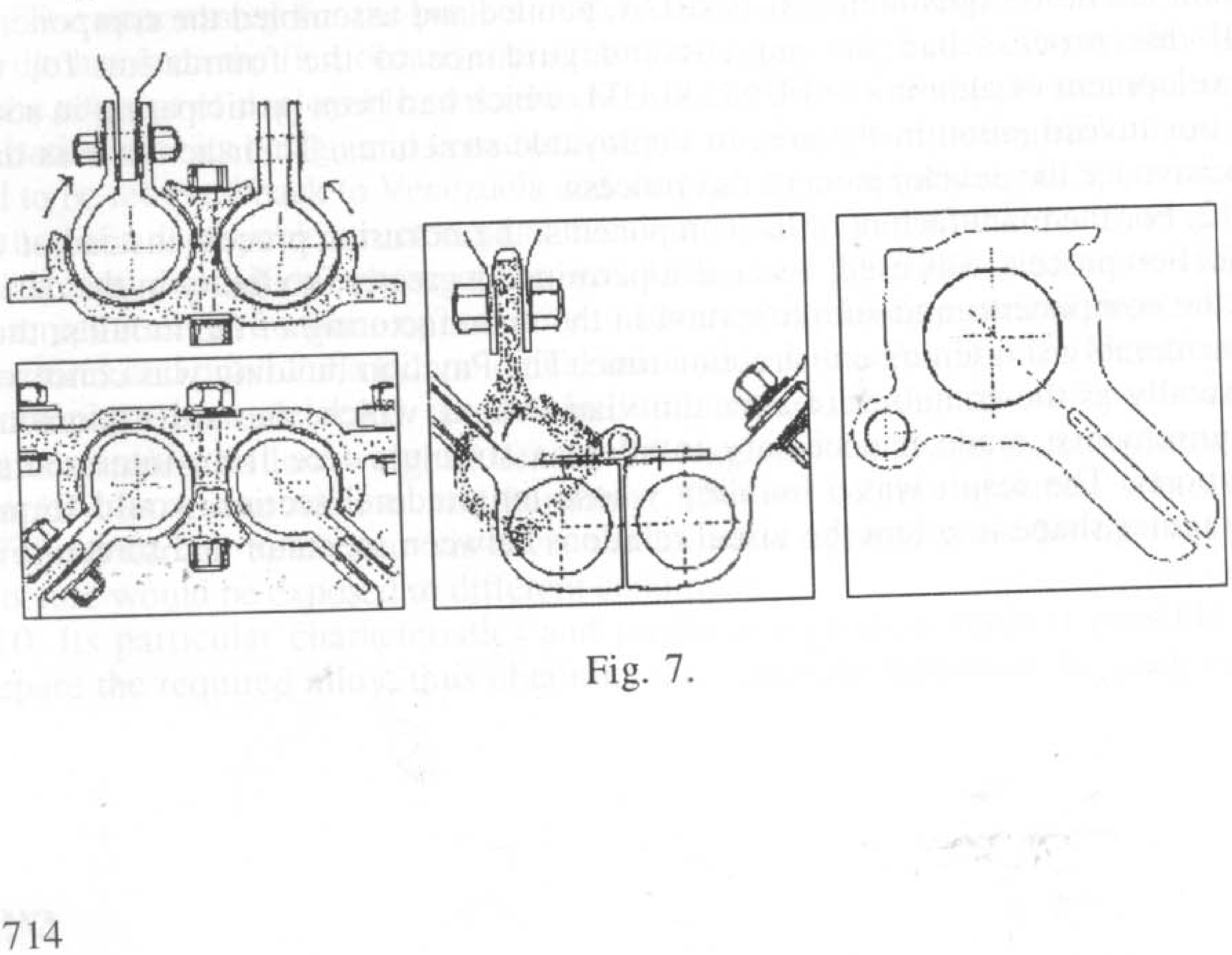

Fig. 7.

15. A system of low-weight panels is incorporated into the structure, designed to provide thermal and acoustical isolation, as well as the interior and exterior finish of the audio-visual room.

16. Because the connections are responsible for the accordion-like movement and for joining together the different components, the design work concentrated on their behaviour (Fig. 7). As a result, two separate pieces were designed, which formed the connection assembly, namely; the hinged-node and the staple.

17. The hinged-node makes up the trusses, allows the accordion like movement, and receives the transverse elements that give stability to the structure in its final state Fig. 8A). The staple maintains the hinge in the right place after unfolding of the structure and it is also the element that carries the cover (Fig. 8B).

Fig. 8A.

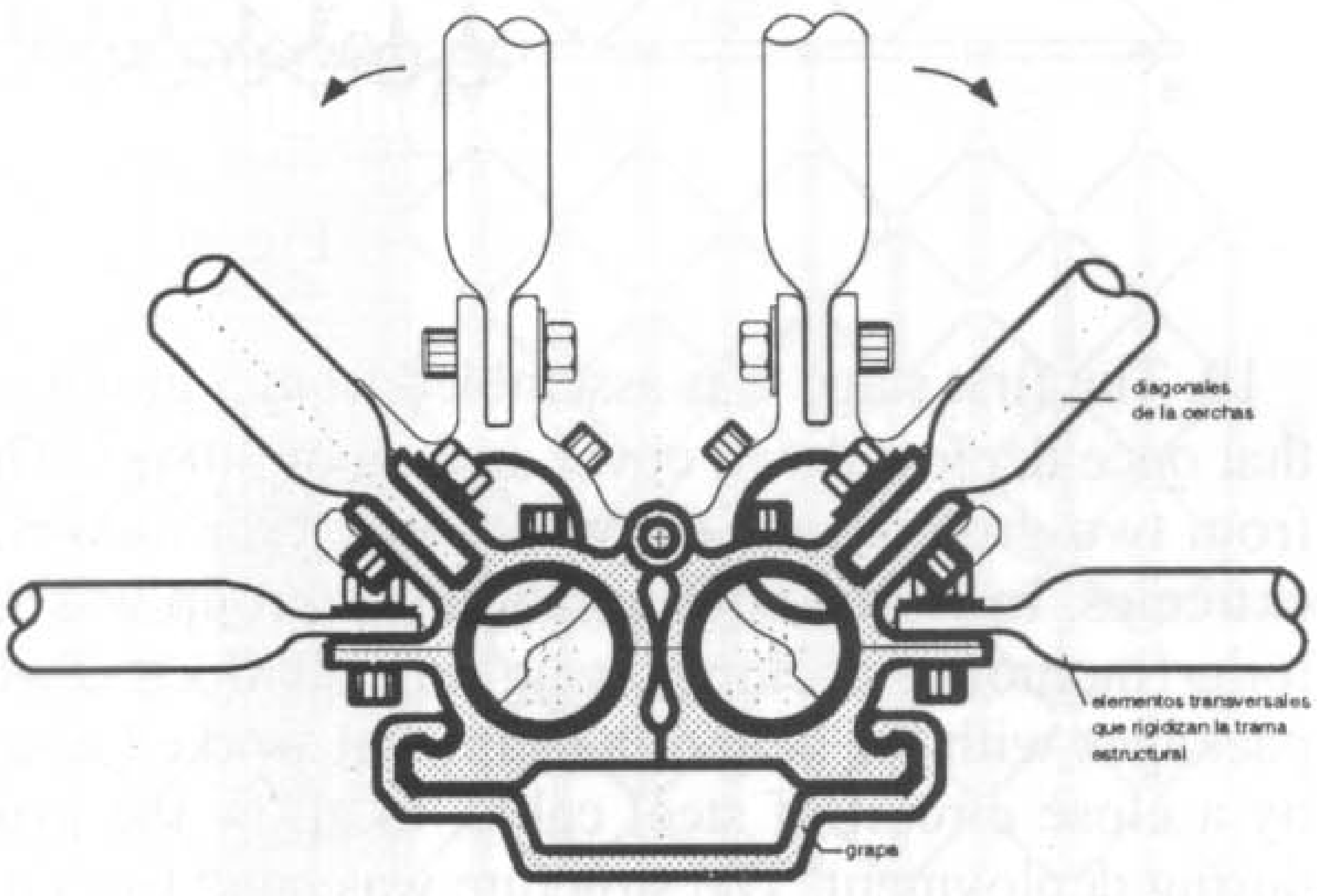

Fig. 8B.

18. For the rest of the components the use of standard production circular sections was considered, to simplify the production and lessen the construction time. Consequently, the trusses are made up of continuous tubular elements, on which the hinged nodes are fixed at 2meter intervals. The diagonals are tubular elements, flattened at the ends, that are bolted to the node leaves. The trusses are positioned parallel to each other and are joined by the nodes in an alternating way. The first truss is connected to the second at the inferior string, and the second with the third at the superior string, and so on, so that the trusses can rotate 45 degrees with respect to each other, allowing extension or folding as an accordion, forming a package to be shipped to Seville (Fig. 9). The process of the roof erection was undertaken according to the geometry of the audio-visual room and to the possibility for mobility on site. Because the superior plane required an intermediate support from the projection room, the erection process was divided into two stages. Stage A that covers the waiting area and the projection room, and stage B that corresponds to the audio-visual room, using the top of the projection room for the rotation axis.

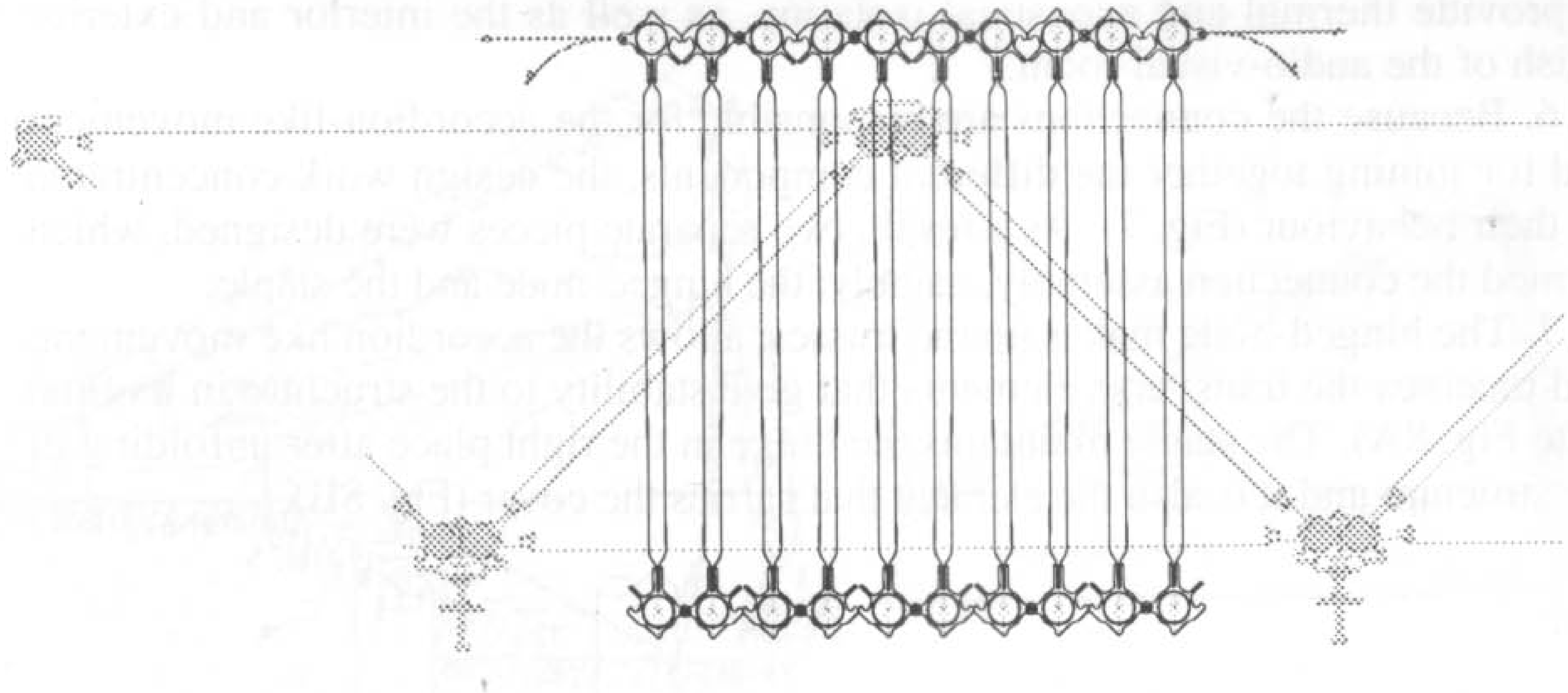

Fig. 9.

19. The first stage was assembled from a group of twenty two 13m long trusses that once deployed will cover an area of 308m^2. The second stage was assembled from two groups each of twenty two 18m trusses, joined together at one of the extremes. In closed configuration this group was 3m high, 2.8m wide and 18.8m long (including packing) weighing 8000 kg. Two cranes were used to lift the packages with the help of a beam that worked as a rail for several trolleys joined by a close circuit of steel cable, to allow the symmetrical movement required during deployment. The structure was hung from trolleys and placed in the centre of the beam deploying in both opposite directions (right and left) in a movement similar to that of opening a vertical curtain held by its centre, thus changing from the initial close dimension of 2.8m (part A, Fig. 10) to the final developed size of 22m wide (part B, Fig. 10)

20. Once the structure was suspended and unfolded, it was fixed to avoid its refolding. This movement was restricted through the use of staples in the nodes. Some tubular perpendicular elements were used as well in the trusses to guarantee the side stability of the structure and the aperture size. All these operations were undertaken while the structure hung from the crane. Subsequently, the net was put into place, already set in its final configuration. In the case of the first section, this was put on top of the anchors on the square, inclining it until it reached the projection cabin (Fig. 11). Likewise, the second section was positioned the same way, which included, as mentioned before, two planes folded on themselves from the top, from which the structure was suspended and unfolded. The structure was made rigid, by using the staples and transverse elements. Subsequently, the structural net was moved vertically until the extreme of one of the two planes rested on temporary supports placed over the projection room, which fixes the bottom seam in place and permitted its rotation (Fig. 12). Then the beam was moved, inclining the structure to the rear wall. This movement permitted the two planes to separate, forming an inverted "V". Subsequently, the other plane took its

final position attached to the anchors on the rear wall (Fig. 9). Finally both nets were connected and the temporary supports from the projection room were taken away.

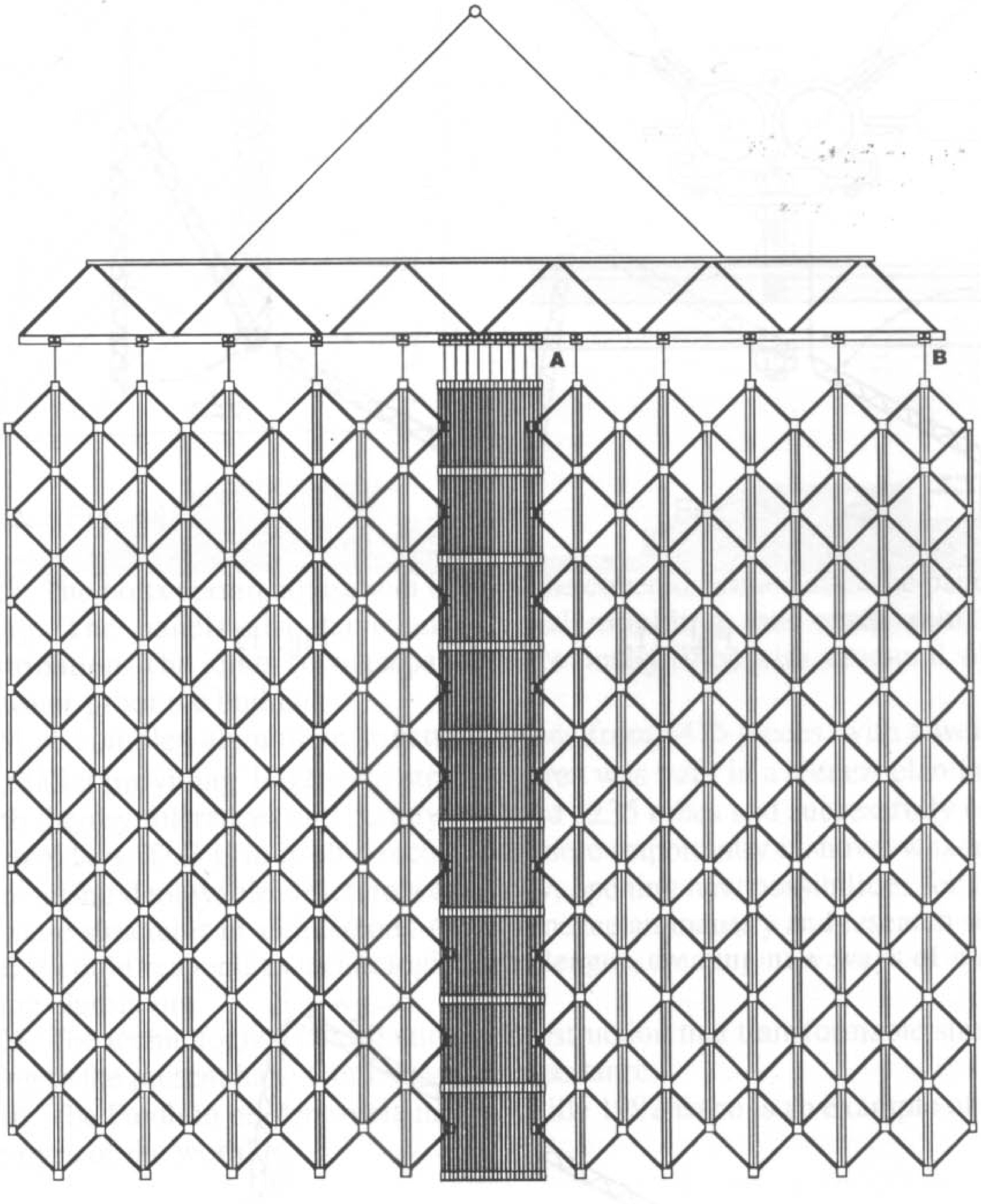

Fig. 10.

21. The system of light panels were then added to the structure. Each panel is composed of an exterior moulded surface, made of polyester resin reinforced with glass fibre 3mm thick, with a light grey gel-coat finish, and an interior surface made up from a galvanised steel sheet, 0.7mm thick, which is covered by a film of dark grey polyvinyl chloride. The interior is made from rigid polyurethane foam, see Fig. 14.

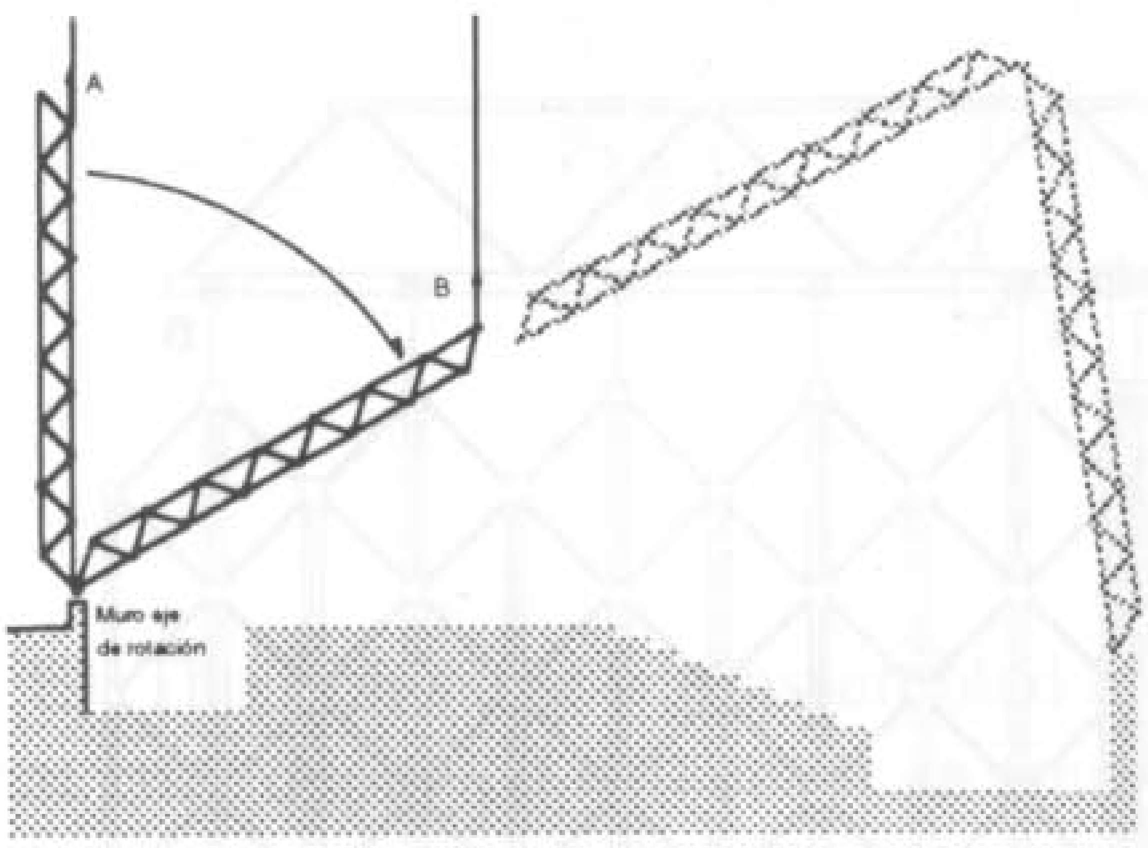

Fig. 11.

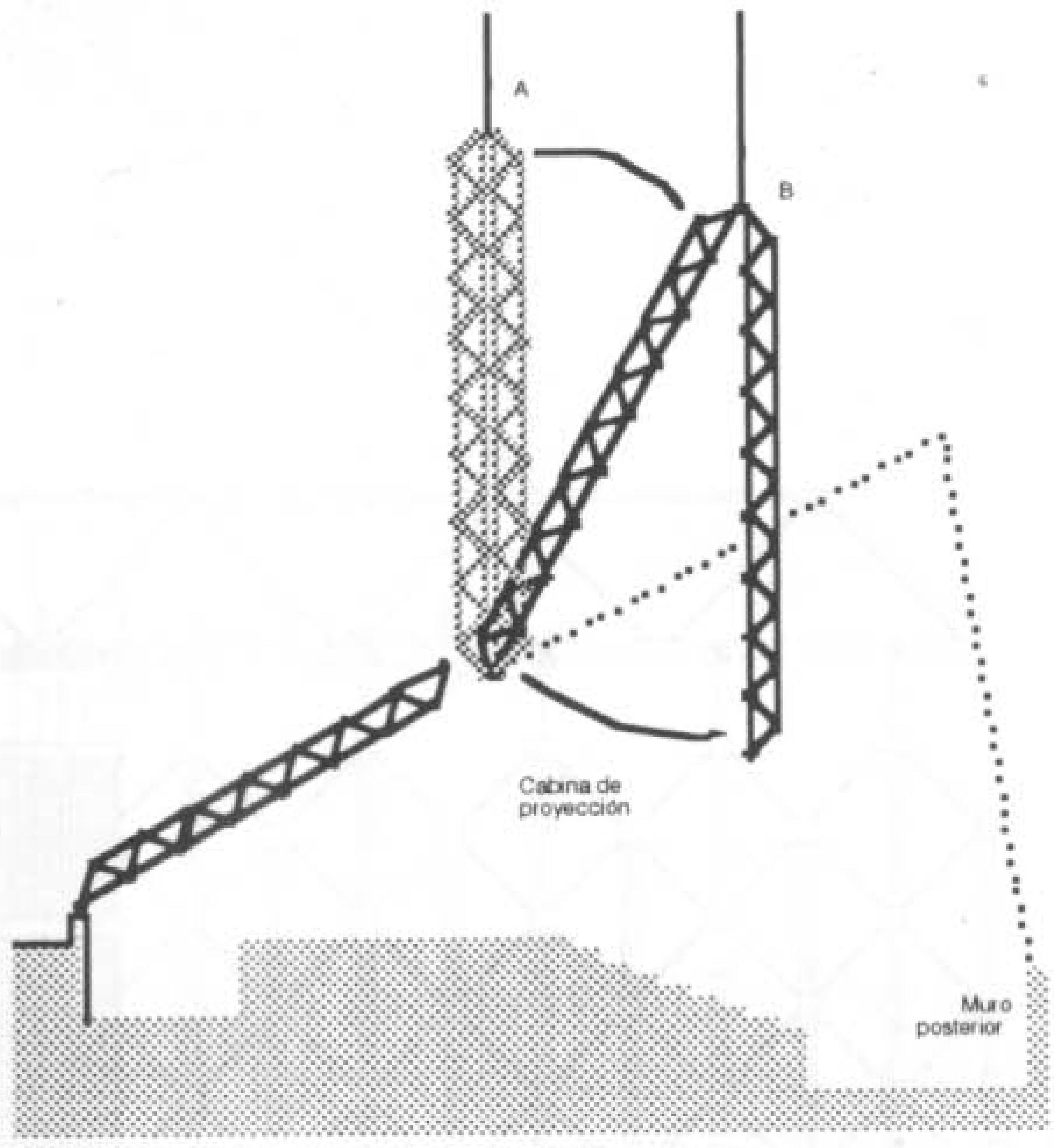

Fig. 12.

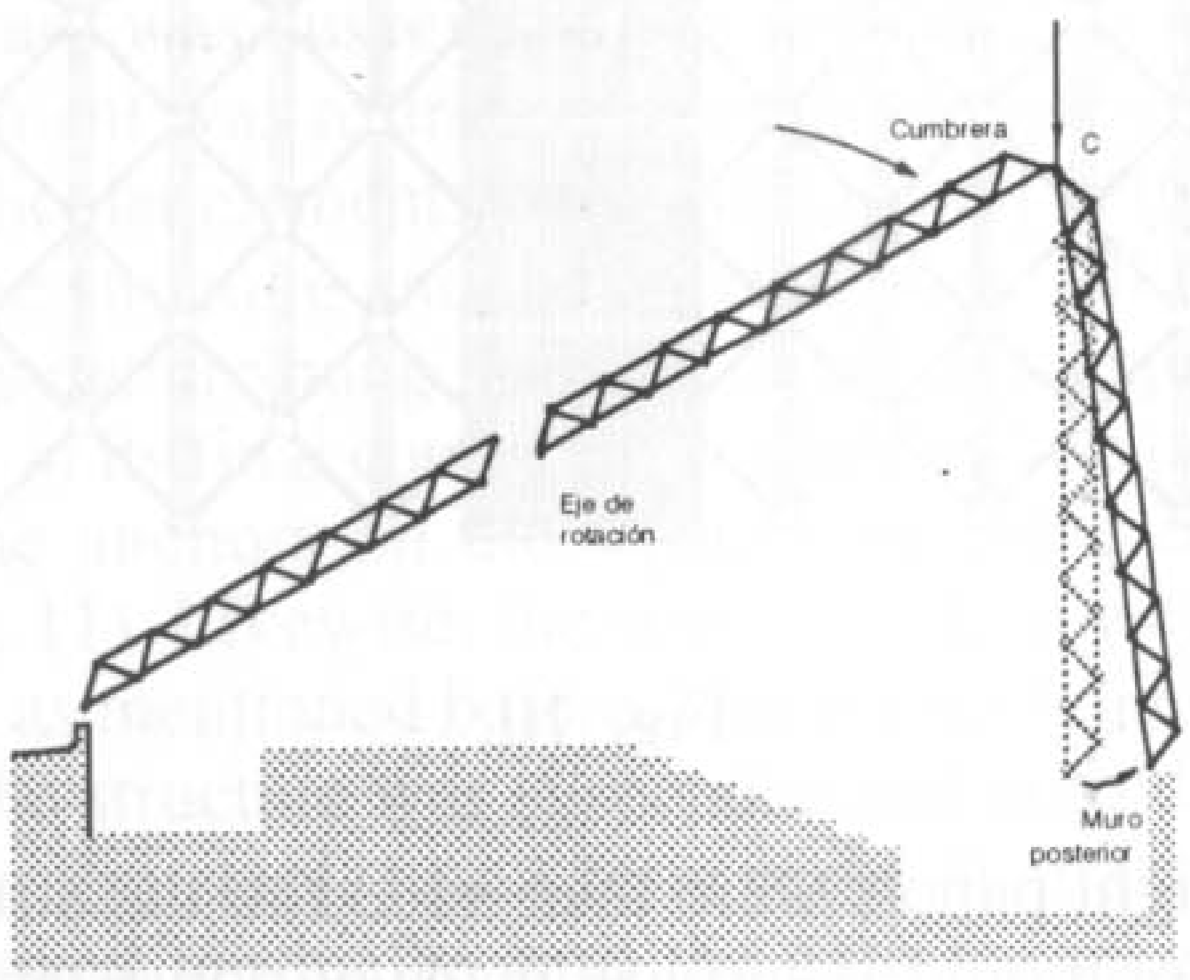

Fig. 13.

22. The panels are suspended from the structure's nodes by adjustable bolts. These bolts support tubular elements, on top of which the panels rest (Fig. 15).

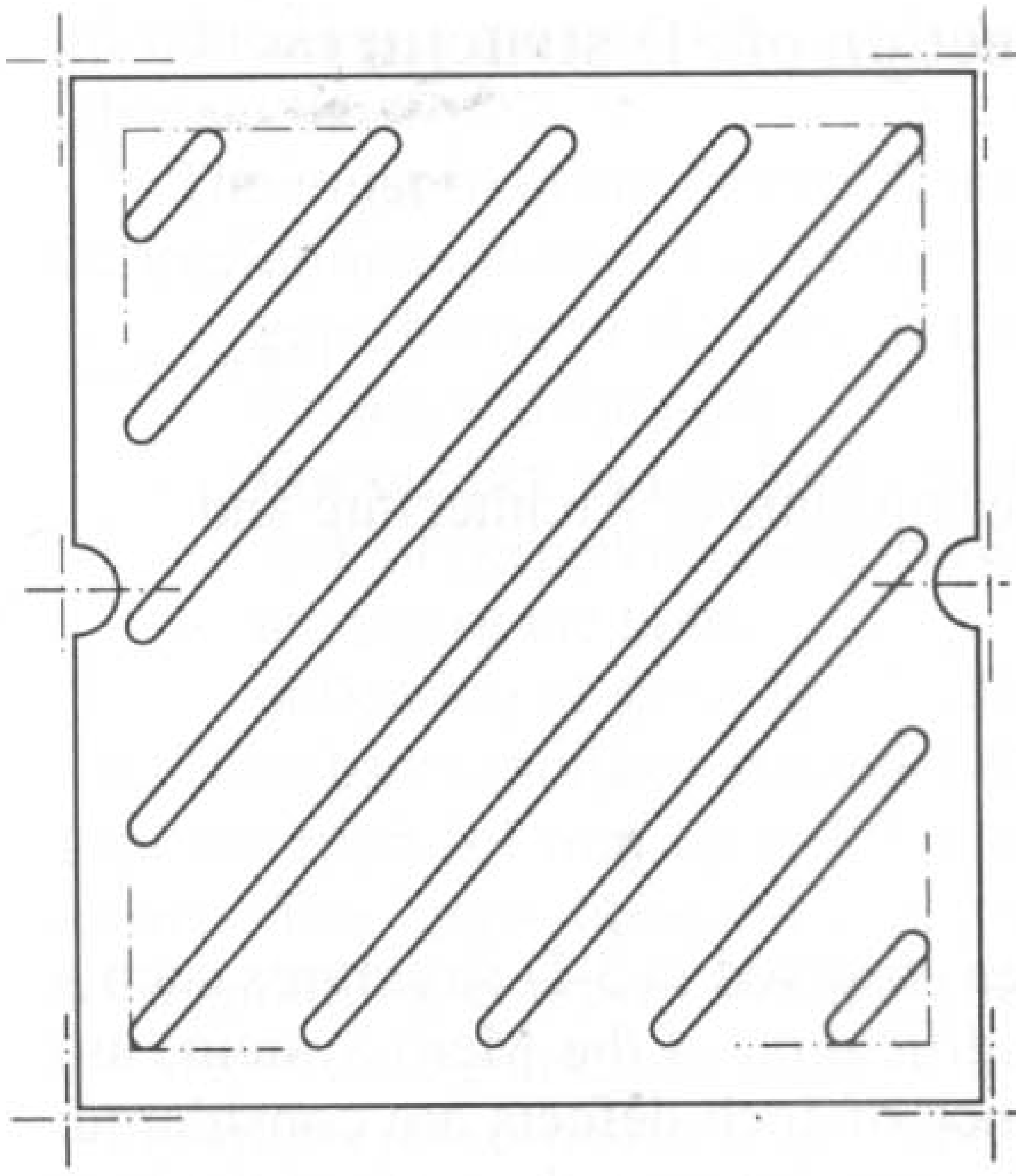

Fig. 14.

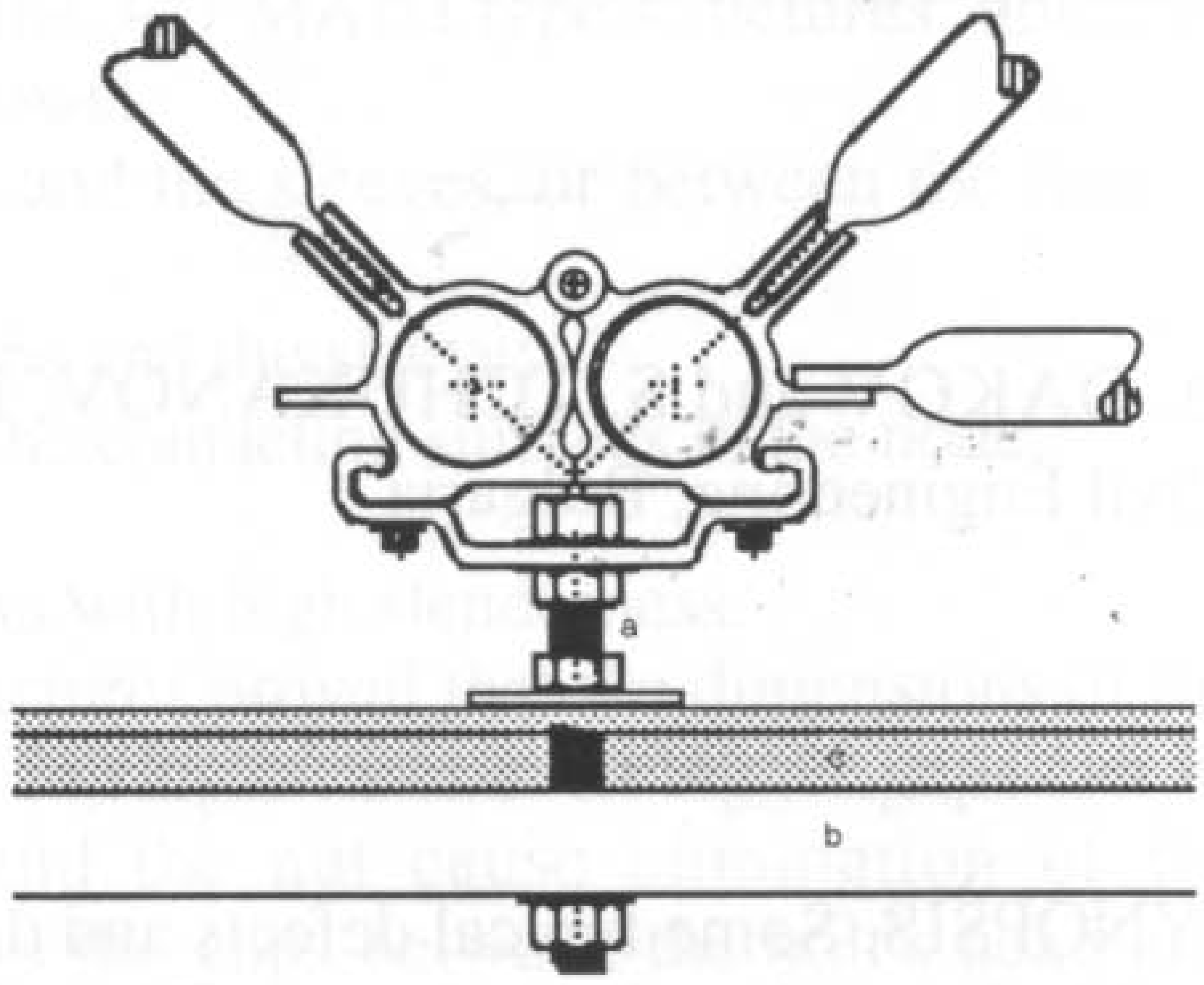

Fig. 15.

23. The bolts permit adjustment to level the covered surface after the panels are hung. The panels also have an external moulding that eases rain water distribution. The joints between panels were finally filled with structural silicone to water-proof the building.

24. A complex aluminium structure formed from 6475 pieces, with a weight of 10,000kg providing 1242m^2 of structure area was built in a Venezuelan factory, with factory tolerances and quality, shipped 5235 miles and successfully erected in two days. This is in itself a record, but more importantly it shows what can be done using deployable structure technology, opening new possibilities for the use of these structures in architecture. Also, Venezuelan industry and research showed that it could respond to technological challenges, creating new ways of building using aluminium.

25. The technological contribution to construction that transformable structures bring to the present have transcendental importance.

26. The Pavilion of Venezuela in the Seville 1992 Expo is an example of this in the eyes of the world.

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