FLORÍN SYSTEM

Double layer spatial deployable structures, with frames of rhombuses and scissors

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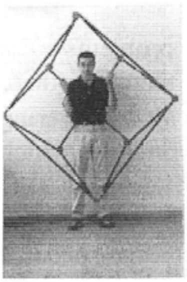

1. Principles

When our wandering ancestors made tents, they strived for two essential qualities: light weight and the ability to be folded and unfolded quickly. They used the materials at hand and reached their partial solutions slowly, by trial and error.

This is still the situation today. But now we enjoy many advantages denied to our ancestors: we have new natural and synthetic materials, and composites made from them; we have advanced fabrication procedures, understand the principles underlying spatial bar structures, and have powerful computational techniques.

Our country, Spain, has a tradition of deployable structures. We remember Emilio Penez Pinero's achievements of 30 years ago. When still a student, he surprised Buckminster Fuller with a four-scissors dome which was completely and easily packable and deployable. At a time when large spans were controlled by fixed

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spatial tensioned structures, and shells were rejected because of their construction costs, an architect had appeared who was able to carry a 'folded building' to the site where it was needed and mount it quickly. This was an important achievement for recreational events, although the geometry, nearly always spherical, left much to be desired; usually the buildings were merely 'covers that rest on the ground'.

Later, other Spanish architects tackled these problems. In his doctoral thesis, Santiago Calatrava elegantly presents the well known *principle of rhombus unfoldability*. In his professional work we see 'parts' of a buildings which 'move' at certain moments, creating diverse sceneries, and showing the buildings as machines that can change shape. The team of Felix Escrig, Juan Perez Valcarcel and Jose Sanchez Sanchez studied simple-scissor meshes which form triangular and quadrangular modules, and obtained cylindrical and spherical geometries. They developed matrix calculation programs to analyse the stresses and movements in the deployed structure.

Elsewhere, there are many architects who have considered the problems from different viewpoints. Of those who have used rhombuses as basic elements, there is Hoberman with his Iris Dome, a deployable dome which, with its covering material, folds at an edge; and Pellegrino who established the principles which govern the foldability of flat multiangled rhombic meshes. There are other designers who continue to offer new ideas such as retractable covers, and tensioned structures which support fixed ones. Today, mounting speed is achieved by using one of two ways: bar deployable structures, and retractable structures. They can both be packaged; once deployed, retractable structures can be refolded telescopically and can have changeable shapes, as needed.

The system that we present (FLORIN, Reg. No 9701926) satisfies both requirements. We note that in the examples we have mentioned, in which the concept of deployment is used, the idea of a mechanism which turns into a structure is more important than the idea of a structure which can be a mechanism for quick mounting, or which can change its shape by means of a simple mechanical or manual operation. The invention which is being presented follows the latter line: a structure which can become a mechanism. Since it is prefabricated and industrialised, it can be made to satisfy stringent control criteria. Not only it can be folded and unfolded easily, and can be packaged efficiently, but it can be mounted in any intermediate positions, as needed.

The invention is a system for the construction of deployable structures; it is composed of layers of rhombic and scissor-like meshes with variable angles.

2. The importance of the system

All the structures that can be built with the modules which will be described later follow the same lines. They are buildings, or parts of buildings, which are built from two sheets of rhombic and simple scissor modules. These can be mounted quickly and can be changed in shape.

The use of two layers has a double purpose: it allows the introduction of two clearly distinguishable architectonic elements, ceiling and roof; it increases the bending stiffness of the element. The use of two layers distinguishes the invention from earlier ones. The distance between the two layers provides the bending stiffness. In the system that we present, this distance is established *a priori*. This is in contrast to other scissor-like structures which must be left partially unfolded to achieve the correct thickness; such structures are highly deformable.

Once stabilised, the structure can be compared to a mesh formed by pyramids held together on the layer formed by the lower joints, or to a mesh formed by strips of frameworks in two orthogonal directions.

3. The elements

The modules are constructed from bars and joints. The bars usually have tubular cross-section, their wall thickness and section geometry are chosen according to need. The joints are specially designed for the invention to provide the precise movements needed for the module, and to provide the required strength and stiffness.

The elements may be fabricated from various materials. The bar material may be light alloy (mainly aluminium), polymer, laminated wood, or even bamboo. The joint material may be galvanised steel, light alloy or polymer. Covers may be made from textiles or plastics.

4. Definition of the elemental module

The module is based on a rhombus, defined as an element with a single scissor degree of freedom in the plane. To maintain foldability and stiffness, each side of the rhombus has two diagonal bars; these lie in the plane perpendicular to the plane of the rhombus, and intersect at the projection of the mid point of the bar. The elemental module is completed by joining the four ends of the diagonal bars to form simple scissors in the plane parallel to the rhombus. The various geometries, flat, cylindrical or spherical, are obtained by joining two elemental modules, or variations of this by the vertices of the higher rhombus and the lower points with simple scissors; different relative lengths of elements lead to different geometry.

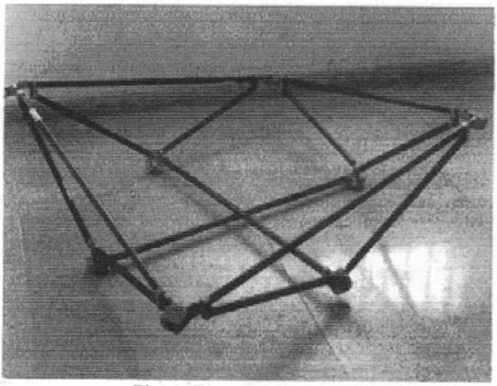

Fig. 1. Elemental module.

5. Flat meshes

These are the easiest. All lower scissors have the same length. A joint consists of a plate with four holes where the bars articulate, allowing them to rotate about the axes perpendicular to the plane of the mesh. Rectangular and circular arrangements can be designed. Rectangular meshes fold in two directions, parallel to the sides of the rectangles; they may be designed to stay flat, or to divide into two meshes which rotate as the structure folds. Circular arrangements fold to the perimeter, a polygon whose shape depends on the number of rhombuses used.

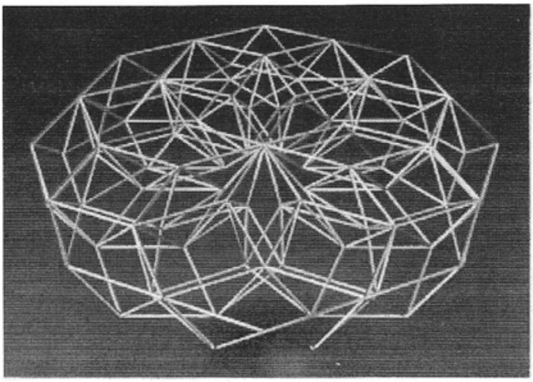

Fig. 2. Circular flat frame.

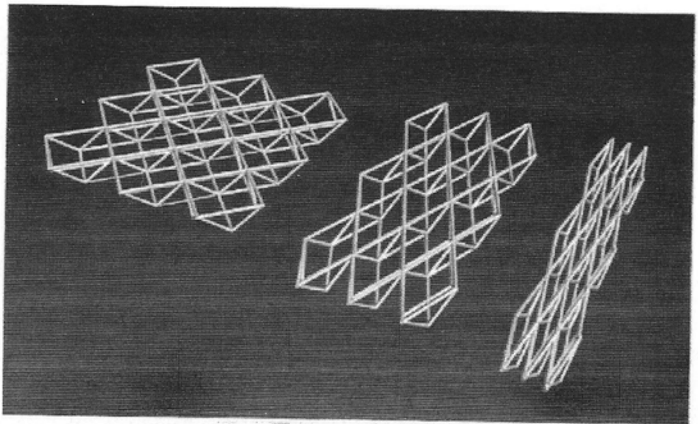

Fig. 3. Rectangular flat frame.

6. Cylindrical meshes

These are obtained by altering the elemental module. The two triangles which form a rhombus in the upper layer are turned (higher layer), and the scissors in the lower layer are shortened (lower layer). The elemental module so obtained may be adapted to form cylindrical structures with various cross sections.

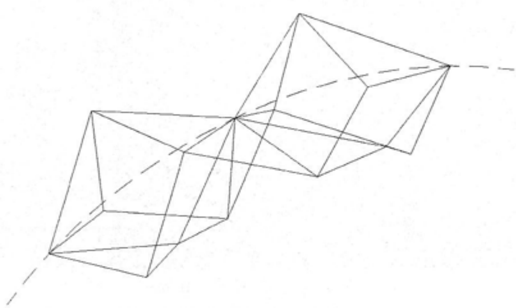

Fig. 4. Cylindrical modules

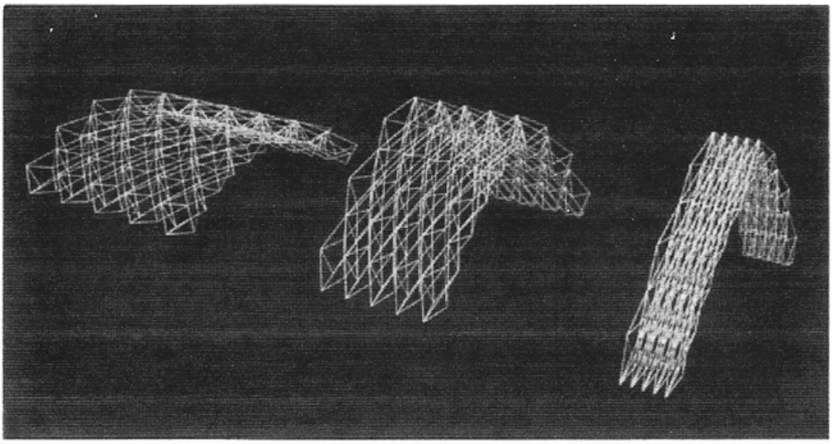

Fig. 5. Cylindrical frame.

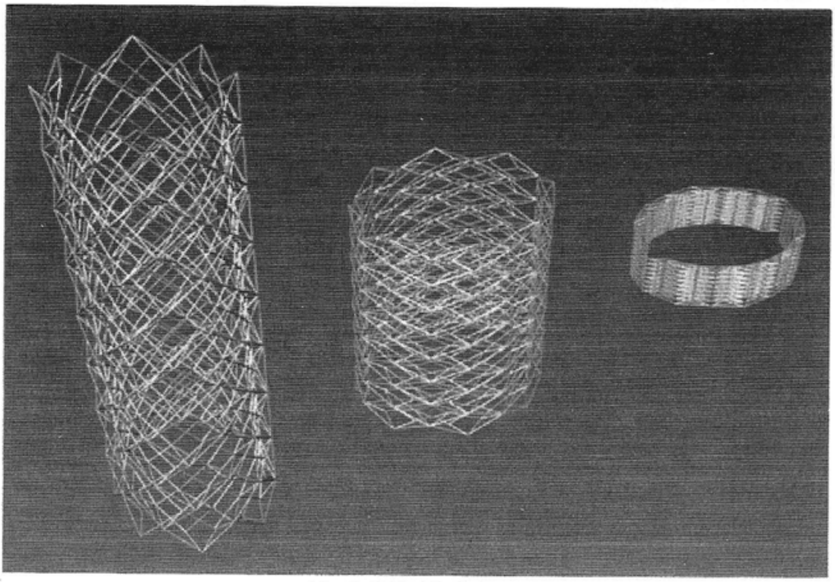

Fig. 6. Cylindrical tower.

Cylindrical meshes may be used as covers for buildings; they may be built easily and quickly.
They can support a single cover for mild weather. Alternatively, they can support a double layer, rigid plastic on the outside and textile on the inside. Such a double layer provides hygrothermic insulation with ventilation between the layers.

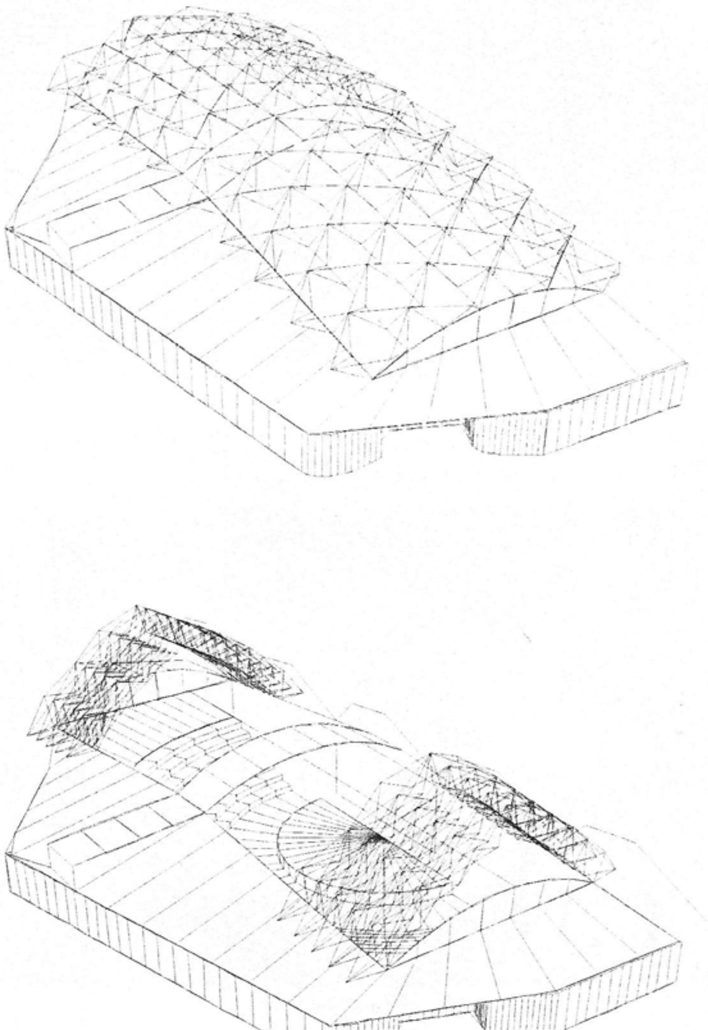

Fig. 7. Theatre in Gines, Sevilla, España (Project)

Fig. 8. Stage "Nadoca", Expo Lisboa'98 (Project)

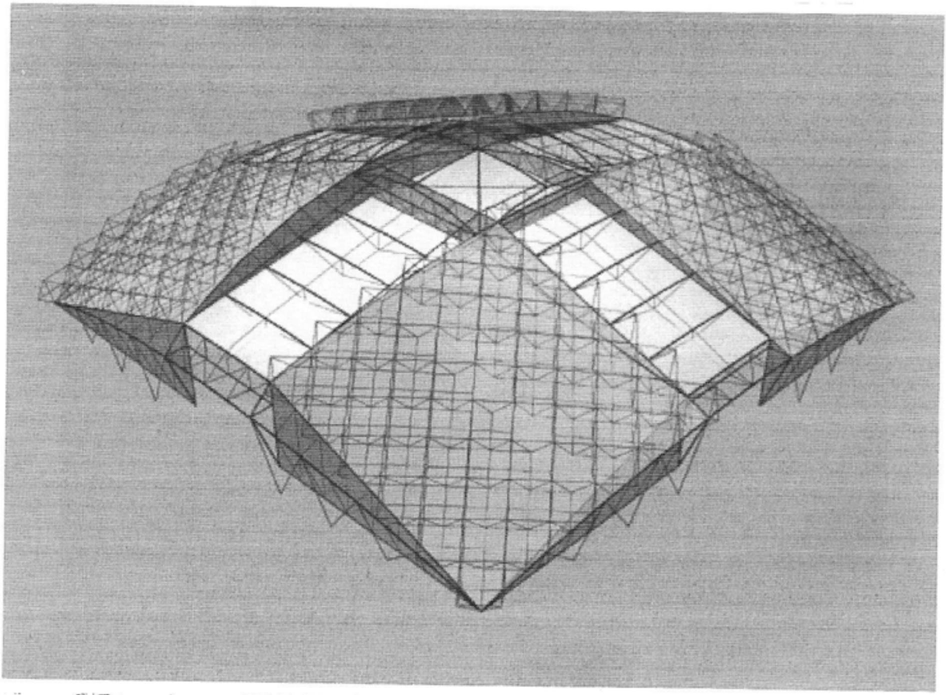

Fig. 9. Opera Theatre in Expo 2000, Hannover (Project)

7. Spherical meshes

These are obtained by another modification of the basic elemental module (joining them with different degrees of opening). They have applications similar to those of cylindrical ones; generally they are suitable for box-like structures, as illustrated in the diagrams.

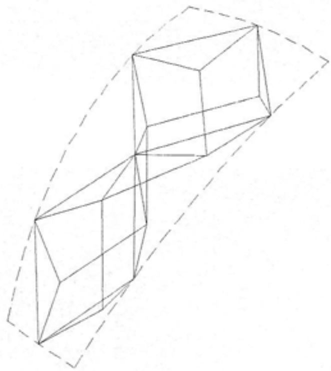

Fig. 10. Spherical modules

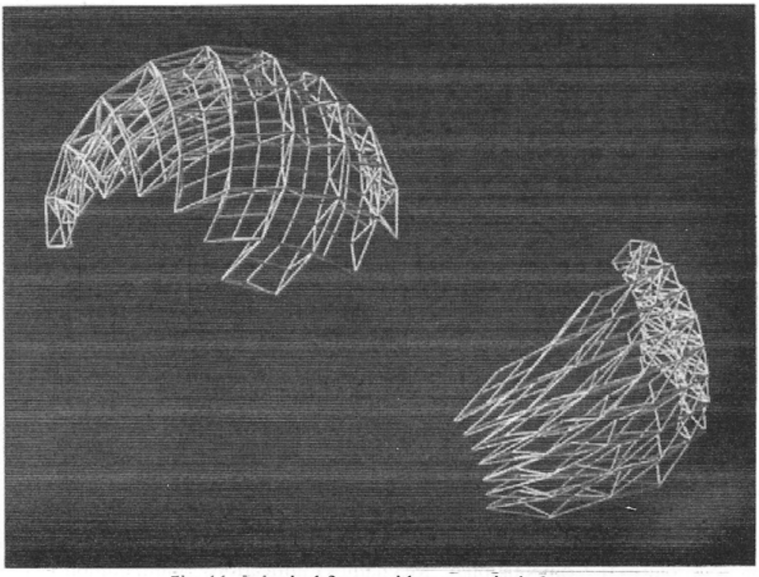

Fig. 11. Spherical frame with two vertical planes.

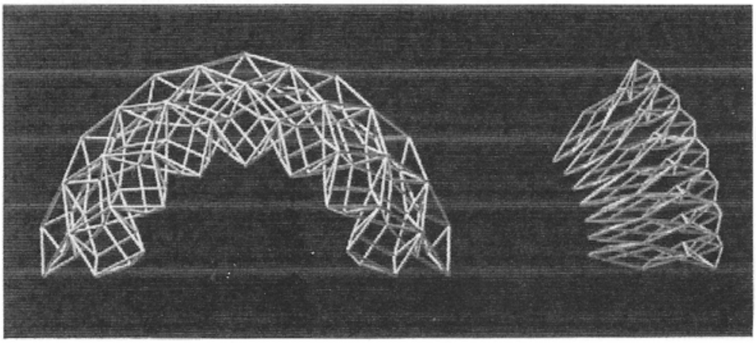

Fig. 12. Spherical frame with two vertical planes, front view.

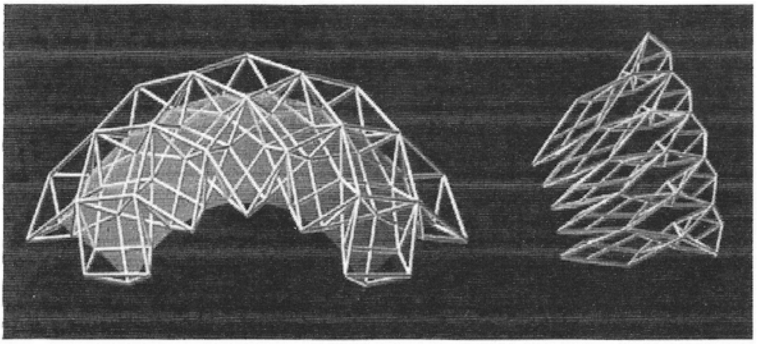

Fig. 13. Spherical frame with four planes. Front view.

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