Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)

System for the construction of double-layer deployable structures: processes of formal definition

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Abstract

The following communication displays the development of the last results of a research which started in 1996.
Our aim is to develop two-layer deployable structures which allow us to give solution to diverse geometrical shapes (flat, of simple and double curvature) for covers and walls.
For the resolution of the different proposed geometries we have used modules based on the compatibility of movements of rhombuses and scissors.

1 The system

In 1996 the authors of this communication developed a system denominated *Florín: System for the construction of deployable structures of two layers, based on meshes of multiangled rhombuses and scissors* [1] [2] [3].
This was patented in 1997 (Florín, N° Reg. 9701926). From the beginning it was conceived both for the construction of complete buildings, and for covers and walls. Its construction is carried out in workshop using tubes of diverse materials according to the case (organic, metallic and synthetic) and joins also patented. They present double layer, and for this reason deflections are controlled from their design process, depending on the foreseen loads and they allow the assembly of double covering material, controlling thus the required level of isolation. Besides, it maintains a controlled perimeter during their folding/unfolding process and the structure, once folded, occupies a minimum space.

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All the generated geometries (flat, of simple and of double bend) are based on the repetition of an elementary module. This, is defined starting from the combination of a rhombus and a scissors. If the mid points of the sides of a regular rhombus are joined in an alternating way with a scissors with sides of the same length as those of the rhombus, a mechanism with one degree of freedom in the plane is obtained. If the rhombus and the scissors are separated by a preset distance (thickness of the structure) and they are joined using diagonal bars that go from the ends of each bar stretching to the projection of the midpoint of these, by means of appropriate joins, we can achieve again, a mechanism of one degree of freedom, but in the space (Fig. 1).

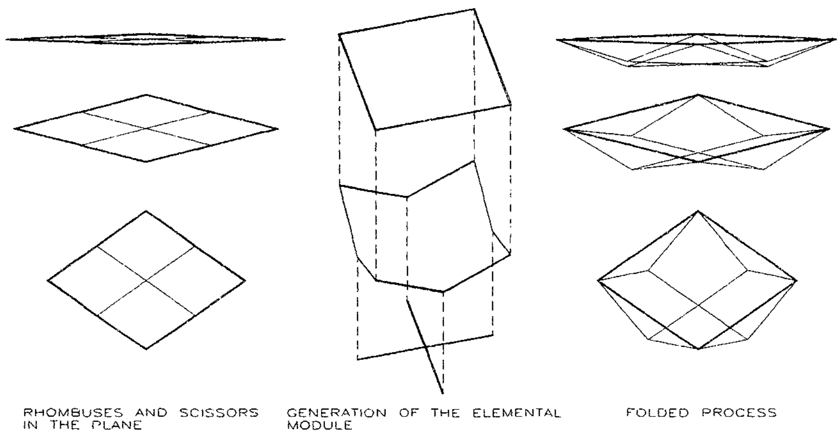

Figure 1: Generation of the elemental module.

Therefore, the higher layer is conformed with rhombuses, and the lower one with scissors. They join together both by means of diagonals at a preset distance that allows to control the deflections that it will undergo the structure.
Diverse variations of this module, generated this way, as for the similarity of lengths between the bars of the higher layer and of the lower one, their angled and way of union, will propitiate the different geometries that are been analysed.
When the structure is conceived as a cover or wall, the supporting and rolling elements, necessary for the process (folding/unfolding) and the change in shape that the structure experiences must be foreseen. That is why it is necessary to control the possible perimeter variations that the structure can experience in the definition of the formal configuration of each one of the proposed geometries.
When the system is used to build a complete building, an auxiliary structure is used, also collapsible, and the diverse elements constituted by cloths of deployable structure can be mounted on it.

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For the creation of the different shapes, software have been developed.
Next a sample of the different analysed geometries, and of the concrete applications that the authors have projected are proposed.

2 Flat meshes

They are obtained starting from an elementary module in which the lengths of the bars of the higher layer and of the lower one coincide. The complete mesh is obtained joining the different modules by the joins of the higher layer and using scissors of same length that join the joins of the lower layer. That is why the angles of the rhombuses and scissors are identical during the process of folding/unfolding of the structure. Seen this way, we can know the shape of the structure for any opening angle (Fig. 2).

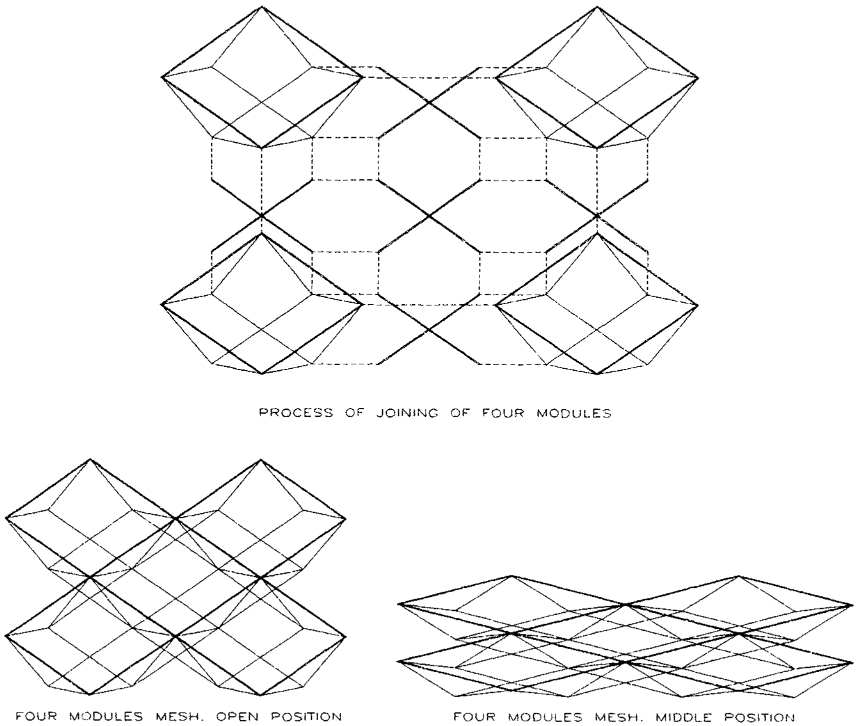

Figure 2: Generation of flat meshes.

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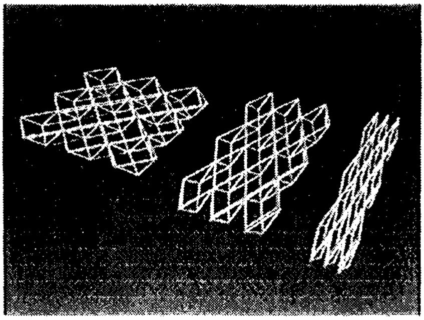

Figure 3: Rectangular flat mesh.

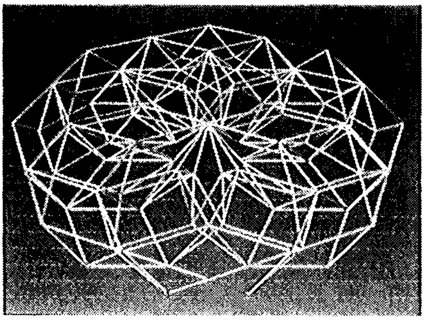

Figure 4: Circular flat mesh.

Two types of meshes have been developed: rectangular and circular (Fig. 3 and 4). Among the rectangular ones, we have distinguished two types: those that present a fixed perimeter during their evolution, and those that don't present it.

2.1 Rectangular meshes with fixed perimeter

We can see in the above figures that during the process of folding of the structure, it grows in a direction that is perpendicular to the movement. If the supports are not prepared for this dimensional variation, the structure could only be mounted once deployed. To avoid this, the following solution is proposed for these situations. The mesh is divided into two parts depending on symmetry axis parallel to the direction of the movement. The number of modules at each side of the axis must be equal and even. The lower crosses that join the modules at each side of the axis are eliminated. For this reason the mesh can be assimilated to a flagstone resting on two supports with continuous articulation in its symmetry axis (Fig. 5).

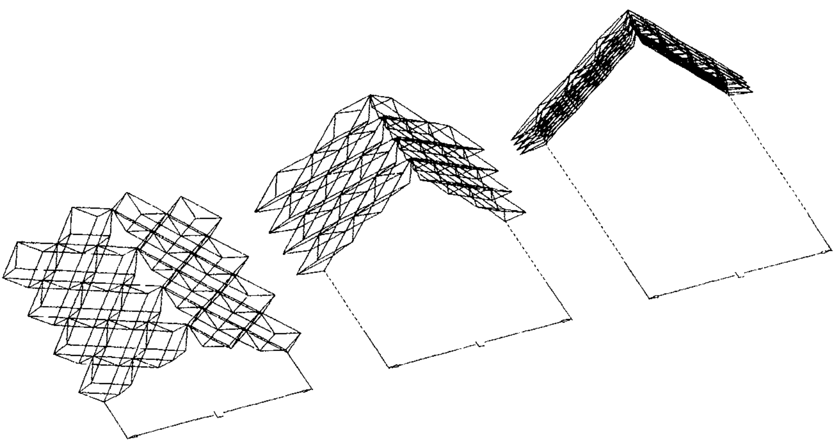

Figure 5: Rectangular mesh with fixed perimeter.

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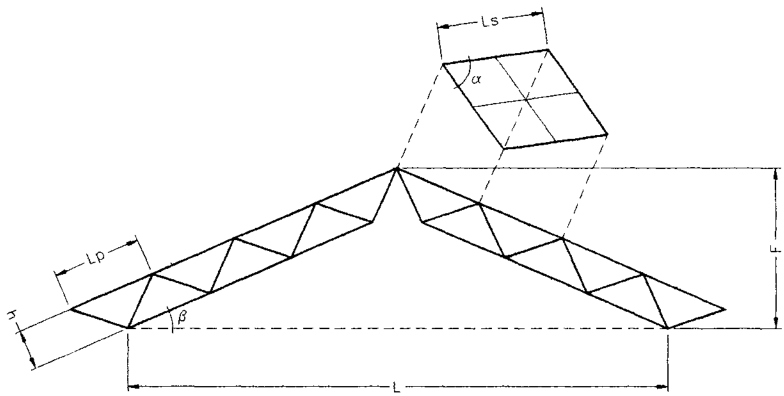
Built this way, maintaining constant the distance between the supports, in their evolution, given the increment of length, the structure is raised a dimension that depends on the final angle of opening, according to the following expressions. Their final form, according to project, can be flat or inclined gablelike.



Known F, L, h and F_r (being F_r = 2modules - 1):

$$L_p = \frac{2\sqrt{F^2 + \frac{L^2}{4} - h^2}}{F_r}$$

$$L_s = L_i = \frac{L_p}{\cos\frac{\alpha}{2}}\ ;\ L_d = \sqrt{\left(\frac{L_s}{2}\right)^2 + h^2}$$

$$\beta = atn\frac{2F}{L} - atn\frac{2h}{L_p F_r}$$

Figure 6: Developing of mesh with fixed perimeter.

2.2 Rectangular meshes with variable perimeter

In the previous section it was already noted how in the case of using continuous meshes, these increased their dimension during their folding process. An immediate application is using it as deployable clothes to be used as covers or walls that once open, are mounted. In this case, they would not be able to be propelled.
However, there are buildings that would need a fixed cover together with a mobile one (sport stadiums, bullrings, etc.). If the fixed part is big enough to accept this change of dimension in the mobile cover, this can be built without necessity of raising its midpoints. We have studied cases of compatibility with circular plant. In these cases (using the proposed expressions) the dimensional variation of the structure and the minimum dimension of the supporting structure, have been analysed using the next expressions (Fig. 7).

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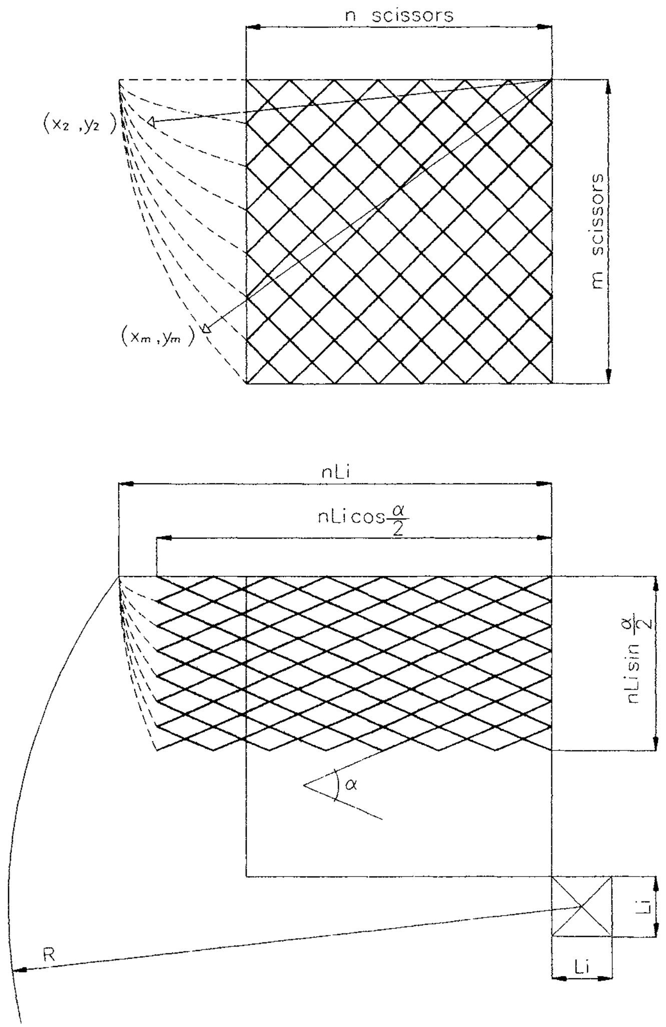

$$\frac{x_m^{\ 2}}{n^2 L_i^{\ 2}} + \frac{y_m^{\ 2}}{m^2 L_i^{\ 2}} = 1$$

$$R = \sqrt{\left(nL_i + \frac{L_i}{2}\right)^2 + \left(mL_i \frac{\sqrt{2}}{2} + \frac{L_i}{2}\right)^2}$$

Figure 7: Evolution of the perimeter and compability with circular plant. (Lower layer).

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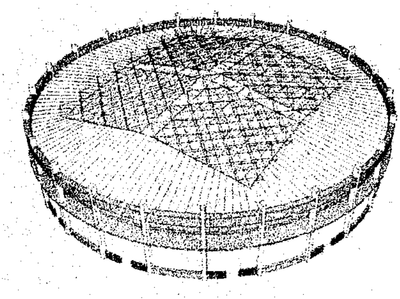


Figure 8: Example (close position).

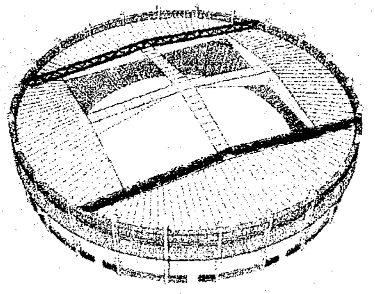
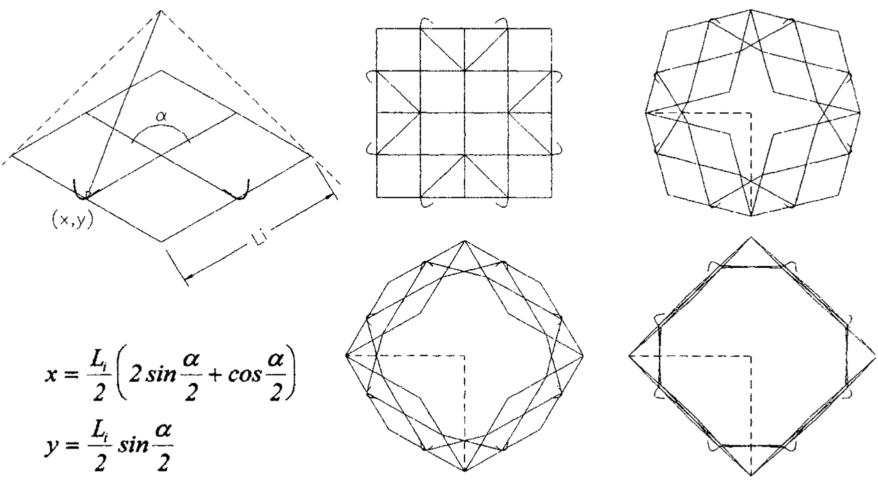


Figure 9: Example (open position).

2.3 Circular meshes

They are obtained by joining modules similar to the previous ones, but with different opening degree, adapted to a concrete circular sector. The structure this way conformed is folded towards the thickness having in their closed position a perimeter similar to the one it has when it is open, but rotated an angle with measures half of the sectors of the angle which defined it.

The lower scissors that join different modules cross in a point different from the middle that is variable along the evolution of the structure, and that it is necessary to keep in mind in the definition of the join. A mesh formed by four sectors is studied as a sample (Fig. 10).



$$x = \frac{L_i}{2}\left(2\sin\frac{\alpha}{2} + \cos\frac{\alpha}{2}\right)$$

$$y = \frac{L_i}{2}\sin\frac{\alpha}{2}$$

Figure 10: Circular flat mesh with four modules

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3 Cylindrical meshes

They are based on the adaptation of the mesh to a certain curve, defined according to a polygonal one, with a preset number of sides, and a relationship rise/span, also preset.
Their formal configuration is generated starting from an elementary module based on the previous ones. In order to get that a line of modules adapts to a concrete bend, the four bars that conform the rhombuses of the higher layer cannot be in the same plane. They should belong to two planes that have been rotated a certain angle. Therefore, since the higher layer was configured as rotated virtual triangles, both the length of the scissors of the lower layer and its angle, are different to that of the bars of the higher layer. Knowing these dimensional variations starting from the geometry of the curve inscribed is essential when defining the meshes.
In the same way, the relative angles that form, according to the horizontal axis the different bars of the structure, vary according to the evolution of these. That is why the design of the joins of these meshes is different to that of the flat meshes.
Figure 11 and the following expressions, clarify the above.
From this point of view, horizontal cylindrical meshes for covers, and vertical for walls and deployable towers, have been generated.
They have the advantage, as opposed to the previous ones, of possessing curved form so that the loadings are led in a quicker way up to the supports and the structure is less deformed, and thus, the thickness can be disminihed.
The meshes inscribed in a circumference arch with fixed borders are analysed as a sample. The points of the modules that converge in the axis of symmetry of the mesh have been articulated again in order to generated them, so that the folded solution presents certain raising with regard to the deployed solution.

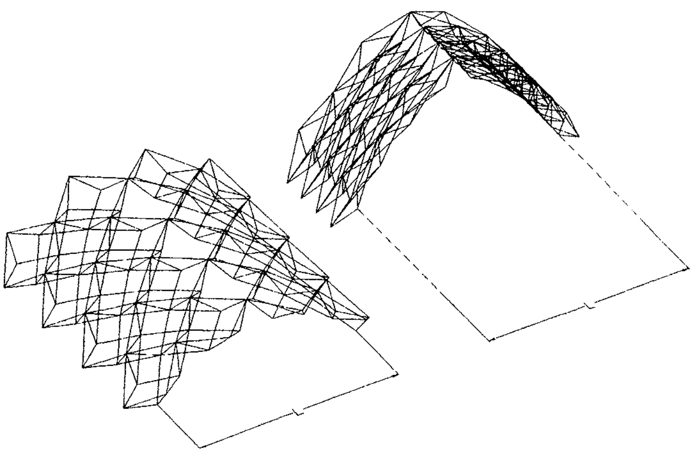

Figure 11: Cylindrical meshes.

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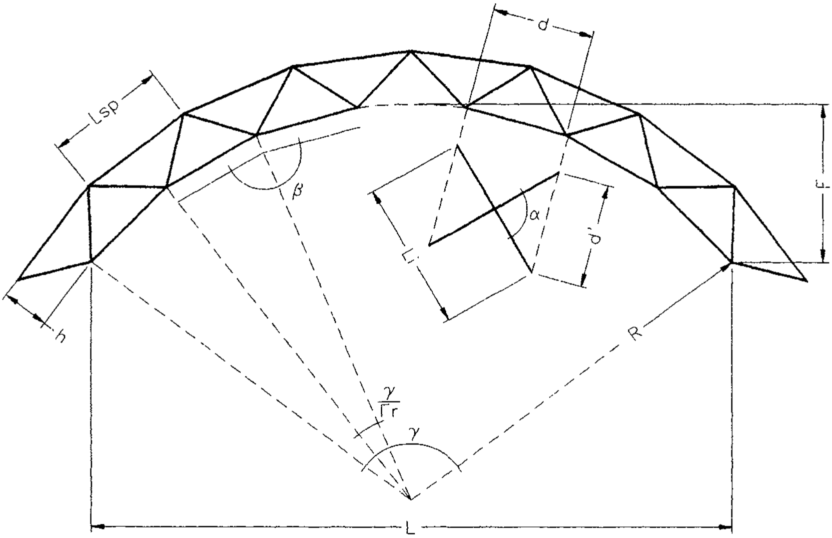
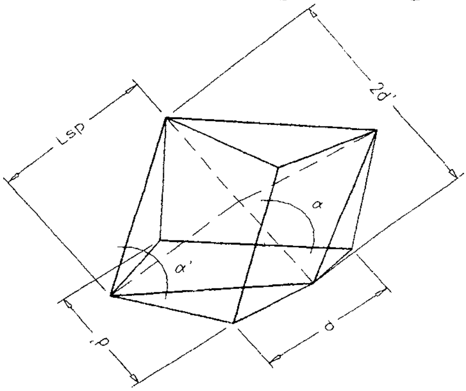


Preset position, known F, L, h, α_o, Fr (being F_r = 2modules - 1):

$$\gamma = 4atn\frac{2F}{L}\ ;\ R = \frac{L}{2sin\frac{\gamma}{2}}\ ;\ d = \frac{L}{sin\frac{\gamma}{2}}\,sin\frac{\gamma}{2F_r}\ ;\ L_i = \frac{d}{cos\frac{\alpha_o}{2}}\ ;\ \beta_0 = \pi - \frac{\gamma}{F_r}$$



$$d' = L_i\,sin\frac{\alpha_0}{2}\ ;\ L_{sp} = \frac{d + 2h\,cos\frac{\beta_0}{2}}{sin\frac{\beta_0}{2}}$$

$$\alpha_0' = 2atn\frac{d'}{L_{sp}}\ ;\ L_s = \frac{L_{sp}}{cos\frac{\alpha_o'}{2}}$$

Figure 12: Developing of cylindrical meshes

4 Meshes of double bend

In the previous case the meshes of simple bend were introduced because they present a mechanical behaviour more suitable than the flat ones; those of double bend improve, even more, this aspect. The developed meshes are always based, in revolution geometries. So that once a sector is defined, the rest of the mesh is obtained by means of rotation of this around an established axis. To obtain sectors of double bend, we start from a certain geometry (synclastic or anticlastic) divided

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into a number of equal parts (lunes) around the revolution axis. To be able to coordinate the double bend, similar modules to the cylindrical ones are joined with different opening degrees. The scissors that join the points of the lower layer, between modules, are cut in points different to the middle. A spherical mesh (synclastic) and a toric mesh (anticlastic), ara shown as examples in fig. 13-14.

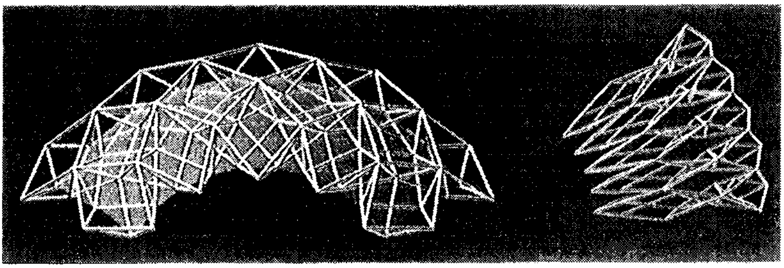

Figure 13: Spherical meshes.

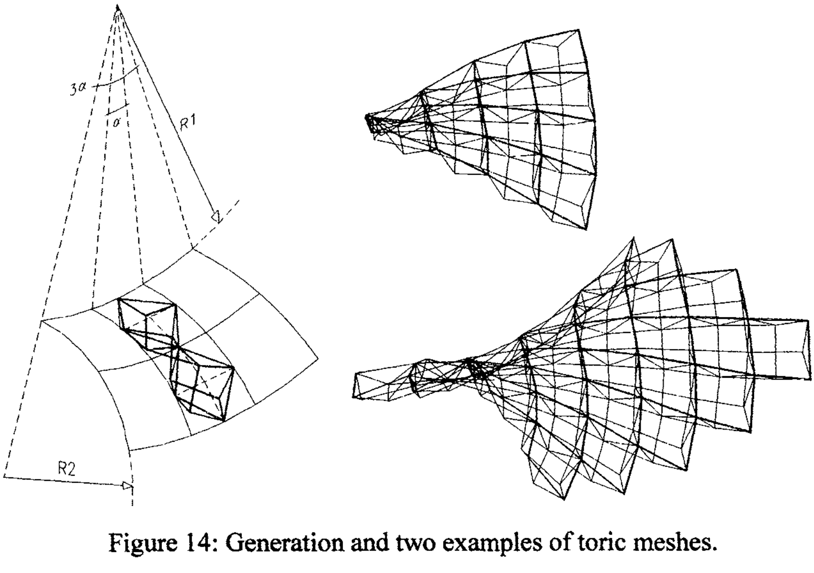

Figure 14: Generation and two examples of toric meshes.

References

[1] Gómez de Cózar, J.C. & García Diéguez, R. *Sistema para la construcción de estructuras estéreas de dos capas, desplegables, formadas por mallas de rombos y aspas multianguladas.* Patente de Invención, Reg. N° P9701926. España, 1997.

[2] Gómez de Cózar, J. C. & García Diéguez, R. Florín System. Doble layer spatial deployable structures, with frames of rhombuses and scissors. *Proc. of the Conf. on Deployable Structures: Theory and Applications.* Univ. of Cambridge, 1998.

[3] Sistema Florín. http://www.construnet.net/empresa/florinsystem.