New designs and geometries of deployable scissor structures.

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ABSTRACT
Deployable grids are not a habitual architectural option but they have a lot of possibilities. This paper intends to explain some of the keys to their functioning and thus the generation process used for building elements, something in which the authors have experience.

1 Basic concepts.

The easiest structures that we can build with deployable scissors are flat ones, constituted of bars of the same length and a hinge at the intermediate point. Curved grids will be obtained with an eccentrically placed interior hinge. A girder, as shown in Figure 1a, can be represented as in Figure 1b. A flat grid can be thus represented as in Figure 2. If we curve this grid in one direction we obtain a cylindrical mesh, as shown in Figure 3, forming a developable surface. If we curve the grid in two directions we obtain Figure 4, which cannot be developable. In both cases we can obtain complex grids capable of being deployed. Nevertheless, curved grids have geometrical difficulties that must be studied in order to obtain the simplest configurations.

In order to make it possible to adapt a deployable mesh to these grids, we choose the following criteria, shown in Figure 5:

1. The generator surface (cylinder or sphere) will contain all intermediate hinges “C” of the scissor. The nodes of the linear reticule will be “D” and the upper and lower joints will be placed along the radii going through “D”.

2. To make deployment possible \( l_{i-1} + k_{i-1} = l_i + k_i \) must be achieved

   Moreover, in the case of circular directrix \( l_{i-1} = l_i ; k_{i-1} = k_i \)

   That is like assuming that \( \delta_{i-1} = \delta_i = \delta_{i+1} = \ldots = \delta_2 \)
Thus

\[ l_i = l_{i-1} = \frac{R \sin \beta_i}{\cos(\delta + \beta_i)} \]

\[ k_i = k_{i-1} = \frac{R \sin \beta_i}{\cos(\delta - \beta_i)} \]

As the radius is variable in the different phases of deployment we can take its magnitude in the initial and final positions where it is necessary to fix the “\( \delta \)” angle of opening the scissor. \( \delta_i \geq \beta_i \) is a necessary condition to make deployment and folding possible because, if not, the structure returns by a different path and does not work (Figure 6). The single additional problem for cylindrical squared meshes is the lateral deformation of each rectangle, a problem that can only be solved with diagonal bars in the flat of the square.

The generation of spherical reticules can be done by different methods.

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2.1. GRID WITH EQUAL LENGTH BARS. In this case we can trace spherical segments on the surface with the same defined length, or the same angular opening, to define a structure with an equal length bars structure. We can start at any point on the sphere with four segments in all joints (Figure 9) or more than four for the starting point as in Figure 10. The model of figure 9 has been built in two 30x30 sqm roofs, as shown in Figure 11 and published extensively [Ref 6].

![Figure 9. Spherical grids with equal bars.](image1)

![Figure 10. Spherical grids with equal bars.](image2)

2.2. GEODESIC GRID. Geodesic grids are obtained by the projection of a grid placed on any plane from the centre of the sphere to its surface. The best known are those obtained from a platonic polyhedron inscribed in a sphere. We have otherwise demonstrated that meshes obtained by projection from a polar point placed on the sphere or near there are optimal for deployability and give more similar bar lengths. But, nevertheless, they give worse solutions than the other methods described in this paper.

![Figure 12. Geodesic grid based on a cube.](image3)

![Figure 13. Grid of meridians](image4)
2.3. GRID OF MAXIMUM CIRCLES. Felix Candela designed this geometry in a brilliant proposal for a fixed scissors grid of trusses for Mexico City’s Palacio de los Deportes. This is a good solution if the spherical segment is not large (Figure 13). We have not built any roof using this system, but we recognise that it could be one of the best of all.

2.4. GRID OF MERIDIANS AND PARALLELS. It is the most irregular of all, but it is the only one which allows completion of a complete sphere (Figure 14). Its great inconvenience is the enormous difference between bar lengths and the different angles that they form during deployment. Also, if we close the sphere completely it remains fixed and does not deploy. But to build a hemisphere is a very good solution (Figure 15). This is the reason for its usefulness, and we go on to explain the way it is generated.

If we use the notation described in Figure 5 with the simplified geometry explained in Figure 4, it is necessary to achieve, in each joint, angular portions of bars that have the same angle on the sphere as shown in Figure 16a. We obtain from Figure 16b

$$\tan \alpha_2 = \frac{\cos \alpha_1}{1 - \sin \alpha_1}$$

This relationship can be repeated in order to obtain the angle \(\alpha_3\) and so on until \(\alpha_5\) in Figure 16a. Thus we obtain the structure shown in Figure 17. This structure has advantages if compared with cylindrical ones because the squared subdivisions make the reticule stable with regard to angular displacements. If we use these forms combined with cylindrical grids as shown in Figure 18 we can obtain structures that combine the advantage of cylinders and spheres: great length and angular stability (Figure 19).

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3. References.


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