Nexorade: a structure for 'free form' architecture

O. Baverel(1)(2), **C. Douthe(1)**, J.-F. Caron(1)

(1) Institut Navier
Ecole Nationale des Ponts et Chaussées,
6 et 8, avenue Blaise Pascal - Cité Descartes - Champs-sur-Marne
F-77455 Marne-la-vallée Cedex 2
baverel@lami.enpc.fr

(2) Ecole d'architecture de Toulouse
Ecole Nationale Supérieure d'Architecture de Toulouse
83, Rue Aristide Maillol
BP 10629
31106 Toulouse cedex 1

KEYWORDS

Mutualy supporting elements, nexorade, form finding

1. Introduction

The objective of this paper is to discuss the geometrical properties of different grids used for the creation of nexorades.
Consider the structure shown in Fig 1. This structure is made from elements using an 'interwoven pattern' as shown. This structure was designed and constructed by O. Baverel and exhibited at the University of Nottingham, UK, during the third Colloquium of the IASS Working Group on Structural Morphology in August 1997.

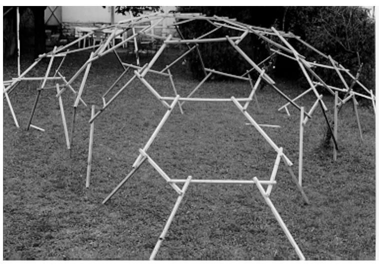

Figure 1. A nexorade, exhibited in 1997 at Nottingham, UK

The structure shown in Fig 1 is an example of what is referred to as a 'nexorade' or a 'multi-reciprocal grid' [baverel 00] [baverel 98]. Each one of the elements that constitute a nexorade is referred to as a 'nexor'. A nexor has four connection points, two of which are at the ends of the nexor and the other two are at two intermediate points along the nexor. The term 'nexor' is a Latin based word meaning a 'link' and the term 'nexorade' implies an 'assembly of nexors'. Historically, sketches from Leonardo Da Vinci showed that he understood the principle of nexorades, also an artist called Rinus Roelofs [Roelofs] did a lot on the subject but not much scientific work was done until now.

The formfinding of nexorade depends on 4 parameters that are the topology of the grid chosen, the diameter of the nexors, the engagement length and finally the length of the nexors. Nexorades have various advantages:

-They could be built with only on type of element
-They could be built with only one type of connection,
-It could be built with low technology components.
-Various shapes can be created with only one type of element and one type of connection

2. A method to find the forms of nexorades

A method using genetic algorithms was proposed to find the form of nexorades [baverel 2004]. The concept is to take an elementary configuration with no eccentricities and no engagement length (figure 2) and to transform it into a nexorade (figure 3). This robust and versatile method permit anyone to propose a configuration and to transform it into a nexorade. With this form finding method different grids were tried.

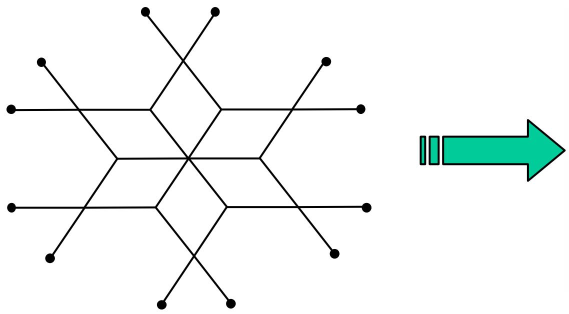

Figure 2: Elementary configuration

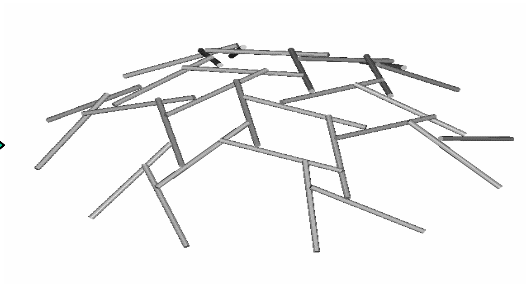

Figure 3: Resulting nexorade

3. Connection

Swrivel scaffolding couplers can be used as a connection for constructing nexorades as shown in figure 4. The corresponding idealised model (figure 5). In this model, the connector C between the beam A and the beam B is composed of three articulations. The first one is the rotation around the main axis of the beam A, its direction is that of the tangent of the deformed curve of beam A (the X-axis on figure 4). The second one is the rotation around the main axis of the beam B, its direction is again that of the tangent of the deformed curve of beam B (the Y-axis on figure 4). The third one is a rotation around the axis of the connector C, its direction is perpendicular to the beam A and B (the Z-axis on figure 4). With this system of three articulations, the orientation of the connector is free of constrain. This property is a key point for the construction of nexorades.

Figure 4: View of a connector

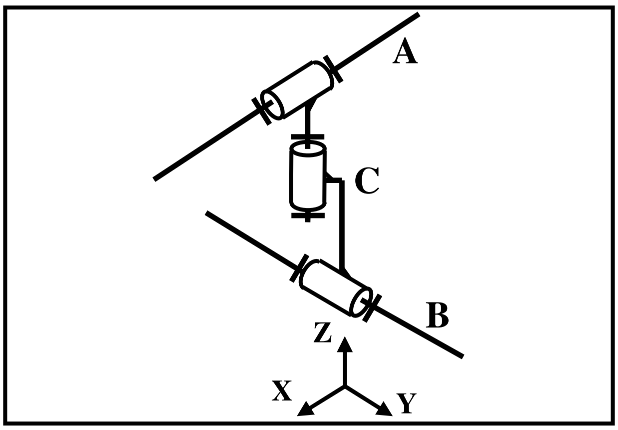

Figure 5: Kinematic scheme of a connector

4. Types of nexorades

The different tests (numerical and full scale model) have shown that we can distinguish three different families of nexorades that are :

-Fully adaptable nexorade
-Adaptable nexorade under constrains
-Rigid nexorade

4.1 Fully adaptable nexorades

A fully adaptable nexorade has at least four nexors connected to each vertex and each face has at least four nexors. We know from Euler formula that for any graph in the plane that

$V + F - E = 2$

Where V is the number of vertices , F the number of faces and E the number of edges. It can be demonstrated that only possible grid for a fully adaptable nexorade is a grid composed of squares (or rectangles or diamonds). The structure will adapt itself what ever the boundary conditions are. Another way to see the properties of this grid is to consider that; a nexorade is already built, for whatever reason someone wants to change the boundary condition or add new elements to the structure. By doing so, the nexorade will find itself a new geometry. Figures 6 and 7 show the in-plane degrees of freedom of an elementary node a nexorade. Figures 8 and 9 show the out of plane degrees of freedom of an elementary node of a nexorade. An example a complete nexorade is shown on figure 10. As there is no bracing along its surface, this type of structure is relatively soft in term of structural behaviour.

Figure 6: View of a fan

Figure 7: transformation into diamonds

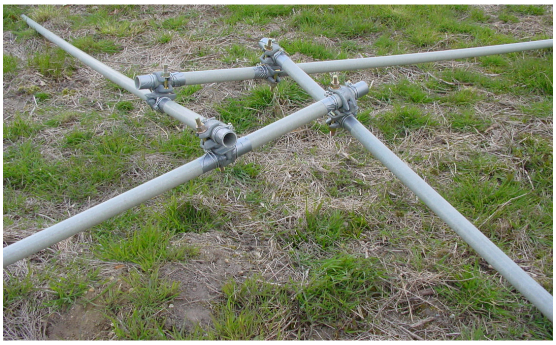

Figure 8: View of a fan

Figure 9: out of plane deformation of a fan

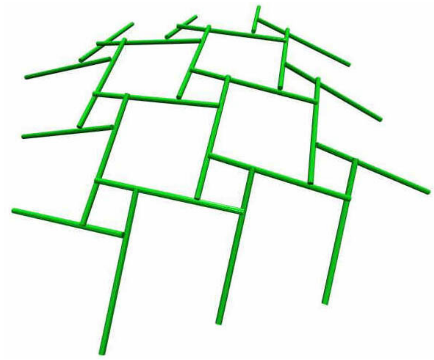

Figure 10: Fully adaptable nexorade

4 2 Adaptable nexorade under constrains

Adaptable nexorade under constrains are nexorades that will create shape with only one curvature. Therefore only conical and tunnel shape can be construct. These structures often use regular or semi regular tilling. For instance, when an hexagonal grid is used for a nexorade, certain geometrical properties are revealed. By assembling three element together a rigid node is created. As it is said in chapter 3, the rotation along the longitudinal axis of each of the three elements is allowed. By building an entire hexagonal grid these possible rotations either cancel each other or rotate in the same manner. Figure 11 shows the way the nexorade can be "folded", the arrow is parallel to the longitudinal axis of a cylinder with an hexagonal grid on its surface (figure 13). Figure 12 shows another way to "fold" an hexagonal grid. An example of nexorade using the symmetry shown in figure 12 is shown in figure 14. This figure represents three inclined arches jointed together. The intersection between the arches is made of diamonds that allow the geometrical deformation. The grid is a composition of hexagons and diamonds.

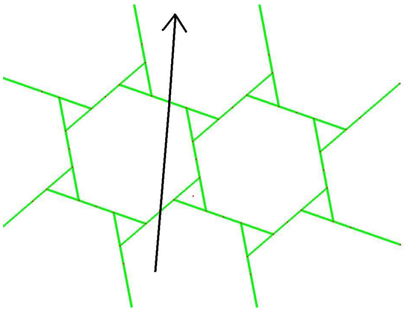

Figure 11: Symmetry A

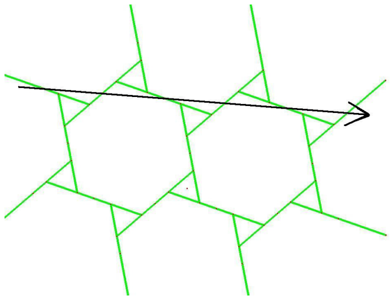

Figure 12: Symmetry B

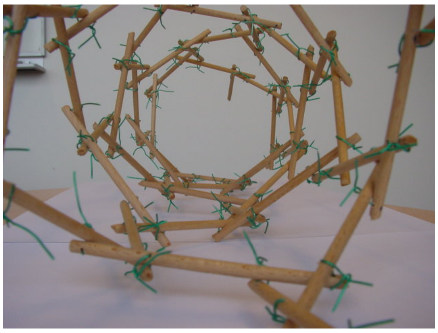

Figure 13: Nexorade with symmetry A

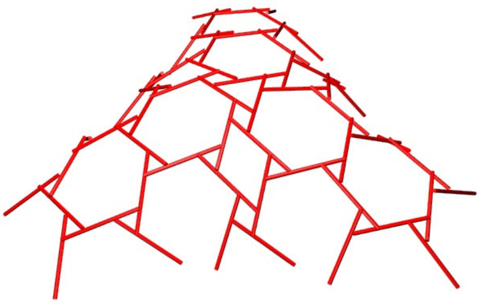

Figure 14: Nexorade with symmetry B

4 3 Rigid nexorade

The two previous families of nexorades had conditions on the connectivity between the nexors and on symmetry of the grid used. As they usually use two dimensional elementary configurations, the resulting nexorade are very different from the initial grid. If none of theses condition are satisfied the nexorade is either not buildable or the resulting nexorade will be very closed from the initial elementary configuration. An example of rigid nexorade is shown in figure 15, the resutlting nexorade is very close from the initial configuartion that is in our example a dodecahedron

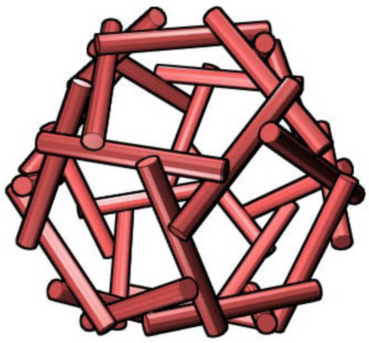

Figure 15: Rigid nexorade made from a dodecahedron

5 Cladding

The cladding of a structure that self-adapt is obviously something difficult to build. A solution of this problem is to use large soft tiles. This tiles could slide slightly beween one another in case of a modification of the boundary conditions.

6 Conclusions

The technology used for creation of nexorade was presented. A specific connection that allow an orientation free contrain between the elements was proposed. Three different type of nexorades have been presented. The fully adaptable grid shows the facinating properties of being able to self-adapt to a given boundary conditions. The adaptable nexorade under constrains has to use the symmetry of the elementary configuration to generate a nexorade. The last family concern all the other type of grids, the resulting nexorade is very close from the initial configuration.
Nexorades could be use as a structure for free form architecture either as a skeleton for a formwork or as a structure covered with a cladding composed of large soft tiles. In this case, the size and the shape could be easily adapted to the need and the wish of the architect.

7. References

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