Summary of the « Form, Design & Structure » group activities

The group's goal was to design and analyzes the definitive shape of the timber gridshell. Flat quadrangular plastic panels were then to be designed and attached on top of the structure to offer protection from the rain and the sun.

1. 3D layout

Using the results from a recent article [1] and the form-finding algorithm derived from it, we first tried to determine a shape that would both fit the program of our project and the structural requirements. In practice, the ultimate design had to comply with the required surface (~50m²), the quantity of timber available for construction and the structural imperatives. The main constraints were the maximum admissible moment and the maximum admissible curvature as determined by the test lead by the "Timber Grid" team (another team of engineers dedicated to designing the timber members of our structure).

Basing our design on these considerations, we devised within the allocated time frame (four days in total to design, produce and assemble the structure), a simple dome-like shape adapted to the site surroundings and its context. The two entrances of the gridhsell were placed facing the main axis of circulation. These entrances create two large openings in the gridshell, which gives an ambivalent feel to the space covered by the structure. The pavilion provides shelter from the sun and the rain but is opening on its surroundings rather than enclosing a space. The initial site ground comprised eight concrete cylinders which are now covered by the pavilion and can, conveniently enough, be used as seats. The pavilion can comfortably shelter half a dozen persons seating on these improvised chairs while enjoying the surroundings.

During the design phase, we used a reverse design methodology, implemented within the aforementioned algorithm developed on Grasshopper (a parametric programming plug-in for the 3D design software Rhinoceros). The procedure used is the following. A 3D surface corresponding to the selected design is generated by swiping one or two generatrix along a guide line. From the shape obtained through this first step, a matching timber frame and a matching quadrangular tiling need to be determined. The definition of the tiling is particularly complex because a network of points forming planar quadrilaterals needs to be define. This step is usually the most complicated when defining a gridshell. However, the method developed in article [1] and implemented in this workshop, allows for an easy definition of such a network and therefore, for a rapid definition of a suitable tiling. The method proceeds as subsequently explained.

Through computation, the pavilion surface is mapped with a Tchebychev network (a network of circles of same dimension *w*). This network is then used to infer the position of the gridshell nodes and of the planar tiling panels (a precise description of the method is provided in article [1]). The main advantage of the method is the automatic generation of a tiling by quadrangular flat panels and of a structural frame with members of constant dimension. These can then be flattened to obtain construction drawings readily usable for production.

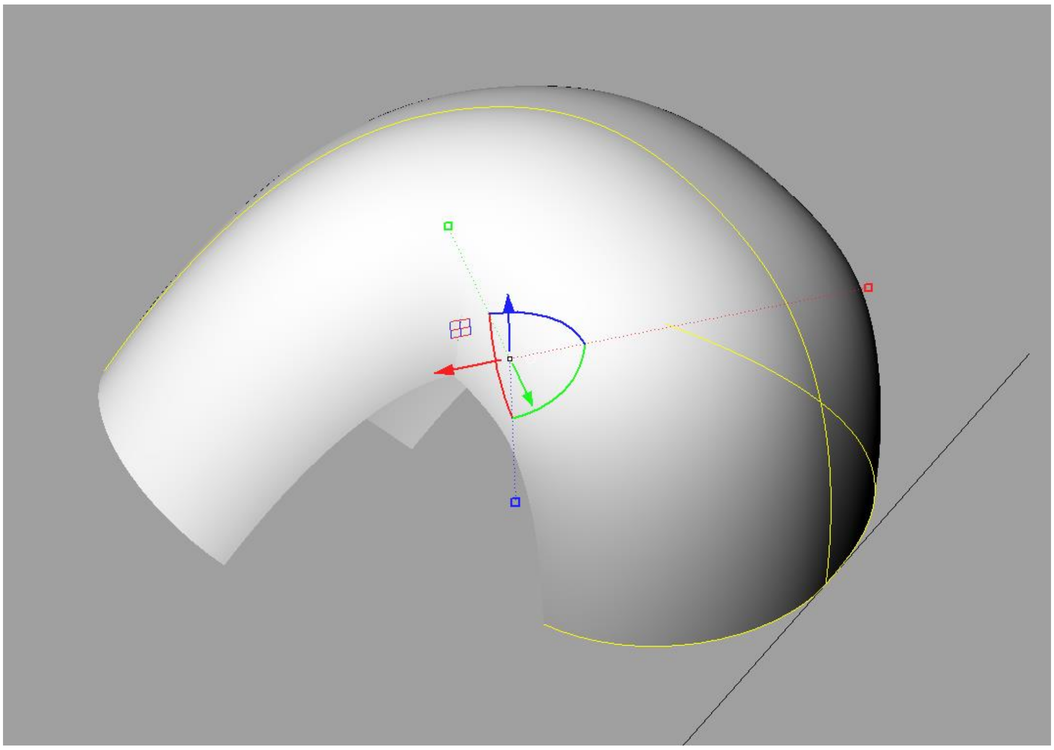

Figura 1 Generating lines of the sweep function

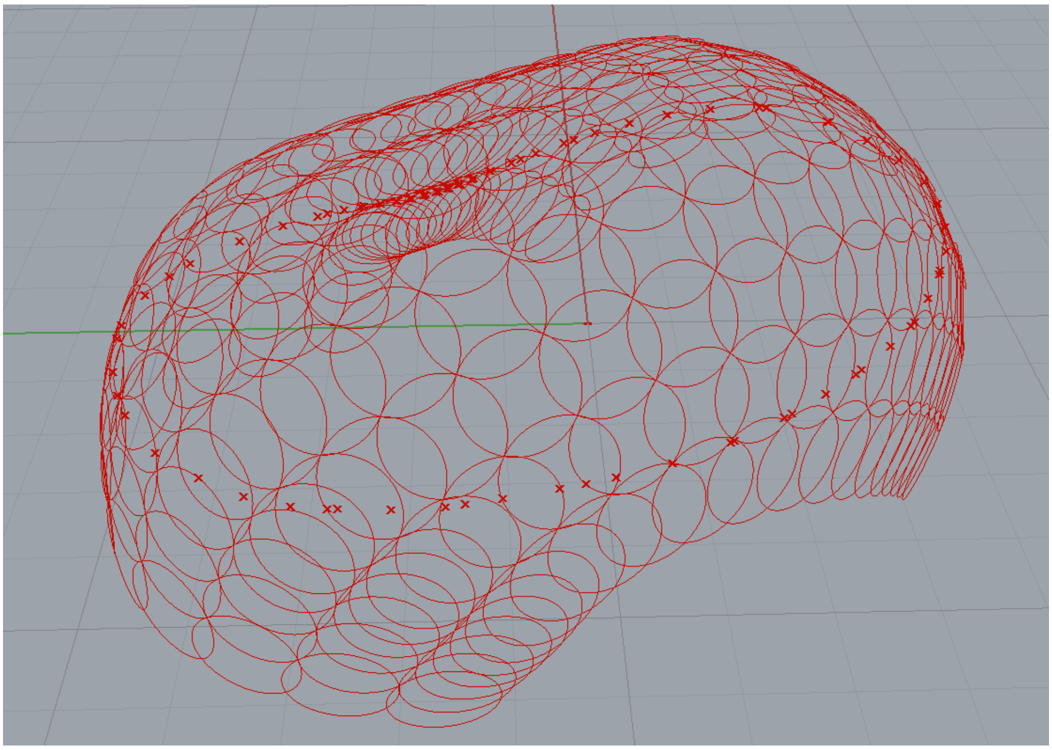

Figure 2 Circles mapping above the surface

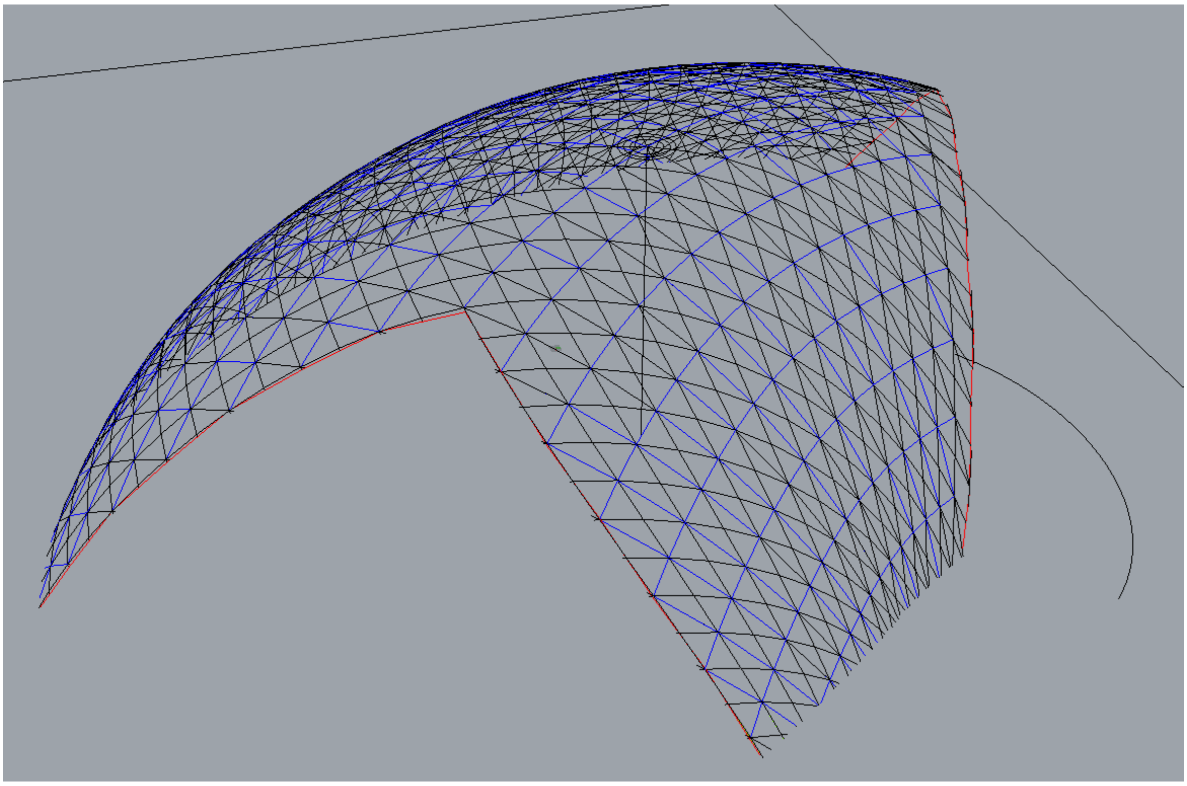

Figure 3 Final 3d design

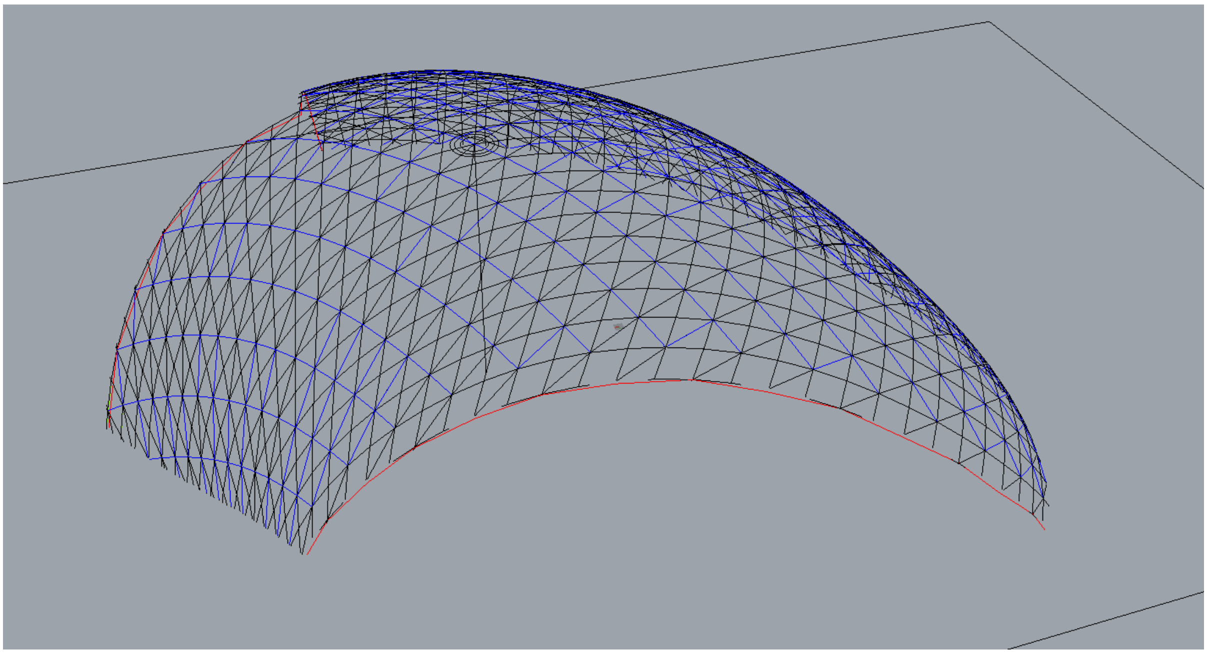

Figure 4 Final 3d design

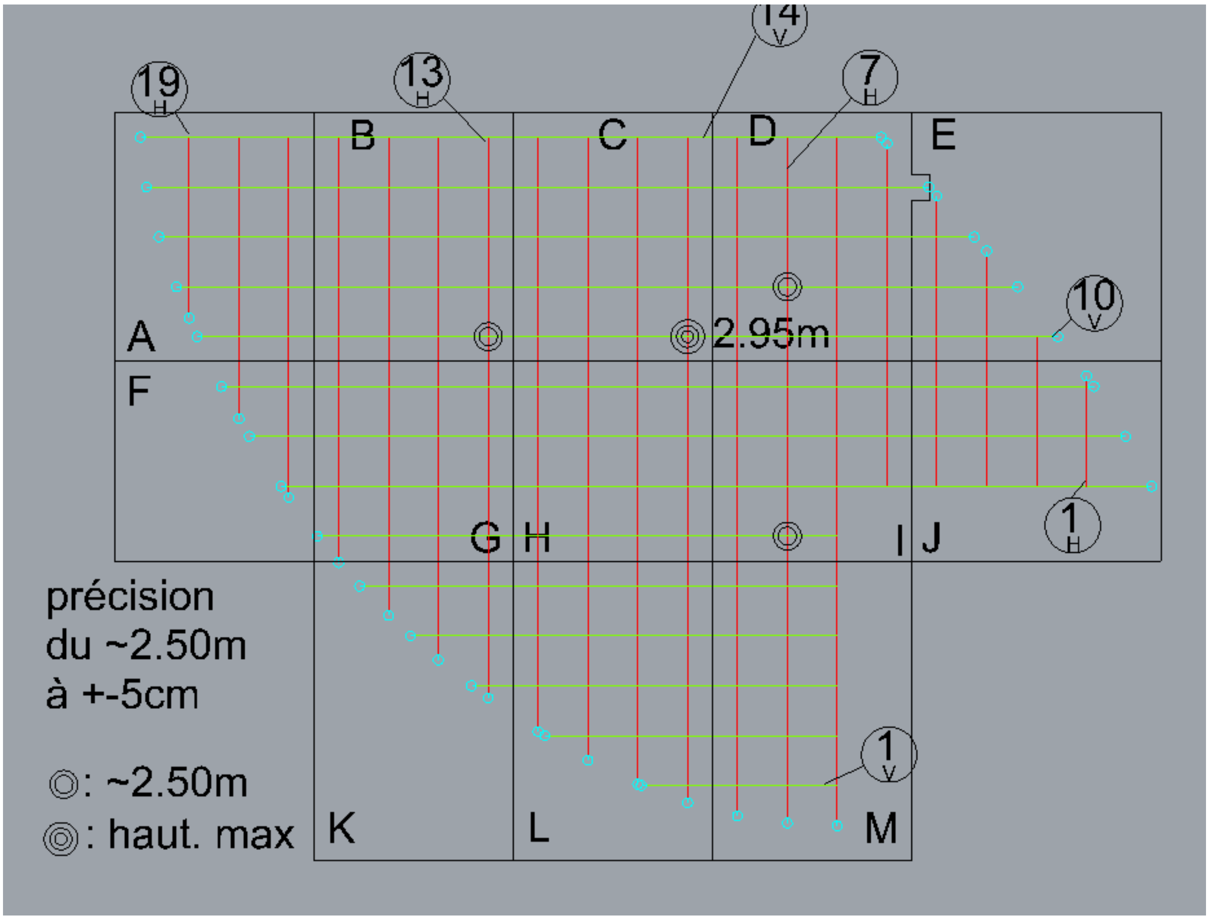

Figure 5 Final structural square grid

2. Dynamic relaxation

The second step in the design method is the dynamic relaxation of the structure. The design obtained through the first step is theoretical and needs to be verified.

A custom dynamic relaxation algorithm is implemented to compute the bending forces in the structural members and the out-of-plane final displacements after relaxation of the structure under self-weight and the prestressing moments due to the elastic deformation of the initially flat grid into its targeted three-dimensional doubly curved shape. In this second step the strain in the structure once in its final three-dimensional configuration is computed and its admissibility verified.

Note that once the actual structure would have reached its final shape after relaxation, we planned to add a layer of prestressed flexural reinforcement cables to greatly increase the stiffness of the structure allowing it to be much more durable and reliable.

3. Learning from experience

There were many lessons to be drawn from this workshop, which constituted a first on many levels: it was the first full scale implementation of the method described previously and was the first elastic gridshell erected by the Navier laboratory using timber as the structural material, finally the pavilion was constructed in record time, the design, production and assembly spreading on only four days.

The experience showed that the method developed in article [1] provides viable and repeatable results. The method showed to be easily understandable, yet powerful enough to produce a viable and adaptable matching gridshell structure from a set architectural shape. The method ease of use along with its computational efficiency are valuable educational and commercial assets.

The main challenges from the design phase was that a particular attention should be payed to openings and curvature.

To create openings in the grasshopper, you leave out the surface at the intersection between the double curvature surface you have generated and a solid. Because of openings, the gridshell is weakened. It is thus preferable to cut the gridshell along one of the lattice member for strength and deflection but also for constructability purposes. In the workshop, in addition to architectural criteria, we chose to cut along the members that allowed sufficient height for people to go through and that allowed us to cut off area of critical stress.

To find the right curvature, it is important to take into account the wood mechanical properties but also the desired height and surface coverage. There is a balance to find between these three elements. The wood properties condition the admissible curvature. The architectural program defines the minimum height (2m at least to allow a person to enter the structure) and the surface that needs to be covered. It was difficult to find a suitable curvature to cover 50 m^2 and have a mean height of more than 2 m at the center of the structure. We succeeded in finding the right balance through many trials but maybe this optimization challenge could be partly automated to offer more guidance to the designer.

The construction phase highlighted the problems that can emerged in the portions of the structure were the mesh is narrowing. In these areas, the initially square mesh is deformed into a diamond shaped mesh and high shear stress will need to be applied so that the grid undergoes this important deformation.

During construction, the building team need to pay special attention to the members of such areas presenting longitudinal connections between laths. These joints introduce local defaults into the structural members and offer diminished resistance against the shear forces that can emanate from the application of non-homogeneous stresses by the builders. In practice, this portion of network will need to be put under carefully controlled and homogeneous shear stress, so that no elements in this region fails.

In our case, a series of such joints failed in the same area and led to permanent strains in the structure. While this did not affect in an important measure the final stability of the structure after the flexural reinforcement cables were fastened, this local default does have a significant visual impact.

Figure 6 Failure of longitudinal joints