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## Space truss built with wastes from the sawmill industry

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### Abstract

It is well known that wood is difficult to assemble and complex steel system is often used for the joints. The solution proposed in this paper is to limit the use of steel connections by using a specific shape of element to take the shear force, thus linking the top and bottom layers of the space truss that are made of circular logs of small diameter. This proposal is a simpler version of the solution suggested in [5].

The material used for the shear components is waste wood from sawmill when the log is squared, it's mostly composed of bark and sapwood. This part of log is considered as a waste and often used as firewood. This experimentation aims to promote that wood as a structural element in the space truss.

The structure was designed by the laboratoire Navier/GSA and ENSAG. It was crafted, erected and tested by the IUT (institute for higher technician). The structure is 6 m by 6 m span and has a height of 0,6 m. The elements that link and brace the top and bottom layer create an hyperboloid that can be simply screwed as the element are tangent to the top circular chord and tangent to the lower circular chord. The structure was tested under symmetrical and asymmetrical loads. The deflections and a detailed observation of the connections during loading was performed using photogrammetry. The behavior of the structure was then compared to the numerical model. Finally, the authors conclude on the economical and environmental aspects of such structures.

**Keywords:** Architectural geometry, gridshell, hexagonal mesh, free-form surface, rationalization, pavilion

## 1. Introduction

The team of the Navier and GSA lab are working for decades to find structures that reduce the environmental impact of structures [1][2][3][4]. This research propose a new attempt to create structures with a very low environmental impact as it mostly use sawmill industry waste.



Figure 1: view of the structure

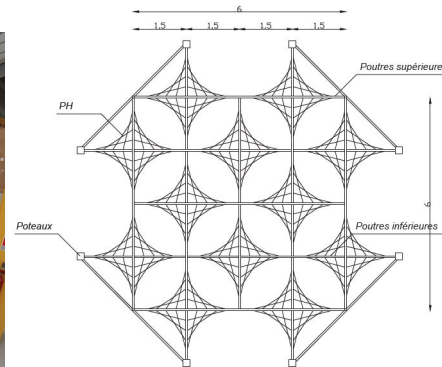


Figure 2 ; Plan view of the configuration

It is well known that wood is difficult to assemble and complex steel system is often used for the joints. The solution proposed in this paper is to limit the use of steel connections by using a specific shape of element to take the shear force, thus linking the top and bottom layers of the space truss that are made of circular logs of small diameter. These logs are usually considered as a waste for the sawmill industry. This proposal is a simpler version of the solution suggested in [5].

The material used for the shear components (in orange on the right of figure 3) is the part of wood which is taken off when the log is squared, it's mostly composed of bark and sapwood. This part of log is considered as a waste and often used as firewood. In our case, it will be cut in two, in order to have two perpendicular sides cut as explained in section 2.

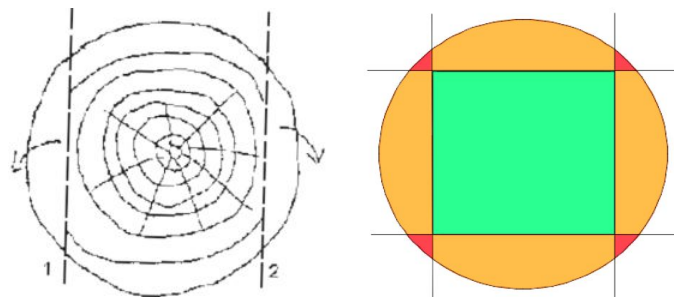


Figure 3: Cutting of the log

Section 2 will explain the different geometrical configurations chosen. It will be based on a hyper to create a space truss. Then the form finding for the connection of the shear element will be detailed, the aim is to link the top and bottom layer. In this section, the morphological potential of these structures will also be discussed. The construction of a prototype is presented in section 3 where the loading test and the comparison with the numerical results are detailed. Finally, the authors conclude on the overall performance of the structure.

## 2. Formfinding of the structure

The formfinding method shown in this section details how to generate a space truss with the top and bottom layer that could be hypars. The shear elements that link both bottom and top layer will also be hypars and tangent to the logs. An example of such configuration is shown in figure 4.

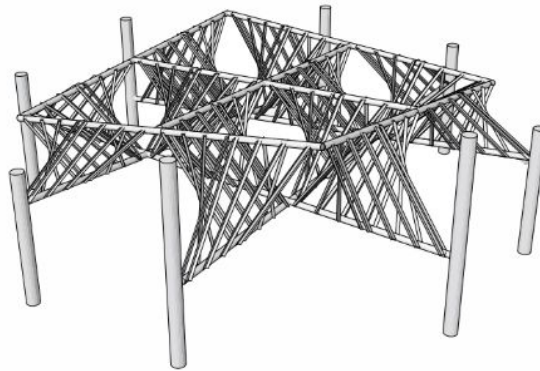


Figure 4 : view of a configuration with top and bottom layer with hypars forms

The raw material used for the hypar is a part of wood mostly composed of bark and sapwood which is not valued. This wood is cut perpendicularly to have two flat edges as detailed in the following paragraph.

The first constraint to be taken into account is that beams of the space truss are cylindrical. The wooden element must then be installed tangentially on the beams in order to improve the assembly. They should be cut with a specific angle so that one of the flat sides is tangent to the upper layer while the second side is tangent to the lower layer. If the beams of a layer are connected with a 90 degrees angle, the cut should also be at 90 degrees.

### 2-1 Modelling methods of a hypar using genetic algorithms

The technique to find the correct position of the shear element that are tangent to the log is to draw circles on the beams of the top and bottom layer. The two circles will be connected by a line (figure 5).

The line must have a right angle with the radius of both circles. This algorithm was implemented and solved with Galapagos. The location of the tangent line to the two circles is found by minimizing the sum of the absolute value of the scalar products between the line and each of the radius to which it is connected. This method is easy to set up and manipulate. However it takes a lot of computing time and gives an approximate position.

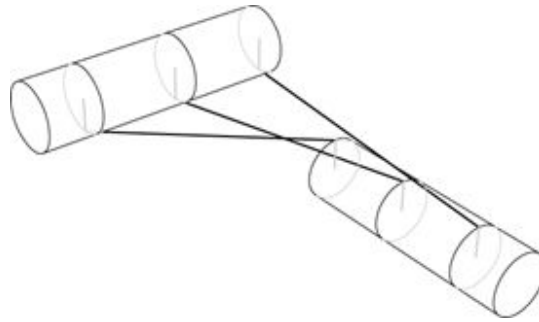


Figure 5: Construction of with the genetic algorithm method

## 2-2 Modelling methods of a hypar using genetic algorithms

The most accurate method consists in finding the tangent's points positions by a geometric construction. A cylinder of the same diameter (in red in figure 6) as the space truss is drawn passing through the center of the circles at which the hypar must hang. The intersection of this cylinder with the circles makes it possible to draw a line tangent to the two beams at the same time. This method was found by Xavier TELLIER. This is a more accurate but more complex method to implement and requires a large calculation from processor.



Figure 6 Construction of the geometric method

## 2-3 Morphological potential of the overall structure

The space truss can be transformed in two different ways: by modifying its plane shape or by varying the beams' tilt.

The variation in plane consists of going from an orthogonal grid to a sheared grid (figure 7). However, this variation has the main disadvantage of involving the cutting of the wooden elements at a specific angle for instance in figure 7 the shear element must be cut at an angle of 135 degrees. This would be necessary so that the elements can be tangent to the beams.

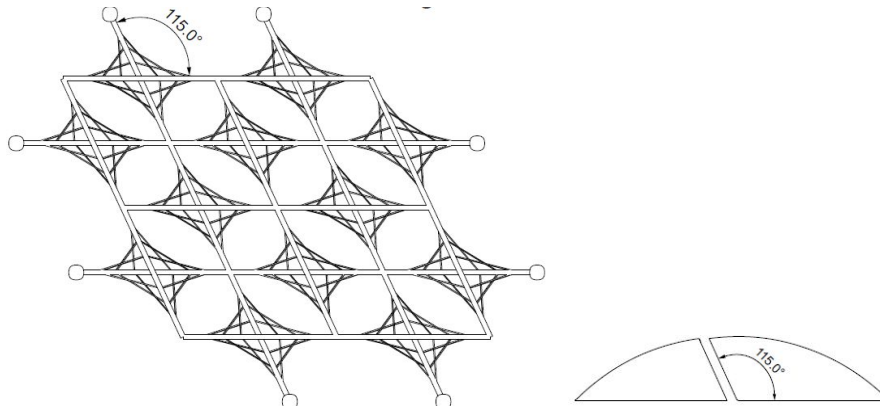


Figure 7: Construction with a shear of the 25 degrees, the shear element should be cut at the same angle

On the other hand, the outcome of plane distortion of the layer has no influence on the cutting of the wooden elements. For this variation, the beams of the two layers are more or less tilted, while keeping the beams completely straight (figure 8) .

The space truss then itself become two hypars linked by hypars. This creates a sense of disorder while maintaining an identical constructive and cutting system for the entire structure. Some prototype were made to prove the accuracy of the algorithm as shown in figure 8.



Figure 8: View of the model with hypar upper and lower layer

### 3. Prototype :assembling and loading test

#### 3.1 assembling of the prototype

The prototype is 6m by 6m span. First the top layer and lower layer were assembled. The second stage was to create tetrahedra to create and stabilise the space truss as shown in figure 9



Figure 9: First steps of construction

Other diagonals were added, a simple screw was used to connect the diagonal to the top and bottom layers (figure 10).



Figure 10: Different views of the constructed truss

### 3.2 Loading test

During the loading test some shear elements were added, first the loading was made with one shear element and then 3, 4 and 5. This method allowed to see the improvement of the stiffness of the structure depending on the number of shear component fixed. The loading test was  $0,3 \text{ KN/m}$  on the bottom layer and  $0,35 \text{ KN}$  at each node of the bottom layer. The total load was then  $75 \text{ KN}$ . The structure was loaded with sand bags as shown in figure 11.



Figure 11: Loading of the truss



### 3.3 Measurement of the deflection

In order to measure the deflection of the structures a photogrammetric technique was used (figure 12). This method is quite simple as it consist of the superposition of the pictures of the structure before and after loading. The measurement of the deflection can then be easily calculated accurately.



Figure 12: technique to measure the deflection

### 3.4 Comparison with the numerical model

A numerical model was done using Robot structural analysis software. A linear elastic analysis was performed but no eccentricities were taken into account. Figure 13 shows that this eccentricity exist and will give a softer behaviour to the built structure compare to the numerical model. The numerical model assume that the shear element are pinned to the top and bottom layer.

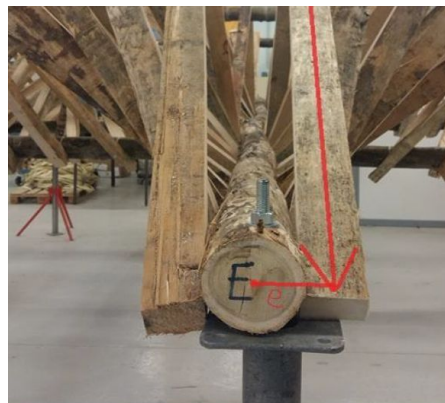


Figure 13: Eccentricities between the log and the shear elements

Number of shear element by hypar	Deflection of the numerical model (mm)	Deflection of the prototype	Weight of the structure (KN)
1	13	22.3	2.27
3	8.5	11.6	2.98

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4	7.34	10.2	3.48
5	7.08	8	3.91

Table 1: result from the tests

The result from table 1 show that the numerical model gives as expected lower deflection compare to the real structure. Nevertheless the difference gets lower when the number of shear element increase.

#### 4. Conclusions

The paper presented an original configuration of space truss made out from waste of the sawmill industry. First, different formfinding methods were proposed showing the different possibilities of configuration such as shearing or tilting grid and keeping a simple process to build the configuration. As detailed in the paper the configuration can have top and bottom layer being hypars connected shear elements that are hypars.

A space truss of 6m by 6m span was assembled, tested and compared to an numerical model. The displacements were taken by photogrammetry and the result showed that for hypar made out several shear elements are quite close (around 13%) to the numerical model.

The structure is efficient and cheap to built, the total cost of material was around 12 euros/m<sup>2</sup>. This is an interesting solution to take the best of the sawmill industry especially when high quality wood is cut such as larch which is also not well suited to be burn in wood stove. The enhance the shear stiffness the hypar could also be continuous like a flat CLT but in this case, it would be ‘CLT hypar’.

#### Acknowledgement

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