



## Hybrid Structural Skin

Pierre Cuvilliers, Cyril Douthe, Lionel Du Peloux, Robert Le Roy

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# BOOBY

## HYBRID STRUCTURAL SKIN

PROTOTYPE OF A GFRP ELASTIC GRIDSHELL BRACED  
BY A FIBER-REINFORCED CONCRETE ENVELOPE

1.

### ELASTIC GRIDSHELL IN COMPOSITE MATERIAL

The simulation and construction of elastic gridshells in composite materials is nowadays a technique that one can consider mastered. This technology allows to build a freeform envelope by bending a flat and regular grid.

2.

### BRACING IS COSTLY

The bracing of the grid in its final form remains however a time consuming step with a lot of manual work. The lack of alternatives to membrane covering is also an important limitation to the development of such technology.

3.

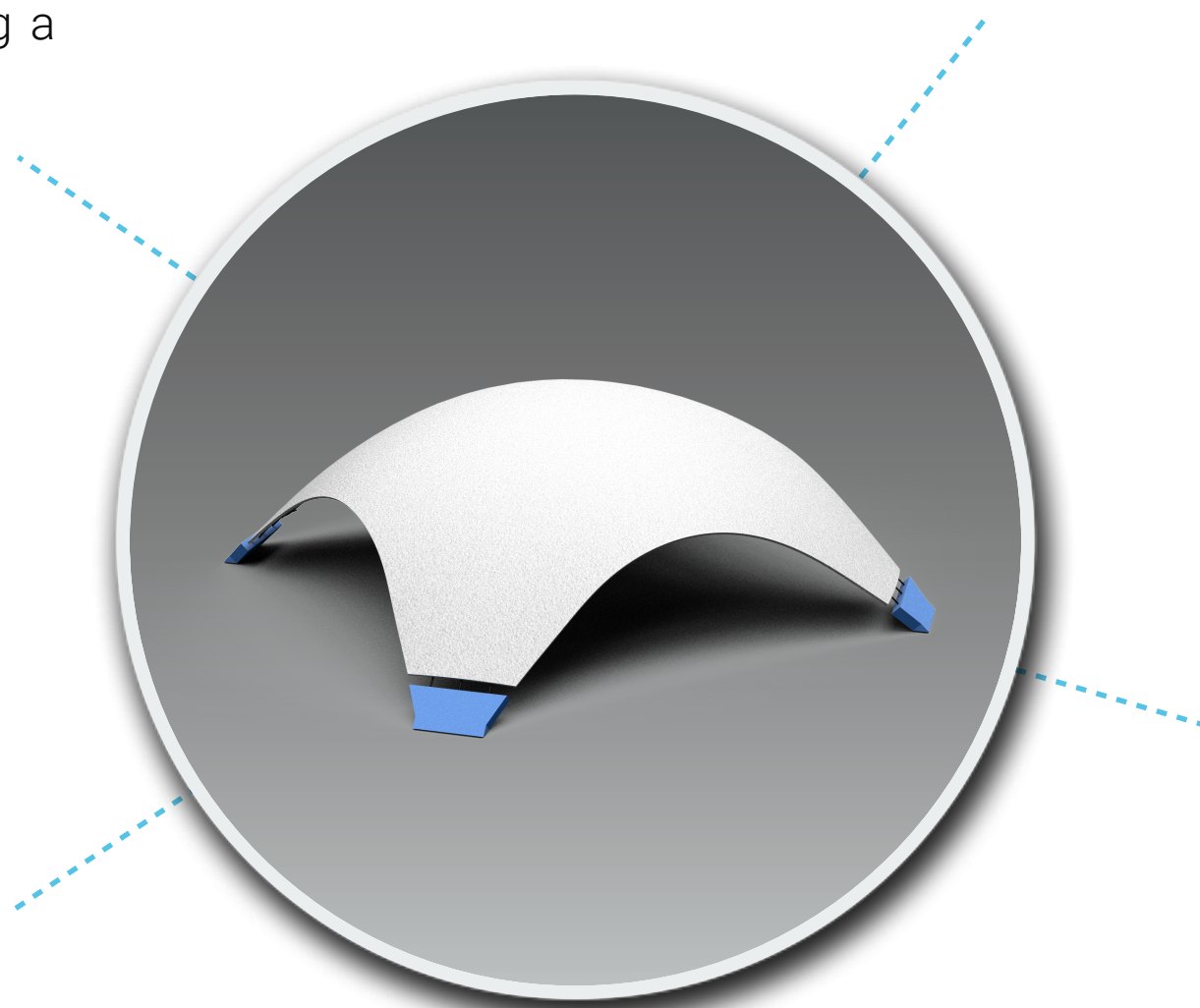
### GRIDSHELL AS FORMWORK

The gridshell is used as a flexible formwork for the thin fiber-reinforced concrete envelope. This is a cheap and efficient technology to build a freeform formwork to pour the concrete on it.

4.

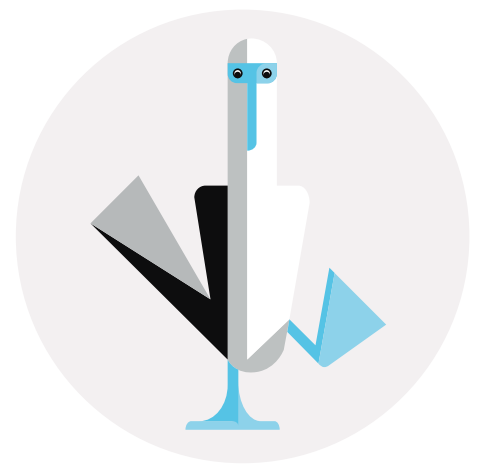
### CONCRETE ENVELOPE AS BRACING

The concrete is poured on the gridshell. A mechanical connection is ensured between the thin concrete skin and the GFRP grid so that the concrete ensures the bracing of the grid and that the thickness of the concrete is reduced to a minimum





# CONSTRUCTION PROCESS

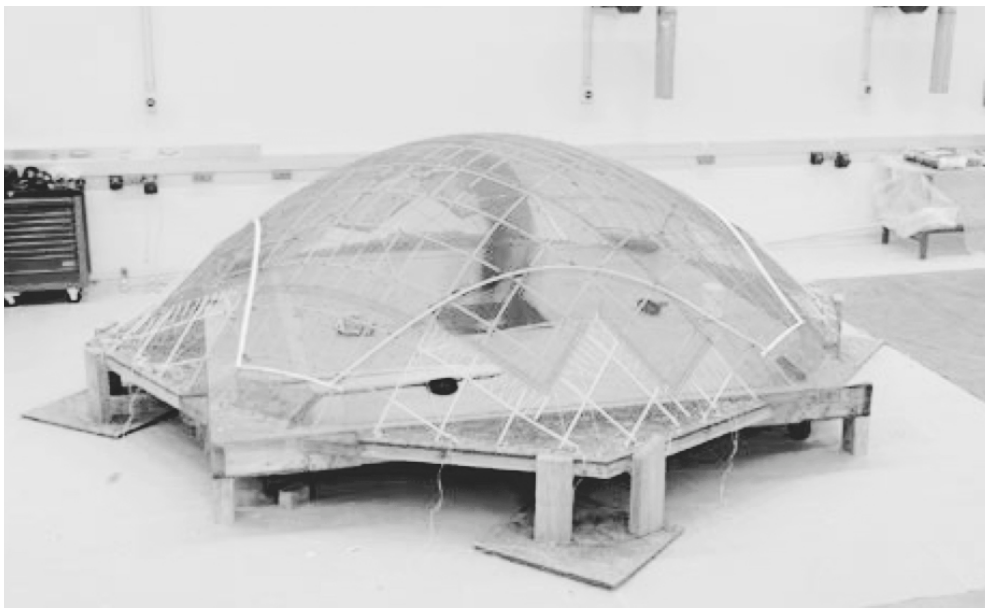


## 1. ASSEMBLE THE FLAT GRID



Prepare the glass fiber reinforced rods for the gridshell : cut the rods at the required length and drill the holes that will receive the connectors at a constant step-size. Assemble the flat grid on the ground. This is unskilled work that consists in bolting together the rods at each node.

## 3. GRIDSHELL ERECTION AND BRACING



Deform this assembly and fix each rod end on the contour. Except at the corner of the base square where supports are permanent, the ground connections are very simple and require little additional work. Brace the gridshell with polypropylene twine in the two diagonal directions. This bracing has a provisory function until the concrete has cured, so that the moderate stiffness of pp and ease of use for tying was a good compromise.

## 5. POUR THE CONCRETE SKIN



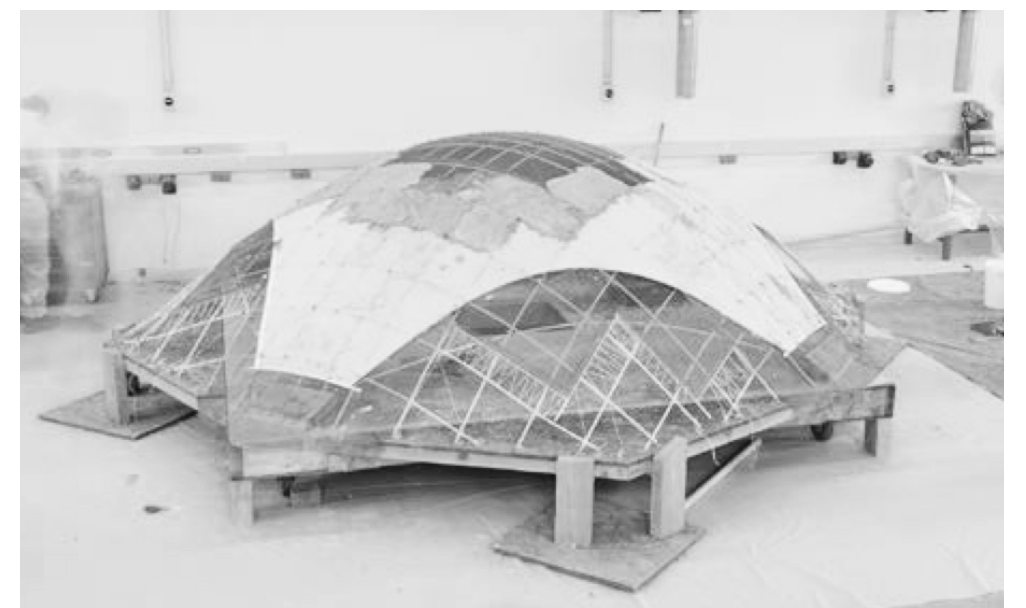
Pour the concrete. The concrete was prepared and poured in three batches of 50 l each, for a total mass of concrete on the structure of 348 kg, and average thickness of 15.4 mm.

## 2. FIX THE FABRIC LAYER



Fix the fabric formwork on the flat gridshell. The chosen fabric is essentially a chebyshev net like the grid, but with a much smaller cell size. If they initially share the same directions, the fabric will follow the grid during its elastic deformation. The formwork is hence laid on the flat grid, which spares the difficult task of patterning and fitting the fabric on a curved surface. The edges of the fabric are sewn into straight sheaths to be able to prestress it in the direction of the grid before deformation and to reduce wrinkling in the most sheared area and sagging under the load of the wet concrete.

## 4. QUICK-SETTING CEMENT LAYER



Prepare the formwork with a quick-setting cement layer. This intends at reinforcing the fabric in form in order to prevent the sagging between the rods. Because in our prototype this layer is visible on the underside, a large amount of time was spent in the finishing and smoothing.

## 6. REMOVE TEMPORARY PARTS

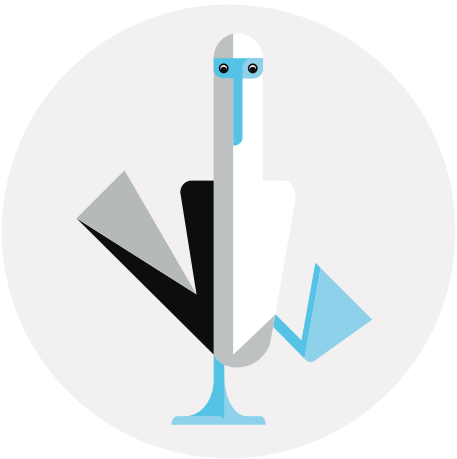


Cut away the temporary parts of the gridshell after the concrete cured seven days. Protect the concrete skin with lime whitewash.





# TECHNICAL CONCEPT



**FIBRA FLEX**

**FIBER-REINFORCED**  
amorphous metallic fiber

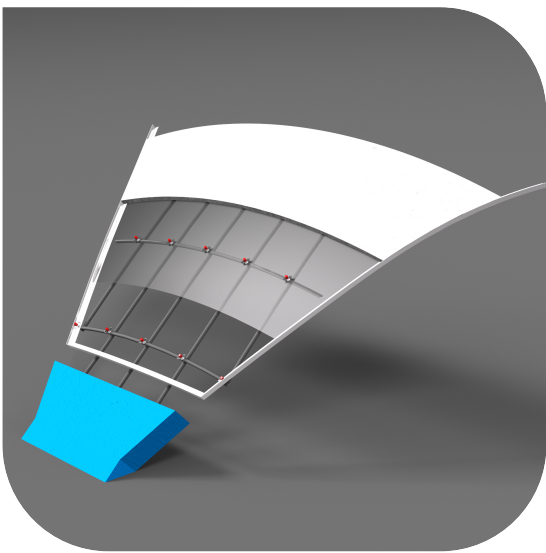
**CONCRETE SKIN**  
15mm thickness

**FABRIC FORMWORK**  
fiberglass mesh

**GRIDSHELL**  
removable parts

**GRIDSHELL**  
permanent structure

**SUPPORT DETAIL**  
flayed structure



IFSTTAR

## AUTHORS

Pierre CUVILLIERS  
Cyril DOUTHE  
Lionel du PELOUX  
Robert Le ROY

## CONTACT

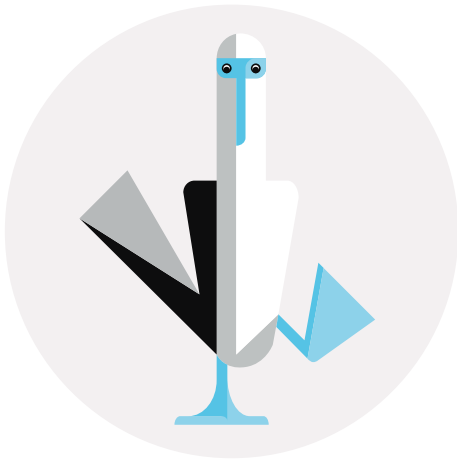
+33 (0)6 83 38 32 47  
lionel.dupeloux@gmail.com  
thinkshell.fr/hybrid-structural-skin/

## LAB

Ecole des Ponts ParisTech  
6/8 avenue Blaise Pascal  
79549 Champs sur Marne

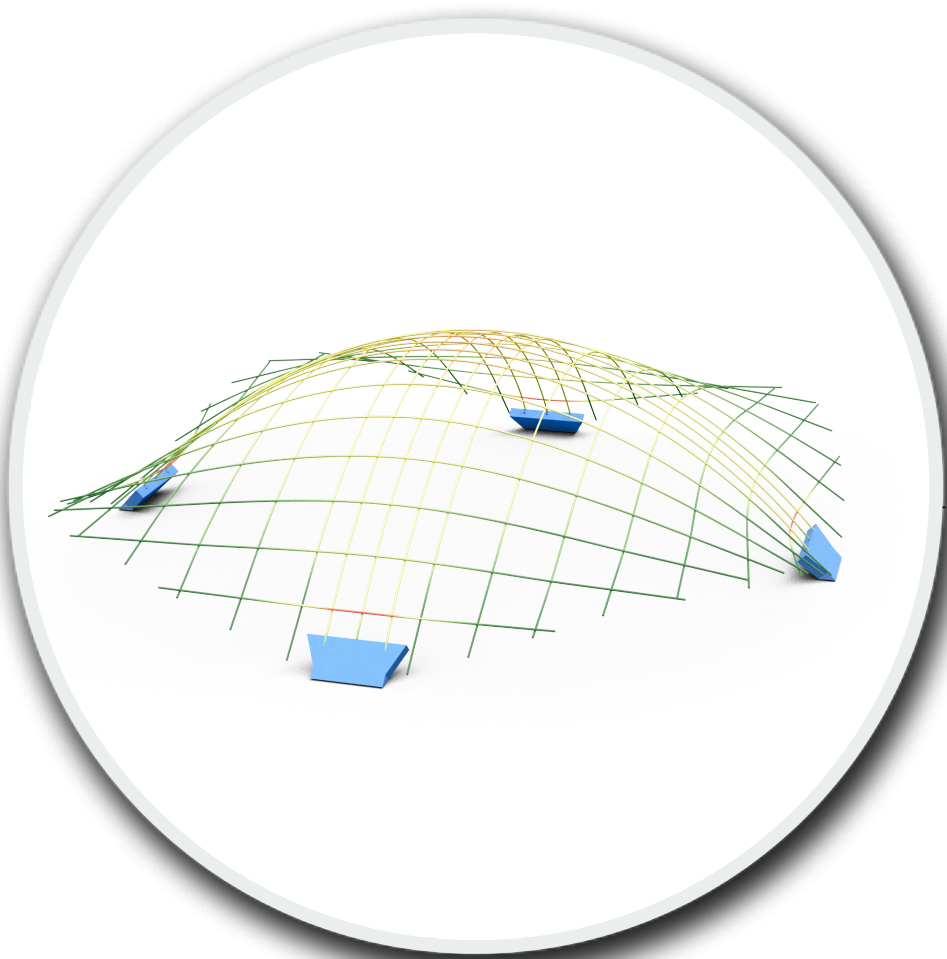


# DESIGN



## GFRP ELASTIC GRIDSHELL

Elastic grids are generally made out of a flat regular grid of long rods, connected at each intersection by a node allowing rotation in the plane of the grid. This grid is then deformed into a 3D shape (by pushing or hoisting it) and pinned on its boundary to the ground. This elastic process is possible because the nodes allow shear movements in the grid. The resulting surface is usually rigidified in a later step by adding a layer of cables, diagonal members or rigid panels.



### FORMFINDING

simulation is done for each stage

## FIBER-REINFORCED CONCRETE ENVELOPE

The concrete mix used for the prototype was formulated especially for this application. It had to be easy to place on the formwork, and to remain on inclined surfaces without slipping. Due to the reduced thickness (15 mm), reinforcement could only be done by incorporating fibers in the fresh concrete



Components [g]	Mix A	Mix B	Mix C
Cement CEM I 52.5MP	1000	1000	1000
Sand -4 mm, dry	3242	2913	2913
Water eff.	400	500	500
Plasticizer F2	20	8	7
Latex SikaLatex	30	30	30
FibraFlex FF/15E0	100	100	200
Property [M Pa]	Mix A	Mix B	Mix C
Flexural	10	11	17
Compressiv strengt	19	40	42

### FORMULATION

several mix have been investigated

THE BUILT **PROTOTYPE PROVED THE FEASIBILITY** OF THE TECHNIQUE AND THE ECONOMIC DATA PROVIDED SHOWS THAT IT HAS **GOOD POTENTIAL** FOR APPLICATION TO **LARGER SCALES**. FOR MEDIUM SCALE, SAY FOR CUPOLAS UP TO 50 M2.

