UHPFRC Folded Pavilion

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Folded mold
UHPFRC

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Abstract

The aim of the Workshop "Material optimisation and geometric exploration" (ENSA Paris-Belleville and University of Naples Federico II) is to discover the possibilities offered by new materials, starting from their characteristics. The final goal is to build a synthetic pavilion, that - for the last session - demonstrates UHPFRC capacities. The Ultra-High Performances Fibre Reinforced Concrete (UHPFRC) is a new material whose characteristics allow new geometries: smooth shapes due to the absence of passive reinforcements, precise finishing due to the ultra-thin aggregates, flat cross-sections due to the high strength. The design with UHPFRC requires to think simultaneously the geometry, the static, the casting (mainly precast) and the implementation process.

The design of the pavilion starts with a widespread geometric exploration using a phylogenetic tree. This approach has the advantage of exploring at the same time different designs without enclosing the creative process in one path. The geometry of the final Pavilion is based on a folded surface, called "Whirlpool", made with triangle rows. The profile of the pavilion is bent in order to give it a double curvature and so, more stability. The modules are multiplied asymmetrically to minimize the number of the moulds, having at the end just one mould for each triangle. The moulds are made with PETG laser-cut sheets which have been folded after. This process has been chosen for both the finishing and the simplicity of fabrication.

1. Introduction

1.1.“Techno-evolution” and “bio-evolution”

How does technical evolution proceed? Although it uses different ways, the “techno-evolution” has been often compared to the “bio-evolution” by historian and prehistorian as André Leroi-Gourhan [Leroi-Gouhran 1973], or by philosopher of techniques as Gilbert Simondon (Simondon 1989). But both have noted the necessity to “objectify” (“*Objectiver*” in French) the process of technical evolution and to not reduce it to a purely biological evolution. First the “techno-evolution” doesn’t proceed by DNA transmission but by “*structural re-organisations*” [Simondon 1989] created by humans. These “designers” are all “*located*” in the social world of the human production. Then the way of selection is due to social factors.

In both cases, the evolution can be separated conceptually in two phases: first the “*structural re-organisation*” and then the “*selection process*”. In biology, the “*structural re-organisation*” is proceeding by the combinatory of the alleles and by mutations. The “*selection process*” is made by the capacity to survive and to transmit its own genetic patrimony. In the field of techniques, the “*structural re-organisation*” is proposed by designers (in its broad meaning) to face problems. The “*selection process*” is a consequence of the *convergence*, a compromise between all the requirements, called by Simondon “Concrétisation”. The resulting acceptable compromise is called “*technical object*”, conceptually defined by its “*structural organisation*”, or using the words of the American architect Louis I. Kahn by its “*Form*” (opposed to its *Design*. “*All the spoons have the same* Form*, but each spoon has a different* Design” in [Kahn 1996]).

1.2.Exploration in building and architecture field

In the building and architecture field, the expression “*technical object*”, widely used in the industrial sector, is usually replaced by “*typology*” or “*construction system*”. When a designer (an architect, an engineer or a craftsman) chooses for a project a *typology* or a *construction system*, he works usually by *induction* and *analogy*: he looks at something similar that has been already done. Making a choice by *analysis* and by *deduction*, which means starting with all the requirements of the project and ending with the technical solution, is very unusual. This fact is due to the time-efficiency of the process of “*Concrétisation*” for the designers. We can observe it in industry too: when a technician designs a motorized vehicle for example, he starts from “*structural organisation*” of the existing cars or trucks, instead of defining all the requirements and the way to fulfil them.

Although the induction method saves time, it has two limitations:

- Are the existing typologies the best technical solutions available?
- How to proceed with a new material or with a new problem?

We already talk about the first limitation in a precedent research [Fabbri & Corvez 2013]. The second one is the topic of this research, focussing on the Ultra-High Performances Fibre Reinforced Concrete (UHPFRC). As academics and designers, we can hardly act on the "*selection process*" of "*Concrétisation*" (resulting from complex social forces), but we can work on the "*structural re-organization*" by questioning and proposing new configurations.

1.3. The Workshop "Material optimisation and geometric exploration"

The Ultra-High Performances Fibre Reinforced Concrete (UHPFRC) is a new material whose characteristics allow new geometries [Fabbri & Corvez 2013]: smooth shapes due to the absence of passive reinforcements, precise finishing due to the ultra-thin aggregates, flat cross-sections due to the high strength. The design with UHPFRC requires to think simultaneously the geometry, the static, the casting process (mainly precast) and the implementation. The aim of the Workshop "*Material optimisation and geometric exploration*" (ENSA Paris-Belleville & Università Federico II di Napoli) is to discover the possibilities offered by new materials, starting from their characteristics [Fabbri, Principe & Leone 2017]. During the last sessions of the workshop we focussed on the UHPFRC. After presenting the material, the work starts with a widespread exploration, using Phylogenetic trees. The work continued by specifying the design according to the "rules" of the material. The final goal is to build a *synthetic pavilion*, that demonstrates UHPFRC capacities. This approach has the advantage of exploring at the same time different designs without enclosing the creative process in one path and questioning the "*structural organisation*".

2. Design phase: Widespread exploration

2.1. Organisation

The workshop is divided in two phases: the first one in Naples for the design of the pavilion, and the second one in Paris for the building of the pavilion.

The "design phase" starts with a presentation of the material UHPFRC: its history, its mechanical behaviours, the casting process and the moulds fabrication. The whole group is then split in 5 bi-national teams, each of them focussed on one kind of surface:

- ruled surface
- revolution surface,
- reciprocal frame,
- folded surface
- sweeping surface.

To promote a widespread exploration and to avoid fascination for a single design, each team proposes 24 short designs, according to a phylogenetic diagram.

2.2.Phylogenetic Diagram

The phylogenetic tree is firstly a tool of classification, used in biology to show the evolutionary relationships among various species or other entities. Each branch split-up is based upon similarities and differences in their physical or genetic characteristics. All life on Earth is part of a single *rooted* phylogenetic tree, indicating common ancestry (the tree of life). The linguistic defines *rooted* phylogenetic trees to show the common origins of the languages (as the well-known phylogenetic tree of Indo-European language). Although the scientific validity of this last diagram is largely discussed, the linguists are considering it as tool for understanding the evolution of the languages. *Unrooted* phylogenetic tree (without common ancestry) are today used in the fields of logic, computer science and taxonomy. Each branch split-up represents a level of classification.

From a tool of classification, the *unrooted* phylogenetic trees are becoming an useful exploration tool, able to show all the combinatorial possibilities. In this research, the phylogenetic tree is used as a tool for the exploration of the “structural re-organisations”. Using the phylogenetic tree (see figures 1 and 2), each student group (see above) design briefly 24 Pavilion proposals, one for each final branch of the tree. The bifurcations of the phylogenetic tree are organized in three levels: at first the “composition” (through the “shape generation” process the pavilion can be designed as a unique surface or as an addition of single elements), then the “static scheme”(Arch, Side wall, Dome and funicular), and finally the “filling” of the skin (continuous skin, openwork skin or gridshell/wireframe skin).

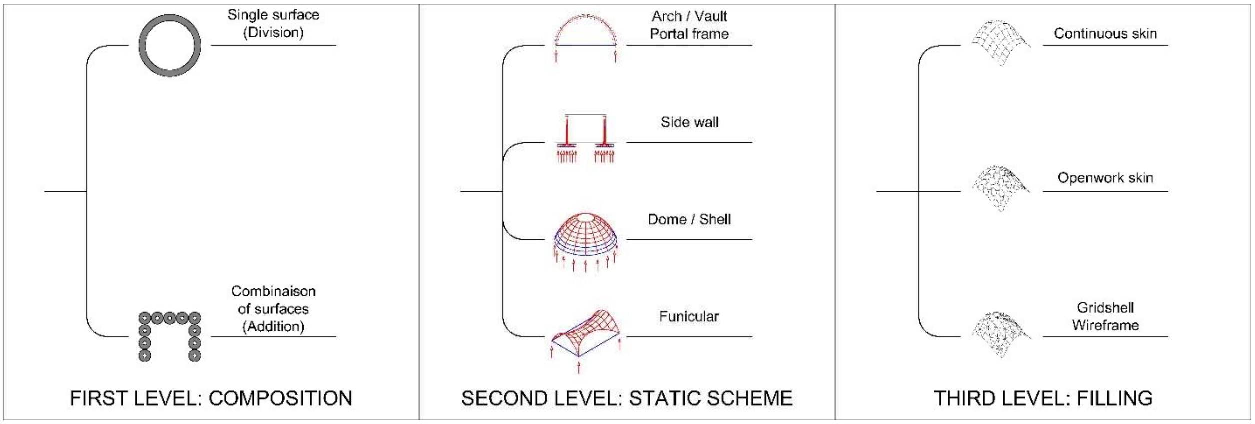

Figure 1. The three levels of bifurcations in the phylogenetic tree

After that, each group decides to develop specifically one of the final branches. We cannot represent the 120 proposals (24 X 5 groups), so only the five developed pavilions are placed at the end of the phylogenetic tree (see figure 2). For each of them, the morphology, the static scheme, the assemblies and the implementation have been defined.

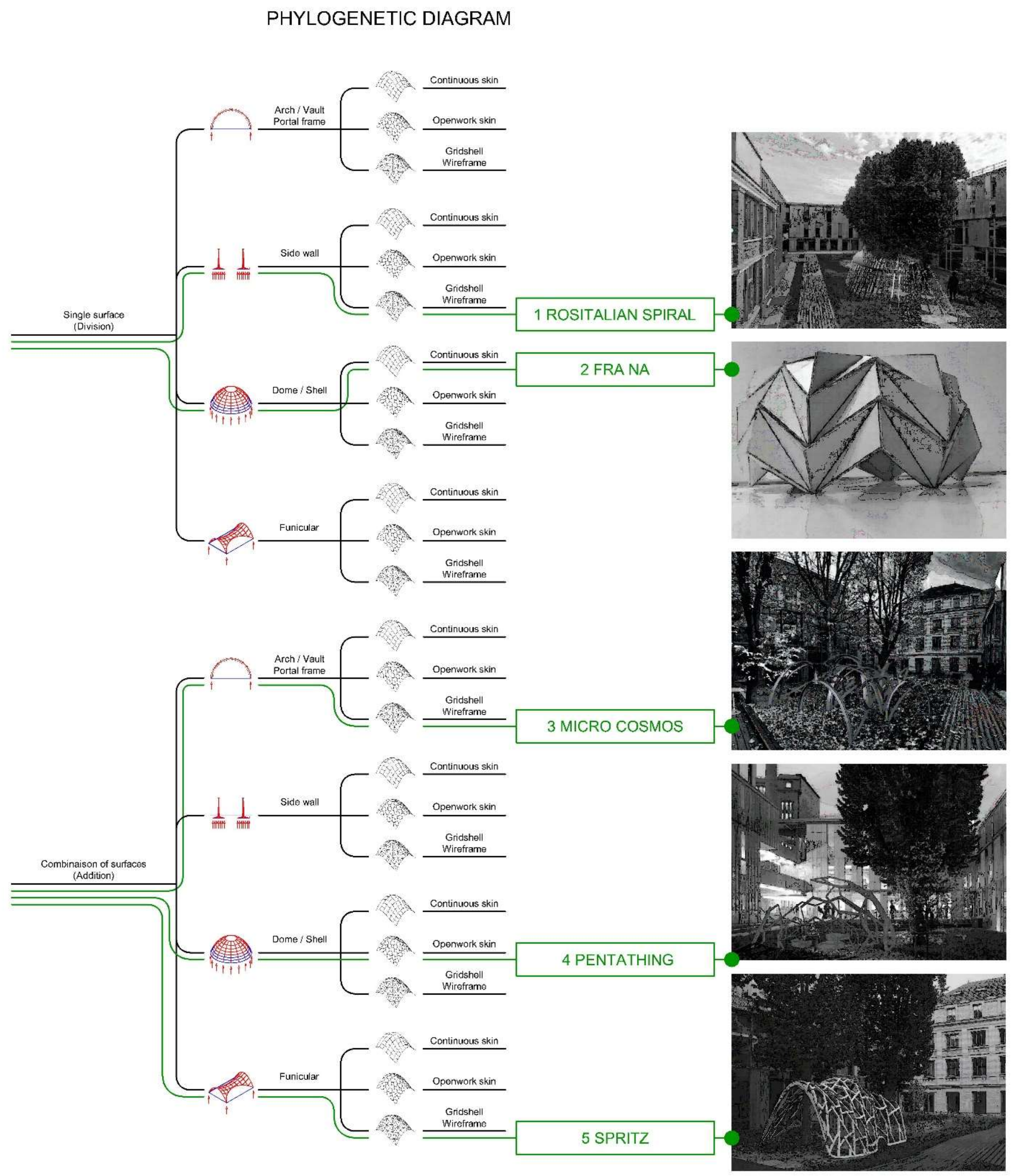

Figure2. The whole phylogenetic tree with the five projected explored by each team

3. Building phase: Synthetic Pavilion

3.1.Morphogenesis

The geometry of the final Pavilion is based on a folded surface, called “Yoshimura folded” or “Whirlpool”, made with triangle rows. The profile of the pavilion is bent in order to give it a double curvature and so, more stability. The modules are multiplied in axisymmetric rotation to minimize the number of the moulds, having at the end just one mould for each triangle. The vertices of the triangles are cut to avoid sharp angles. The centre of the element is open, for both light and weight reasons.

The figure 3 presents the main steps of the morphogenesis:

1/ The 10 basic triangles generated by the bending of the Yoshimura folding pattern.
2/ The cut of vertices of the triangles
3/ The contact surfaces between blocks
4/ The internal void of the blocks
5/ Holes for the bolts
6/ Axisymmetric rotation
7/ Mirror and trimming

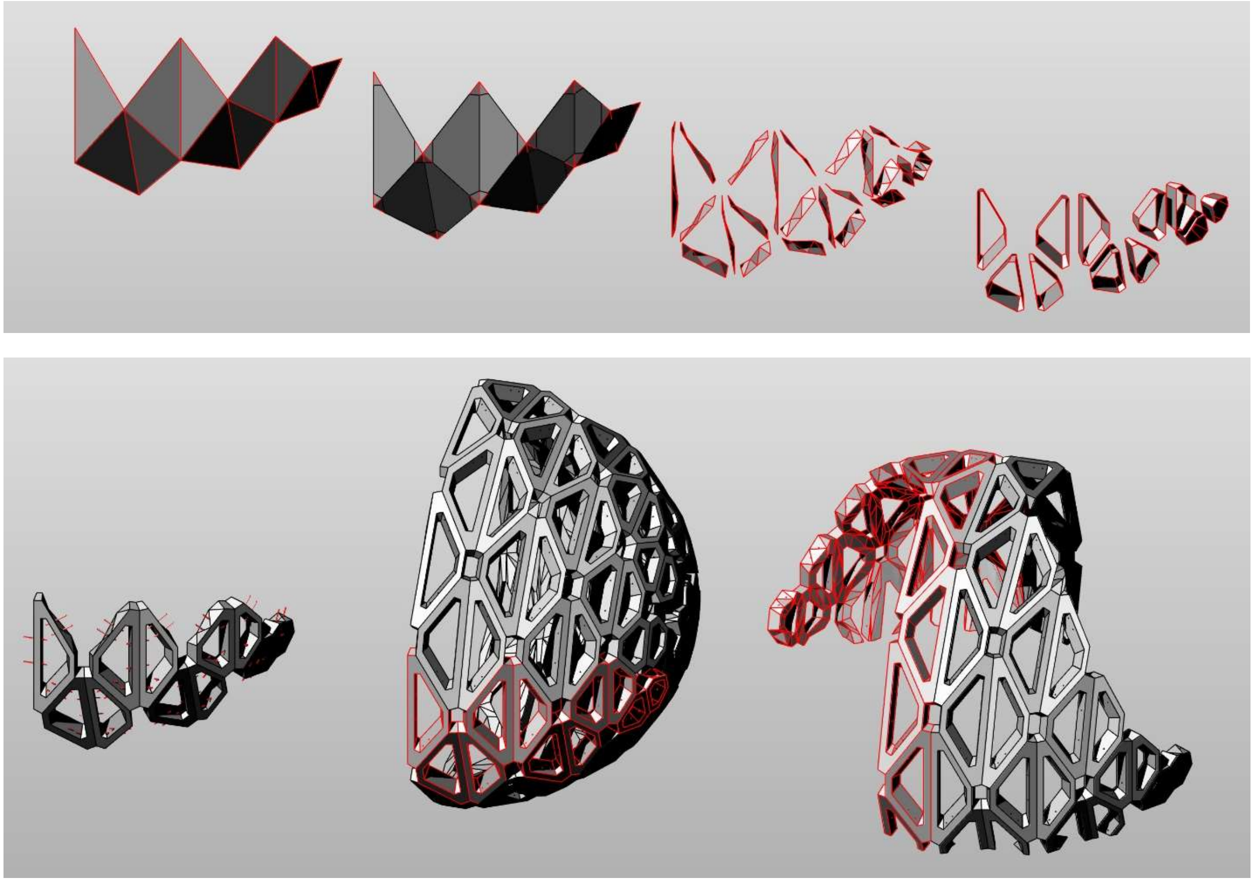

Figure3. The main steps of the morphogenesis

3.2. Casting process

The moulds are made with laser-cut sheets in PETG (Polyethylene Terephthalate Glycol) which have been folded after. This process has been chosen for both the finishing and the simplicity of fabrication. The PETG sheets are easy to fold and to clean, but they have weak bending stiffness. That is why they are reinforced by wood boards cut on measure. The internal void is made by a polystyrene block.

Figure4. Pictures of the moulds

The UHPFRC used for the casting is the DUCTAL NAW3 from LafargeHolcim. The mould was externally watertight, but sometimes concrete flowed between polystyrene and PETG. To solve this issue, we added a compressed foam-joint in-between. The mould has been slightly improved during the 5 days of casting, but the general concept has been maintained for its efficiency.

Figure5. First cast elements

3.3.Implementation

The triangles are assembled together with bolts while a cork sheet is placed in between the connecting surfaces to guarantee a good contact. Moreover, the contact surfaces are also folded to block the shear.

Figure6. Pictures of the cast elements and the assembly

4. Final pavilion and future works

The implementation of the pavilion will occur in April 2019. For the next research, the use of PETG folded moulds opens to new innovative fields in adaptative geometries. In precast buildings, the repetitive geometries are used for reducing the cost of the moulds [Aubry & Bompas 2013]. Implementation without shoring is an important point to develop in further works. The UHPFRC is a poured material with a shaping capacity much greater than the stone one: the contact surface can be more sophisticated, and the centre of gravity can be moved by retrieving material at the right positions.

Figure7. Render of the final Pavilion

5. References

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