Innovative Timber Constructions

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Summary

The research being undertaken in the EPFL's Timber Construction Laboratory aims to question in depth the relationship between engineering sciences and architectural conception. The IBOIS is firmly ingrained in the Institute of Structures, as well as being involved in architecture through the setting up of a workshop for architecture masters students.

Timber construction certainly has a great future in the face of global sustainable development challenges. The advantages are well-known as far as low energy consumption for the production of building components (planks, boards, beams, etc.) is concerned. Savings in time and energy consumption are also noticeable in timber structure assembly and dismantling processes. But the challenges of sustainable development also concern the issue of architectural form. How can one introduce a process of formal and technological innovation in a perspective of sustainability?

1. From Origami to Free-Form Shell Structures

It is interesting to note the variability of Origami structures, as shown [1]. This investigation could lead to more complex forms being made out of timber block panels. The following research shows some possible applications.

Fig. 1 Origami folded prototype

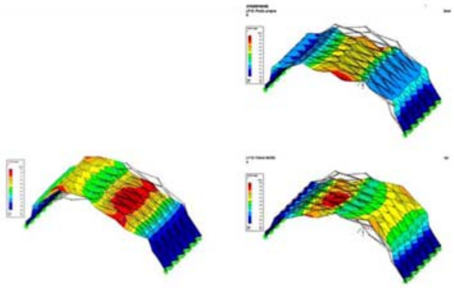

Fig. 2 FEM simulation

Origami-inspired new timber construction is the subject of a presentation by Hans Ulrich Buri [2]. We believe further possible developments could be of interest. Instead of using folded geometric patterns, as previously proposed, Gilles Gouaty and Ivo Stotz [3]of the IBOIS have developed a modeller, which can be seen as a geometric tool to develop a wide range of folded structures (as shown before) and also free-form structures. The goal of this research is to create files as a data base for construction reasons (to be exported for reasons of dimensioning and automated production

- the so-called “digital chain”) which are mathematically “clean”, meaning that they work exclusively with discrete elements. The Iterative Function Systems (IFS) used present the advantage that they allow for the exportation of discrete geometrical surfaces, lines or volumes. By using IFS, no constant curvature will be produced, in contrast to the use of splines where such curvature may occur.

Furthermore, Iterative Function Systems may be used for a wide range of geometrical patterns. The user’s choice will be to select the algorithm which best suits their formal, spatial geometrical or structural needs. Once the general geometric layout is defined, the modeller allows for the intensification of the subdivision in certain areas if needed. Shell structures, for example, may be optimised while increasing the number of folds in areas where more rigidity might be needed according to the load flows occurring. Increased subdivisions may also be needed for architectural reasons, lighting, or construction-orientated design subdivisions.

A second advantage of using IFS is related to the notion of scale, since the subdivision process can be applied at various scales. The surface of a roof panel itself might be threaded in such a way that its surface using IFS subdivision geometry will improve its acoustic performance, for example, because it has been moulded.

A wide range of possible geometric patterns can be produced. The type of surfaces can be smooth or rough. Both can be of interest for contemporary architectural needs. Such techniques could be applied specifically to timber construction. Timber has indeed a role to play in contemporary public architecture. We believe that the modeller referred to here could be applied specifically to timber construction. As we always start from fairly small pieces which need to be assembled afterwards, the modeller helps to define a more direct path between free-form shapes and automatic production.

The following figure illustrates this variability. We can see two forms whose surfaces were generated by a tensor product of two curves. On the left side, a smooth curve has been combined with a fractal curve. On the right side, two fractal curves have been combined. The dotted lines show control points which stay on a two-dimensional grid.

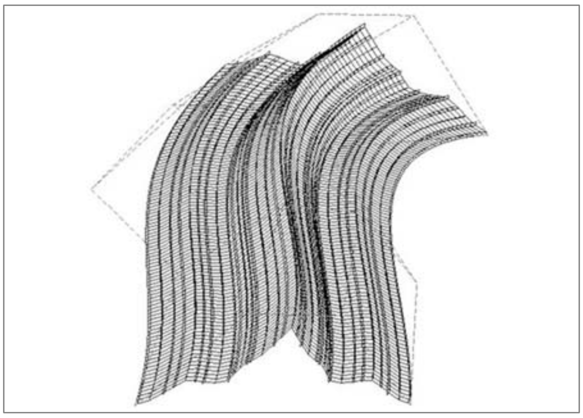

Fig. 3

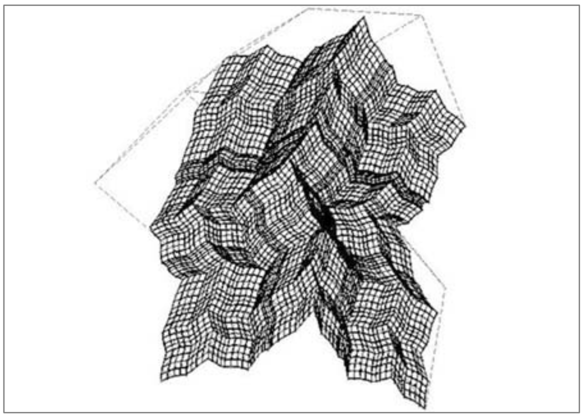

Fig. 4

These examples illustrate the basic and rich variability of producing forms with this modeller.

A further step consisted of imposing constraints to “produce” exclusively planar surfaces. For this reason, the modeller was implemented in such a manner that two geometric sums of two curves could then be added. The result is shown in the following figure.

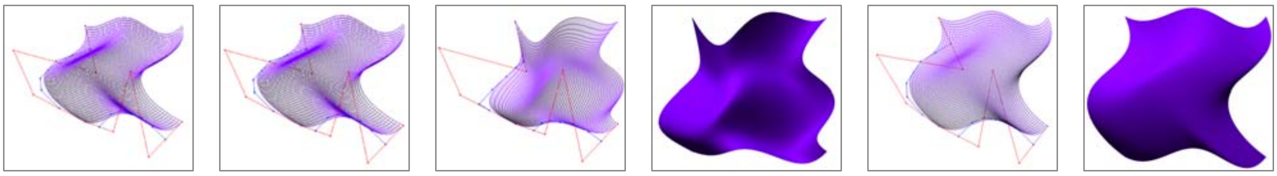

Fig.5 Surfaces generated by a geometric sum of two curves

Fig. 5 shows a series of surfaces that are generated by a geometric sum of two curves. By this construction method, the control is more limited than by tensor products, as the control points are located only on two sides of the surfaces. However, this procedure ensures that meshes consisting only of planar faces can be obtained. The use of homogeneous coordinates allows the production of meshes whose opposite sides are not necessarily parallel (middle figures), permitting greater design possibilities.

2. From Rip Shells to Woven Structures

The second family of innovative timber constructions is seen as another possible evolution for new timber constructions. In the past, rip shell structures have been built, but more so in singular situations. Nowadays, with the increasing demand for architectural purposes, architecture could develop so-called free-form shapes. These free-form shapes were the subject of a paper presented by Claudio Pirazzi in 2006 [4].

In order to optimise grids of timber rib shells in the face of the bending stress of the boards due to initial curvature, the GEOS software was developed at the Ecole Polytechnique Fédérale de Lausanne (EPFL) between 2002 and 2004. The construction of a prototype in the summer of 2005 proved the reliability of the assumptions upon which the program is based.

The following article describes the steps which were undertaken, starting from the generation of the form and the design of the optimised grid, through to the final construction of the prototype. Loading tests were carried out to evaluate the structural calculation model. Finally, the article briefly addresses the comparison between calculated and measured deformations.

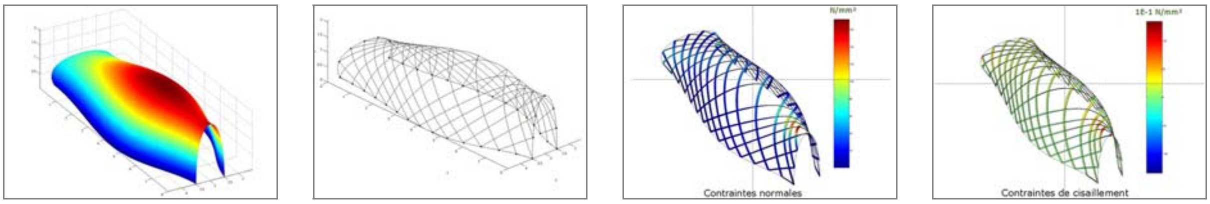

Fig. 6 Claudio Pirazzi: "Geodesic Lines on Free-Form Surfaces - Optimised Grids for Timber Rib Shells"

Rip shell structures have been taken further as the subject of another thesis, which Johannes Natterer is presenting at this conference [5].

Fig. 7 Experimental Rib Shell Structure

His work addresses the mechanical analysis of the rib shell structure. When, as a conclusion of this promising work, a precise understanding of the bending behaviour for nailed or screwed rib shell structures is known, then shell forms may emerge which can support more intensive bending moments. This will lead to the possible realisation of such a structure inspired by weaving techniques.

3. Woven Wood

Markus Hudert (IBOIS) is proposing to investigate a new family of timber constructions based on the logic and principles of man-made fabrics and biological tissues. The first phase of his work involves an intense theoretical and historical analysis, evaluating textile production techniques and structures, as well as the peculiarities of their natural counterparts. In a second phase, the ramifications, constraints and potential of applying these structures on a building scale will be assessed. The conclusions and insights gained will be completed and verified using large-scale models and prototypes, accompanied by appropriate methods of structural calculation. Finally, detailing of the structure and the question of how to realise an enclosure will be addressed, keeping in mind the projected outcome of at least one large-scale functional prototype.

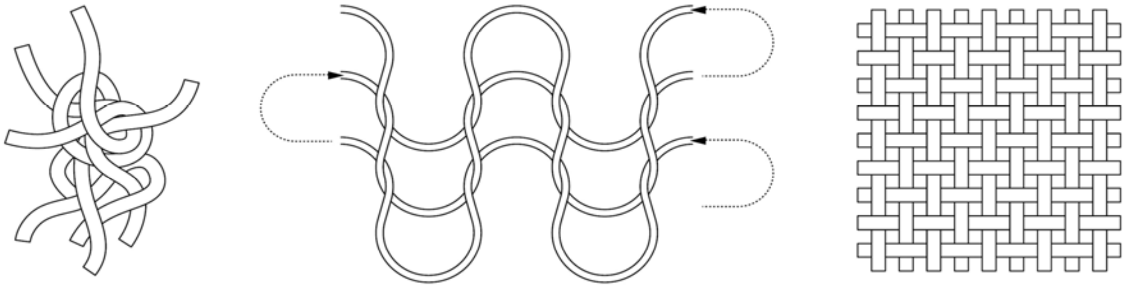

Fig. 8 Felted fabric; mesh fabric; weave fabric

Fig. 9 Woven timber structure

The system factor of such structures will be interesting to define. The combination of thin and rigid panels and the integration of structural and architectural considerations could lead to new forms of woven arch or shell structures.

From a structural point of view, we have to determine at what point these structures become shell structures, or still adopt linear 2D behaviour.

4. Architecture Studio Weinand

The Tokyo fish market was the subject of the Architecture Studio Weinand for the academic year 2006-2007. Architecture student Sophie Carpientieri designed an exciting woven structure. Interconnecting Kerto Panels will form a suspended structure. The main difficulty was in understanding a structural geometry at different scales. At every scaled level, different parameters emerge. One of them is the rigidity, which is not directly in proportion to geometrical dimensions. The influence of these parameters was understood and their influence analysed.

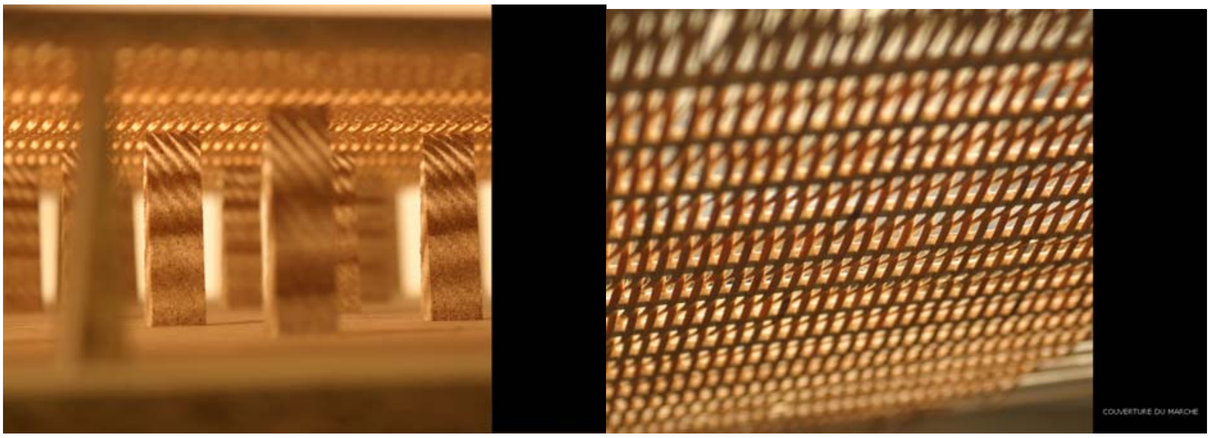

Fig. 10 Tokyo Fish Market: Woven timber structure

During the academic year 2007-2008, Jacopo Laffranchini produced a very promising structure. His first attempts were small-scale models already made out of wood. Precise geometrical observation led to the definition of a range of crucial variable parameters. The number of ribs, their thickness and width, and the general curvature and local curvature may change the structural layout significantly.

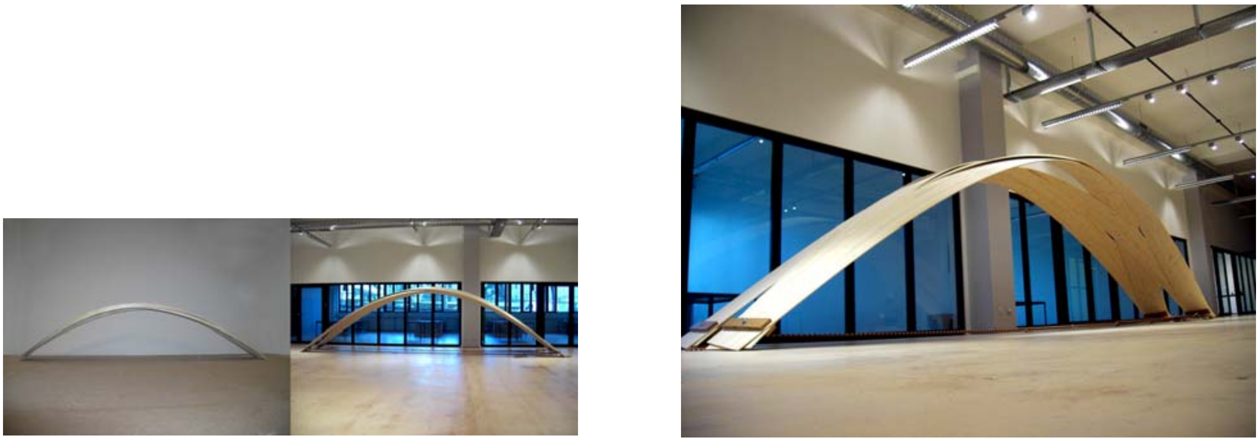

Fig. 11 Braided Timber structures

5. Conclusion

Timber structures made out of rectilinear elements have defined timber construction and carpentry for centuries. With the development of new digital tools, timber construction could be introduced into a new and wide field of application. As shown by the use of these various tools, other geometries and constructions may emerge, which will thus introduce a new range of civil engineering challenges of interest in the field of timber construction. Structural analysis has not been as widely applied to timber construction as it has to steel or concrete construction. Now, the use of planar structural elements made out of timber-derived products and of curved linear elements will help to introduce timber in public buildings.

6. References

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