# Design, Fabrication, Digital

## *Between digital design and digital fabrication*

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**Abstract:** *This paper represents an educational practice aiming at analysis of the link between digital design and digital manufacturing. CFD (conception, fabrication, digitale) is a one week workshop with graduate (master recherche) students of architecture school of Nancy. Having passed the first semester with a focus on modelling principles, computational logics and formal data representation, students are well prepared to apply them all in the process of form generation. The exercise is based on experimenting with new approaches in computational form generation interweaving geometry, aspects of construction and fabrication technologies.*

**Keywords:** *CAD/CAM technologies; form generation; digital design; digital fabrication; constructability; architectural education.*

### Introduction

Since the early applications of computer science in architectural design, this interdisciplinary cooperation has greatly developed. Started from graphic visualization tools, the real role of so-called computer aided architectural design tools was limited to assist the presentation of final results. The insufficiency and the incompatibility of these applications with the essence of the design process were since discussed.

Due to the use of advanced computing techniques in design, a new generation of tools was brought about. The evolution from presentation tools to "generative tools" provided architects with the opportunity of extending computational power throughout the whole process of design from early stages to the end. While new tools are capable of dealing with digital geometric models supporting algorithmically generated forms, they seem to be impotent to encompass other kinds of data related to the process of form generation. So a holistic approach containing fabrication information is required.

This paper explores the relation between architectural morphogenesis and information necessary to support the process of construction.

### Architectural Morphogenesis

From an etymologic point of view, the term Morphogenesis, coined around 1890, derives from the Greek "morphe" which means shape and "genesis" which represents creation. Putting them together, it denotes the process of development and formation of a form, a structure or a system as well. It arises from procedural changes during the process. Biological morphogenesis refers to the shaping of an organism through differential growth of "embryo".

D'arcy Thompson (1967) was one of the pioneers to apply mathematical and physical data to the process of biological growth. In "on growth and form" he discusses the generation of form through a comparative analysis of inter related states of change, each containing the spatial data (three dimensional coordinates) of the next. This study reveals the potential of geometric models to deal with both biological and architectural morphogenesis.

Biological morphogenesis differs from the architectural one in two different but related facts. First of all the biological growth is a dynamic process entwined with the concept of time. "Morphogenesis is the creation of forms that evolve in space and over time" (Micheal Weinstock, 2004). Secondly, the biological growth is interwoven with the process of physical materialization, while in architectural morphogenesis the last one is distinctly separated from form generation. A third point would also be added to these; feedbacks have significant role in the process of morphogenesis. In the case of architecture the environmental feedback includes also the specificities of cultural context. This essay is focused rather on the second point; materialization.

The discrepancy between design and fabrication processes in architectural design is somehow reflected in a distinction between CAD and CAM tools. While CAD tools provide us with digital 2D, 3D models of generated forms, divers' aspects of fabrication are usually taken into consideration when the whole process of design is worked out. "*One danger with using purely geometrical design tools that are not tied in with any physical simulation tools or any verification software for the intended fabrication process is that it is easy to forget the physical aspects of the emerging construction*." (Sequin 2008)

This exercise would be an aid to investigate the idea of constructible form generation.

## CFD (conception, fabrication, digitale)

CFD (conception, fabrication, digitale) is a one week workshop with graduate (master recherche) students of architecture school of Nancy 2nd – 7th Feb 2009. The main issue of the exercise is to deal with tree parallel matters at the same time: the process of form generation as a result of the combination of certain geometric operations, possible ways of fabrication based upon a classified group of methods employed in the process of construction and a process of digital manufacturing based on CNC technologies. Geometric description of the model is as much in relation to the idea (represented via a selected image) as the construction and assembling techniques. Students were free to think of different programmes for final results.

The process of form generation of the exercise is inspired by "école de nancy" (Nancy School) which has been developed as the spearhead of "Art nouveau" in Nancy, France around 1900. The original aspects of the école de Nancy lies in the fact that there is a close bond between art and industry. Using plants and animals as a main source of inspiration, the aim is to integrate form, material and technique (Figure 1). Our inspiration from "école de Nancy" concerns rather its specific approach to design than its formal results.

The first step starts with choosing an image, containing two or three dimensional shapes, as the source of inspiration. Students were supposed to figure out geometric operations involved in the process of form generation. Here the task is to extract geometric operations and to combine them into a series, conducting the modeling of the chosen form. Geometric modelling was done in MAYA, other software were also used if needed. A database of images, mostly from nature, containing different kinds of trees, plants, cauliflowers, animals, sea animals (seashells, lobsters, crabs …), is provided as a source.

Selection and composition of chosen operations relies also upon specific method of construction. Analyzing a number of erected projects such as saint

Loup chapel (Switzerland) designed by Mondada and Localarchitecture (*figure 2*), *Centre Pompidou* (Metz, France) by Shigeru Ban (*figure 3*), *Napier University* (Edinburgh, Scotland) designed by Richard Woolsgrove (*figure 4*) and *etc*. certain methods of construction are revealed. Pilling up, tessellation, timber framing, ribs, shell-shaped surfaces, entangled ribs … are methods undertaken by architects. This part of the exercise is supported by different scripts, developed and implemented, able to unfold a tessellated surface, to slice the 3d model in two perpendicular directions and also to create the intersection of two slices.

This step is supposed to investigate the degree of constructability of geometric operations.

The last step is to fabricate forms which are already modelled in Maya. A package of CAM and CNC software (ArtCam and WinPC-NC) is used to cover the linkage between digitally designed forms and the machine in order to manage the process of rapid prototyping. A 3-axis Milling machine is used for this. At the same time, students were also supposed to consider different modes of assembling.

## Analysis of projects

In order to analyse the continuum of design to manufacturing, two examples are described step by step.

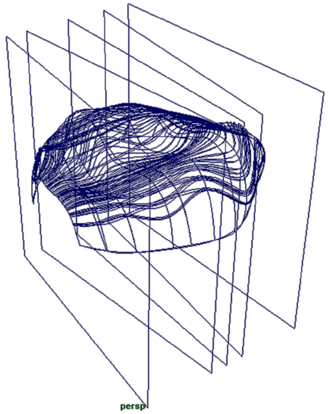
The selected image as the inspiration source for the first project was a "nest", so the first step was to create a model in the form of a nest. For that, two possibilities were explored; digital modelling through MAYA and creating the final surface by manually deforming a piece of wire mesh.

*Figure 1 (left)*
*The canopy of the chamber of commerce and industry Nancy, France*

*Figure 2 (right)*
*saint Loup chapel, Mondada, Switzerland*

*Figure 3 (left)*
*Centre Pompidou, Shigeru Ban, Metz, France*

*Figure 4 (right)*
*Napier University, Richard Woolsgrove, Edinburgh, Scotland*



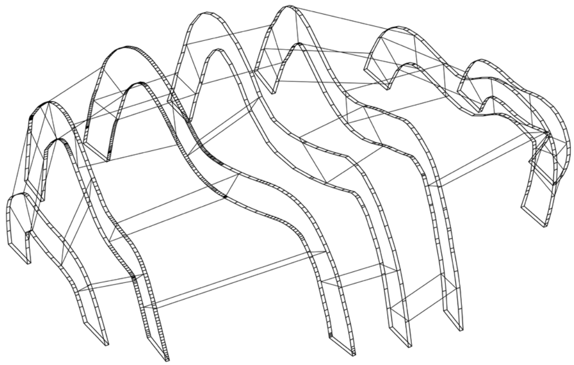



*Figure 5 (left)*
*Cutting the deformed surface by vertical plans*

*Figure 6 (right)*
*Rectangles created randomly between curves*

As one of the objectives of the exercise, geometric description of the model was supposed to be based on other considerations. Firstly, the choice of a nest as a mental image refers to a series of randomly positioned pieces of wood. Secondly the selected construction method was possible either trough an entangled (crossed) rib mesh or by bracing two pieces with another wooden piece.

These issues, the concept crystallized through a mental image and also the desired construction technique, can absolutely affect the process of form creation and geometric modelling. A nest might be seen as a randomly deformed surface while aiming at a specific construction technique such as the two explained above, it might not be limited to a sole envelope. Each geometric element (point, edge …) would respond to specificities of the constructional method. This demands a new adaptation of the geometric model based on its constructional identity.

In the case of the first way of modelling (a digital model in MAYA), the nest was the result of the intersection of two series of ribs. To create the first series a deformed surface was needed so that the curves get the correct deformation. After trying different possibilities, "lofting" seemed to be the most appropriate strategy to achieve the wavy amorphous surface of the nest. This surface is created so that we achieve the entangled rib mesh. These curved ribs are the result of the intersection of some random vertical planes, which are not parallel, and the original surface of the nest (*figure 5*).

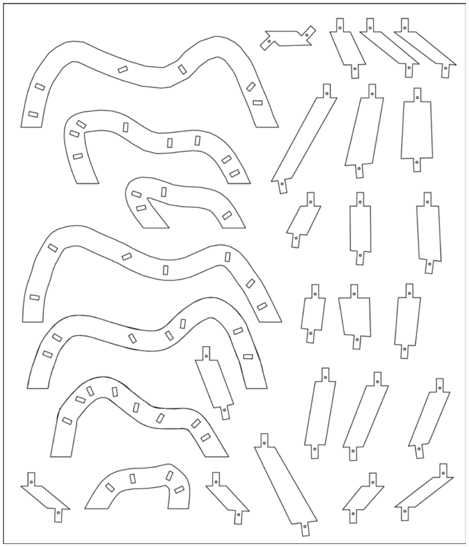
First series of curves (intersection of deformed surface and vertical planes) created in MAYA are then exported to AutoCAD to have more control and precision on final design. In other words second series of ribs and holes were created in AutoCAD. First curves were extruded to create bands of 3 centimetre width. They are later cut out from a 0.3 centimetre thick wooden board. Series of rectangular holes should be also cut out from these curved strips through which second series of ribs will be connected to first ones. The 3 centimetre width was chosen to avoid the tin wooden strip to break and also to reserve enough space for holes.

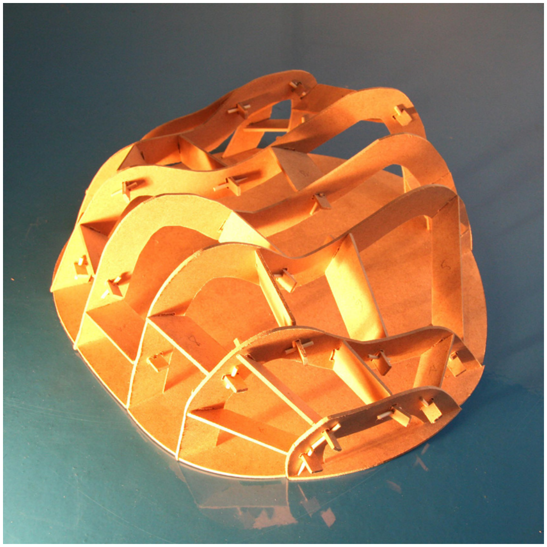
To control the connection between first and second series of ribs, second ones were first drawn, in perspective view, between first ones (*figure 6*). Second series are in the form of rectangles with different dimensions. To have the two dimensional outline of both first and second series of ribs, an operation of alignment was applied on them. Each rib of second type must contain two small pieces on its sides via which it is connected to two ribs of first type.

The last step is to export this two dimensional figure to "ArtCam", so that it be cut out from wood boards (*figure 7*). Finally a third piece of tin wood is

Figure 7 (left)
Final setting of pieces ready to cut

Figure 8 (right)
The assembled final model





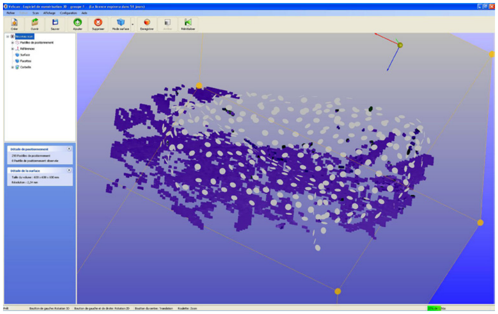
used to brace and fasten them (*figure 8*).

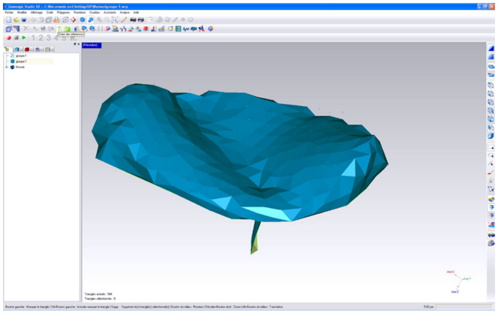
The same project was realised in another way. The geometry of the nest was not digitally modelled, but created out of a wire mesh, deformed manually. It was then captured with a laser scanner (handyScan. EXAscan). The resulted data cloud (*figure 9*) was then converted to a polygonal mesh surface (*figure 10*). This was done in "geomagic 10". The surface was then exported to MAYA. It is supposed to be the base to create entangled (crossed) ribs. To this a script was applied which is able to cut the surface in two perpendicular directions and also to draw a precise figure of the connection of two perpendicular crossed parts (*figure 11*). The result is then exported to ArtCam to be cut by the milling machine (*figure 12*).

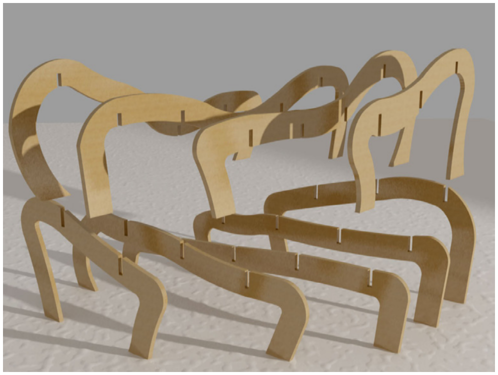
The second project was inspired by a seashell (*figure 13*). The process of modelling was done in MAYA. The whole surface of the seashell was modelled through "lofting". It was then cut horizontally, via Boolean operation, to facilitate the stability of the final result on a flat plane. A helix and a circle were used for lofting. In other words the triangular subdivision of the seashell surface was the direct result of the number of segments of the circle. This adjustment was related to formal aspects of the surface

Figure 9 (left)
Data cloud captured by scanner

Figure 10 (right)
Polygonal surface created in "geomagic"







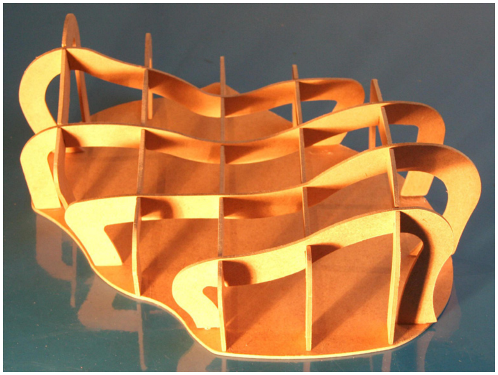


*Figure 11 (left)*
*Surface sliced by the script*

*Figure 12 (right)*
*Final result, assembled*

as well as construction and assembling techniques (*figure 14*).

This project was supposed to be constructed with a series of wood panels connected together by their contours, in a way that they can be decomposed, assembled and disassembled. Each panel corresponds to one triangular facet of subdivision and each facet is connected to one beside by sewing.

The subdivided surface of the seashell should be unfolded, so that facets can be cut out from wood panels. For this a script was applied which was able to put facets one beside the other and put a number on the model as well as the unfolded facets. It is necessary to have numbers on both model and unfolded facets to control the final spatial arrangement of the model.

To deal with the assembling method, series of holes should be drilled all along the three edges of facets. Radius of holes was equal to the drill's one; 0.3 centimetres but the distance between them was adjusted at random, about 1.8 to 2 cm. The distance between holes and each edge was adjusted in a way to prevent panels from breaking after removing holes; this was again affected by the scale of the model. This part of model (assembling design) was prepared in AutoCAD.

As explained above, the script was just able to unfold the surface and put facets one beside the other, but we would also need to know which edges of each two panels should be connected (sewed) together later. To do that the unfolded facets, were reconnected to create a two dimensional flat model

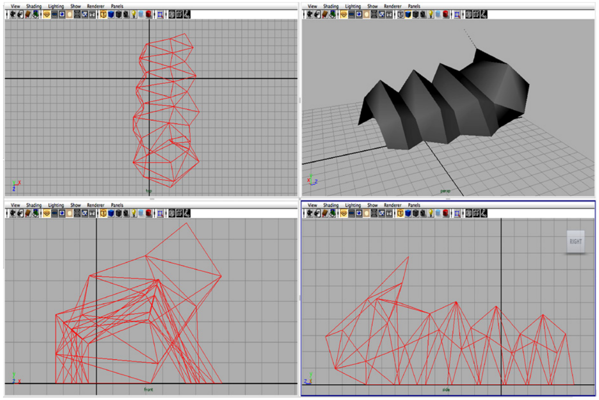


*Figure 13 (left)*
*Source of inspiration; seashell*

*Figure 14 (right)*
*Geometric modelling in MAYA*

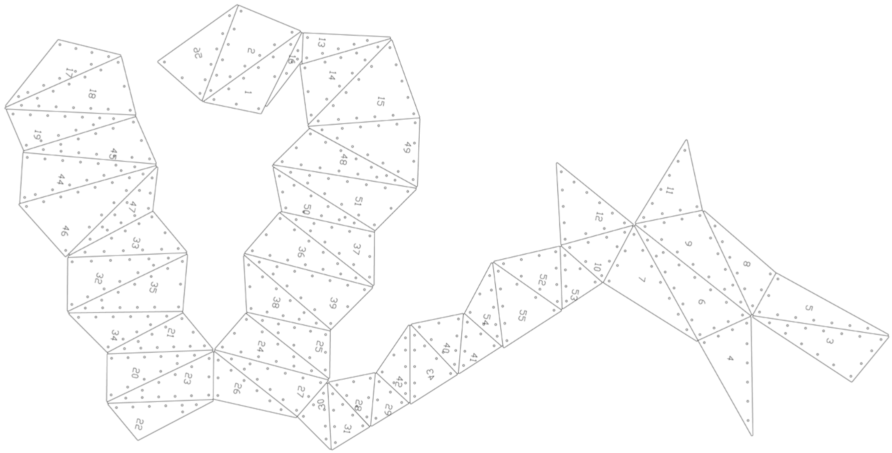


*Figure 15*
*The subdivided surface was unfolded. Facets were then reconnected to create a 2D model*

of the seashell surface (*figure 15*).

Passing through ArtCam, panels were cut and then connected by the string passing through holes (*figure 16*) and (*figure 17*).

## Conclusion

It is obvious that construction methods widely affect the geometrical description of a form, what is digitally modelled will not match the constructed form thoroughly. Considering the construction methods during early stages of design can provide an improvement in architectural morphogenesis.

Although specific aspects of geometric modelling such as position and dimension of elements were supposed to be adjusted in relation to construction or assembling considerations, they were widely affected by the scale of the model. Certain issues are not reflected nor treated in the model the same way as they are in reality. There is not enough

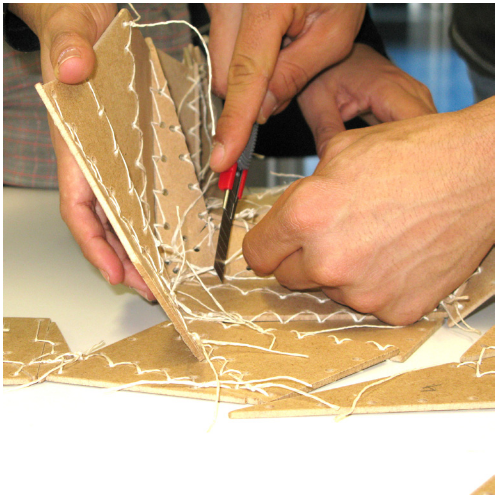


*Figure 16 (left)*
*Assembling panels by string*

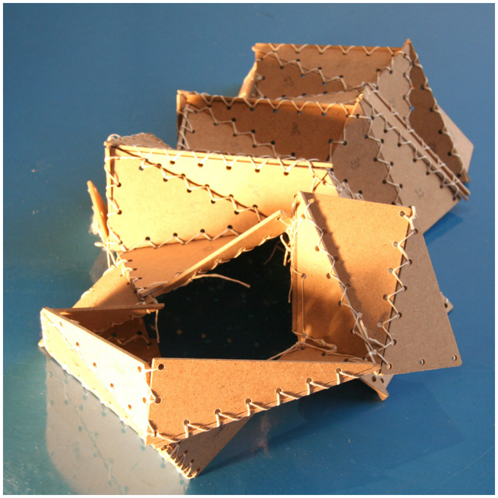


*Figure 17 (right)*
*Final model*

fidelity between model and the real object.

In the first project, the position of holes on the curves of fist series was found randomly. The width of curved bands was 3 centimetre to avoid them to break, but this was totally dependent on the model scale. In the second case study, position and dimension of holes should be based on assembling technique as well as material properties. Even the degree of subdivision should be based on construction criteria.

Geometric operations and construction related issues were both handled in different software, while specific assembling methods were poorly supported by these. The important point is that a model represents a final "finished" object which can support the spatial order and composition of the object, while we need often to know the chronological order and composition of components. A model capable of representing the object "being created" or "being completed" would be more helpful.

The objective of the exercise was to investigate the links between different stages of development of architectural form during its life. Paradoxically to the continuity of data during the process, the link is supported by a discontinuity of software.

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