Rationalization: Geometry, Computation and Construction

Integrated constructible form generation

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Abstract: Architectural design is confronted to a renewal of formal vocabulary regarding the advancements on computational techniques. Recent advancements in digital representation and geometric description of architectural form are raising more and more questions in regard to materialization. Construction and assembling constraints are parts of data needed to rationalize a geometric model. This paper reports on part of a research activity aiming at elaborating a tool capable of transforming geometric description of a non-standard form to constructive geometry.

1.   INTRODUCTION

Architectural design is confronted to a renewal of formal vocabulary regarding the advancements of digital design tools. However, the capacity of representing and modeling more and more complex geometries (curves, surfaces …) has been the principal driving objective of the development of many of these design tools. While first generation of such tools were capable of representing and managing basic geometric elements such as points, lines and Euclidean space, recently developed modeling systems offer the possibility of representing and manipulating advanced geometries and higher dimensional spaces (Nurbs, complex curvature …). Although providing the

possibility of modeling non-standard complex morphologies design oriented tools tend to restrict the final design to a geometric configuration.

Architectural design's tradition has for long time prioritized the generation of form over its materialization. Materialization and production become important issues only once the design process is worked out. The introduction of CAD-based tools forces architects to work on two and three dimensional geometric representations. This restrictive quality of digital geometric modeling -as explained above- enriches somehow this situation. The family of non standard morphology is transforming to a utopia universe of non constructible virtual object. "If architects don't try to feed material constraints into software, they become moviemakers or image manipulators instead of designers who actually construct things." (alexandro zaero-polo, 2004).

Recent generation of computational assistance to the process of architectural design (associative computer aided design and manufacturing technologies) is based on establishing a flow of information between design and production stages. In such context the issue is to make a link between geometric data and material characteristics of the final design. This is to say how to enrich the geometric model so that it can support the post design phases.

This paper reports on elaborating a parametric model aiming at adding a semantic layer to the geometric model – in the specific field of timber construction. The parametric model is then used to develop a tool capable of generating the structural volume of a non standard surface based on a specific timber construction system. The objective being to provide data needed for production phases, the parametric model is supposed to integrate materiality based on classified timber construction methods.

2.   DIGITAL - MATERIALIZATION

Architects often claim they cannot think of a solution, or proceed with the design, when they don't know how and on what it is going to be realized. The decision about how the design's result will be fabricated is thought of usually as the last question. The idea of digitally bridging design and materialization processes in architecture has been explored by several researchers.

Fabian scheurer and his team have questioned through several projects (Camera Obscura Trondheim 2006, Hungerburg Funicular Stations Innsbruck 2007, Centre Pompidou Metz 2008 …) the materialization of a digital model. Based on logic of component as he explains, and the information needed to describe it their experiences challenge the translation of a non scaled digital model to a one to one real object. Shifting the definition of "complexity" -from formal configuration to the context of information processing- the firm works on the basis of parametric description of components to be fabricated. The use of parametric modeling is because of its adaptive capacity to changing context of construction and manufacturing constraints.

Their experiences reveal that construction, assembling process and fabrication methods bring post design processing to the geometric description of the final shape. In translating design data to manufacturing information one crucial issue concerns construction decisions. According to Scheurer's diagram (figure 1) of the information flow between design and fabrication an important part of the bridge between CAD and CAM model is the construction dimensioning. Detailing and precise two dimensional documents needed to control the CNC machine are not provided by the free form modeled in a CAD environment.
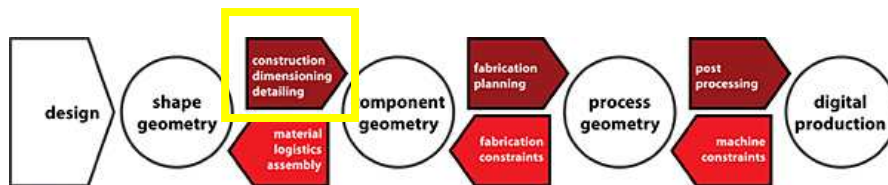

Figure 1. Fabian scheurer's diagram; information flow from design to fabrication

Researches done by Sass, Michaud and Griffith (Griffith, Sass, Michaud, 2006 and 2007) address another issue concerning post-design processing; the problem of assembly modeling. They characterize the process of design to fabrication as following; the process consists of four steps; preparation of a first three dimensional CAD model, elaboration of a construction model (as

they name it) containing description of components adapted to local geometry, providing two dimensional arrangements of 3D components to be numerically fabricated and finally the assembling of fabricated pieces.

Focusing on problems posed by assembling of fabricated components, they question the relation between shape modeling, structural and assembling systems. They explore methods of integrating assembly modeling in the CAD model so that design's result be less altered once arriving at assembling phase. Also based on logic of component or sub-object the issue of their researches is based on physical and mechanical behavior of components at their connections.

They have previously developed a plug-in tool – based on a bilateral network of connected ribs– to rationalize complex geometry. As explained above the study is focused on structural efficiencies of bilateral assembly of free form surfaces. This is why parameters related to physical and mechanical characteristics of joining (connections) such as density, friction and thickness affect the behavior of the geometry and are therefore used to generate the bilateral network. Both vertical and horizontal ribs are created based on number of divisions defined by user where vertical ribs are the result of projection from center of the form to the surface (figure 2). Ribs are joined with rivets and the geometry of the intersection is calculated by the algorithm.

These studies reveal the importance of integrating construction and assembling knowledge as semantic information in the geometric model, they indicate also the use of parametric modeling in this regard. However, they reveal on the other hand the lack of a generic parametric model to better assist the digital-fabrication link. A model which -by integrating post design information- is capable of supporting production phases.

Figure 2. Output model; assembled bilateral network of ribs

3.   PARAMETRIC MODEL – TOOL

In this work we try to provide a parametric model with integrated construction and assembling data for timber construction, as the basis of an algorithmic based tool to support production phase.

Our work is characterized by non-standard geometry and its technical vocabulary is focused on timber construction. The principal goal is to generate the structural volume of a given free form. First step was to categorize 5 families of construction methods; Pilling up, tessellation, mesh, membrane and structural frames, as well as assembling; "slotting together", "mortise and tenon" … .This step was followed by elaboration of a parametric model based on morphological, topological and technical characteristics of defined families. The model is then used as the basis for the development of an algorithmic-based tool - a plug-in implemented in Maya. The tool is capable of generating the structural volume and construction dimensioning necessary to provide tool-path.

3.1   Morpho – constructional families

As the first step the work started by categorizing 5 families of construction; pilling up, tessellation, mesh, membrane and structural frames and assembling; "slotting together", "mortise and tenon" …

Construction knowledge refers to topological information and 3D positioning of components while assembling logic defines types of connection and joints between them. This will be the basis for a parametric description of construction and assembling systems providing the possibility of a dynamic interaction between user and the 3D structural volume to be generated.

The piling-up refers to the superposition of horizontal regular or non-regular elements. Following a corbelling system it can support upper superposed elements. The friction between the elements cancels the horizontal forces. A distinction could be made between layered piling-up and modulated piling-up (figure 3a). The tessellation splits up of a structural surface with similar (or no similar) elements, which is usually compatible to the structural frame. Differences between facets would be in terms of shape (triangle, rectangle, pentagons …) and the folding angle between them. A distinction could be made between facets and waffles (figure 3b).

Figure 3. a) BWIF Sculptures, Bergen, Norway. b) Saint Loup chapel, switzerland.

A mesh here is considered as a grid of arcs or network of bars. Interconnected bars are subject to traction and compression. Meshes can form sorts of structural free forms enveloped by a subdivided surface (figure 4a). The (structural) frame is a composition of various structural elements that build a three-dimensional shape. This shape could receive an envelope surface (figure 4b). The membrane is a continuous structural surface made with linear (planks) or surface (panels) elements but assembled with no

angle. Vaults or shells represent a variation of the membranes.

Figure 4. a) Weald & Dowland museum, Chichester England b) Observation platform, Trondheim, Norway
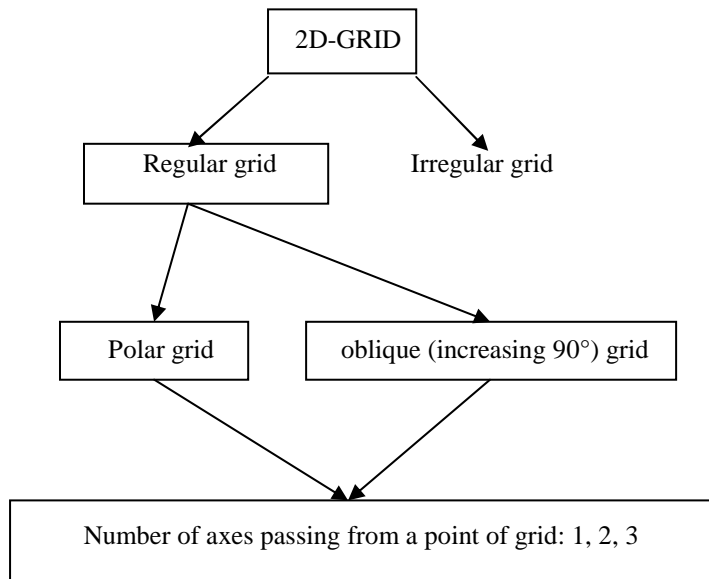
3.2   Parametric model

As the following step a parametric model was developed based on families explained above. The model provides a parametric description of topological and morphological behavior of predefined techniques of construction and assembling –knowing that the assembling part is not still integrated. To digitally assist the bridge between design and fabrication, the model represents an intermediate phase. It allows for a transformation from a general volume to a detailed representation of components.

The categorization done in the first step showed that the transformation of non-standard geometric model to a 3D construction model can be provided by a network – a grid, an abstract mesh – and a section or better to say a profile. The grid is here a sort of operator which integrates part of construction knowledge. The model will then give a parametric definition of the grid and sections specified for timber construction methods.

The grid is -as the first step of the development- considered as a two dimensional regular grid (figure 5). Two kinds of 2D grid are considered here: regular and irregular one, where the irregular refers to a grid created by random mathematical operations.

The relation between axes of grid and a section (a profile) can be of two kinds (figure 6): faceted surfaces or better to say the facets of a subdivided surface encountered by grid axes (edges) or a section extruded along the projected axes (edges). In the case of extruded sections they can be either of

standard type or customized. The type of a profile (section) refers to its form; rectangle, circle … as well as its dimensions.

```
                        ┌─────────────┐
                        │   2D-GRID   │
                        └─────────────┘
                         ↙           ↘
            ┌───────────────┐      Irregular grid
            │  Regular grid │
            └───────────────┘
                ↓         ↘
      ┌──────────────┐  ┌──────────────────────────┐
      │  Polar grid  │  │ oblique (increasing 90°) grid │
      └──────────────┘  └──────────────────────────┘
                ↘         ↙
      ┌────────────────────────────────────────────────┐
      │ Number of axes passing from a point of grid: 1, 2, 3 │
      └────────────────────────────────────────────────┘
```

If "1"*:

1- Organization of axes: linear – circular – elliptic
2- Distance (interval) between axes:
- Constant → distance value
- Non constant → ratio

If "2":

1- Organization of axes n° 1and n°2: linear – circular – elliptic
2- Angle between axes n°1 and n°2 : $0 < A > 180$
3- Distance (interval) between each two axes of axes n°1:
- Constant → distance value
- Non constant → ratio

4- Distance (interval) between each two axes of axes n°2:
- Constant → distance value
- Non constant → ratio

If "3":

1- Organization of axes n°1, n°2 and n°3: linear – circular – elliptic
2- Angle between axes n°1 and n°2, between axes n°2 and n°3 : 0 < A > 180
3- Distance (interval) between each two axes of axes n°1:
- Constant ➔ distance value
- Non constant ➔ ratio

4- Distance (interval) between each two axes of axes n°2:
- Constant ➔ distance value
- Non constant ➔ ratio

5- Distance (interval) between each two axes of axes n°3:
- Constant ➔ distance value
- Non constant ➔ ratio

Figure 5. Parametric model of a section (profile)

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          SECTION (profile)
            /        \
       Facet         edge
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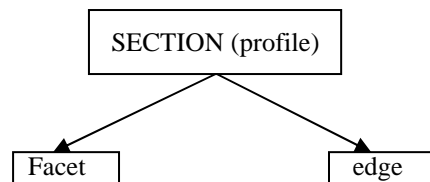
If edge:

1- Type of the section (profile): standard / customized
2- Number of sections (profiles) along each axes: 2,3 …
   2-1-   If 2:
           The position of two sections at two ends of the edge, for each section (profile):
                              2-1-a)   shift on Y
                              2-1-b)   shift on Z

   2-2-   If 3:
           The positions of three sections:
           For two "end" sections (profile):
                              2-2-a)   shift on Y

2-2-b)	shift on Z

For the third one:

2-2-a)	shift on Y
2-2-b)	shift on Z
2-2-c)	shift on X

3- Rotation of each section around the axe: $0 < A > 180$

If facet:

1- Type of the section (profile): standard / customized
2- The position of the section (profile):
   2-1   shift on Z

Figure 6. Parametric model of a section (profile)

The next issue to be parameterized is the category of different assembling methods which is not for the moment integrated in the model.

Parameterization of the "Napier University", Edimbrough, Ecosse (figure 7) shows as an example the use of parametric description.

Figure 7. "Napier University", Edimbrough, Ecosse

Here the grid is a regular oblique grid with two axes passing from each point. Organization of both two axes is linear and the angular value is about 45°. Intervals of both two axes are approximately constant. The profile is an extruded standard section in the form of circle. Sections at the two ends are identical and there is neither a shift in X nor in Y direction.

3.3   Plug-in development

On the basis of two previous steps a plug-in is being developed which proceeds as following;

The process starts by a "grid" creation, based on the parametric model. To capture the corresponding 2D grid on a non-standard form, the grid – parametrically defined by the user – is projected on the form. From this the program can generate the structural volume of the received geometry based on predefined profiles. Final step is to create assembling geometry in intersection points of rib network- this step is not still developed.

The associative relation between the grid and the structural volume enhances user's control on the process. Once grid created further manipulations either on its intervals or on angular value will directly affect the three dimensional volume. It is also capable of providing the construction dimensioning ready to pass through a CNC machine. The developed plug-in is implemented in Maya.

To validate the pertinence of the plug-in, it was first used to regenerate the structural volume of an existing project (figure8 and 9). At the second time it was used in an educational experience (workshop) with master students of architecture school of Nancy, to create structural volume of a non standard form and to provide its necessary construction dimensioning to be fabricated (figure 10 and 11). It resulted in fabrication of a small prototype with a 3-axis milling machine.
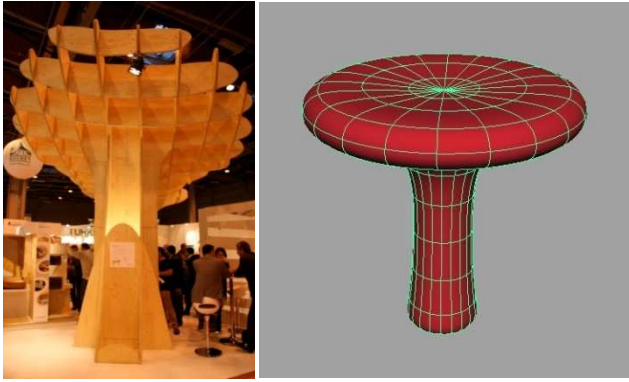
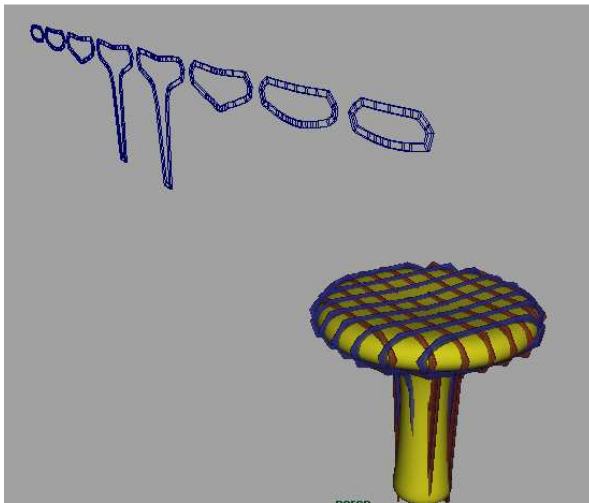*Figure 8.* A wooden mock_up and its geometric model in Maya

Figure 9. Result of the plug_in applied on the geometric volume
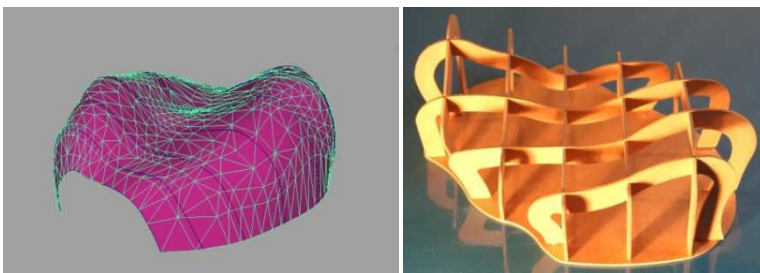

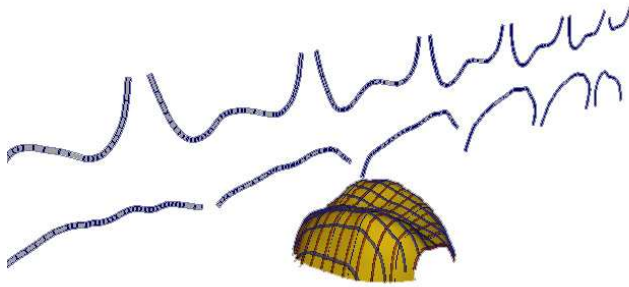*Figure 10.* Educational experience; from geometric modeling to digital fabrication

Figure 11. Educational experience; Constructive interpretation, fabrication preparation

4.   Conclusion

Materialization of complex curved forms is hardly based on a geometry rationalization based on construction strategies. A solely geometric model is impotent to handle post-design developments. Previous works reveal the lack of a generic parametric model to better assist the digital-fabrication link.

In this work we tried to provide a parametric model with integrated construction and assembling data for timber construction, as the basis of an algorithmic based tool to support production phase.

A plug-in is being developed, implemented in Maya and validated during a workshop.

5.   References

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