Geometry, Design and Construction: A Parametric Model for Non-standard Timber Construction

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ABSTRACT

Architectural design is confronted with a renewal of formal vocabulary regarding the advancements in computational techniques. Recent advancements in digital representation and geometric description of architectural form are raising more and more questions concerning materialization. Construction and assembling constraints are parts of the data needed to rationalize a geometric model. This paper offers a report on part of a research project aimed at elaborating a tool capable of transforming geometric descriptions of non-standard forms to constructive geometry.

KEYWORDS: digital fabrication, materialization, parametric modeling, timber construction, digital design tool.

Design and Construction

Architectural design is confronted with 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, etc.) has been the principal driving objective of the development of many of these design tools. While the first generations 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, etc). Although they provide the possibility of modeling non-standard complex morphologies, design oriented tools tend to restrict the final design to a geometric configuration.

The tradition of architectural design has for long time prioritized the generation of form over its materialization. Materialization and production become important issues only once the design process is complete. 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— somehow enriches this situation. The family of non-standard morphology is transforming into a utopian universe of non-constructible virtual objects. "If architects don't try to feed material constraints into software, they become moviemakers or image manipulators instead of designers who actually construct things" (Zaero-polo, 2004, 98).

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

This paper reports on the elaboration of a parametric model aimed at adding a semantic layer to a geometric model, specifically in the 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 parametric model is supposed to integrate materiality based on classified timber construction methods with the objective being to provide the data needed for production phases.

Digital Materialization

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

Fabian Scheurer and his team have executed several projects (Camera Obscura Trondheim 2006, Hungerburg Funicular Stations Innsbruck 2007, Centre Pompidou Metz 2008) questioning the materialization of a digital model. As he explains, based on the logic of the component 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 descriptions of the components to be fabricated. They use parametric modeling because of its adaptive capacity to change the context of construction and manufacturing constraints.

Their experiences reveal that construction, assembling processes and fabrication methods bring post-design processing to the geometric description of final shapes. One crucial aspect of translating design data into manufacturing information concerns construction dimensioning. Detailed and precise two dimensional documents needed to control the CNC machine are not provided by the free form modeled in a CAD environment. Research done by Sass, Michaud and Griffith (2006, 2007) address another issue concerning post-design processes—the problem of assembly modeling. They characterize the processes moving from design to fabrication as follows: prepare a first three-dimensional CAD model, elaborate a construction model (as they call it) containing a description of components adapted to local geometry, provide two dimensional arrangements of 3D components to be numerically fabricated, and finally assemble the fabricated pieces.

Focusing on problems posed by the assembly of fabricated components, they question the relationship between shape modeling, and structural and assembling systems. They explore methods of integrating assembly modeling into the CAD model so that design’s result is less altered once arriving at the assembly phase. Also based on their focus on the logic of components or sub-objects, the issue of their research is based on the physical and mechanical behavior of components at their connections.

They had previously developed a plug-in tool based on a bilateral network of connected ribs to rationalize complex geometry. As explained above, the study focused on the 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, which is capable of supporting different methods of construction because it integrates post-design information.

Parametric Model and Tools

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

Our work is characterized by non-standard geometry and its technical vocabulary is focused on timber construction. The principal goal of this exercise is to generate the structural volume of a given free form. The first step was to categorize 5 families of construction methods, namely, piling-up, tessellation, mesh, membrane and structural frames, as well as assembly techniques such as “slotting together”, “mortise and tenon”, etc. This step was followed by the 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 a tool path.

Morpho-constructional Families

Just as the first step in this research began by categorizing 5 families of construction (piling-up, tessellation, mesh, membrane and structural frames) (Fig. 1) and assembly techniques (“slotting together”, “mortise and tenon”, etc.), construction knowledge refers to topological information and 3D positioning of components, while assembling logic defines the types of connection and joints between them. This will be the basis for

Figure 1. top-left) piling-up, BWIF Sculptures, Bergen, Norway. top-right) tessellation, Saint Loup chapel, Switzerland. Bottom-left) mesh, Weald & Dowland museum, Chichester England. Bottom-right) framework Observation platform,

a parametric description of construction and assembling systems that provide the possibility of a dynamic interaction between the user and the 3D structural volume to be generated.

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. Tessellation splits up a structural surface with similar or non-similar elements, which is usually compatible with the structural frame. Differences between facets would be in terms of shape (triangle, rectangle, pentagons, etc.) and the folding angle between them; a distinction could be made between facets and waffles.

Trondheim, Norway

A mesh here is considered a grid of arcs or a network of bars. Interconnected bars are subject to traction and compression. A mesh can form a kind of structural free form enveloped by a subdivided surface. The structural frame is a composition of various structural elements that build a three-dimensional shape; this shape could receive an envelope surface. The membrane is a continuous structural surface made with linear (planks) or surface (panels) elements but is assembled with no angle. Vaults or shells represent a variation of membranes.

Parametric Model

In the following step a parametric model based on the families explained above was developed. The model provides a parametric description of topological and morphological behavior of predefined techniques of construction and assembly–recognizing that the assembly phase 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 a non-standard geometric model to a 3D construction model can be provided by a grid (an abstract mesh), a section, and finally, nodes or intersection points between axes of the grid. The grid here is a sort of operator which integrates parts of construction knowledge. The model will then give a parametric definition of the grid and sections (profiles) specified for timber construction methods. Parameterization of nodes will manage assembly.

Two kinds of 2D grids are considered here: regular and irregular, where irregular refers to a grid created by random mathematical operations, and regular, that can be either an oblique (containing orthogonals) or polar grid. As the first step of the development we focused on a two dimensional regular grid. An important parameter concerning a grid is the number of superposed sets of axes, or better to say number of axes passing from each node. It varies from 1 to 3, where the first case concerns layering and stratification. In any case, each set of axes is defined by its organization (linear, circular, elliptic, etc.), the angle between two sets being the angle between two of their axes and the intervals between the axes of each set. Constant and non-constant intervals exist.

The relation between axes of grid and a section (a profile) can be of two kinds: the facets of a subdivided surface encountered by grid axes (edges) or a section extruded along the axes (edges). A section is defined by its type, its position along the axis and its rotation around it. The type of a section refers to its form (rectangle, circle, etc.), as well as its dimensions. Extruded sections can be either standard or customized. The position of each profile is defined by the distance between its gravity center and one end of the axes. In the case of facets the only possible distance from the grid will be along the z axis. Parameterization of the Edinburgh Napier University, Scotland (Fig. 2) shows an example of the use of parametric description.

Here the grid is a regular oblique grid with three axes passing from each point. The organization of all three sets of axes is linear and the angular value is about 60°. Intervals of both two axes are approximately constant. The section is an extruded standard section in the form of circle. Sections at the two ends are identical and there is neither a shift in the direction of x or in y. The next issue concerns the categorization of different assembly methods which is not, for the moment, integrated in the model.

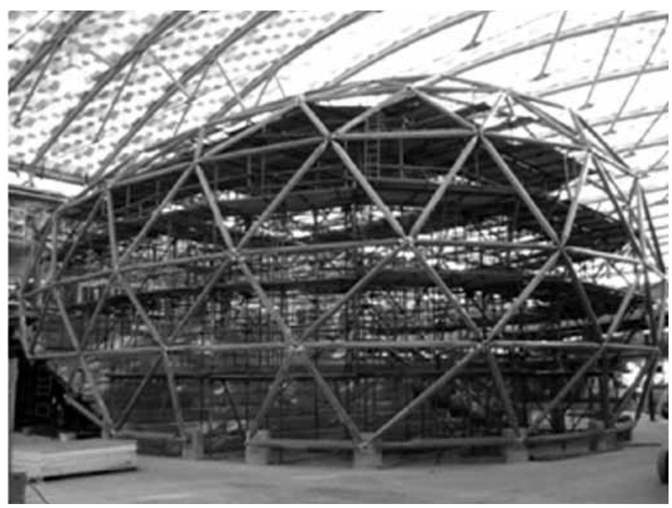

Figure 2. "Napier University", Edinburgh , Scotland

Plug-in Development and Validation

On the basis of two previous steps a plug-in is being developed that aims, for the first time, at validating the parametric model. The process starts by creating a "grid" based on the parametric model. The corresponding 2D grid will be used to transform the initial geometry to the structural volume. The final step is to create an assembly geometry in intersection points of a rib network; this step is not yet developed.

The associative relationship between the grid and the structural volume enhances user control over the process. Once the grid creates further manipulations either on its intervals or on its angular value, it will directly affect the three-dimensional volume. It is also capable of providing the construction dimensioning (2D documents) ready to pass through a CNC machine. The developed plug-in is implemented in Maya.

To validate the pertinence of the model, it was first used to regenerate the structural volume of an existing project (Fig. 3). The second time it was used was in an educational workshop with masters students of the architecture school in Nancy to create the structural volume of a non-standard form and to provide the construction dimensioning necessary for fabrication (Fig. 4). It resulted in the fabrication of a small prototype with a 3-axis milling machine. Of course, experiences based on one morpho-constructional family do not validate the very generic characteristics of the model proposed; it partially validates the principle methods and concepts at the core of our research. Future work will consist of integrating other morpho-constructional families.

Conclusions

The materialization of complex curved forms is hardly based on a geometric rationalization based on construction strategies. A solely geometric model is impotent in handling post-design developments. Previous works reveals the lack of a generic parametric model to better assist the design-fabrication link. In this work we try to provide a parametric model with integrated construction and assembly data for timber construction as the basis of an algorithmic-based tool to support the production phase. A plug-in is being developed, implemented in Maya and validated during a workshop.

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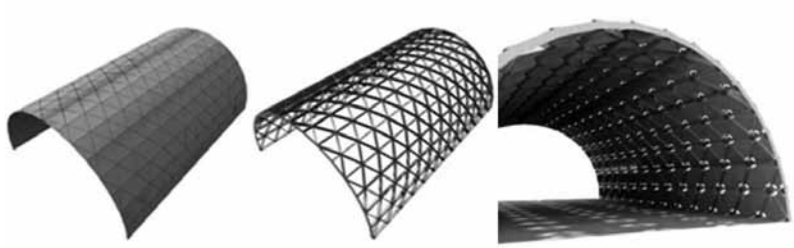

Figure 3. kartontheater Apeldoorn, Hans Ruijssenaars, Netherlands, 1992. Creation of grid, structural volume and the final result using proposed model

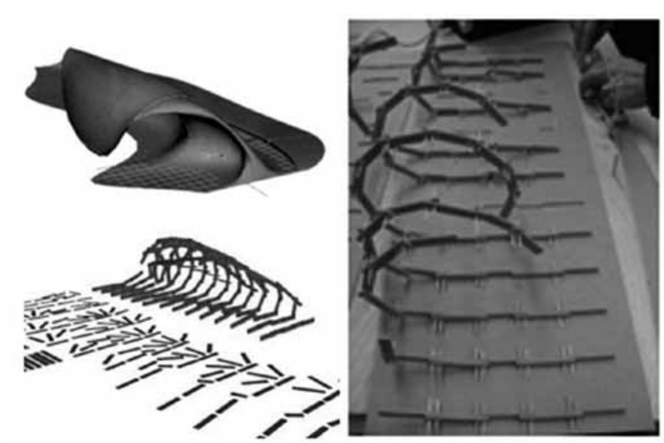

Figure 4. Educational experience; Constructive interpretation, fabrication preparation