# Architectural morphogenesis
# Towards a new description of architectural form

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*Abstract. Introduction of computational techniques and numeric potentials to the process of architectural design has significantly challenged the process of form generation. Architectural morphogenesis denotes the generation of architectural form via its geometric adaptation to materiality and constructability. This work is presented as a part of a research activity which investigates integration of construction information as well as material properties to geometric description of the architectural form. Different aspects of architectural form are explored. Basic issues of the research were examined through a one week workshop experiment with architecture students.*

*Key words. Computational form generation, materialization and constructability, geometric adaptation, geometric model, CAD/CAM technologies.*

## Introduction

The process of form generation is a problematic task within a process of iterative adjustments of existing conditions and possible responses. Architectural design is confronted to a renewal of formal vocabulary regarding the advancements on computational techniques.

Design oriented tools are mostly limited to the geometric generation and representation of architectural form. While supposed to deal with the complexity of architectural form, they seem to be impotent to encompass other kinds of data related to the process of form generation.

Within recent advancements the state of architectural form in CAD tools is facing a paradoxical development. 3D modelers such as 3ds max, Maya … allow on one hand for a free and advanced geometry, the result of which is complex morphologies not carrying technical characteristics. BIM modelers such as ArchiCAD, revit and … on the other hand permit the integration of data other than geometry, while the formal aspect is restricted to a predefined typology. Even the non-geometric data integrated in this kind of software cannot support the link between a form geometrically defined and a form technically constructible.

Based on the assumption of these concepts, this work seeks to investigate the link between geometric description of the architectural form on one hand and construction logics, fabrication constraints and material properties on the other hand.

## Architectural form in CAD tools

CAD tools are facing advancements in both geometric representation and integration of design methods. From sketchpad of Ivan Sutherland as one of the pioneers of interactively drafting systems, to shape grammar as one of the promising mechanisms to support the computational generation of design solutions, we assist a rapid development in both sketch and generative tools.

While first generation of CAD tools were capable of representing and managing basic geometric elements such as points, lines and Euclidean space, recently developed tools offer the possibility of representing and manipulating advanced geometry and higher dimensional spaces welcoming irregularity and complexity in architecture.

While first generation was aimed at supporting design results, recently developed tools are more and more integrating divers' methods of design process. Parametric design, constraint based design approaches and now generative mechanisms have been and are being integrated in computational tools. Started from layer structured models cad tools offer now the possibility of expressing relations (parameters) via parametric and constraint based controls.

Advanced modeling tools like 3d studio max, Maya and … can now manage double curved surfaces. Applying some modifiers one can reach a more complex geometry. Furthermore implemented generative tools like grasshopper (figure 1), integrated with Rhino's tree dimensional modeling, allow for generating or better to say creating new geometries. With grasshopper it is possible to define complex geometries from the first step in difference to others in which the geometry is first created through primitive objects and then manipulated. The designer can define geometric components and directly manipulate the relationship between them. Parametric control of the geometry raises the complexity.
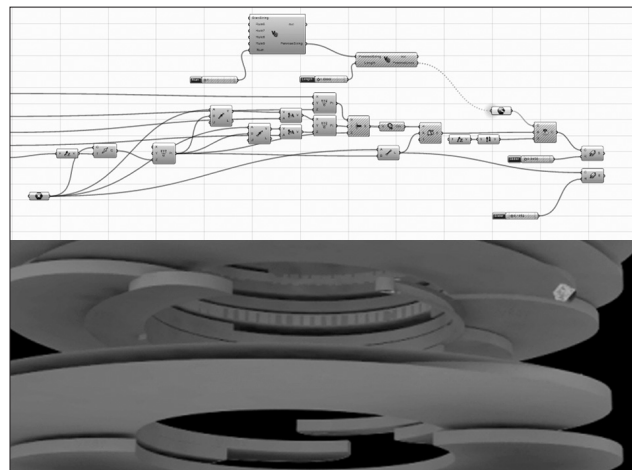


Figure 1, Parametric control-Relation definition in grasshopper.

Another parametric and generative tool is "generative components" (figure 2) which is also based on representing design components and relationship between them. It enables designer to not only design geometric components but also design "the design" itself. This is possible through feature creating. Defining the abstract relation between entities empower the designer to overcome the limits of CAD tools. Architectural form is no more limited to a typology of walls, stairs, and windows … as what happens in tools like ArchiCAD, Revit...
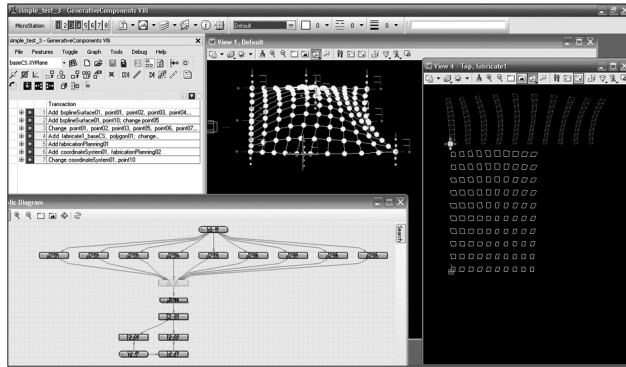


Figure 2, Geometric modeling-symbolic diagram-fabrication feature in GC

In another generation design and engineering oriented tools are near to be bridged. Offering generic to specific solutions, these allow for embedding data other than geometry. CADenary a digital form-finding tool developed by Axel Killian is the extension of an algorithm based on physical simulation. A spring based particle system is used to represent the flow of force. Also Tess3D developed by Erik Moncrieff, provides a compatible conceptual design and engineering production. Focused on the design of double curved structures it handles also snow and wind loading. In addition to these we face "tool making" enabled via scripting and individual programming which allows designers to create their own project specific digital tools.

# (Re) thinking architectural form

"Design rarely relies on a single type of representation or description but rather on a network of geometric and non-geometric representations." (Kilian, 2006)

In the process of design, form generation generally refers to synthesis of solutions which respond to divers' aspects of a project. What will be constructed is the result of the holistic effect of involved aspects. The one which is represented through the language of geometry carries also structural exigencies, material properties (elasticity …) and assembling logic. Geometric description is a sort of abstraction which can exist in virtual world. The geometry of the final solution should be rationalized to be constructed.

"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) 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 discrepancy between development of advanced geometry in CAD tools and fabrication preparation in CAM tools, enrich somehow this situation. Although the fabrication preparation is supported in associative CAD/CAM tools, there exist still construction techniques and methods of assembling to be integrated.

Existing software facilitate the slicing of a complex surface to pieces with precisely defined geometry. However, it would be more complicated when this slicing should be based on a specific spatial and chronological order defined by construction and assembling logic.

Computational techniques provide the opportunity of a continuum that can bridge the gap between design and construction. In "computational morphogenesis" (Menges, 2007), Achim Menges posits the idea of an integral computational model embedding materialization process within it. This concept would lead to a model based on a definition which is not limited to geometric description of a form but contains different aspects of morphogenesis such as constructional behavior and material properties, as well. This proposition seems to be promising to constitute a new basis for the process of form-finding in architectural design.

# Constructible form generation

Based on issues discussed in previous parts, this paper aims at embedding construction and assembling knowledge to the geometric model of architectural form. This is possible through the rationalization of the geometry; the process in which dimensional and compositional behavior of the geometric model will pass from a general state to the state of precisely and detailed definition of components and relation between them.

Rationalization is a process of adaptation through multiple back forward adjustments which result in a data enrichment (figure 3). To the first pure geometric data represented in the initial model should be added other field-specific data. Construction knowledge, assembling logic and material properties will gradually rationalize the geometric behavior of the initial model.

Not ignoring the effect of other kinds of information on geometric model, this paper addresses the construction and assembling knowledge and that specifically in the case of wooden construction. Construction knowledge refers to Topological information; positioning and relation definition between
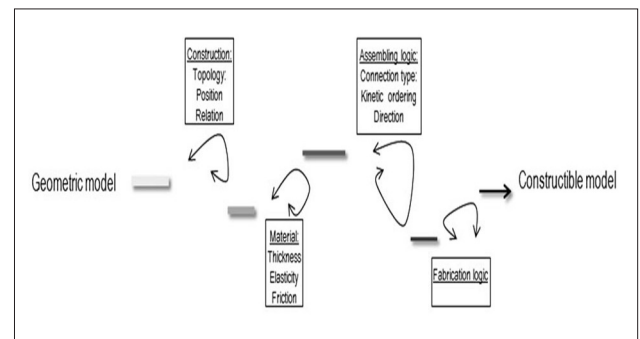


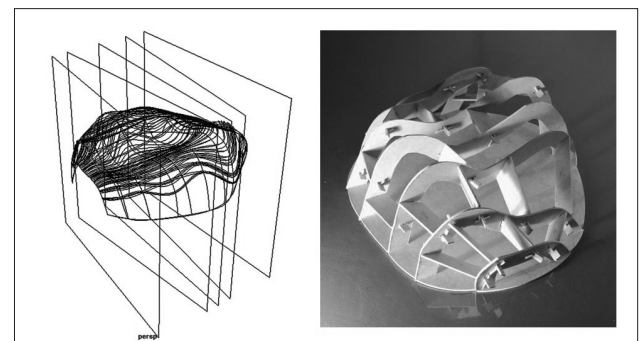Figure 3, gradual data enrichment to the geometric model



Figure 4, Geometric model adapted to construction data

components while assembling logic defines types of connection and joints between them. Geometric model should gradually accept information related to spatial composition, chronological composition (order) as well as direction of each connection. To support the assembling of the final product the model should carry information capable of describing the object "being created" while graphical representation describe often the final "created" object.

The study presented in this paper is based on a current research at CRAI, started at the first step by the analysis of a database of executed projects. This contributed to the identification of five methods of construction and assembling. Pilling up, tessellation, mesh, membrane and structural frames are identified. Types of connection would vary between "slotting together", "mortise and tenon" or bracing two superposed or intersected elements with a third one.

In the second step the work is focused on meshes and tessellation as selected methods of construction. 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. Tessellation is to split up a surface 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.

Two algorithms are developed to support geometric adaptation of an initial model to the two selected construction and assembling methods. The first one is capable of slicing a non-standard volume to a grid of perpendicular arcs to create a structural mesh. The assembling type is "mortise and tenon" and is supported through creating holes on one series of arcs and additional parts on respective arcs. The possibility of a modification on the angular position of the networked arcs will be integrated in the next step. Second algorithm allow for the triangular folded tessellation of a non-standard surface. The subdivided surface is then unfolded to facets which will then be connected by a third element. To this facets should be enumerated on their edges so that the assembling be supported.

The following example illustrates an essay by master students of architecture school of Nancy (figure 4). The application of the first algorithm was tested and contributed to the fabrication of a small prototype with a 3-axis milling machine.

## Conclusion

Architectural morphogenesis is the iterative process of geometric transformations adapted to constructional and material constraints. Current development of CAD tools is still facing incompatibility with the nature of architectural form generation. The process of design to construction should be supported by models integrating non-geometric as well as geometric data. This data enrichment contributes to the reduction of uncertainty and an increase of precision needed to guide numerically controlled machines.

The work presented in this paper tries to enhance the degree of constructability of wooden muck ups by integrating construction and assembling information to the geometrical model. Five families of construction methods and related assembling types are identified. An algorithmic based tool is proposed to assist the process of geometric adaptation to construction knowledge. An educational practice validated the supportive role of computational tools in the continuum of design to construction.

Future work consists of integrating more technical data to the geometric model supporting other methods of construction and assembling.

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