Reframing Structures

Construction of Parametric Design in Architectural Education

Ivo Vrouwe[1], Peter van Swieten[2]

[1]*LUCA Association KU Leuven, Department of Architecture, Brussels, Belgium / Eindhoven University of Technology, Faculty of Architecture, Eindhoven, the Netherlands,* [2]*Delft University of Technology, Faculty of Architecture, Delft, the Netherlands*

[1]*http://www.ivovrouwe.net,* [2]*http://www.swietenpartnes.nl*

[1]*info@ivovrouwe.net,* [2]*p.vanswieten@swietenpartners.nl*

Abstract. This paper aims at the discussion of opportunities and challenges of using specific construction sub-problems as active parameters in the physical construction of digital parametric design models. To create an overview, a taxonomy of sub-problems for construction is introduced. By using prototypes as a physical interface for the digital model, the different sub-problems become an integrated part of the digital design process. By a reflective process the digital model is informed by the material parameters gradually.

A case study is presented to discuss two different implementation strategies. The students acting in this study are presented with a combination of five sub-problems. Starting with these sub-problems, the student design a product digitally. By a reflective process, the object is materialized digitally and built physically.

Keywords. Framing; Parametric Design; Craft; Structures; Education

Introduction

For a long time, craft and computation seemed total opposites. Where craft strongly resonated with the material world, computational architecture emulated an immaterial world of dots, lines, surfaces, scripts and algorithms. Since digital production techniques have become more accessible, the distinction between design generation and design production has decreased rapidly (Leach, 2004). Through digital fabrication, the traditional craft, precision and techniques, former practiced and trained during a great part of the craftsmen’s existence, became available for computational architects directly (Bonwetsch, 2006).

For skilled, traditionally trained and educated designers and architects, this tendency is enriching the design immensely. For example, traditionally labor intensive wood and steel connections are rethought and reworked in CNC scripts and machined precisely in the real-world scale based on intimate knowledge of and experience with material properties and production techniques. In education, this tendency often discourages the student or aspiring architect lacking knowledge but moreover lacking this vital practical experience. Split between the digital world of CAD procedures and the physical environment of materials, products and processing, often CAD programs and procedures are mastered before its physical application is educated. Focusing on geometry, studio design and research exercises often do not prioritize the importance of material and techniques. In this context, technical aspects are considered as a neutral set of knowledge that is discussed briefly in later stages of the design process (Weinand, 2008). However, decisions in material and fabrication methods are no innocent choices. Integration of material and techniques correctly in earlier design phases often brings forward a more fluent process and a more cohesive result (Oxman, 2007). In our opinion this integration is early phases is even imperative for a coherent final design and a more fluent design process.

In this paper a visual taxonomy with different parameters of a design construction in architecture is presented. The taxonomy aims to assist design students in multiple layers of the digital and physical design process. By subdividing a design task into manageable active parameters, the student is able to address each problem individually in its most suitable medium before integrating it into the final design.

In the first part of the paper, craft and construction in artistic and architectural education is introduced shortly. In the second part of the paper, the proposed taxonomy is introduced. Each supertype is described shortly. In the final part of the paper, different design approaches to integrate the framework sub-problems into the parametric design process are discussed.

Digital Craft in Artistic Education

Basically, digital design in art and architecture is meant to reinforce the final built design. By processing something digitally, the designer anticipates on construction in later stages of the design process. Because architecture's mainstream practice has shifted from a craft oriented discipline to a manufacturing multi-disciplinary process, this model is sufficient. With architecture being an exercise in the synthesis of off-the-shell products (Sopeoglou, 2007), most architects have the knowledge to construct digitally without physical reflection. In more progressive construction this model often fails. With advanced architectures, a new way to inform the design by the applied material and corresponding properties, processes and characteristics has to be explored in their new design context.
(Menges, 2011).

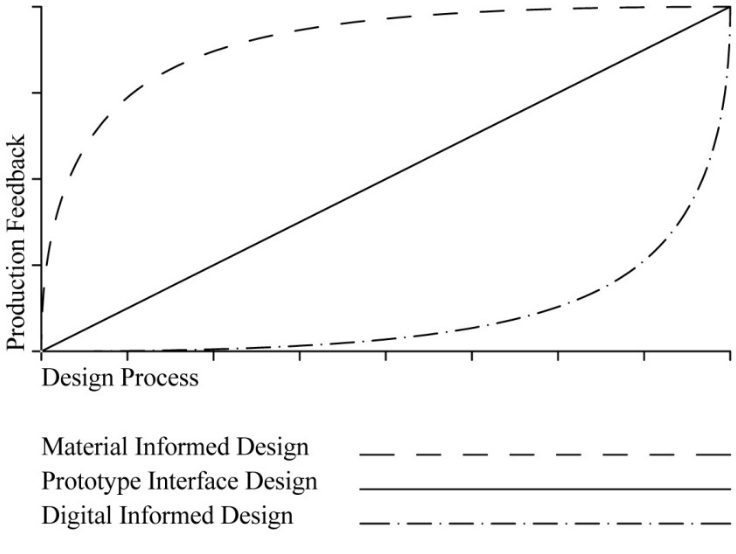

Figure 1 Production Feedback in the Design Process

The traditional craftsman explores the dimensions of skill, commitment and judgment in construction in a particular manner to create an intimate connection between hand and head, material and processing (Sennett, 2008). Every part of this *material* *informed design* process (*figure 1*) is reflected upon to result in a cohesive and reliable whole. At the start of this design process, materials and techniques have a strong influence on the design process. Because of a rich building tradition, the later in the design process, the less the design is influenced by material parameters.

Since the introduction of digital technology, architecture is dealing with a growing abundance of information in geometrical as well as technical parameters (Tamke, 2009). As a result, it is easy for students to skip fundamental parts of the design construction by presenting designs with a complexity not easy to grasp. In this *digital informed design* process (*figure 1*), construction is lifted to the end of the design process. With a steep materialization curve, the initial model is often harmed in construction.

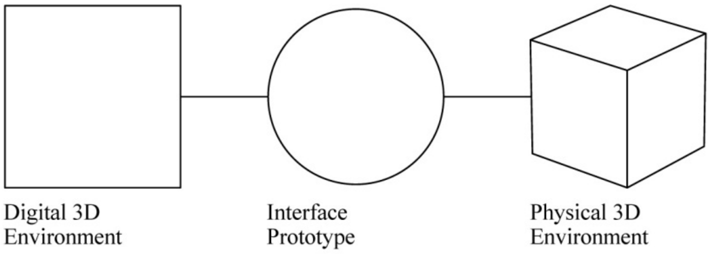

Figure 2 Interface Prototyping

To assist craft digitally with a complementing construction, the student has to be informed about the physical basic principles first. By using materials and techniques as active parameters, the design process should continuously be informed by an evolving understanding of the applied material properties, processing and construction applied (Sopeoglou, 2007). The digital model and the physical representation are calibrated by an interface of models and mock-ups. Through physical exploration and experimentation the *interface prototypes* balance the digital and the physical 3D environment.

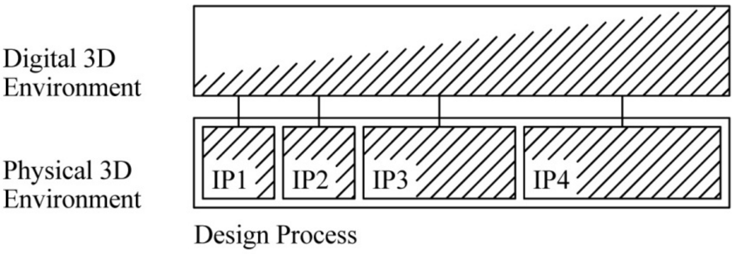

Figure 3 Interface Prototyping in the Design Process

By using specific sub-problems (discussed in the following chapter) as interface prototypes, the digital 3D environment is informed gradually by the physical 3D environment. In this reflective process, the two environments share information by using contrary media in different steps of the design process.

Parametric Designed Structures in Construction

In research in digital craft and tectonic, multiple abstract interpretations and parameters of built structures and architectures are made. For example, Oxman (2007) describes three forms of fabrication informed production processes in which the notion of craft is manifested: Material Selection, Fabrication Methods and Assembly Logic. In the work of Bell (2004) and Menges (2011) the importance of material orientation is discussed. Accordingly, Bell describes an overlap in design themes of structure, material, pattern, geometry and parametric control.

In the following taxonomy, these themes and production processes are complemented using the work of Martin (1996) and Bucquoye (2002) in material sense, by Ashby (2007) and Kula (2009) in technical sense and by Engel (2007) in structural sense. Resulting, the proposed frame taxonomy is divided into seven supertypes.

The following supertypes are distinguished: Materials (Mt.), Products (Pd.), Processing (Ps.), Connection (Cn.), Finishing (Fn.), Orientation (Or.), Structure System (St.).

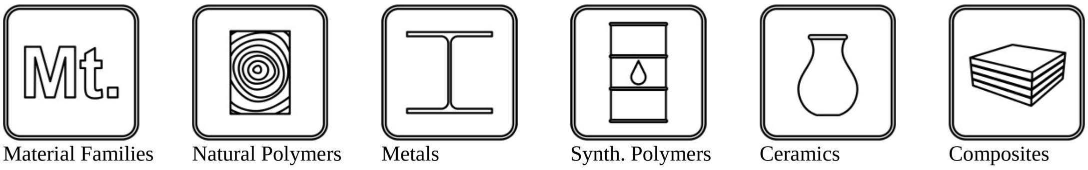

Table 1 Material Families supertype with coherent subtypes

In literature there is no final consensus on material differentiation. Most literature agrees on the distinction of *material families* in three groups being: Metals and Alloys, Ceramics and Glasses, Polymers and Elastomers (Martin, 1996). In some cases the fourth group represents Composite Materials. Others argue that because of the exceptional qualities of Carbon, this material should be a group by itself (Bucquoye, 2002).

In this frame taxonomy, user friendliness and materials used in artistic design are favoured over a theoretical bulletproof theory. Because of a rich use of resin-based structures, composites are used as an individual subtype. Because of wood being of great importance in construction and architecture, a distinction is made between natural polymers and synthetic polymers.

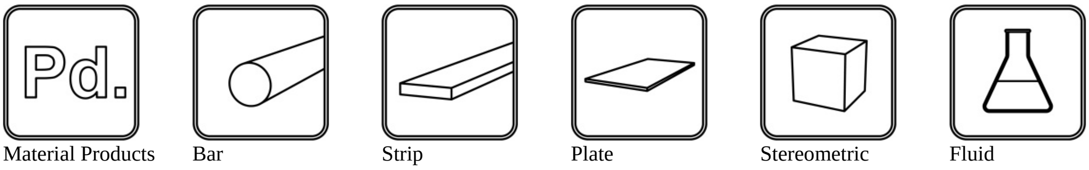

Table 2 Material Products supertype with coherent subtypes

The subtypes of *Material Products* consist of a combination of standards used in metal, wood and ceramic industries. Some distinctions seem unnecessary at first sight. For instance, a narrow plate can be a strip, and a narrow strip can be a rod. In application in design and geometry, and communication in workshops and education, the distinction proved rather valuable.

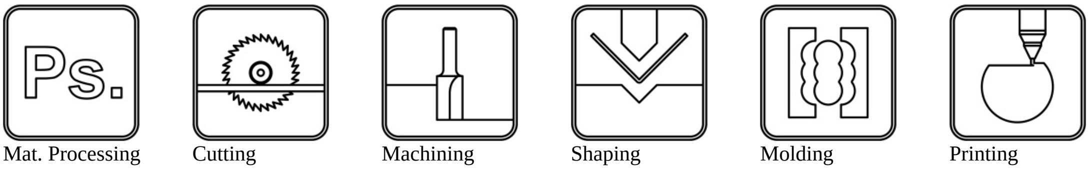

Table 3   Material Processing supertype with coherent subtypes

The supertype *Material Processing* consists of procedures that are used to manipulate Material Products (Ashby, 2007) (Kula, 2009).

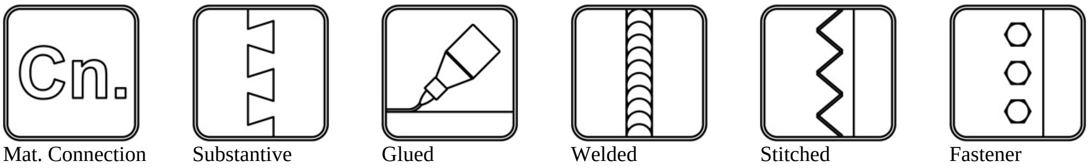

Table 4   Material Connection supertype with coherent subtypes

The supertype *Material Connection* consists of procedures that involve the joining of materials. The description is chosen as a noun to communicate a part of a design instead of an action (Ashby, 2007).

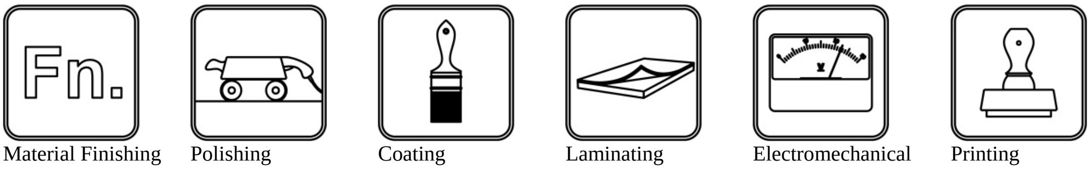

Table 5   Material Finishing supertype with coherent subtypes

The supertype *Material Finishing* involves all procedures used for finalizing the surface of a product or object. This treatment can have an ornamental value, protective value or a combination of both (Ashby, 2007) (Kula, 2009).

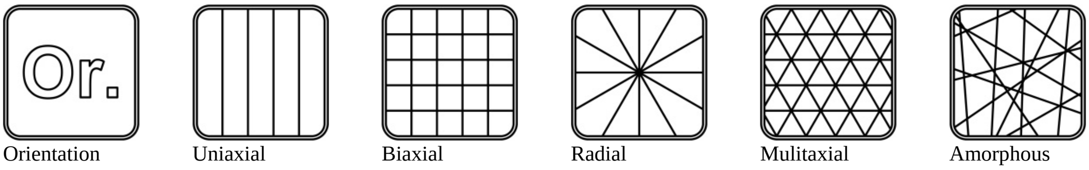

Table 6   Material Connection supertype with coherent subtypes

The supertype *Orientation* is introduced because material and construction orientation can have great influence on a system. In composite engineering, for instance, material orientation has great influence on the material behaviour under tension or compression. In structural geometry in general and weaving geometry in specific, orientation of its components has great influence on the structure’s stability.

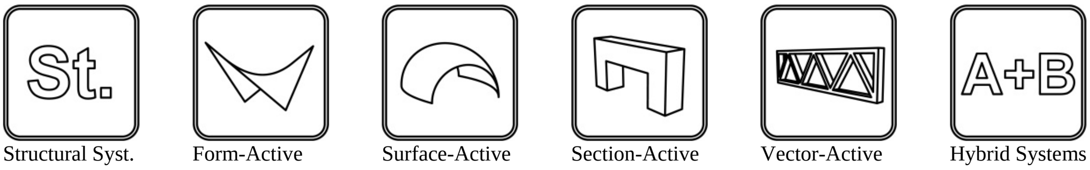

Table 7 Material Connection supertype with coherent subtypes

The last supertype is *Structural Systems* as described in the same titled book by Heino Engel. In the description of these systems the focus is on visual explanation with regard to the design effects of the structures (Engel, 2007).

Case Study: Utrecht School of the Arts

The case study discussed is a design brief, carried out in a course at the Spatial Design Bachelor Study at Utrecht School of the Arts. The Spatial Design study discusses a wide range of design disciplines. Education ranges from small and middle scale design disciplines like furniture design and interior design to design on larger scale like urban design and landscape design.

The class consists of 33 second-year design students. 2/3 of the students are female and 1/3 of the students are male. Generally the second year bachelor students are in their early twenties. The vast majority of the students start the bachelor study after secondary school directly.

The case study is carried out over a course of 5 classes of 3 full hours. All lessons are divided into a theoretical part of 45 minutes and a practical part of two hours. During the first course, the design brief is explained. Over the following courses, techniques and materials as implemented in the design brief are discussed theoretically first and reflected upon in a physical context next.

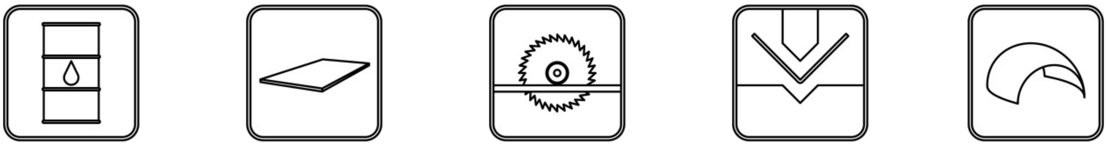

Table 2 Visual Design Brief, Icons describing the design parameters.

The design brief consists of a textual part and a visual part. Information concerning planning, reflection and reviews is presented in text. The actual design brief is presented in text, accompanied by the design parameter presented as icons (Vrouwe, 2013).

In the design brief the student is asked to design an element in their field of interest within the scope of the Spatial Design study. Designs may range from interior and exterior furniture design to models for small-scale architectures and follies. The design study has to include a combination of the following parameters: a plastic material, a sheet product, processed by cutting, formed by folding, behaving as a double curved surface-active structure system.

Figure 4 Laser Cutting Machine and Pattern Result

The object has to be designed in a digital environment first. No software in particular is set. By using scripts, procedures or Pepakura software, the student is challenged to rework the design into a model of flat or single curved components. By unrolling the components digitally, cutting patterns are generated. Next, the patterns can be materialized by laser cutting or by printing and manual cutting.

During the design process every design parameter has to be reflected upon in a physical environment before being implemented in the final design as described in *figure 3*. For instance, the designed geometry has to be built in papers first. Next the different design parameters have to be integrated one by one.

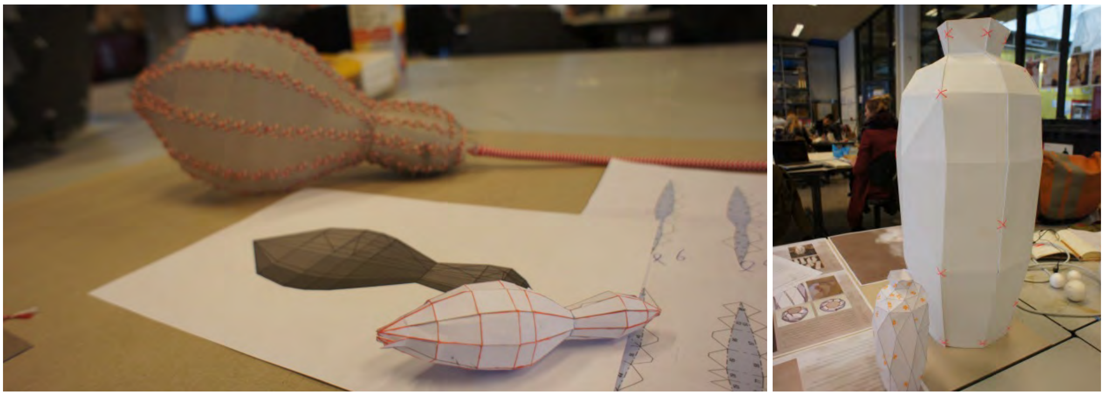

Figure 5 Paper Geometries and Final Models

At Utrecht School of the Arts, Google SketchUp is the software commonly used in form studies and design representation. As a result, the second year students have little 2D AutoCAD or Rhino3D drawing experience and no 3D CAD drawing experience. Because the 3D engineering capabilities of SketchUp are limited, the student showed rather eager to learn the 3D capabilities of engineering CAD software over the first lessons. By using basic 3D procedures like Extrude, Revolve and Loft, the student is well able to design a 3D model over the first part of the course.

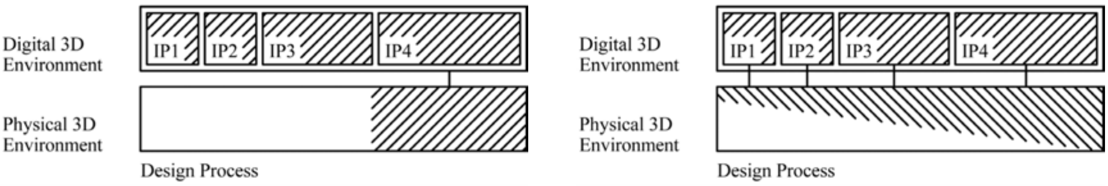

Figure 6 Integration strategy model 1 (Left), Integration strategy model 2 (Right)

In *figure 3* the integration of the design parameters from the physical world into the digital model is discussed. In the integration of the design decisions from the digital world back into the physical world, two main design integration strategies are noticed.

In the first strategy (*figure 6*), the student starts with a paper geometry study first, next the design parameters are studied. Small interface models are produced to study connection details, folding techniques and structural and material capabilities. After deciding on the separate techniques, the different parameters are reworked into the digital model. For example, holes and edges for connection are made and folding seams are generated. After finishing the digital preparations, all decisions studies are integrated into the final model directly.

Figure 7 Cutting and Connection Details, a Second Strategy Example

In the second strategy (*figure 6*), partial implementation is used. Step-by-step the separate design parameters are implemented from the digital environment into the physical design. Starting with a paper geometry, the material and product parameters are implemented in small scale material studies first. Design decisions on connection detail and finishing are bypassed by using glued or tape connections. After successfully finishing the interface model, the difficulty is increased until all design parameters are integrated and the final model is realized.

Learning outcome reflections

The use of the suggested frame taxonomy in interface prototyping was successful in highlighting the sub-problems of the design at hand. On the one hand, by dividing the abstract task into noticeable elements, design decisions become more meaningful and better contextualized. By addressing the sub-problem within its own context, the design solutions become easier to work on as well as more memorable.

The introduction of the two discussed integration models were not intentionally introduced beforehand. The models are a result of the student's design process and strategy. When comparing the first model to the second, the second model was more successful. By increasing the difficulty of the construction process gradually, the student is able to reflect on the process and can adjust when necessary. In the first strategy model, the integration of all parameters in the physical design often proved to be a challenge. When one decision in the interface prototypes failed it was often hard to adapt in the process.

Conclusions

In the presented case study, the suggested framed taxonomy accommodates a helpful overview of the complete gamma at hand. Second, the suggested taxonomy provides an efficient interpretation for the student of the physical basic principles of construction. Herewith the taxonomy is successful in highlighting the active parameters of the construction of the parametric design at hand.

In digital design, the use sub-problems proved to be an efficient way to explore properties and processes. The effectiveness of the separate sub-problems is increased by using visual representations of its components. By using visual representations of the content, communication proves to be more efficient. On the one hand, design briefs are understood more precisely. On the other hand, students find it easier to address their questions to specific topics or problems.

In construction, interface prototypes proved effective to address the different design parameters of the design at hand. By a distinction of the main design problem into manageable parts, students are able to discuss every parameter in its own most suitable context. After deciding on the most fitting solution, every parameter is reworked into the digital model in a more effective and fluent manner.

In building the digital model in the physical world, two models were noticed in the case-study discussed. In the first model a more traditional approach was used. The digital model was prepared by using building plans first. The building plans were constructed next. In the second model, the student introduced the interface models step-by-step into the physical production. By increasing the difficulty gradually, the building process showed more fluent compared to the first model.

The framed taxonomy is promising in terms of teaching more efficient and helping students to materialize digital parametric models in an effective and reliable manner. We believe including the added knowledge collected by rigorous testing, the use of sub-problems in combination with interface prototypes can serve as a valid tool for education in digital construction and fabrication in architecture and design schools.

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