A pedagogical introduction to parametric modeling as a formal research tool

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ABSTRACT

This paper starts with an overview of parametric modeling pedagogy in architectural design, notably with regards to mathematical perspective, and the inputs it generates in the design process. We focus on the pedagogical approach developed within the course "Digital Culture and Generative Processes of Form", part of the Master Program of the Faculty of Architecture (University of Liège, Belgium). We then develop the evaluation methodology applied in this context. Finally, we discuss the conduct of such a learning process.

Keywords: architecture, parametric modeling tools, formal research, pedagogical process.

1. INTRODUCTION

The course, "Digital Culture and Generative Processes of Form", is part of the Master Program of the Faculty of Architecture ULiège (Belgium). Our main objective in this course is to develop themes, related to formal and material research, within the architectural project approach. This perspective seems relevant as it combines, by digital means, the emergence of form, its control, and the media devoted to the materialization of designed objects. Based on parametric modeling, this relevance is reflected in the use of tools, whose performance in terms of design assistance, allows increased project control. The use of design tools has taken off in recent years, allowing increased methodological opportunities. We propose to address the concepts of geometry underlying the research of architects concerned with the genesis of architectural form and space. We introduce students to the use of programming language, specific to the selected modeling software, to generate complex 3D forms and to control them. Project-based learning enables students to develop their skills. Students learn through different means and information sources: theoretical contains, expert interventions (GH-Archicad© connection, Dynamo© connection, RElab Liège Fablab), exercises and tutorials.

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2. PEDAGOGY OF PARAMETRIC MODELING IN ARCHITECTURAL DESIGN

On the one hand, Altet [1] defines pedagogy as the articulation between teaching and learning processes, involving knowledge and aims. Teaching refers to a process of transmission of knowledge by a teacher, learning refers to the process of acquiring knowledge by doing. On the other hand, as developed by Oxman [2], “any new framework for design pedagogy must be responsive to condition in which digital concepts are integrated as a unique body of knowledge consisting of the relationship between digital architectural design and digital design skills”.

In her thesis, to answer the question « How to define the most relevant pedagogical positioning for parametric modeling in architectural design? » de Boissieu [3] highlighted several skills needed to be developed in parametric design: theoretical, know-how and soft skills. She identified two kinds of knowledge: one fundamental and stable, and the other evolving rapidly and according to the development of the tools necessary for numerical parametric modeling.

Theoretical skills’ knowledge is given via a non-exhaustive list:

- knowledge specific to geometry and mathematics;
- knowledge related to computer science in general and programming in particular;
- digital knowledge in general;
- knowledge of mechanisms based on the propagation of parametric modeling;
- software specific knowledge;
- knowledge related to architecture and construction;
- and architectural design knowledge.

Concerning the know-how skill, de Boissieu mentions the pattern concepts developed by Woodbury [4], which consist of the division of a parametric modeling project into identifiable and understandable subsystems with simple interactions, which are then modeled using patterns. Finally, and still referring to Woodbury, the parametric design process is characterized by three principles according to which:

- designers develop rules and define their logical relationships while creating 3D visualization models;
- designers can modify their model at any time;
- and design alternatives can be developed in parallel at any stage of the process.

Finally, we can mention, without developing them, certain soft skills mentioned in the thesis [3]: abstraction, organization and anticipation, participation and maintenance of a network, curiosity and initiative.

Based on de Boissieu's work, we analyze retrospectively the content of our teachings going through the seven aforementioned skills' knowledge and others skills listed in this section.

3. PARAMETRIC MODELING EDUCATION METHOD AND MATHEMATICAL PERSPECTIVE

Connected to the skills' referential developed in the Faculty of Architecture of Liège, all teaching in the digital culture will enable students to develop specific skills. For our course, we identified two learning outcomes. The first one is **defining an architectural question**. The skills are developed by studying the various components of the theme and context (historical, landscape, economic, legal, technological, etc.). The second one is **drafting a spatial response** by:

- using verbal, written and graphic language as a means of designing, structuring, verifying and questioning thought;
- introducing experiments with implementation as a design parameter;
- and adjusting spatial resolutions through exploratory questioning (question-response-spatial validation and new cycle of questioning).

In our course, we encourage architectural practices such as non-standard architecture design or complex shape generation using parametric modeling. As developed by Gallas et al. [5], the proposed process is structured in three steps: analysis, implementation, and experimentation. This process associates digital design and fabrication tools to physical representation. As we know, mathematics plays an important role in the design and materialization processes that characterize non-standard architecture. This form of architectural expression uses a sequence of tools and devices embodying the concept of the digital continuum. We therefore refer to mathematical concepts to encourage students to use them in the early stages of design, either as a source of inspiration (cognitive engine of creation) or as a rationalization tool. We are mainly interested here by architectural geometry using constructability criteria directly linked to the mathematical characteristics of surfaces [6]. Kelly [7] defines parametric geometry modeling as a field studying algorithm that computes geometry. Modeling a free-form surface means more than fine-tuning control points. It is necessary to obtain a constructible result, which implies the understanding of mathematical concepts hidden behind these surfaces, and connect them to the material world. Among the options that allow us to design these surfaces, we retain the ruled and developable surfaces, curvatures (Gaussian, Mean) and polar, cylindrical, and spherical coordinates. Curved surfaces have mathematical (geometric) properties that directly influence these options and most CAD (Computer Aided Design) programs can visualize them. It is of course up to the designer to interpret them through color code and then decide to either change the result to meet the expected material, or find the material that will best correspond to the desired project [8]. Geometrical tools are then used to analyze the shape and relevance of a desired transformation, and thus avoid unwanted effects. To develop effective solutions, the properties of the shape and material must be known precisely in the 3D model, which implies that the mathematics behind the physical behavior must also be known. According to the project that the groups of students develop, we direct them towards the exploration of other mathematical concepts such as Computational geometry (Voronoi diagram, A*Algorithm); Self-organized system (cellular automaton, swarm system); Rule-based system (L-system, shape grammar); and Optimization (genetic algorithm).

In parallel, we present examples of contemporary architecture such as the Lars Spuybroek Water Pavilion, the Toyo Ito Serpentine Gallery Pavilion, and the Norman Foster Great Court Roof of the British Museum. We describe their geometric process respectively: the beam structure as concatenation of circular segments; complex weave out of repeated nesting of rotated squares and extension into field of intersecting lines; algebraic overlay of three surfaces and shape optimization by method of relaxation [9]. These few examples allow us to share some digital culture on architecture, a culture poorly developed among our student community.

A brief overview of the integration of parametric modeling in Belgian architectural offices also helps to make students aware of the digital practices developed in their own country [10].

Digital culture, mathematics, and structural morphology are the three key themes in this teaching unit. We can summarize each one as follows:

- the influence of digital culture on architecture;
- the influence of mathematical sciences on the Fine Arts and architecture in particular, in the contemporary and modern periods; Mathematics and the genesis of form, non-Euclidian geometry, fractal design, and creation by iteration;
- and the contribution of structural morphology, free forms and controlled forms.

The integration of the mathematical theories during the analysis phase helps students to define the structure of the designed models, the project form, but also the process itself [5]. As geometric or positional numerical constraints are related to form a consistent set, they thus constitute a group of heterogeneous elements defining the parametric model [3].

These subjects taught in a frontal traditional way give some theoretical skills knowledge mentioned in the previous section.

It is important, at this point, to remind ourselves that to think complex geometry, appropriate tools, especially software, must be used to simulate these geometries, and especially to control their properties. The designer must then optimize both the form and the manufacturing processes for the benefit of visual printing [11].

In our course, pedagogy remains central to our teaching but we insist on the use of online learning resources to continue to deepen the learning of parametric modeling. This also allows students to stay up-to-date with rapidly evolving digital knowledge (as developed in the previous section). It is therefore necessary to teach students to learn, so that they can then learn by themselves by means of manipulation. The idea is to give the basic notions, basic explanations and what they provide. From the first session, exercises are proposed to the students. They allow them to get in direct contact with the software and the underlying programming. The exercises, which allow them a wide variability in their choice of design, quickly lead students to use tutorials to find explanations related to the programming itself. This way of proceeding enables them to discover the parametric programming community and other networks. Figure 1 shows different results from the first proposed exercise. As these columns are divided into three distinct but related parts, the exercise allows them to discover the notions of constraints and parameters. In particular, they become familiar with concepts such as project parameters, constants and variables.

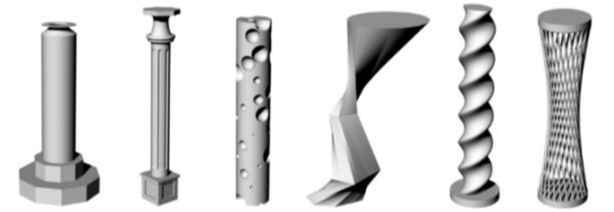

Figure 1: Examples of columns design by students from the first proposed exercise.

With the continuous aim of developing their know-how, and some of the theoretical skills connected to software and programming, we offer students different design/architectural concepts (waffle, Voronoi, origami, curve, ...). We model some of them, and present the Grasshopper components to the students. For this step of learning, we assist students in class but we also advise them to refer to the AAD Algorithm-Aided Design book [12], as a reference to define the steps of their parametric approach. Beside this cognitive reflection, some students use 3D printing machines and digital fabrication devices, enhancing a digital continuum from digital file to physical object, as proposed by Marin and his colleagues [13]. The interest of 3D printing is introduced at the beginning of the teaching through the first exercise. The columns proposed by the students are then printed in 3D. This exercise allows students not only to familiarize themselves with the software but also to understand the benefits of the continuum design manufacturing. The visit of the RElab (Liège Fablab) and the opportunity to work in collaboration with it, encourage students to develop their project in the design-manufacturing continuum and to anticipate whether they will move towards 3D printing, laser cutting or CNC (Computer Numerical Control) machine.

In order to build software-specific knowledge, we invite experts to introduce GH-Archicad© connection, and Dynamo© connection. Students are then introduced to other software allowing parametric modeling. These sessions show them what this modeling can lead to, as the links to the BIM process are then presented.

Even if one difficulty lies in the transition from paper sketch to parametric structure [14], the defining characteristic of a parametric model is not the final project, but rather the construction and maintenance of relationships associated with the model. Rather than the formal product, it is the creation and the development of the process that is at the heart of the reflection involving and challenging some soft skills. The transition from sketch to logic model diagram, and the integration of material and structural constraints, will be the result of a computation process in which the user must manipulate geometric concepts through a visual representation program. The use of the parametric puzzle as a parametric design device can help students to create different levels of abstraction during the parametric modeling process. This device, experimented and developed during the digital modeling courses of the Faculty of Applied Sciences of the University of Liège is described in Gallas et al [5]. The parametric puzzle components can help to materialize defined modeling steps. Sketches are translated in graphical algorithms, integrating geometrical and logical entities as a middle-level abstraction step. Different ways of modeling are generated and the most pertinent can be selected. The last step of the modeling process integrates the translation of the graphical algorithm, using physical components, to a graphical algorithm, using Grasshopper components as a low-level abstraction activity.

4. STUDENT PROJECT EVALUATION

For the final work of this course, we ask students to carry out an exercise in which they present an architectural premise, including structural characteristics, so that the form is potentially feasible. This modeling work has to be done using the combination of the Rhinoceros© and Grasshopper© software and the results of their research are communicated in two forms: a poster and an oral presentation. In their visual communication, they are asked to detail the problems encountered, the solutions provided, and to evaluate if they have achieved their objective. This work does not entail carrying out yet another "project", but rather a methodological approach to formal and architectural research, on which the evaluation will be based.

The following example illustrates the project of a lamp modeled by two students: the anemone lamp. Figure 2 presents the evolution of their research and the final result the students have chosen to present. They mention that the lamp could be printed in plaster (gypsum) and is designed to be placed on a table, but it could just as easily be hung or placed on a stand.

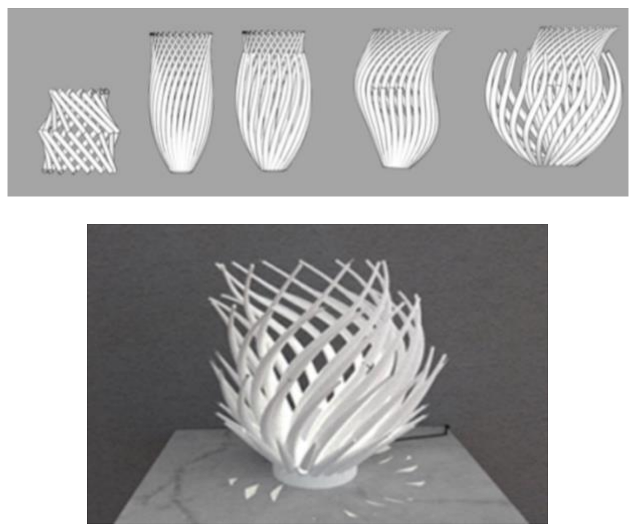

Figure 2: The evolution of transformation (on the left) and the final project (on the right): The anemone lamp.

Since the designer, in this case the students, decides which parameters to use and which range of variation is most relevant, the first criteria for assessing the final piece of work is the relevance of the choice of parameters, and how they impact upon the possibility of structuring form. Therefore, we evaluate the quality, method, and description of the approach (inventiveness, limits, solutions, etc.). They have to consider and present different possibilities (instances) by “playing” with the values of parameters. Figure 3 illustrates instances of the anemone lamp. The different results were obtained according to the position of the circle on the X axis, the scale of the circles, the numbers of rods or some shifts on the lists in Grasshopper respectively.

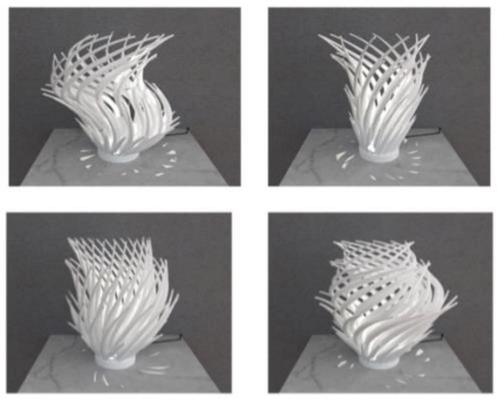

Figure 3: Different varieties of the anemone lamp, according to the position of the circle on the X axis, the scale of the circles, the numbers of rods, or some shifts on the lists in Grasshopper, from left to right respectively.

Finally, we ask students to illustrate their parametric design model, on the one hand, by the GH chain, and on the other hand, in a schematic conceptual representation (graphical IPO style). The construction, identification, and organization of the generative modules are taken into account.

5. STUDENT EVALUATION OF PROPOSED DEVICES

The different devices and information sources proposed to students have been evaluated by means of a questionnaire. We asked students about their interest in expert interventions to show GH-Archicad© connection, Dynamo© connection, and the visit and opportunity to work in collaboration with the RElab (Liège Fablab). Within the same survey, we also evaluated students' opinions of the main section structuring the course. The questions were mainly based on the interest of theoretical contains, the aim of a first exercise, the use of 3D printing and the importance of working in groups of two people.

The results of the survey show a great interest in visiting the RElab, both for the discovery of the machines, and their functionalities, but also because they allow a concrete and direct materialization of their project.

Although they did point out the lack of time allocated to the digital course (2ECTS) at the Faculty of Architecture of Liège, the students appreciated being confronted with several parameterization software, even though it presented a certain complexity. The intervention of an Archicad expert showing the link between this software and Grasshopper was also appreciated. It was of particular interest to them because of the functionalities it offers. Also, GH-Archicad© connection allows direct applications related to modeling and therefore a concretization of the latter.

The majority of students highlighted the interest in working on a small scale (here the modeling of a lamp). According to them, this scale allowed them to develop their creativity through parametric modeling, which offers several options. In addition, this scale allowed different tests to be carried out and materialized. Some have however deplored the lack of links between the course and the design studio.

According to them, collaborative work must be limited to two people given the difficulty of programming. However, it allows for a richer reflection: "Alone faster, two of us go further".

6. CONCLUSION

The course integrates a computational approach, both theoretical and practical, allowing the student to acquire a culture in contemporary architectural practices, knowledge and parametric modeling skills. It also enables experience in "design to manufacture continuum". To achieve this, the course is divided into three main steps: spread of digital culture; exercises to familiarize themselves with the software, and develop the ability to undertake a parametric approach; and a global project taking into account the architectural and material approach of a project.

Regarding our role, we consider ourselves to be facilitators, providing the tools and the opportunities to redirect students to the best sources of information for their own projects. With regards to our teaching and learning processes, we stimulate both the theoretical skills' knowledge, fundamental to parametric modeling, and skills evolving rapidly as defined by de Boissieu (2013). We stress to students the importance of developing the necessary skills in order not to become “magicians” who could lose control of the form.

This course provides students the basics they need to continue learning on their own and to develop a critical approach to learning.

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