Parametric Design in Architecture: A Proposal for Hybrid Teaching in a Postgraduate Course Focused on Innovation and Constructive Experimentation

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Abstract. The objective of this article is to present how the postgraduate course in Parametric Design in Architecture was developed, focusing on a theoretical and practical approach aimed at enhancing technical skills related to form, materiality, and tectonics in spatial conception. The course adopts a learning methodology through action and experimentation, allowing students to create design methods supported by parametric processes, exploring technical, material, and constructive alternatives. The course is offered in a hybrid format, with an emphasis on in-person and synchronous classes, enabling the participation of students and professors from various regions, fostering an enriching dialogue among different contexts. The final project of the course consists of constructing pavilions at a 1:1 scale through the application of construction and fabrication logics. Thus, the main contribution of this study is to highlight how the creation of the course seeks to introduce new forms of innovation in the construction sector, stimulating emerging reflections and discussions in the field of architecture.

Keywords: Architecture Education, Project-based Learning, Hybrid Teaching, Tectonics, Critical Theory of Technology.

1 Introduction

The incorporation of digital parametric processes in the field of Architecture has been one of the main drivers of changes in how we conceptualize, manage, and build, determining, in recent decades, methods of spatial conception supported by technological processes that bridge the gap between design and construction. However, despite the growing demand for professionals skilled in the use of emerging computational tools, the availability of postgraduate courses that promote this education is scarce in the Brazilian context. It is understood that to address this lack of qualified workforce, it is necessary to invest in training programs for professionals who wish to use computational design and digital fabrication resources to enhance solutions and contribute to the technological advancement of the construction industry. It should be noted that initiatives in parametric design and digital fabrication have been occurring in Brazil for almost two decades, with educational programs, research groups, and labs studying the topic, primarily at postgraduate levels.

The aim of this article is to demonstrate how the construction of the postgraduate course in Parametric Design in Architecture, hosted at the Pontifícia Universidade Católica de Minas Gerais, sought to establish a theoretical and practical formative path to develop technical skills related to form, materiality, and tectonics (FRAMPTON, 1995) in spatial conception.

The course proposes the development of technical skills and cognitive strategies, allowing students to create design methods through learning processes in action and experimentation (SCHÖN, 1987). To achieve this, the pedagogical project is based on technology and the construction of parametric processes to explore technical solutions organized from formal possibilities, material exploration, and constructive experimentation.

The course is offered in a hybrid model, with predominantly in-person and synchronous sessions. Currently, including students and graduates, we have a total of 41 students distributed across more than 15 cities in South America and Europe. The remote synchronous mode also enables the teaching staff to be in different parts of the world, facilitating effective dialogue with various contexts (DUBBERLY; PANGARO, 2015).

As the final project of the course during the in-person phase, the activity focuses on the construction of pavilions at a 1:1 scale, considering the virtual approach to materiality through the incorporation of construction and fabrication logics as guiding design behavior (MENGES, 2015). The objective of the activity is for students to recognize the possible problems and contradictions that arise in the translation from the digital model to its actual construction at full scale. Therefore, through a process of learning through reflection-in-action (SCHÖN, 1987), students can begin to explore in their future projects complex relationships between form development and its possibilities of materialization, based on procedural design, fabrication, and work logics (FERRO, 2010).

Thus, this work aims to demonstrate how the construction of the course sought to incorporate innovation processes for the construction industry and how the discussions raised can open up possibilities for the emergence of new reflections that have arisen from their application contexts (FEENBERG, 2013).

2 Objectives

The overall objective of the course is to provide education and training in parametric design applied to constructive experimentation. According to Carpo (2011), he argues that this direction of the digital process represents the development of information-based systems, where it promotes a new prominence to collaboration and constructive decisions incorporated into the project's conception.

Thus, the program aims to offer theoretical and practical support to develop technical skills related to form, materiality, and tectonics in spatial conception (Fig.1). The focus is placed on the potential of digital technologies as tools to aid professionals in decision-making. The specific objectives are as follows:

- Education: Provide students with theoretical foundations related to the application of digital processes in the field of construction;
- Skill Development: Cultivate technical skills in parametric modeling for the conception of complex geometries;
- Specific Knowledge: Explore computational methods used for form generation, performance analysis, and structural optimization;
- Targeted Practice: Develop projects using parametric processes that encompass the stages of conception, analysis, and synthesis.

3 Methodology

The proposed methodology involves students working at the interface between architecture and computational programming, facilitated by the use of parametric digital tools. The program is divided into three modules (Form, Materiality, and Tectonics), adopting the following methodological approach:

- Theoretical foundation through lectures, case studies, and supplementary readings;
- Instrumental training by learning and manipulating parametric modeling software;
- Introduction to digital fabrication resources, aiming to prepare digital models for physical prototyping at different scales;
- Content consolidation through the completion of exercises focused on generating complex geometries
- Workshops to promote interaction between design and physical prototyping at various scales;

- Broadening technical and theoretical knowledge through participation in seminars, lectures, and extracurricular activities;
- Development of a final project as a way to apply the skills acquired in the postgraduate program.

The course modules follow a sequence of teaching and learning that starts with basic knowledge about modeling complex forms and an introduction to digital fabrication, progressing to advanced processes of analysis, optimization, and construction materialization. Thus, each module operates as follows:

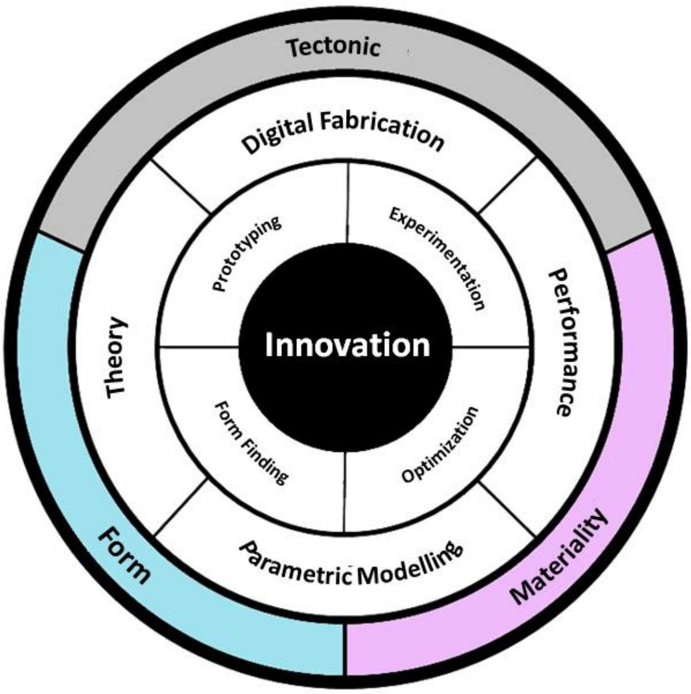

Figure 1. Master's pedagogical guidelines. Source: Author, 2022.

3.1 Form

In the first module titled "Form", the main objective is to introduce the theme of parametric design within the theoretical and practical context, aiming for exercises in skill-building and critical reflection in the offered disciplines.

For this purpose, in the course "Theory of Digital", a historical perspective on the use of digital tools for design is undertaken, spanning from the 1960s to the most recent initiatives of the second decade of the 21st century. This involves reflections on new forms of thinking for design practice within the digital culture.

In the courses "Modeling in Rhinoceros" and "Modeling in Grasshopper", the goal is to establish a foundation and provide skills in three-dimensional modeling. This involves learning interfaces, tools, and methods for modeling complex geometries. Beyond modeling, an introduction to algorithmic thinking and computational programming language is also provided.

In "Introduction to Digital Fabrication", students are introduced to digital fabrication techniques and technologies. This includes exploring modeling methods focused on the use of 3D printers, milling machines, and laser cutters. Methods of materialization such as weaving, folding, paneling, and sectioning, followed by labeling and nesting for CNC machining, are also covered.

To consolidate the knowledge gained in the previous courses, in "Workshop I: Parametric Systems", students are guided to undertake practical activities using the Rhinoceros software and Grasshopper plug-in. This is for developing complex geometries for furniture and small to medium-scale buildings. Additionally, students are encouraged to explore digital fabrication resources for prototyping at a reduced scale.

In order to engage with professional practice, the course "Special Topics I" includes virtual conferences with participation from professionals active in the field of digital design and fabrication applied to contemporary architectural production. These conferences are open to the general public and also serve to inspire students to build professional trajectories within the possibilities offered by computational design.

3.2 **Materiality**

In the "Materiality" module, students are led into practices that focus on the concept of performance within the design process.

In the course "Unconventional Structures", applications of non-conventional construction systems (such as reciprocal, retractable, tensegrity, and gridshell systems) are explored within the field of architecture. Alongside the theoretical approach, students engage in experimentation through computational modeling and physical prototyping.

The course "Methods of Form Finding" introduces strategies for form generation (form finding) both analog and digital, with a focus on structural conception. Parametric modeling and interactive simulation of the physical behavior of funicular structures are achieved using Grasshopper and Kangaroo 3D plugins.

For evaluating material performance and optimizing systems, the course "Material Analysis and Optimization" explores visualization and structural behavior analysis using the Karamba 3D plugin. This course concentrates on parametric modeling and analysis of structural components such as beams, frames, trusses, and shells.

In the course "Evolutionary Processes", evolutionary methods for performance optimization based on pre-established criteria are introduced. Students are equipped to manipulate genetic algorithms through the Galápagos plugin.

In "Special Topics II", a return to theoretical, critical, and reflective aspects allows students to dialectically problematize prevailing parametric architectural practices. Through readings and class discussions, students are invited to construct new perspectives based on their own contexts.

Similar to Module I, the course "Workshop II: Performance-Based Design" involves practical activities using parametric tools, focusing on developing projects based on performance. In this project, students are encouraged to work on a study of medium to large-scale building design, focusing on the integration of material optimization and spatial articulation for design generation.

3.3 **Tectonic**

The third module, named "Tectonics", aims to simulate the design, optimization, and construction cycle at a 1:1 scale, considering material, environmental, and construction aspects. The proposal of this module consists of a reflection regarding a possible loss of the notion of scale and materiality in digital practice, as discussed by Picon (2010) when referring to a crisis of scale and tectonics in contemporary design through computational tools.

In the course "Energy Efficiency", simulation, visualization, and analysis of environmental and thermal energy performance are explored using the Ladybug plugin. In the practical exercise, students evaluate the performance of their work from Workshop II for thermal comfort optimization and generating new design possibilities based on environmental parameters.

As the final project proposal to be developed in the course "Workshop III: Design and Construction", students are tasked with creating a project based on a given problem (related to scale, material, performance, or cost). They must justify the strategies developed to address the required parameters. In this project, parametric models are developed, incorporating some form of performance analysis. It is required that the project be prototyped at a reduced scale using digital fabrication techniques learned previously.

Lastly, the work carried out in the course "Topics III" directly corresponds with the project proposed in "Workshop III". In this activity, the professors of the respective courses collaborate on a project to be manufactured and assembled on the PUC Minas campus. This is the only moment when students physically come together, concentrated on the final weekend of the course. The objective of this work is to provide hands-on experience in designing, fabricating, and assembling a 1:1 scale pavilion.

Through the assembly of the pavilion, students are expected to observe the transition from design to construction, problematizing the potential for a recursive practice that directly engages with the construction site. By identifying potential assembly and construction issues, the materialization of the project becomes a tool for understanding the inherent contradictions between theory and practice.

4 Results

In the first module of the course, students acquire the necessary skills for modeling complex geometries (Fig. 2) and materializing forms through digital fabrication. In this stage, they are encouraged to explore their own resources for prototyping the components, considering the potential for developing and constructing a similar project within their regional contexts.

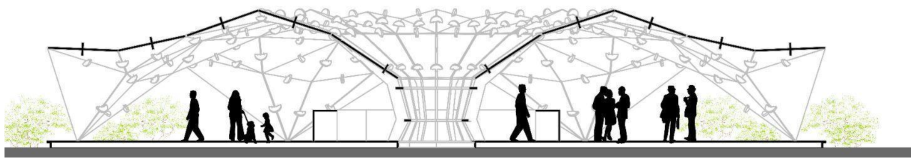

Figure 2. Student proposal. “Workshop I” course. Source: Author, 2022**.**

In the second module, students further develop their understanding of digital modeling and fabrication (Fig.3). This involves incorporating tools that simulate the behavior of forms into the process. Consequently, the design synthesis is driven by the building performance, where computational processes seamlessly integrate structure, material, and form within the framework of manufacturing technologies. This approach entails procedures that simultaneously address form efficiency, material conservation, and construction ease (OXMAN, 2014).

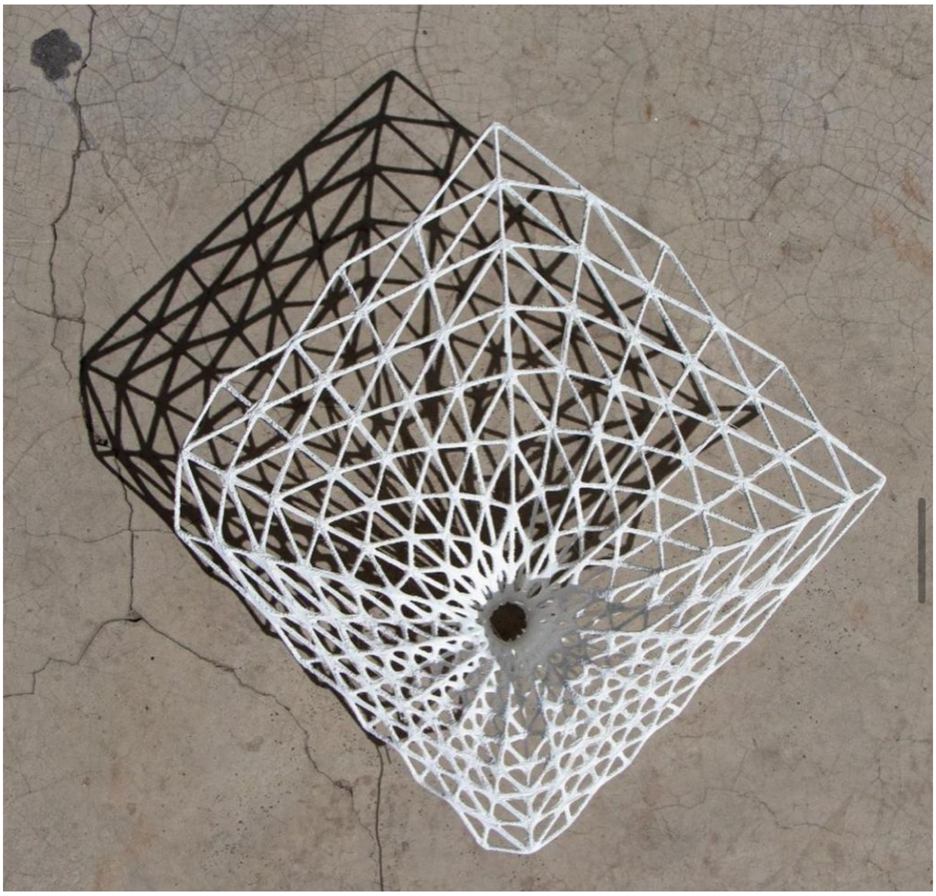

Figure 3. 3D Printing prototype. Digital fabrication course. Source: Author, 2022**.**

The final course projects are conducted in groups and are presented in person when students come to the university campus. During these presentations, students introduce the project concept and outline the strategies employed for performance analysis and materialization of the form. A 1:10 scale prototype must also be showcased to provide insight into the construction process on a smaller scale and to highlight any potential issues that might arise during prototype construction (Fig. 5).

In the first cohort, the concept of the "269 Pavilion" revolved around the repetition of an industrially produced element not conventionally used in construction, which served as the foundational component for shaping the structure. Through the development of a code using the Rhino/Grasshopper software, the individual module was adapted to an existing surface, crafted based on an analysis of its structural behavior. For assembly, 259 plastic benches and 301 connections milled from 10mm plywood were employed, joined together using screws, nuts, and washers. This configuration covered an approximate projection area of 40 m² (Fig. 4).

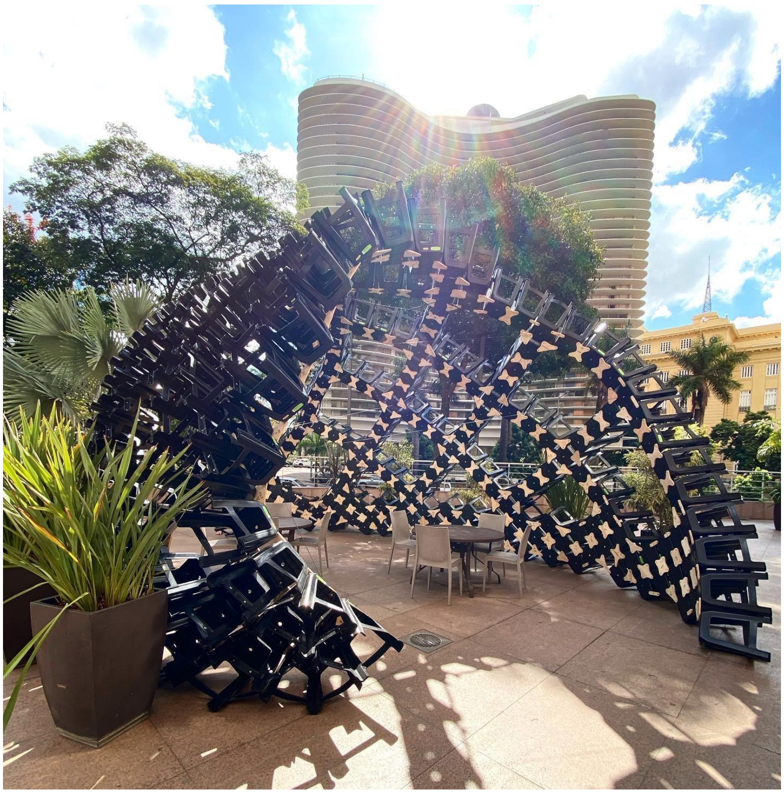

Figure 4. “269 Pavilion” assembled as the final activity of the master's degree.
Source: Author, 2022.

The assembly process turned out to be less manageable than initially anticipated. In the first attempt, we adopted a row-by-row assembly strategy, but the form didn't maintain stability, lasting only 24 hours. In the second attempt, we turned to structural analyses conducted using the Karamba plugin to comprehend the points of failure and reinforce the weaker areas. For assembly, we embraced a "form finding" strategy to stabilize the shape. This process was highly empirical and incurred significant costs in terms of time and physical effort from the participants. Thus, as a proposition for the "259 Pavilion" in the second cohort, we aimed to develop a more controlled assembly process. We initiated the project by focusing on assembly strategies. We endeavored to create a symmetrical shell shape with three support points, where the top would function as a compression ring to stabilize the junction of the modules composing the structure. The 1:1 scale prototype was designed to be assembled with 2mm cardboard and supported on a base made of 15mm MDF (Fig. 6).

Figure 5. 1:10 Scale model of “269 Pavilion”. Source: Author, 2023.

Figure 6. 1:1 Scale assembly test. Source: Author, 2023.

As part of our assembly proposal, we aimed to optimize the limited time available for completing the activity (around 8 hours). We decided to divide the work into teams, where each team would assemble horizontal rows, and then the final step would involve the vertical fitting of these horizontal modules. However, this strategy didn't work out due to a relative lack of precision (a matter of millimeters) in the alignment of the pieces. The misalignment caused the rows to not coincide, rendering the assembly impossible within the given time. This experience highlighted the need for greater attention to the control of fitting to avoid failures in the construction strategy.

Consequently, the assembly process of the pavilions led us to recognize the necessity of establishing a stronger connection with the construction industry. This would enable better control over the prototype and foster meaningful dialogues with other stakeholders in the construction sector. Looking ahead, we are exploring opportunities for collaboration with manufacturers of materials and industrial components. This collaboration aims to identify potential challenges in innovating the construction production process.

In this context, the processes of constructive experimentation through prototyping serve as crucial mechanisms for testing and validating new models, materials, and technical arrangements. We believe that the teaching of digital technology should be directed towards facilitating dialogic processes, where the digital potential for hybridization is explored with utmost efficiency. This approach should aim not only at producing products but also at constructing processes, fostering dialectical relationships in both realms.

5 Discussion

Therefore, the proposal of the postgraduate course "Parametric Design in Architecture" seeks, beyond technical instrumentalization, a reflective practice that can provide students with an awareness of their role as agents of innovation in the mechanisms of production and reproduction within the field of architecture and the construction sector. The use of digital tools must transcend formal experimentation and instead work towards a reordering of the entire production process. In this way, we hope that the methods of teaching technology in the field of architecture are increasingly oriented towards processes that address the responsibility of technical action and promote its application in human and natural contexts, based on the awareness that technical choices are politically and morally significant (FEENBERG, 2013).

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