Reflections on the introduction of parametric thinking into design education

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How to quote this text: Romcy, N.M.E.S., Tinoco, M.B.M. and Cardoso, D.R., 2015. Reflections on the introduction of parametric thinking into design education. *V!RUS*, São Carlos, n. 11, 2015. [online] Available at: <http://www.nomads.usp.br/virus/virus11/?sec=4&item=2&lang=en>.
[Accessed dd mm yyyy].

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ABSTRACT

This paper aims to investigate the specifics of parameterization and its role in design education, considering new educational approaches. The methodology included literature review and a research for case studies that apply parametric processes in education, including national and international scenario. Based on the literature review, both contemporary design education and the skills for parametric design emphasize the design studio as a place to stimulate research and collaboration. Thus, design education must change from the conventional simulation of professional praxis, with focus on the product, to encourage experimental practices that focus on the process. As a challenge, in addition to training in specific software, a new understanding of design must consider the systemic approach, where the definition of relations and interactions between parts affects the generation of the final product. The control of design and production, through association of parametric tools and manufacturing equipment, approaches the stages of design and construction, and enhances the importance of physical models. However, complexity increases with the advent of new skills that go beyond the expertise of a single discipline.

KEYWORDS
parameterization; education; design process.

1. INTRODUCTION

During the last decade researchers and educators have begun to address the need to integrate digital design in design education by investigating various forms of educational approaches. However, any detailed investigation of these educational developments as they have emerged at Columbia University, Harvard University, Architectural Association School of Architecture and elsewhere have been strongly motivated by individual digital practitioners as compared to the influence of a comprehensive pedagogical agenda (Oxman, 2008), which denotes some limitation.

In Brazil, the Ministry of Education published the Order 1.770 in 1994, which established for the first time the obligation of computer education in architecture courses. In addition to establishing computer aided design as a professional matter, these curriculum guidelines determined that schools should make use of computational tools during "everyday learning", including "information processing and object representation" (Celani, 2008). Nonetheless, although the discussion on the impacts of these new technologies are not recent, the results are not widely identified in design studios across architecture schools in Brazil. Specific disciplines were included in the curriculum, but are still not enough to cause significant changes in design education (Rufino and Veloso, 2005).

Within this context, we highlight parametric models as computational representations of objects, created with attributes that can be fixed or variable. Parameters and rules may represent the variable attributes, in order to allow automatic adjustments according to user control and context changes (Ruschel and Andrade, 2009).

In addition to architecture, parameterization followed up the contemporary trends of product design, which now has a need to increase its informational robustness (Pimentel et al., 2014). Emphasizing the importance of relating decision criteria, parametric modeling enhances the design operations and emerges as a promising technique to generate numerous variations of a product, by manipulating their characteristics (parameters).

Given new possibilities, which go beyond graphic representation and visualization, it has become necessary to reflect on the specifics of parametric thinking in design education, considering new educational proposals. Thus, the question consists on how to teach design, including processes and computational tools that work objects based on their parameters.

2. METHODOLOGY

This paper is part of a thesis in progress, which the main objective is to understand the specifics of parametric design, and propose methodological guidelines for its application in design education. We will present the theoretical framework that supports the hypotheses of this study.

The methodology includes literature review on design education and parametric design, as well as case studies applying parametric processes in education around national and international scenarios.

In order to search for these applications, we used CUMINCAD (Cumulative Index of Computer Aided Architectural Design) as a virtual reference library about computer-aided design. From the analysis of the case studies and bibliographical review, we identified strategies and obstacles related to introducing parametric thinking into design education.

3. DESIGN EDUCATION

In current schools of Architecture and Urbanism, disciplines based on design studios are still the central point, which demonstrates that practices initiated in the *École Des Beaux-Arts*, during the 18th century, still prevails. In so-called design studios, the teacher guides students

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to develop architectural projects related to predefine topics, and usually conduct them to reproduce what he considers as a good architecture, in order to evaluate them (Carvalho and Rheingantz, 2003).

Thus, the teacher acts as a client and creates a simulation of praxis which, according to Veloso and Elali (2003), shows up as didactically inadequate, since the student is not yet experiencing a real activity, but a preparatory stage to gain experience and knowledge.

Regarding to product design area, a specific theoretical basis is ongoing, but practical issues are still debated without necessarily generate reflections on design operations. Although pedagogical activities are applied, they still lack an educational philosophy – foundation for referral of issues about educational practices (Necyk and Ferreira, 2010).

According to Bonsiepe (2012), a series of questions still surround the cognitive state of product design area; since it is most oriented to everyday life, instead of generate new cognitive knowledge. Unlike science, which sees the world for the research perspective, design is characterized by looking at the world through design perspective.

Comas (1986) states that in design studio occurs transmission and acquisition of knowledge, however, randomly and without proper critical thinking in some cases. As difficulties, the author highlights weaknesses in the theoretical foundation of design and its education, added to the fact that the simulation of professional praxis is necessarily selective: it is impossible to cover the multiplicity of problems presented in real praxis. An underway shift aims to transform the design studio into a theoretical and practical discipline, where transmission and acquisition of knowledge gradually occurs in a systematic and critical way, reducing the limitations of selectivity.

This attitude, still under construction, aims to (re)place design as a research field and specific role of designers, but also researchers and especially educators. These new professionals will not work necessarily in private offices but, laboratories, research groups and model offices of universities, provided by research projects and extension activities (Veloso and Elali, 2004).

Considering that design must be learned by action, since designers are professionals who reflect in action and on action (reflective practitioners), we highlight design education based on the reflective practice approach (Schön, 2000). One of its main aspects is the dialogue between teacher and student, accomplished through words or performance. Students attempt to learn and reveal their questions, while instructors respond with advice, criticism, explanation, descriptions and their own performance. When the dialogue works well, it turns into a reciprocal reflection-in-action.

The social-interactional trend also affects this pedagogy, since it recognizes knowledge as both individual and collective, generated by social interaction. The focus shifts from the product to the process of knowledge construction – product quality is a direct result of the processes and interactions occurring while students pursue knowledge (Rheingantz, 2003).

According to Rheingantz and Azevedo (2014), in this context the teacher assumes the role of "motivator of action", being able to foster collaboration and participation from the students throughout the whole process, which also includes evaluation. As an alternative to overcome the challenges previously pointed by Comas (1986), this approach enables discussion and redefines the design process to include different narratives. Thus, it is possible to enhance the understanding of results and the critical appropriation of knowledge, produced collectively.

The contemporary context includes questions regarding to the importance of new technologies for architecture and product design education, and the need for further research involving the relations between design teaching and digital media.

One of the academic objectives consists in training teachers to ensure the quality of studies and disciplines established by national curriculum guidelines. According to Celani (2008), only investments on research about computer-aided design may ensure excellence in teacher's training referred to this subject and their constant updating. Despite localized efforts that have been taking place in Brazil, many courses still takes computer education in old-fashioned way, only to meet market expectations, without worrying about a critical thinking.

We can compare this new scenario to the crystallization of Modernism as a pedagogical model during the period of the Bauhaus, due to conceptual changes in both content and tools. The Bauhaus provided a theoretical orientation to modern design through the integration of art and design, in order to introduce new forms, new materials, and a new orientation to design in an Age of industrialization. In order to support this new curriculum, a new generation of teachers was educated, presenting a strategy that integrated skill (craft techniques, making) with new conceptual content (Oxman, 2008).

In the present era, which is characterized by intense scientific, technological and industrial innovation, the need to generate knowledge from the perspective of design becomes evident, especially when it comes to complex problems that exceed the know-how of a particular discipline. According to Bonsiepe (2012), examples in education called "project-based learning" or "problem-oriented teaching" already exists.

Sedrez and Celani (2014) also highlights this approach as "Project Based Learning" or "Problem Based Learning" and its importance to contemporary design education. This methodology starts from a problem or challenge posed to students, which demands knowing the subject, acquiring new skills, and practicing collaboration/communication during evaluation processes that involves critical thinking. Therefore, being able to propose a well-justified way of solving the problem is part of the learning process and creates opportunities for innovation.

4. PARAMETRIC DESIGN

Within this new context, the investigation about how to adopt parametric processes and tools in design education brings the discussion about what skills teachers and students should develop throughout design process.

Woodbury (2010) sets a series of skills that designers must develop to apply parametric modeling effectively and highlights that some are new and some are already familiar to them. These skills include:

a) Conceiving data flow: the way in which data flows through parametric models deeply affects the possible designs and how the designer interacts with them. Conceiving, arranging and editing dependencies is the key parametric task.

b) Dividing to conquer: consists into dividing design into parts, design the parts and combine them into an entire design, all the while managing the interaction among them. This requires knowledge from both the design domain and about how to structure parametric designs so that data flows from part to part in a clear manner.

c) Naming: parts must have specific names, in order to facilitate communication. Developing and refining appropriate names for the parts of a parametric model allow less effort for its further understanding.

d) Thinking with abstraction: an abstraction describes a general concept rather than a specific example. To abstract a parametric model is to make it adjustable to new situations, to make it depend only on essential inputs and to remove references or overly specific terms.

e) Thinking mathematically: historical facts confirm the use of mathematics by designers and parametric systems can enhance this practice. Active and visual mathematics can become means and strategy to the ends of design.

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f) Thinking algorithmically: the author highlights two characteristics of an algorithm – it is the description of a process to be specified step by step, and must be precise because one misplaced character means that the algorithm likely will not work. In contrast, designers often describe objects and not processes, and work with inaccurate representations that rely on human readers to interpret them properly. The parametric system brings the algorithm closer to design models, both as expressions that define constraints, and automatic update methods.

Among the skills mentioned, conceiving data flow, dividing to conquer, and naming are related to structuring the parametric model, in order to establish a coherent representation of the designer's ideas and to facilitate subsequent adjustments, uses and investigations.

Thinking with abstraction and thinking mathematically is related to the efficiency of the parametric model, regarding its use and exploration of new design alternatives. The author highlights that both are already familiar to designers.

Lastly, the greatest challenge among the presented skills is thinking algorithmically, because of its relation to the description of processes that require precision, and computer languages that are not familiar to designers.

In order to reduce these difficulties, visual scripts have been developed, which include Generative Components (Bentley), Grasshopper (integrated to Rhinoceros 3D – Robert McNeel & Associates) and Dynamo (plug-in for Revit – Autodesk)

Since they are programming languages that incorporate visual expressions in its syntax, such as diagrams, icons and graphic objects, visual scripts may help users without programming experience (Vaz, 2011).

The need to increase those skills brings back the discussion about what characterizes education in design studios. Oxman (2008) also defines the conventional educational model in the design studio as a simulation of professional praxis, driven by a theoretical interpretation of program, site, and conditions. Nevertheless, the author points out that models and processes of digital design allow different stages of exploration that can only be achieved by freeing the student from such expectations. The educational process need not necessarily start from a program or specific site presented at the inception of design, but from the investigation of materials and models according to students' motivation. The educational approach proposed by Oxman assumes that design studio is experimental and encourages research-oriented activities.

Describing the experience of the course about Responsive Architecture, taught at Unicamp by architect Anne Save de Beaurecueil with intense use of computer methods, Sedrez and Celani (2014) also highlighted the Performance Model and Craftsmanship. The Performance Model consists in Oxman's description for processes of formation that are driven by a desired performance, and use parametric tools to optimize and integrate the data flow. Craftsmanship concerns to the integration of cognitive and manual skills, in order to produce quality products, both in design and execution.

As for the changes related to design process, Malé-Alemany and Sousa (2003) state that design based on parameters involves the creation of a model that acts as a system of interconnected information. Due to its potential to incorporate parameters that respond to different disciplinary fields, the parametric model promotes the convergence of all these interests and supports collaboration and dynamic processes. Thus, conception, simulation, analysis, detailing and construction may happen simultaneously in a fluid and interactive environment.

Such characteristics are important if we consider that design problems are often multidimensional and highly interactive, which makes frequently necessary to devise an integrated solution to a whole cluster of requirements. According to Lawson, "if there was one single characteristic which could be used to identify good designers, it is the ability to integrate and combine" (Lawson, 2011, p.66).

Therefore, when applied to education, parametric modeling encourages an idea of integrated and multidimensional design, and provides to students an experience that flows from conception to representation and technical description, including manufacturing prototypes in 1:1 scale.

Based on the literature review, we perceive that both contemporary design education and skills for parametric design emphasize the design studio as a place to stimulate research, generation of knowledge, convergence and collaboration of different interests. Thus, design disciplines must change from the conventional simulation of professional praxis, with focus on product, to encourage experimental practices that focus on process.

5. CASE STUDIES IN NATIONAL AND INTERNATIONAL SCENARIOS

Traditionally, architecture and design curricula are formatted as an aggregation of individual cells, representing courses to be taken and mapping a student's trajectory through the program. Most contemporary curricular diagrams illustrate hierarchical relations through separation and stratification, where the resultant strata are typically labeled as year levels and focus areas such as design, technology, theory, history, practice and electives. In this configuration, the only place to relational thinking arises through courses prerequisites.

Karle and Kelly (2011) consider parametric design as a series of questions to establish the variables of a design. The authors state that framing projects and curricula from the beginning as parametrically derived consists in less pressure on the designer to generate the right design and more pressure on them to ask the right questions.

Concerning the case studies, the results achieved through CUMINCAD's research included the following situations: 1. investigations about parametric thinking through the study of predefined patterns or rules; 2. inclusion of parametric processes in conventional design studios, where the activities start with a specific site and program; 3. use of parametric tools to support activities and disciplines that do not involve the design studio.

Investigations through predefined patterns or rules are related to the challenge of work how to establish relations between the parts of an object, in order to generate different solutions in accordance to the desired properties. Thus, activities that involve the analysis of pre-existing patterns and their application in design aims to exercise the understanding of an object according to the systemic approach, which is essential for parametric thinking.

A system consists in an aggregate of elements that are related to each other to the point of sharing properties. The elements may present any nature, that is, systems may include different entities. Such generality suggests that the systemic approach is a good choice when it comes to study complex entities. In those cases, the unified elements may be diverse, but gain consistency during the design context and turn into significant and aesthetic wholes (Vieira, 2008).

In design education, the application of system concept added to parametric thinking should discuss not only how to structure relations between the parts of a parametric model or a designed object, but how such structure generates different solutions, all according to predefined properties – thus, generative processes may be defined.

At Georgia Institute of Technology, Baerlecken and Riether (2012) presented the studio methodology for Design 1, in which students investigated pattern systems (aggregations), as basis to develop an architectural project by using digital methods. The list of aggregations for analysis included patterns as crocodile skin, metal alloys and flocking of herds. First, the students worked in pairs and studied one of the given pattern through images and diagrams, in order to gather a fundamental understanding about their aggregational system. Thereafter,

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the students should transform the analyzed material into 2D/3D patterns and morphologies, and explore how aggregated systems could respond to the typology of a given architectural program and site.

At Oklahoma State University, Ra (2011) presented the experience from the "Introduction to Computers" course, where each student's work was produced as a series of variations by using the same procedures, but varying the parameters. The final work consisted of a collaborative project, where a 3D model of a grid structure was initially given, including a curvature that would constrain how each component would be designed. Students should choose one of the grid components to design and construct, considering that each form should have at least one complete opening to allow light to pass through. Each form was manufactured with laser cutter and assembled together to generate the whole structure. This work led the students to explore how changing parameters in their components and openings affected the quality of light and the composition with the neighboring forms, which empathized the collaborative process.

The challenge of understanding design considering the systemic approach becomes even more evident in case studies that applied parametric processes in design studios where the activities started from a predefined site and program.

Moreover, most students only have previous experience with traditional CAD and drawing, which focus is on representation of final form, described geometrically. Parametric methods, by contrast, force a prior procedural representation in which the form is resulting from this designed procedure. Unlike traditional tools, that allow easy changes to the final form, revising a parametric model is difficult to make changes at the level of final representation – it must be modified at the procedural level. According to Hanna and Turner (2006), that is the common cause for frustration in design students introduced to parametric design for the first time.

In the case of Design 3, accomplished at the Institute of Architecture and Urbanism – University of São Paulo (IAU-USP), the course included two modules: the first emphasized the design and construction of complex geometries, while the second focused on the use of BIM technology (Nojimoto, Tramontano and Anelli, 2011). In order to introduce a design strategy unknown by the students, the activity related to complex geometries consisted in proposing a shelter for passengers, and involved the parameterization of different components, using Rhinoceros software and its plug-in Grasshopper.

During the activities, the authors checked that, while some students were willing to face the challenge of setting parameters and logical procedures to design a geometry that corresponds to their design intents; others defined a complex geometry only by the processing power of Rhinoceros, based on an initial form and not the possible relations between the elements.

The second case study is from Technical University of Darmstadt, where studios and workshops resulted in the planning and fabrication of two exhibition stands for the department. The teach method was based on close connection between the procedure of form generation and the realization of the design (Karzel and Matcha, 2009). The design task was to conceive a singular object that would fulfill a multiplicity of needs and be adjustable via several parameters to accommodate changes in arrangement of functions, size and number of functional areas. Like the previous case study, from IAU-USP, the result indicated two approaches: a solution defined by an initial form, and a solution subdivided into smaller parts, that were related.

In addition to the challenge of adopting new design processes, the case studies from IAU-USP and Technical University of Darmstadt highlighted another important issue for design education: possible contributions of relating parametric modeling and computer-aided manufacturing.

By manufacturing of physical models during design process, it is possible to verify constructive solutions and associate them to changing parameters, in order to study different alternatives and improve adjustments and decision-making. At the end of the process, a parametric model

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may generate, not only a specific object, but a whole family of related objects. An integrated digital production chain allows for the production of several objects, all from the same design, but adjustable to situation specifics –thereby mass customization may be applied.

Lastly, we present case studies that applied parametric tools as support for subjects that are not directly related to design studio. Considering that parametric thinking involves changes that exceed the contents of a single course, introducing these new processes at the beginning of the curriculum and applying activities with low complexity are important alternatives to a gradual implementation.

The first case study includes a methodology focused on activities of novice designers to acquire knowledge about the performance of a system, using computational tools as parametric modelling and BIM (Sanguinetti, 2013). In the approach, students learn how to develop parametric components and build the model as a bottom-up assembly. The testing process consists of changing design parameters, visualizing and evaluating the effects of theses variations, considering relations, conditions and rules. The author proposes the performance test as an evolution of the "problem-solving" paradigm. The students analyze given solutions and suggest alterations, according to performance parameters.

The second case study presents a didactical approach for introducing generative design at the beginning of the curriculum, through courses about geometry and computer (Brod, Pires and Silva, 2012). The disciplines included Digital Graphic Geometry III (2nd semester) and Computer-aided Architectural and Urban Design I (5th semester) at the Federal University of Pelotas.

Both disciplines discussed parametric design through activities that worked curved surfaces applied to architecture, by modeling existing buildings. The activity used Grasshopper and was developed in stages, which included the creation and manipulation of geometric entities presented in the studied building (points, lines, surfaces) and the generation of the final model. After creating the model, the students were asked to explore different forms, by changing design parameters. In both disciplines, the students pointed out that parametric modelling contributed to the understanding of how to construct a specific geometry and how to use a generative system during design process.

6. CONCLUSION

Based on the literature review and case studies, we perceive certain strategies and challenges for introducing parametric thinking into design education.

As a challenge, far beyond training in specific software, a new understanding of design is required, considering the final form as a result of predefined logics, and design process as systemic – relations and interactions between parts affect the generation of the product.

Therefore, thinking algorithmically and working with parametric models as dynamic systems turn design focus into describing processes, instead of a single product. This new approach interferes into the conventional studio model, described as a simulation of professional praxis and characterized by predefined contexts as the starting point (site and program).

Considering a gradual introduction of parametric thinking at the beginning of the curriculum, we observed the following activities: 1. analysis of existing patterns and systems with subsequent application within a design context; 2. evaluation of predefined models and proposal of changes by manipulating their parameters.

During design studio's activities, exploration and collaboration are highlighted as important features of design, where the parametric model may arise as an integrated and multidimensional system of interconnected information. The design and production control from the association of parametric tools and manufacturing equipment approaches design, development and construction stages. The importance of physical models for education is

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enhanced by the generation of different alternatives through parameter manipulation, added to the production of components in real scale, which allows mass customization.

Lastly, the considerations presented are consistent with contemporary design education, in which design studio is set as a place to stimulate research and collaboration, and the investigation on problems/solutions promotes the generation and sharing of skills and knowledge. However, complexity increases due to some factors: 1. engagement of different stages of project, which includes from design to construction; 2. education based on process, instead of product, 3. the advent of new skills that go beyond the expertise of a single class.

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