THE IMPLEMENTATION OF PARAMETRIC DESIGN PRACTICE IN ARCHITECTURAL TEACHING – HOW IT CAN BE IMPLEMENTED IN INDONESIA?

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ABSTRACT

Parametric design practice has been thriving in architecture for the last decade. This development is caused by the dynamic progress of computational design technology, allowing the designer to engage in complex geometry generation and parametric optimization in the design process. The interoperability of parametric design tools with building simulation software is the key to the parametric design trend that enables designers to solve different socio-environmental problems. Considering its potencies and development, this study investigates how parametric design practice should be implemented in architecture education, especially in Indonesian universities. In different universities' teaching case studies, parametric design should be implemented in architecture teaching, starting from advanced 3D modeling and design fabrication practices. A framework of parametric design teaching is proposed, which can be feasibly implemented in the context of Indonesian universities where the awareness of parametric design trend is just growing.

Keywords: *Parametric Design, Parametricism, Architecture Teaching, Rhinoceros-Grasshopper*

INTRODUCTION

Parametric design has become a new architectural design trend thrived since the last decade. It is based on the concept of parameter change to manipulate complex geometries and generate many design alternatives by using parametric modeling software. In the past, designers recognized parametric design merely as a technique to aid the design process, which must involve using a computational tool (Yasser, 2012). However, parametric design has evolved to be a new and unique style, parametricism (after modernism), as it has inspired a new collective movement with new ambitions and values (Schumacher, 2009). It is more about a way of thinking about design than software application (Woodbury, 2010). Additionally, parametricism is moving towards solving socio-environmental problems using new technologies and computational design tools (Heidari et al., 2018).

The primary purpose of parametric modeling software is not only for model creation representing the design object but is more about design manipulation, exploration, and optimization. This application differs from parametric design from previous digital architecture trends such as CAD (Computer-Aided Design) and BIM (Building Information Modelling). In parametric design, the relationship among design objects can be defined, which is not previously considered in conventional design thinking using conventional CAD software, pen, or paper (Woodbury, 2010). Conventional design thinking does "add and erase." In contrast, in parametric design, designers can "relate and repair," leading to the generative capability in the design process where many design options can be produced and considered efficiently (Yasser, 2012).

Now, parametric modeling software has been connected to various building simulation software. One parametric modeling, Rhinoceros-Grasshopper, has interoperability with various building simulation tools. It can be connected to several open-source simulation packages such as EnergyPlus, ENVI-met, Radiance, and CFD software through several plugins in Grasshopper. This connection allows designers to engage in parametric optimization, where various design possibilities can be evaluated based on their performance from simulation. This way, a range of optimal solutions can be found among a few or even thousands of design possibilities (Naboni et al., 2013) (Pratt & Bosworth, 2011).

Several studies have demonstrated the application of parametric modeling integrated with several simulation tools to address socio-environmental problems in the design process. Aman et al. (2021) developed the building envelope optimization workflow utilizing parametric simulation modeling and virtual reality to help stakeholders understand the environmental impact of design variables of the container housing system. Anton & Tănase (2016) developed resilient architectural forms (e.g., canopy and skylight) based on parametric modeling integrated with energy analysis. For the context of the urban environment, Naboni et al. (2019) tested a multi-parametric workflow integrating a series of environmental simulation plugins in Grasshopper to evaluate the urban design performance. Ackerman et al. (2019) tested different urban environment scenarios by utilizing parametric workflow integrating Computational Fluid Dynamics (CFD) and building energy simulation to produce strategies for urban heat island mitigation and climate change adaptation.

Realizing the potencies of parametric design and its development, it is essential if parametric design or parametricism can be implemented at university-level architecture education. Sooner or later, the parametric design will likely be a standard architectural design skill (Riekstins, 2018). Also, the advance of technology demands the younger generations of architects to master various digital design tools, and this can be directed to the parametric design tool as an improvement of architecture education (Radziszewski & Cudzik, 2019) Unfortunately, there is little research related to the parametric design in Indonesia, which indicates an unawareness of parametricism at the university level. Also, a wide range of parametric design approaches could be practiced in architecture. This study focuses on how parametric design can be initially included and practiced in the learning program of architecture in Indonesia, especially for undergraduate students.

THEORY/ RESEARCH METHODS

First, a literature search was conducted to explore how parametric design has been introduced and implemented at the university level worldwide. The exploration focuses on the papers that demonstrate and discuss the application of parametric design software such as Rhinoceros-Grasshopper in architecture teaching. This can give insight into how parametric design can be included in architecture courses at the University.

Next, a survey was conducted among architecture lecturers in different regions of Indonesia through a questionnaire. The questionnaire was developed to gather information about the lecturer's ability and experience using various digital design tools, including parametric design software. Then, it specifically asked the lecturers whether they have been using parametric design software for teaching, study, or personal project, as well as their opinion about the importance of parametric design. Lecturer's responses to the questionnaire can provide an incomplete picture of the trend of digital design tools, especially the use of parametric design software in Indonesian architecture education. Those responses can also give a clue about the possible application of parametric design that can be practiced at the University (undergraduate) level in Indonesia.

The literature review and survey results were discussed to identify the potencies and challenges in implementing the parametric design in Indonesian architecture education. Figure 1 illustrates the methodology of this study, showing the keyword search in Google Scholar for the literature review and the types of information gathered through the questionnaire.

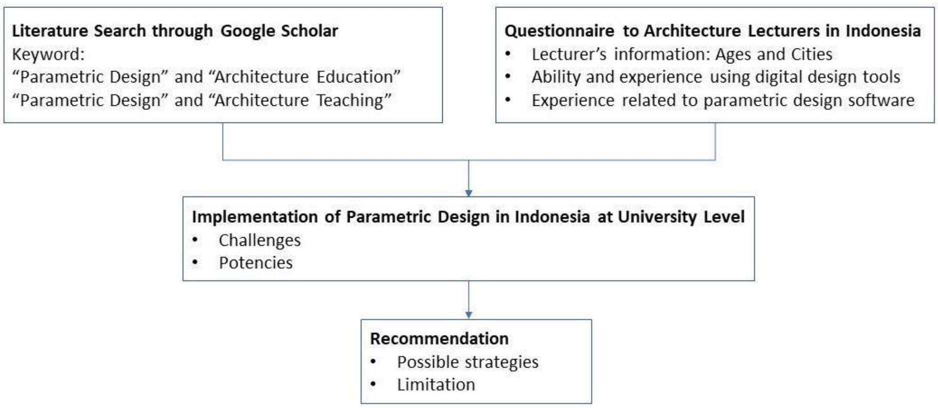

Figure 1. The methodology of this study.

Literature Review

There are nine studies found through the search in Google Scholar, which shared and discussed their experience teaching parametric design in architecture education at the University. It should be noted that the literature review in this study is only limited to these nine case studies, which are not representative of various parametric design teaching developed in many parts of the world. However, they could explain how parametric design can be practiced at the university for architecture education.

Table 1 shows the results from the literature search. Parametric design teaching in almost all studies has been introduced and practiced through the university course except in Indonesia case studies (Putro & Pamungkas, 2019) (Putro & Wirasmoyo, 2020) introducing parametric design through the workshop.

Table 1. Literature Review Results

Reference	Case study & location	Teaching activities & method	Findings
(Vrouwe, et al., 2020)	Master Program, University of Liege, Belgium	● A Course: Design and produce a lamp model (fabrication) with the parametric concept – form study, software practiced, introduction and discussion of parametric concepts, explore and refine the model, produce the model (physical)	● Communication between student and teacher is essential in teaching parametric design. ● Form-study using the physical model as the primary medium for effective communication ● Do not apply a strict method in teaching parametric design ● Students can converge their design ambitions more specifically when parametric software is practiced
(Radziszewski & Cudzik, 2019)	Undergraduate Program, Gdańsk University of Technology, Poland	● Two courses: (1) Introduction & essential exercise of parametric design and software; (2) Modelling contemporary architectural objects, simulations are complementary ● Elective Seminars: making a parametric model for digital fabrication ● Workshop: 3D modeling based on optimization and fabrication	● A basic introduction to design and digital fabrication are the essential steps for showing the potential of parametric design to students ● Both theoretical and practical classes are required ● Handcraft modeling and drawing are still essential in learning parametric design

Reference	Case study & location	Teaching activities & method	Findings
(Romaniak & Filipowski, 2018)	The undergraduate program, Cracow University of Technology, Kraków, Poland	• Courses: Introduction and utilization of parametric design software • Workshop for last year's students to familiarize the parametric design software • Scientific groups in the University support competitions and workshops	• The first-year students are moderately interested, while the final-year students are highly interested in parametric design • Designing and producing a parametric model promotes interdisciplinary cooperation • Learning parametric design software allows students to follow the newest trend (generative architecture)
(Putro & Wirasmoyo, 2020)	Undergraduate Program, University Technology of Yogyakarta, Indonesia	• Workshop: Parametric design learning and optimization process using Grasshopper for the digital fabrication process. The 3D scale model was produced: waffle structure, Voronoi surface, and structure	• Using parametric design software for digital fabrication brings up comprehension and interest for students taking digital fabrication as an elective course
(Putro & Pamungkas, 2019)	Undergraduate Program, University Technology of Yogyakarta, Indonesia	• Workshop: introduction of parametric design software; Form studies and processing architectural shapes in Rhinoceros-Grasshopper (10-15 storey tall buildings)	• The prepared algorithm definition in Grasshopper used by students for form studies is practical to introduce parametric design • The positive response from students indicating the parametric design should be applied to the lecture curriculum
(Airbus, 2018)	Fatih Sultan Mehmet Vakif University, Istanbul, Turkey	• Elective course: Students develop a parametric model based on a metaphor theoretical framework and continue to make 3D models from digital fabrication	• The use of metaphors in parametric design is adequate for short-time period teaching, especially in the form-finding process – it limits the parameters forming design options
(Riekstins, 2018)	The undergraduate program, University of Monterrey (UDEM), Mexico	• A course: introduction and exercise of geometries modeling in parametric design	• The combination of theory and practice is the key • Parametric design software

Reference	Case study & location	Teaching activities & method	Findings
		● software; experiment and build the design object (a complex surface)	● helped students think outside the box and get ideas on how to design and fabricate objects.
(Wannan, 2016)	Birzeit University in Palestine	● A course: introduction and utilization of parametric design software for digital fabrication. A pavilion design object was built.	● Thinking parametrically helps students to understand the nature of the design process: iterative and cyclic. ● It helps students' analytical thinking and engagement with material systems and properties. ● The parametric design reduced the time in the form-finding stage and fabrication process.
(Gallas, et al., 2015)	Master program, University of Liege (Belgium) and school of architecture of Nancy (France)	● A course in Belgium: introduction to parametric design software, an essential exercise to generate complex 3D forms and control them ● Combining a course and workshop in France: making contemporary architectural design objects (complex geometry) using parametric modeling, 3D printer, and digital fabrication devices. Students used a reference object from the natural shape	● Proposed a method for teaching parametric design with three significant steps: ● Analyze: describing the transformed geometries of the parametric model ● Implementation: translating the geometries transformation to parametric modeling software (Grasshopper) ● Experimentation: explore and assess the design options through simulation, and evaluate the physical and material reality of the designed object for fabrication

As mentioned, integrating parametric design software with building simulation software gives potency to solve various socio-environmental problems through architectural design. However, a parametric design practice in all case studies focuses on complex geometry modeling and design fabrication. Only Radziszewski & Cudzik (2019) introduced building simulation and performance optimization as complementary material in the advanced course, while Gallas et al. (2015) proposed the integration of building simulation as a part of parametric design teaching. Most case studies have a similarity in teaching procedure which can be summarized into three stages: (1) Introduction: theory and basic software tutorial; (2) Experimentation: creation and exploration; and (3) Design fabrication.

In the introduction stage, theory and practice must be balanced (Riekstins, 2018) (Radziszewski & Cudzik, 2019) (Vrouwe et al., 2020). The student should understand the principle and application of parametric design before using the parametric modeling software for their project. Form studies of several parametric design precedents should be conducted, which allows the student to analyze and explain the parametric transformation of the selected design object. Sketching or handcraft modeling should be done in this phase before learning parametric modeling software. Alternatively, the prepared parametric model (algorithm definition) can be used effectively for form study (Putro & Pamungkas, 2019). Then, the basic tutorial of parametric modeling software in Rhinoceros-Grasshopper can be taught by the lecturer and learned independently by the student.

The second step is experimentation which assigns the student to make a design object (complex geometry) which are entirely created and explored through parametric 3D modeling. A reference design object is needed in this process to limit the parameters forming design options so that the form-finding process can be done efficiently. Students should be free to select a reference design object that can be studied and developed further (Vrouwe et al., 2020). The reference object can be based on metaphor (Agirbas, 2018), nature shapes (Gallas et al., 2015), or contemporary architectural objects (Radziszewski & Cudzik, 2019). Active communication between lecturer and student is essential in this step, where the student should be asked to analyze and describe the transformed geometries (Vrouwe et al., 2020) (Gallas et al., 2015).

Design fabrication is the last critical stage in learning parametric design. Student needs to build a scale model from the parametric model they developed. Almost all case studies included the fabrication stage at the end of their course or workshop. It helps the student to understand the actual application of parametric design in the fabrication of complex geometries and develop their analytical thinking of how those geometries can be feasibly built by considering the material aspect (Wannan, 2016). Making a scale model from parametric modeling gives comprehension and interest to the students in digital fabrication (Putro & Wirasmoyo, 2020). Also, it can lead students to think outside the box to design and fabricate architectural objects (Riekstins, 2018) and engage in interdisciplinary cooperation (Romania & Filipowski, 2018).

The case studies suggest that the parametric design approach can be feasibly practiced at the university level, starting from its application for advanced 3D modeling and design fabrication. Applying parametric design for advanced modeling (complex geometry) seems fundamental as it can encourage the student to be more creative and explorative in the design process. Also, making a scale model from a parametric model is an essential part as it stimulates students' analytical thinking of how complex geometry can be realistically made/fabricated.

RESULTS AND DISCUSSION

Survey: Parametric Design and Architecture Lecturers in Indonesia

The survey through questionnaires received 109 responses from architecture lecturers in different cities in Indonesia (see Figure 2). Most of the respondents are from big cities in different universities, especially on Java Island, such as Jakarta, Surabaya, Bandung, and Yogyakarta. Respondents are also from a different generations (see Figure 3).

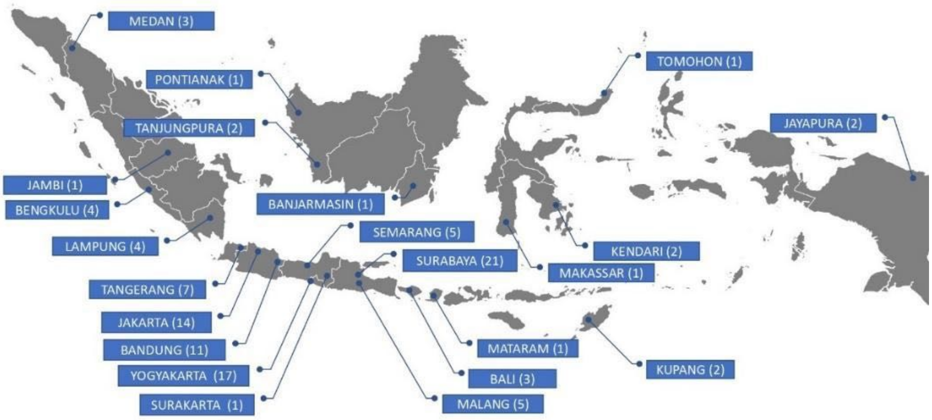

Figure 2. The Location of The Respondent's University

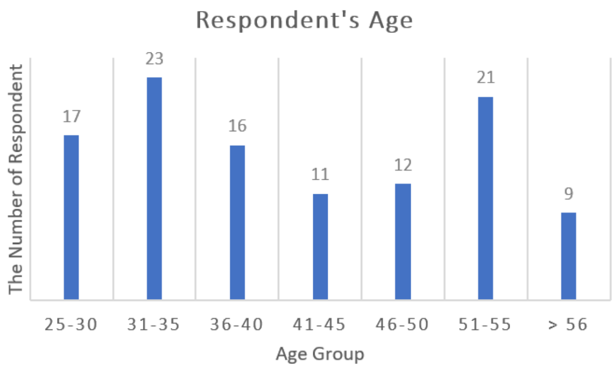

Figure 3. Respondents' Age

The first part of the questionnaire asks what digital design tools and building simulation software the lecturers had ever used and mastered (proficient). Some popular software was listed in the checkboxes question, and the respondent can write the additional answer (other boxes) if using other software outside the list. Figures 4 and 5 show the refined responses, excluding any tools used or mastered by less than 1% of the total respondent.

Most of the respondents (about 90%) have experience using SketchUp and CAD software, while more than half are proficient in using this software (see Figure 4). Only a few have ever used BIM and parametric design tools, such as Rhinoceros-Grasshopper (23%), Revit (28%), and ArchiCAD (39%), with at most one-tenth of total respondents mastering this software. This indicates that architecture lecturers in Indonesia are familiar with conventional design tools, mainly used for drawing and 3D modeling. Also, the lecturers have been aware of the application of advanced digital design tools such as parametric design and BIM software, although these are much less practiced.

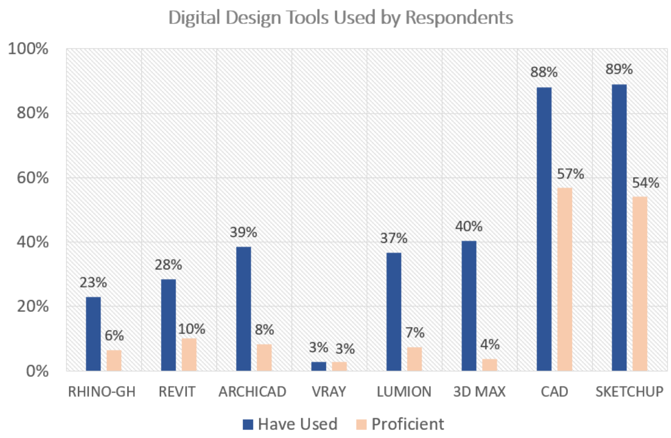

Figure 4. Lecturer's experience in using digital design tools.

The following question concerns their experience and ability to use building simulation tools. Ecotect and Dialux are the most popular tools among lecturers (see Figure 5). About half of the respondents have experience using Ecotect for building energy simulation, while about a third used Dialux for lighting analysis. A quarter of a quarter has experience using other tools such as EnergyPlus, ENVI-met, or CFD software. Also, Ecotect and Dialux are proficiently used by 25% and 17% of the total respondents, which are the simulation tools mastered by lecturers. In comparison, the others are mastered by about 5% of the total respondents. These percentages (5% to 25%) might reflect a ratio of architecture lecturers in one University who have expertise in thermal and lighting engineering and teach a course related to building physics.

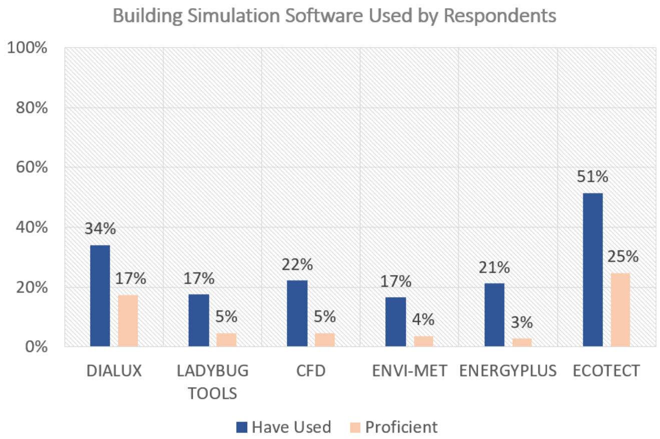

Figure 5. Lecturer's experience in building simulation software

The second part of the questionnaire asks about the lecturer's experience in parametric design software: whether they have learned or used it or supervised students applying it to their project. At least 45% of respondents have learned parametric design software (see Figure 6). Most of them learned Rhinoceros-Grasshopper (26.6%) while others filled Revit-Dynamo (3.7%) and both software (5.5%) (see Error! Reference source not found. Right). A few respondents mentioned other tools (4.6%) and filled in the blank (4.6%). 27.5% of respondents use parametric design software for teaching, research, or personal projects (Figure 6). Rhinoceros-Grasshopper is likely the most parametric tool used for these purposes. As shown by Figure 4, some respondents (23%) used parametric design software such as Rhinoceros-Grasshopper. In comparison, only a few (9.2%) recognized Revit as a parametric design tool in the learning phase (see Figure 7). This also indicates that most of the respondents utilizing Revit (see Figure 4) are for Building Information Modelling (BIM) purposes. In this case, Revit is a BIM software that provides a Dynamo plugin that enables parametric modeling.

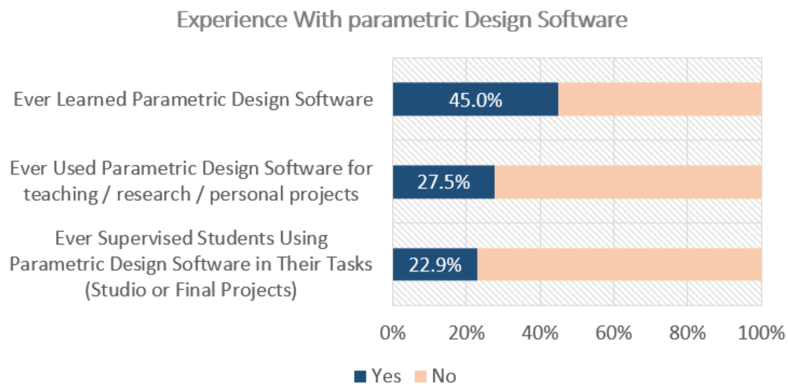

Figure 6. Lecturer's experience with parametric design tools

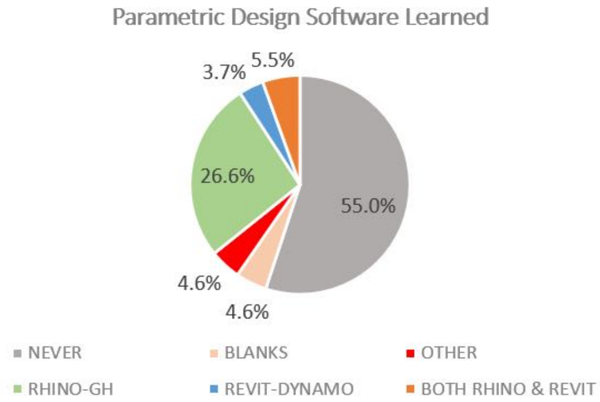

Figure 7. Parametric Design Software Learned By The Lecturers

The survey results in figures 6 and 8 indicate that parametric design has recently begun to practice in Indonesian universities through architecture courses and or by some students independently in their projects. Besides, some lecturers (22.9%) have experience supervising students who use parametric design tools in their projects. Additionally, most lecturers agreed with introducing parametric design to students in university courses (see Figure 8). Also, there has been an awareness of the parametric design trend growing within architecture education at Indonesian universities.

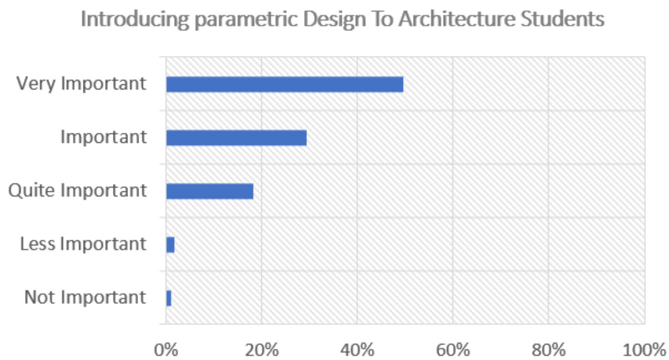

Figure 8. Lecturer's opinion about the importance of parametric design

The Implementation of Parametric Design in Architecture Teaching in Indonesia

As mentioned, design optimization based on parametric simulation practice in the parametric design approach can solve socio-environmental problems. For now, this practice can be a big challenge in architecture education at Indonesian universities since requiring sufficient knowledge and ability in parametric design and simulation software. The survey results show that maybe one of the twenty lecturers had familiarised parametric design software (Figure 4) and simulation plugins (Ladybug

Tools) (Figure 5). Also, fewer lecturers are familiar with simulation tools such as EnergyPlus and ENVI-met connected to the Ladybug Tools plugin. As Radziszewski & Cudzik (2019) highlight, parametric teaching design should be supervised with appropriate knowledge and skill so that students can adequately connect and use the parametric design tools.

Meanwhile, the case studies from different countries show that parametric design was introduced and practiced in architecture teaching, mainly for complex geometry modeling and fabrication. Only two case studies (Radziszewski & Cudzik, 2019) (Gallas et al., 2015) integrated simulation in parametric design teaching as complementary material. This implies that parametric simulation for design optimization is an advanced practice for parametric design teaching. Interdisciplinary cooperation might be needed among the lecturers to implement this practice– those familiar with the parametric design tool and those who are experts in building simulation.

The literature review and survey findings suggest that parametric design should be implemented in architecture teaching for advanced 3D modeling and design fabrication practices. Figures 9 and 10 illustrate complex geometries that can be generated by parametric 3D modeling for fabrication practice. This implementation is feasible for the context of Indonesia universities where four out of twenty architecture lecturers have ever used parametric design tools (mainly Rhinoceros-Grasshopper), and one or two of them are proficient in using that software (see Figure 4 and Figure 6)

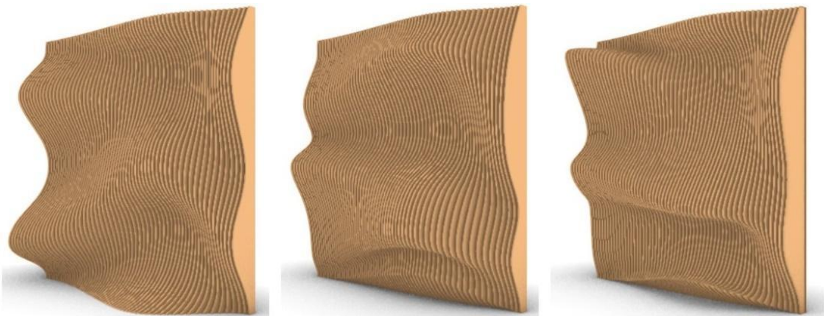

Figure 9. Various alternatives of the sectioned wavy form (personal documentation)

Figure 10. Variation of pixelated twisted forms (personal documentation)

Advanced 3D modeling practice is about how the student uses the parametric design tool as a digital crafting medium. In this case, students can produce and develop a new complex geometry or unconventional form for architectural elements. It also allows the student to engage in generative modeling that explores a range of design alternatives (see Figures 9 and 10). This practice can lead students to be more creative and explorative with a new digital skill, supporting the design process in an architectural studio. The implementation of this practice is supported by numerous parametric modeling tutorials on the internet that allow students to learn parametric modeling skills independently. Thus, a lecturer/ mentor with less experience in parametric design can still guide the students in advanced 3D modeling practice.

Meanwhile, the fabrication practice encourages students to solve how a complex architectural form can be built realistically in a scale model by considering the material system and construction technique (Wannan, 2016). A supplementary seminar or workshop can be done further for the advanced practice, such as parametric simulation and optimization, by involving external parties (experts or practitioners) experienced in this practice. These practices should be implemented within a course to respond to a growing awareness of parametric design trends at Indonesian universities.

CONCLUSIONS

Parametric design teaching should be included in the architecture learning program (undergraduate) to respond to a growing interest in parametricism at the University in Indonesia. It should be realized through an elective/particular course focusing on building parametric design skills (thinking and modeling). The implementation of parametric design in that course should start from its application for advanced 3D modeling and design fabrication practices. These practices are feasible to realize in the architecture learning program and can support students to be more creative and explorative in the architectural studio project. Additionally, parametric simulation and optimization are the advanced practices of parametric design that can be taught further through workshops or complementary programs. These advanced practices are the key to parametric design for solving socio-environmental issues but require sufficient knowledge and skill, and interdisciplinary cooperation for their implementation.

This study proposes a conceptual framework of parametric design teaching that can be feasibly implemented in a university course based on the context of Indonesia (see Figure 11).

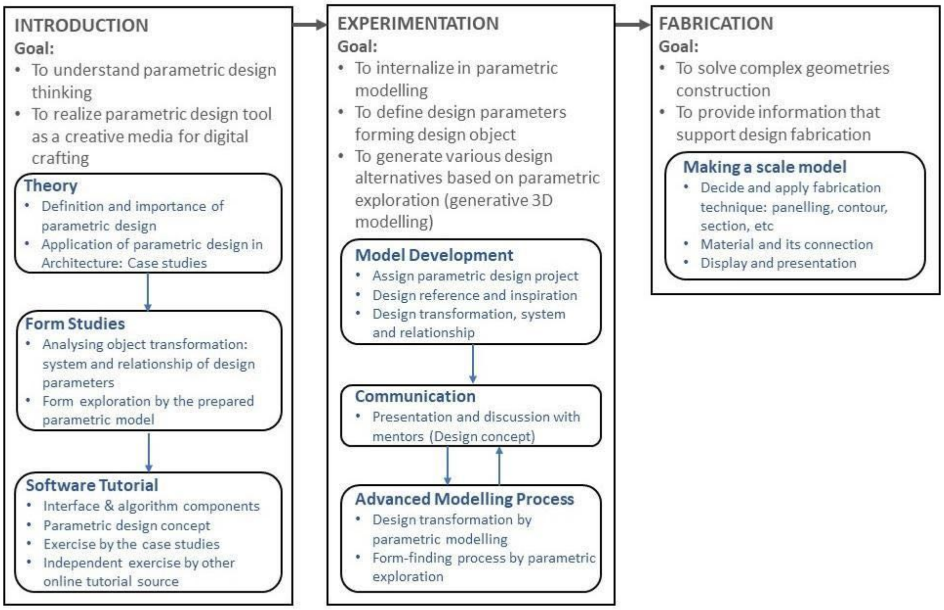

Figure 11. Proposed framework for parametric design teaching for Indonesia university

The proposed framework for parametric design teaching consists of three stages: introduction, experimentation, and fabrication. The introduction provides basic knowledge about parametric design thinking in architecture and a basic tutorial on parametric modeling software (Rhinoceros-Grasshopper). In this stage, architecture students should realize the application of parametric design tools for digital crafting that can improve their creativity. Advanced 3D modeling using a parametric design tool is practiced in the experimentation stage, where students should create and develop a parametric design object. The lecturer or mentor should allow students to select their design references and communicate with them actively when developing the design idea. Also, the students should be pushed to explore and study various parametric modeling tutorials relevant to their project from other sources during the experimentation stage. That is the key to the feasible implementation of the proposed framework for architecture learning programs in Indonesia, as only a few Indonesian lecturers are experienced in parametric modeling software. The last is the fabrication stage which allows students to solve the construction of complex geometry models they generated during experimentation. Through parametric modeling, the students are expected to generate information that can support the fabrication process.

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