

## Parametric modeling practice for the first-year architecture students learning

Wendy Sunarya<sup>1\*</sup>, Jackobus Ade Prasetya Seputra<sup>2</sup>, Afif Fajar Zakariya<sup>2</sup>

<sup>1</sup>Faculty of Architecture and Design, Universitas Pembangunan Nasional “Veteran” Jawa Timur, Jl Raya Rungkut Madya No.1, Gunung Anyar, Surabaya, Indonesia

<sup>2</sup>Department of Architecture, Universitas Atma Jaya Yogyakarta, Jl. Babarsari No.44, Yogyakarta, Indonesia 55281



ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received March 30, 2023 Received in revised form July 17, 2023 Accepted July 26, 2023 Available online August 01, 2023</p> <p><i>Keywords:</i> Architectural pedagogy Design creativity Form exploration Parametric design Parametric modelling Rhinoceros-grasshopper</p> <p><b>*Corresponding author:</b> Wendy Sunarya Faculty of Architecture and Design, Universitas Pembangunan Nasional “Veteran” Jawa Timur, Indonesia Email: <a href="mailto:wendy.ar@upnjatim.ac.id">wendy.ar@upnjatim.ac.id</a> ORCID: <a href="https://orcid.org/0000-0002-3899-5301">https://orcid.org/0000-0002-3899-5301</a></p>	<p><i>Parametric modelling has been regarded as a prospective skill in architectural education. It offers design capabilities to instantly generate numerous design options and create complex geometries, which can enhance students’ creativity. However, incorporating parametric modelling into architecture curriculum can be a challenge due to the involvement of programming as design paradigm and the broad use of parametric modelling tool. Thus, this study investigates how parametric modelling can be effectively practiced in early architectural education. The findings of this study are based on the observation of the parametric modelling workshop participated by 150 first-year architecture students in Indonesia. The purpose of this study is to examine how parametric modelling improves the students’ design skill and how they perceive the course of the workshop. It is found that parametric modelling can be feasibly practiced by first-year students as a medium to enhance design creativity. Additionally, parametric modelling can improve students’ design intuition in some respects, that can smooth the design skill development in architectural learning. The lessons for the effective parametric design learning were also discussed in this study, active communication between student and lecturer, metaphorical thinking strategy and emphasis on the inspirational tool.</i></p>

### Introduction

Over the last decade, parametric design had emerged as a strong trend in architecture. It has been regarded as a distinctive architectural design style with new aim and movement (Schumacher 2009). Parametric design is a design method that describe the design object by the use of parameters (Caetano, Santos, and Leitão 2020). In contemporary architectural practice, parametric design is substantially supported by parametric modelling software to define parameters. Computer Programming technique based on data and algorithms is used in parametric modelling to

specify design parameters to generate geometries (Zou, Wang, and Luh 2023). The reformulation of design parameters allows designers to produce various complex geometries without redrawing the model each time a change is required (Alalouch 2018). Parametric modelling has become an interactive medium to discover design variations, which can enhance creativity in the design process.

What differentiates the parametric modelling software from the conventional design tool is the design mindset in using it. Conventional Computer-Aided Design (CAD) or 3D modelling software focuses on the visualization of design

appearance. Meanwhile, parametric modelling creates a systematic logic of design intent behind the design appearance. Parametric modelling application requires a mindset shift from a process of creating design representation to that of transforming design intent (Jabi 2013).

With the recent development in technologies, programming in parametric modelling software can be easily practiced by designers due to its user-friendly interfaces. One of the most common parametric modelling software used by designers is Rhino-Grasshopper. Rhinoceros (McNell 2022) is a Computer-Aided Design (CAD) software for 3D modelling while Grasshopper (Rhinoceros Plugin) enables the programming to define and update the Rhinoceros-visualized 3D model. Grasshopper provides graphical algorithm editors to engage in programming process without any skill of scripting. Various plugins are also available for Grasshopper to connect to building and environmental simulation tools. This allows designers to potentially solve socio-environmental issues through parametric design approach (Heidari et al. 2018).

Realizing its potential, it is important to incorporate parametric modelling into architecture education. In this case, there is a growing adoption of parametric design in architectural design practice (Gu, Yu, and Behbahani 2021). The generative capability of parametric modelling tool can potentially enhance creativity in the design process (Putro and Pamungkas 2019). Some universities in different countries also had begun to introduce parametric modelling application in their curriculum (Soliman, Taha, and El Sayad 2019). Meanwhile, there is a growing interest in parametric design learning at the universities in Indonesia (Sunarya et al. 2022). Thus, parametric modelling may be feasible and relevant to introduce to current first-year architecture students.

However, teaching parametric design can be a challenge as it means introducing a new design tool with programming paradigm (Ostrowska-Wawryniuk, Strzała, and Słyk 2022). Also, parametric modelling tool has a broad use for the design purposes and this can confuse a new learner to determine where to start to delve in. Thus, the main question addressed in this study is that how to develop an effective teaching model so that students can easily comprehend parametric design paradigm and use parametric modelling tool practically to support their design project later on. This study investigates a parametric-

design teaching based on the experience from a parametric modelling workshop participated by the first-year architecture students. It aims to examine how parametric modelling can enhance students' creativity and design skill as well as their perception and satisfaction during the course of the workshop. Evaluating the workshop output and learning process perceived by the students are important for the development of parametric design teaching that can be incorporated to architectural curriculum.

## Method

This study is based on the evaluation of the parametric-modelling workshop conducted by the Department of Architecture at the University of Atma Jaya Yogyakarta. The workshop was a part of an architecture course, "Digital Design Technology", that was participated by all first-year students in four weekly meetings in 2022. Each workshop meeting lasted for 2-3 hours, including material introduction, tutorial, and discussion. The workshop was participated by about 150 students online. first aligned text to the left and bold, with font-size 12.

### Workshop material and observation

The workshop focused on the application of parametric modelling software, Rhinoceros-Grasshopper, to explore design variations and create complex geometries for architectural elements. Each workshop meeting's activities were summarized in **Error! Reference source not found.** Every meeting began with an introductory presentation by the instructor before engaging in parametric modelling tutorial in Rhinoceros-Grasshopper. The presentation illustrates the parametric model, concept, and technique that students would practice, as well as its application to architectural design. During the tutorial, the students may ask questions openly if they encounter any difficulties. Then, the students were assigned to discover design variations from the tutorial model and another relevant tutorial from the recommended online source (YouTube).

Figure 1 depicts the tutorial model that students developed in each meeting. The students are assigned two tasks during the workshop. The task 1 is to parametrically explore the tutorial model in each meeting. By modifying the specified parameters, the students can transform

the model into a new design object that they find unique or aesthetically pleasing. The Task 1 aims to encourage the students to explore a variety of design possibilities and comprehend parameters

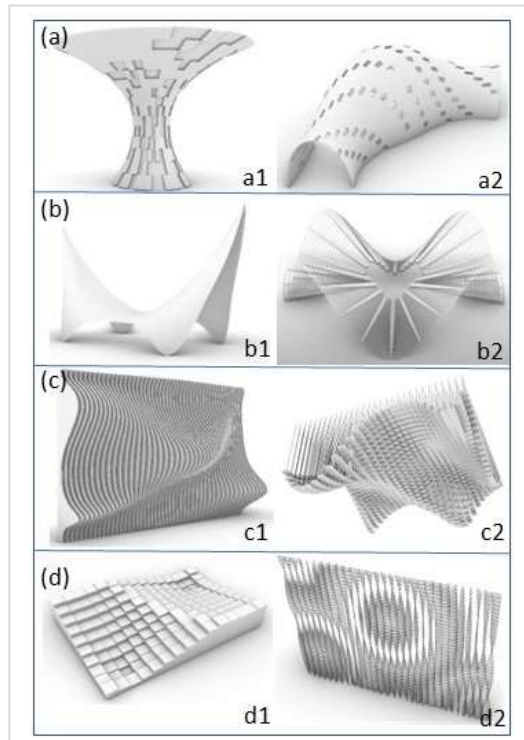
relationship defining the model. In the Task 2, the students were free to develop a new parametric model from any inspiration and to create an original design object.

**Table 1.** Table captions, uppercase only at the beginning of a sentence

Week	Material
	Introduction to parametric design <sup>1</sup>
1	Basic Rhinoceros-grasshopper tutorial (figure 1: a1) <sup>2</sup>
	Subdivision Technique: Random pattern generation based on shell structure subdivision (figure 1: a2) <sup>3</sup>
2	Parametric free form modelling <sup>1</sup>
	Shell structure based on graph mapper (figure 1: b1) <sup>2</sup>
	Parametric wavy-form structure (figure 1: b2) <sup>3</sup>
3	Parametric modelling for fabrication <sup>1</sup>
	Fragmentation Technique: sectioning a free-form model for fabrication (figure 1: c1) <sup>2</sup>
	Point-projection technique: projecting point on the free-form surface for modular design (figure 1: c2) <sup>2&amp;3</sup>
4	Point attractor Technique: application and case studies <sup>1</sup>
	Point attractor for dynamic creation of contour and façade design (figure 1: d1 & d2) <sup>2&amp;3</sup>

<sup>1</sup>Presentation; <sup>2</sup>Tutorial and discussion; <sup>3</sup>Independent learning

The workshop outcomes produced by students were observed to see how parametric modelling can enhance their creativity. The observation was based on the three indicators of creativity: (1) abundance (number of form generation), (2) flexibility (inspiration-source variety); and (3) originality (form uniqueness) of design outcomes (Jordanova et al. 2009) (Torrance 1966).



**Figure 1.** The tutorial model of the task 1

### Questionnaire

A Likert-scale questionnaire was developed for measuring the attitudes, perceptions, and opinions of the students towards the parametric modelling workshop (see appendix, table 2). The questionnaire also attempts to identify issues and challenges encountered by students while practising parametric modelling Grasshopper (see Appendix, table 3). The questionnaire's application of the Likert Scale's five levels ranging from strongly disagree to strongly agree (Statement no. 1 to 12). In general, there are five aspects examined through the questionnaire (page 1) in the parametric-modeling workshop:

1. Workshop material (Statement 1-3)
2. Instructor teaching (Statement 4-5)
3. The creative process (Statement 6-8)
4. Rhinoceros-Grasshopper use (Statement 9-11)
5. Parametric design learning (Statement 12)

### Result and discussion

The workshop observation and outcome

The analysis of the workshop outcomes was based on the observation of the submitted digital sheet presentation (see **Error! Reference source not found.**). Out of 150 first-year students, 136 submitted their workshop assignments. The students presented the parametric model they developed and the inspiration for their idea.

In the task 1, most of the students had successfully transformed a single parametric

model into various forms that can be applied to decorative or architectural elements, especially from the first and third meeting. Figure 3 shows decorative objects that are practical to fill architectural and interior space, such as vase, lamp, pottery, fountain, canopy, table and chair (see figure 3). About half of the submitted work (60 out of 137) drew inspiration from different natural objects, particularly from the second and fourth meeting. Figure 4 depicts various models mimicking natural shapes like octopus, bug, squirrel, leaf, butterfly, etc. In this case, the students demonstrated the expansion of design possibilities based on a single parametric model. They also show a flexibility in creating complex forms by associating the explored model with unique objects that they had seen (e.g., animal or plant shapes).



Figure 2. Samples of students' assignment presentation from the parametric modelling workshop

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Figure 3. Samples of the explored model (task 1): design objects from the first and third meeting tutorial  
Source: Personal documentation

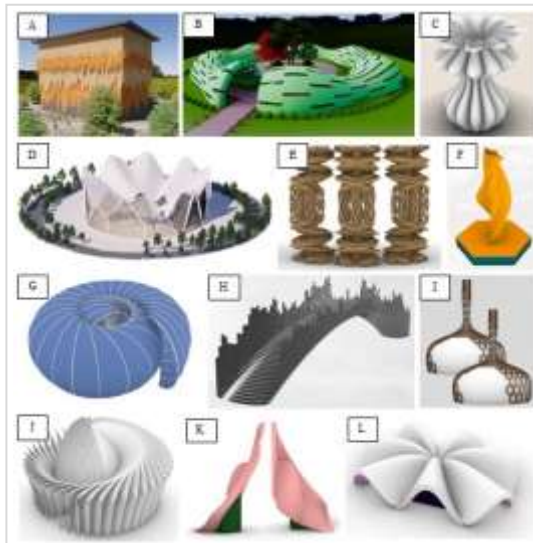


Figure 4. Samples of the explored model (task 1): metaphorical design objects from the first and third meeting tutorial

Parametric exploration also led the students to achieve a harmonious composition in their design objects. The outcomes of second and fourth meetings shows that many students (87 out of 136) intuitively produced symmetry, rhythm, and/or pattern in their design forms, which are all regarded as ordering principles. These principles are fundamental to avoid monotony or chaos in

architectural composition (Ching 2014) and can be described mathematically in the form of a number order or graphical function in parametric modelling.

The outcome of the task 2 shows design objects that have been freely developed by the students. Most of the students (64 out of 136) created various models for architectural design concepts, such as a tower, pavilion, canopy, façade, and shed (see Figure 4: A, B, C, E, F, G and H). Meanwhile, 38 students built decorative architectural objects such as a pillar, vase, and monument (see Figure 5: D, I, J and K) and others created interior elements such as the chair, table, and partition. Many students also employed a metaphorical approach in the Task 2. Most of them (45 students) are influenced by natural forms such as wave (see Figure 4: B and C), flower (see figure 5: I and K) and snake (see figure 5: J). Eight students attempted to express a quality and experience into an architectural form, such as aerodynamic capability and audio spectrum (see figure 5: E and L). These results suggested that Task 2 had stimulated students to control parametric exploration based on the determined inspiration during the creative process. The students had also considered form and function simultaneously when exploring the model parametrically.



**Figure 5.** Parametric design object of the Task 2: (a) rhythmic façade; (b) undulating tunnel; (c) flower vase (d) wavy pavillion; (e) knitted wood pillar; (f) snake monument; (g) shell façade; (h) audio-spectrum bridge;

(i) shed; (j) aerodynamic surface; (k) flower monument; (l) meatbun roof

However, most of students were still limited to produce an original parametric form. Most of the task 2 outputs share a similarity to the models of the Task 1 or to that from other tutorial sources. Most of the outputs (73 students) are characterized by wavy forms which are based on the concept of the tutorial models. This limitation could be reasonable due to their lack of experience in parametric modelling. Even so, they can still utilize parametric modelling effectively to explore new forms and freely express their inspiration.

The workshop results show that parametric modelling improves students' design skills in some respects:

- **Exploration skill.** In parametric modelling, students can generate an abundance of design forms that they can consider, develop and so on. This process enables first-year students to recognize the iterative nature of the design process. They could realize how an exploratory process can be initiated by understanding the relationship of parameters defining a design model. The parametric modelling practice imparts students' awareness of the role of parametric design thinking in the creative process by exploring different design alternatives (Putro and Pamungkas 2019).
- **Metaphorical Creativity.** Most of the students conceptualized the design forms based on the real-world object in the task completion. They mostly obtain inspiration from natural shapes (plants, animals, waves, etc.). The metaphorical objects developed by students can be viewed as background knowledge for the initial creative process. Then, based on this idea, the students can create various forms that are unique or previously unimaginable. Additionally, metaphor approach in parametric modelling can help the students to control and focus on a few parameters that can transform their imagination (Agirbas 2018).
- **Ordering principles.** Students intuitively demonstrated the ordering principles such as symmetry, rhythm, and pattern when completing the task 1. Ching (2014) emphasized that the ordering principles has a role in architectural composition for producing unified and harmonious design arrangement. These principles can be

described by mathematical principles in the form of number order and graphical function in parametric model. This suggests that parametric modelling has successfully become a digital crafting tool to improve design intuition with a simple of mathematical principles.

- Reverse-engineering thinking. The model that students would create were shown in the beginning of the tutorial. During the tutorial, the lecturer gave a clue of how the hidden structure of the model shapes its appearance and determines the its design variation. Then, the students are guided to transform the model appearance into concepts in parametric modelling. These steps are basically reverse-engineering process where students analyse the hidden structure behind design product for reproducing all or part them. This can accelerate skill acquisition in rapidly changing fields (Friedman 2021), such as architecture that is evolving due to technology advancement. Through reverse engineering, the students can deeply comprehend the design product with limited understanding of the design procedure (Hashemnejad, Sharbaf, and Sharbaf 2016).
- Form-function reasoning. The students considered both form and function simultaneously in parametric model exploration. They started to consider not only what a form could look like (metaphor), but also what it could be used for. They become critical and responsible for the generated forms. This way of thinking could be contradictive to the “form follows function” method promoted by Modern-Movement Architecture. However, this thinking might enrich the student to alternative design methodology that can be applied to their future project (Agirbas 2018).

Students’ perception towards parametric design workshop

The questionnaire of the conducted parametric modelling workshop was answered by 125 students. Figure 6 and 7 shows that most of students participating the workshop do not know about parametric design previously and have never used Rhinoceros-grasshopper software. Meanwhile, Figure 8 shows the students’ perception of the conducted parametric modelling workshop. The reliability of the students’ ratings

was analyzed by using Cronbach’s Alpha formula with a value of 0.902 – indicating a high degree of consistency between responses (S1-12).

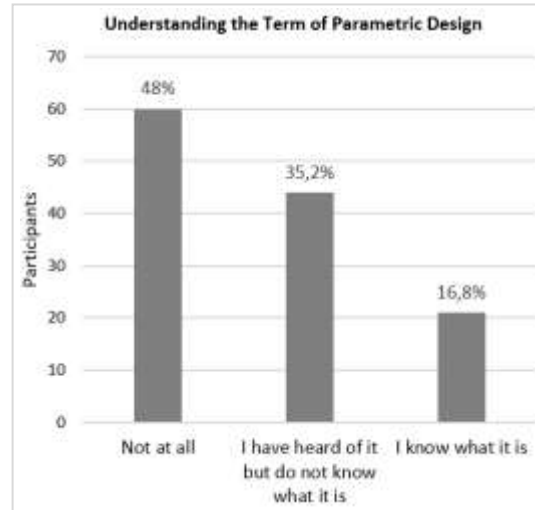


Figure 6. Number of students knowing the term of parametric design

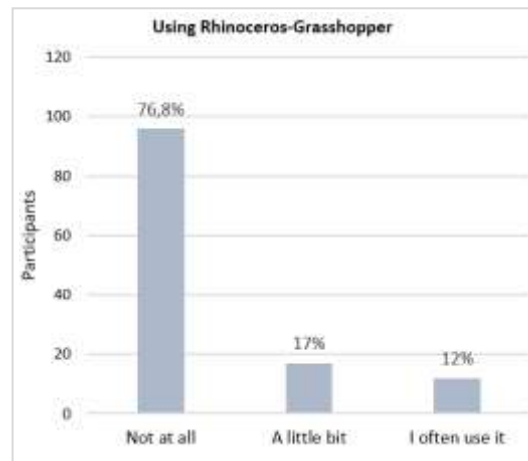


Figure 7. Number of students using rhinoceros-grasshopper

The students generally gave positive attitudes towards the workshop in every aspect. The average assessment for most items (S1-8) reflects satisfaction with the workshop's content, instruction, and creative process. From the instructor’s perspective, the results of these three aspects could be interdependent. The workshop materials could effectively support the instructor's ability to exhibit parametric exploration in the creative process. Meanwhile, the instructor's teaching could lead students to view the material as a creatively beneficial technique. The

workshop successfully emphasized how to engage in parametric modelling for the inspiration-seeking process. Consequently, the students regarded Rhinoceros-Grasshopper as a prospective design tool (S10 and S11) for future-leaning and application. They also agreed that parametric design education should be incorporated into the University's architectural program (S12).

However, the student's responses are close to neutral (3.30) in the S9 – Whether Rhinoceros-Grasshopper is easy to use. This result may indicate difficulties in operating the software during the workshop. According to the responses on the page 2, question 1 (**Error! Reference source not found.**), 39.2% of students encountered hardware-related issues when following the tutorial, as they wrote: "PC lagging, slow or not responding, inadequate hardware". Meanwhile, the 34.4% students reported some difficulties in understanding modelling workflow in Grasshopper. Most of them specifically stated that it is difficult to understand and memorize the function of Grasshopper components, especially at the beginning of learning. They also admitted that it was easy to follow the tutorial by instructor, but were confused when creating a model on their own, especially in completing Task 2. It is important to note that most of students have not used digital design tools, especially parametric design software. So, their judgement of whether Rhino-Grasshopper is easy to use is not based on the comparison experience with other software.

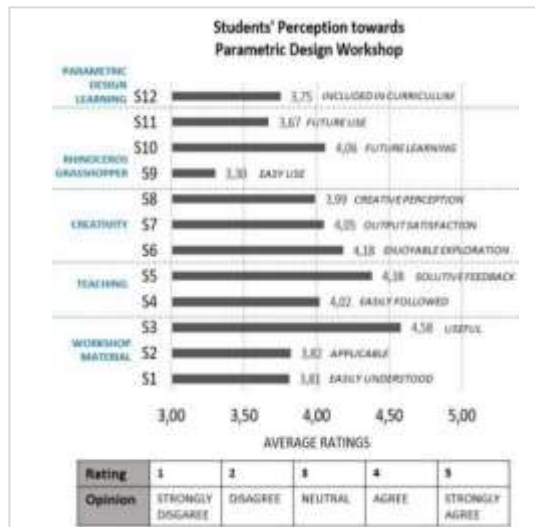


Figure 8. Students' perception of the parametric design workshop

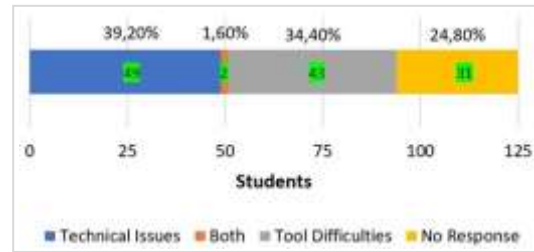


Figure 9. Students' comment related to difficulties in parametric modelling tutorial

The online workshop could be the main reason for the reported technical issues. In this instance, the students utilized their own personal computer or laptop, some of which do not meet the system requirements for parametric modelling software. The lecturer also could not directly monitor the student's progress and realize those issues during the tutorial online. Another problem with the online workshop is that the lecturer could not perceive if the tutorial explanations could be understood properly by the students. Based on the questionnaire (Q2, page 2), 34 students commented that the lecturer's explanation is sometimes too fast and difficult to follow.

The reported difficulties during tutorial can be seen as an inevitable problem when learning a new design tool. These difficulties could be resolved when the instructor gave feedback on the reported obstacles and questions during the tutorial. The students gave a high score (averaging 4.38) to the S5 (**Error! Reference source not found.**) indicating that the instructor had given effective feedback for every reported difficulty. Thus, two-way communication between lecturer and students is required for the effective learning in parametric modelling.

Overall, the questionnaire results show the acceptable parametric modelling learning by the first-year architecture students. Despite their limitation in design experience and digital modelling, they generally could follow the workshop material and instruction. Importantly, they can comprehend and use a new design tool for digital crafting, which can improve their creativity in the design process. They also started to realize the potencies of the parametric modelling software, Rhinoceros-Grasshopper, as well as parametric design paradigm. This suggests that parametric modelling can be introduced and practiced in early architecture curriculum, particularly for students exploring architectural design variations.

### Lessons learned

Some lessons for the effective learning of parametric modelling in the early architecture curriculum are discussed by reflecting to study results and literature review findings:

- Comprehension and inspiration by metaphorical thinking. Metaphorical thinking can boost students in understanding a parametric model with flowing inspiration. In each random change of parameters, the students can find any inspiration by associating the generated form with a similar real-world object. At the same time, they can learn the consequence of parameters change and lead the model to the intentional metaphorical object. Through this process, design inspiration can flow naturally and be enhanced further with students' comprehension. It can give students a sense of freedom in developing design object. Riekstins (2018) suggested that a freedom in finding inspiration is important for the success parametric design learning. Metaphorical thinking can also help students to narrow the excessive number of design possibilities (Agirbas 2018).
- Two-way communication. Visual programming in Grasshopper requires accuracy in matching the input-output data and the students can be discouraged by the unintentional error they made during that process. Active communication between instructor and students are required during the tutorial to resolve this issue. The instructor should frequently give pause throughout tutorials, allowing questions from students and two-way communication. Besides, communication between the student and instructor is required in parametric exploration (Vrouwe et al. 2020). In this case, the students can generate numerous design alternatives through parametric modelling, which can lead them to confusion in determining the ideal alternative. The lecturer's guidance can help the student to filter and select the design variations based on relevant considerations. Additionally, parametric exploration process can be a medium for students and lecturers to develop design ideas together (Cristie and Joyce 2021).
- Emphasis on inspirational tool. Parametric modelling is an important tool to express a new design paradigm that is parametric design

thinking (Aish and Hanna 2017). It is also beneficial tool for architect worldwide to expand design possibilities (Romaniak and Filipowski 2018). Thus, parametric modelling learning should emphasize parametric modelling software as an inspirational tool rather than a support graphic program. This perception is the key to generate the future interest of the architecture student for learning parametric design in the early curriculum.

### Conclusion

This study has evaluated the parametric-design teaching experience based on the parametric modelling workshop participated by the first-year architecture students. It can be concluded that it is feasible to incorporate parametric modelling in the early architectural curriculum. Although the workshop was conducted in a relatively short period of time, the students had been able to produce various complex geometries of design objects from different source of inspirations. This suggests that students have successfully used Rhinoceros-Grasshopper as a digital crafting medium to explore much more design possibilities. The students can feel more creative in exploring design variations and this can improve the satisfaction of their design outputs. Parametric modelling practice also directs students to habituate iterative design process where they should assess, select, develop the generated design forms, and so on. This process enhances students' design intuition in finding harmonious and unified design compositions.

Parametric modelling also provokes logical and analytical thinking in conceptual design thinking. Simple mathematical principles can be described and reformulated in parametric modelling for the form-finding process. The number sequences and graphical function can be specified as parameters to shape a design object. Conversely, the hidden structure behind a design appearance can be analysed and translated to parametric model in the form of mathematical principles using parameters. This process enables students to conceive an underlying concept of design product with a little design experience, which can smooth the design skill development. Additionally, the students can be more critical in parametric modelling exploration as they are

stimulated to consider the function and aesthetic aspects simultaneously of the generated form.

This study also presents the material of parametric modelling teaching that can be feasibly practised by first-year students of architecture in a short period time. However, the effectiveness of the teaching material is highly dependent on the expertise of the lecturer in communicating with the students. Open discussion should be allowed during the tutorial to resolve any difficulties encountered by students. Communicating with student is also about leading the students to filter numerous design variations by relevant consideration. Metaphorical-thinking approach can be emphasized in this stage to stimulate flowing inspiration and filter the design options. Besides, lecturer should also lead the students to view the parametric modelling software as an inspiration-seeking instrument rather than merely a visualisation tool. This perception is essential to pique the attention of first-year architecture students in parametric modelling.

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#### **Author(s) contribution**

**Wendy Sunarya** contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

**Jackobus Ade Prasetya Seputra** contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

**Aff Fajar Zakariya** contribute to methodology, supervision, and validation.

## Appendix A

**Table 2.** Questionnaire page 1: Students' perception of parametric modelling workshop

QUESTIONNAIRE PAGE 1									
Name :									
Email :									
Year Of Entry (College) :									
No	Question	Answer (Tick the box)							
1	How much do you know or understand the term of "parametric design" before participating in the workshop?	<input type="checkbox"/>	Not at all						
		<input type="checkbox"/>	I have heard of it, but do not know what it is						
		<input type="checkbox"/>	I know what it is						
2	How far have you used and studied Rhinoceros-Grasshopper software before participating the workshop?	<input type="checkbox"/>	Not at all						
		<input type="checkbox"/>	A little bit						
		<input type="checkbox"/>	I often used it						
No	Statement	Answer (Tick the box)							
		SD	D	N	A	SA			
1	The workshop material can be easily followed and understood								
2	The workshop material is relevant to be applied and developed for architectural design								
3	The workshop material is useful and important for architectural learning								
4	The explanation and tutorial by the workshop instructor were easily understood and followed								
5	The workshop instructor gave an effective feedback and solution of every question and difficulty during the tutorial								
6	I enjoy the creative process of forms exploration in Rhinoceros-Grasshopper by parameters changing								
7	I am satisfied with the result of design exploration and creation in Rhinoceros-Grasshopper								
8	I feel more creative in developing design form through parametric design approach using Rhinoceros-Grasshopper								
9	Rhinoceros-Grasshopper is easy to use								
10	I would like to learn more about parametric modelling using Rhinoceros-Grasshopper								
11	I consider using Rhinoceros-Grasshopper to develop my project in architectural studio for the next semester								
12	Parametric design learning should be included in the curriculum of architecture program in university								
SD: Strongly Disagree		D: Disagree		N: Neutral		A: Agree		SA: Strongly Disagree	

**Table 3.** Questionnaire page 1: Students' perception of parametric modelling workshop

QUESTIONNAIRE PAGE 2	
No	Question
1	What kind of issues and difficulties in learning and using Rhinoceros-Grasshopper, that you found during the workshop? (Please write) ..... .....
2	Please give comment, critique or suggestion related to the workshop material or instructor in teaching the workshop material! (Please write) ..... .....

