Concept Learning Through Parametric Design

A Learning Situation Design for Parametric Design in Architectural Studio Education

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Over the past few decades, architectural practice and, consequently, the design studio have been increasingly challenged. Indeed, the development of digital tools and parametric design, in particular, has given rise to a new type of architectural knowledge. Among the IJAC publications over the past three years, we highlight the current diversity of vocabulary used to discuss this knowledge and develop why we focus our study on conceptual knowledge. We then report a learning situation through studio design education. This paper finally presents the steps developed to measure this knowledge and hypothesizes on the future work needed in order to have relevant quantitative results. The purpose of this paper is to observe the evolution of students' understanding when shifting from a traditional teacher-student relationship to an engaging learning environment, considering the specificities of parametric, and not to suggest a strict method to follow when learning parametric. This could guide teachers to adapt to their own situations.

Keywords: *Pedagogy, Learning, Parametric Design, Form Study*

INTRODUCTION

According to various academics, the difference between traditional architectural design and digital architectural design is significant (Oxman, 2008). As a result, in research on digital design in general, and parametric design in particular, the necessity to update the traditional pedagogical methods used in architecture education is frequently addressed (Varinlioglu et al., 2017). In order to address this update effectively, in this study both the content and the context of education are considered.

Firstly, on the one hand, parametric designers need to process more than the traditional content of the architectural curriculum (Oxman and Gu, 2015). For example, in addition to fundamental architectural principles, these designers need to train skills related to parametric design (Oxman, 2017). Among these skills, some are stable (e.g. mathematics) while some are rapidly evolving (e.g. software-specific knowledge) (Jancart and Stals, 2019), which results in a constantly evolving and non-exhaustive list of educational content (Jabi, 2013; Pottmann et al., 2007; Woodbury, 2010). On the other hand, Woodbury (2010) claims that parametric designers need a 'different' or 'new' kind of knowledge compared to traditional architects. In his book 'Elements of Parametric Design' he explains this knowledge through a thorough list of parametric concepts (e.g. points, vectors, and equations), and the introduction of various knowledge types (e.g. technical knowledge, mathematical knowledge, and geometric knowledge). Accordingly, as a result of the complexity of this new knowledge and the expanding list of information and skills required to practice parametric digital design, effective designs of educational programmes are not necessarily easily developed.

In order to consider the so-called 'New Knowledge' in a broader range of publications, IJAC articles (International Journal of Architectural Computing) published in 2018, 2019, and 2020 (Volume 16 and 17 issues 1-4, and 18 issue 1) were analyzed. As a result, a total of 29 articles were used. In each article, the names of the knowledge types as introduced by authors were highlighted. Next, the number of articles that mentioned knowledge types by the same name were added. For example, when an article mentions a knowledge type once or several times, the count is one. When the next article mentions a knowledge type once or more times, the count is two.

As presented in Figure 1, a total of 41 types of knowledge were mentioned in the articles reviewed. Of these knowledge types, 36 types were not repeated in other articles, three knowledge types were repeated twice (i.e. domain knowledge, domain-specific knowledge, and local knowledge), one type of knowledge was repeated three times (i.e. design knowledge), and one type of knowledge was repeated 4 times (i.e. new knowledge). Based on this study, in research in architectural computing, many knowledge types are considered. However, there is limited consensus on the definition and designation of knowledge types. As a result of this disunity of knowledge type definition, multiple consequences become apparent. For example, by using various definitions, the comparison of research output becomes less efficient. Additionally, without a consensus on knowledge types, a broadly-supported update of traditional pedagogical methods becomes a challenge.

Secondly, as a result of the continuous introduction of new knowledge into parametric design research and education, in this study, the traditional teacher-student relationship (Hooks, 1994, pp. 13-22) is revised. According to Hooks, in this traditional relationship, the teacher is considered as an active knowledgeable participant, and the student as a passive listener. In this context, teaching is one-directional, in which knowledge is transferred from the teacher to the student. Consequently, learning cannot be effective without the presence of a teacher. In parametric design education, this teacher-student relationship is likely to be ineffective. As a result of the continuous change in parametric design tools and procedures, teachers are challenged to keep up with these developments, which pressures the traditional top-down educational approach. So as to address this situation, in this study, aspects from the problem-posing educational model of Freire (Freire and Ramos, 2000) are considered. In this model, the traditional teacher-student relationship is liberated, by introducing a two-directional teaching-learning approach. By dissolving the teacher-student contradiction, both teachers and learners become active participants in the educational context, opening up teaching and learning opportunities for both teacher and student. Therefore, to respond to the request of various scholars (Kotnik, 2010; Oxman, 2008) for the formation of a theoretical framework to introduce digital design (e.g. parametric design) into a pedagogical agenda, three aspects are discussed in this study. Firstly, the knowledge type as referred to as 'New Knowledge' is further elaborated and framed. Secondly, a two-directional learning situation design to construct this type of knowledge is explained, and a preliminary learning situation is designed and developed. Additionally, a learning situation design aiming at this

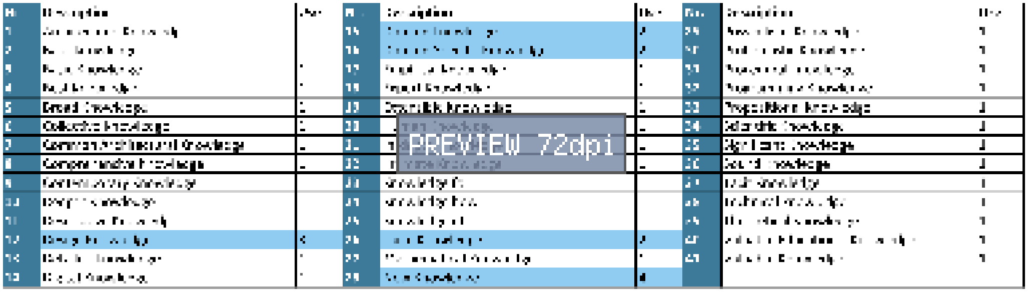


Figure 1
Overview of the recurrence of knowledge types in the 29 IJAC publications selected in 2018, 2019, and 2020.

type of knowledge is tested. Finally, we discuss and conclude our findings.

KNOWLEDGE DIMENSIONS

As discussed in the previous section, knowledge as required in parametric design education and practice is a composite of many. Depending on the field of research, or mode of education, various knowledge types are addressed. Although in research a wide range of knowledge types are introduced (Figure 1), the vast majority of vocabulary used does not directly overlap with frameworks used in lifelong learning (European Commission, 2018), cognition (Anderson, 2015), or pedagogy and didactics (Illeris, 2007; Krathwohl, 2002). This limited overlap suggests that these types are developed independently of these domains, which complicates the development of a shared pedagogical agenda, and the design of effective educational programmes.

With the intention to organize the various knowledge types as used in parametric design education, and define learning outcomes for educational programme design, the knowledge dimension defined by Krathwohl (2002) is used. This dimension is a revision of the taxonomy of Bloom (Bloom, 1984, p. 18), and serves as a widely used framework in pedagogy and learning design (Anderson and Sosniak, 1994). In the revised taxonomy, four categories are distinguished (i.e. factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge). (1.) Factual knowledge consists of the basic aspects a learner must know to become familiar with a discipline. (2.) Conceptual knowledge consists of the interrelationships a learner has formed between the aspects of factual knowledge. (3.) Procedural knowledge consists of methods of how to do something. (4.) Metacognitive knowledge consists of awareness and knowledge of the learner's personal cognition. In this study, factual, conceptual, and procedural knowledge are considered.

In order to frame the three dimensions of the revised taxonomy into parametric design, three learning outcomes are introduced. Firstly, when a parametric design learning programme mainly aims at factual knowledge, the learner can reproduce definitions for aspects like functions, variables, and vectors. Secondly, when a learning programme emphasizes the formation of conceptual knowledge, the learner develops mental models in which aspects like functions, variables, and vectors are interrelated. Finally, in the case of learning programmes that aim at procedural knowledge, learners will, for example, be able to parametrically define a cube. Consequently, once these three dimensions are recognized, learning programmes need to be designed particularly to meet the intended learning outcomes.

In order to consider learning outcomes used in contemporary computational research and education, and to frame the so-called 'New Knowledge' into one of the knowledge dimensions, the number of analyzed IJAC articles is extended with the issues of volume 14 and 15. As a result, based on the issues from 2016 to 2020, five definitions of new knowledge were introduced. The first definition refers to new knowledge in terms of age (Karakiewicz, 2020). In this case, knowledge of recent years is considered. In the second and third definitions, new knowledge is considered to be the result of experimentation. Firstly, Symeonidou (2016) considers new knowledge as a result of knowledge construction and reflection. Based on constructivist learning theories, she states that learners construct knowledge through experience, critical reflection, and experiment replication. Secondly, Trilsbeck and colleagues (2019) consider new knowledge as a result of intervention, disruption, and informed experimentation. In the fourth and fifth articles, new knowledge is formed through a process of mapping. Firstly, Tosello and Bredanini (2017) relate new knowledge to concept development. Secondly, de Vasconselos and Sperling (2017) consider new knowledge as the result of research activity, mapping complexities, network visualization, and the collection and connection of dispersed information. When the second to fourth definitions of new knowledge are framed in the four knowledge dimensions, the second and third inform the educational process more strongly on the mode of learning and the fourth and fifth on the learning outcomes. Nevertheless, all four definitions can be considered in relation to conceptual knowledge. Therefore, in the following section, conceptual knowledge is further elaborated and linked to these studies. Additionally, the ways to form this type of knowledge are introduced and explained.

KNOWLEDGE CONSTRUCTION

As discussed in the previous section, conceptual knowledge consists of a network of relations between factual knowledge aspects. Through these relations, learners organize information into mental models so as to differentiate particular aspects based on their properties (Klausmeier, 1973). For example, when a novice learner in parametric design has formed a mental model of geometry, the student understands that lines, planes, and solids are included, and functions, values, and variables are not. Accordingly, based on particular properties, each learner forms their individual structure of understanding. Furthermore, as introduced by Tosello and Bredanini (2017) and Vasconselos and Sperling (2017) in the previous section, novel experiences are linked to this structure, for the conceptual knowledge to expand, and mapping visualization exercises can be applied to structure and explain. As a result of this individual process, the structure of mental models differs from one designer to the other and varies per stage of development. For example, when the mental models of novice and expert designers are compared, the following distinction can be made. Regarding specialized conceptual knowledge, the mental model of the novice designer is relatively small and rudimentary. Firstly, as a result of the smaller size, novice's mental models have limited coverage in solving specialized design problems. Secondly, because of the rudimentary characteristics, design problems are often more consciously and specifically defined. By specifying the problem situation explicitly, appropriate knowledge can be constructed as a means to solve the problem in a structured manner (Wankat and Oreovicz, 2015, p. 68). Compared to novice designers, expert designers tend to work with larger mental models of a more general character. Provided with a mental model of highly structured concepts, the expert is able to access information associated with the problem more efficiently, and therefore solve design problems more effectively (Simon, 1996, pp. 85-94). In parametric design for example, as a result of efficient knowledge structure, expert designers spend limited time on the parametric model construction and focus on the use of the parametric definition in design problems. Because of the rudimentary knowledge structure of novice designers, generally, a large part of their studio time is spent on the construction of parametric definitions, which leaves them with limited time to use their programs in problem-solving (Gallas et al., 2015). Consequently, as the result of the differences in mental models between novices and experts, different teaching and learning approaches are often favored.

When the new knowledge teaching strategies of Symeonidou (2016) and Trilsbeck and colleagues (2019) are considered, mainly two approaches can be distinguished. The first teaching and learning approach is through experience, disruption, and reflection. In pedagogical research, this approach is often referred to as learning through trial-and-error (Wankat and Oreovicz, 2015, p. 69) or try-it-and-see (Hicks, 2004, p. 2). In this mode of learning, individual conceptual knowledge is formed through design and practice first. Then, the individual knowledge is structured and explicated through critical reflection and experiment replication, to verbalize and align conceptual knowledge. The second learning approach is learning through informed experimentation. In this process, specific tools and strategies used by expert designers are introduced first (Cross, 2011, pp. 3-28). Then, these tools and strategies are applied to design exercises. Both approaches have their opportunities and challenges. For example, the first approach allows the learner to progress at their own pace, using their preferred learning style. As a result, various strategies are formed, and novel approaches are introduced. Nevertheless, individual critical reflection is time-consuming, which makes this approach more feasible for smaller groups. The second approach supports the learner by a framework to structure their design process. Subsequently, all participating learners follow a similar track, which makes learning outcome comparable, and peer learning more efficient. Nevertheless, by aligning the design process, deviations are less likely to happen, which reduces the change of unexpected innovation. The courses addressed in this study are limited in time and include a larger group of students. Therefore, for the preliminary learning situation design, the second approach is emphasized. Although reflection moments are introduced, the design process is set, and choices are restricted. To measure the effectiveness of this design, in the following section, the preliminary learning situation is introduced and tested.

PRELIMINARY LEARNING SITUATION DESIGN

To test the learning approaches as introduced in the previous section, the course "Digital Culture and Generative Processes of Form" is used. This course is a part (2ECTS) of the Master Program of the Faculty of Architecture (ULiège, Belgium), and aims to develop formal and material research. The main assignment of the project was to design and develop a lamp. For this course, a framework to structure the student's design process is defined. Accordingly, learners followed a similar pathway, which makes the learning outcomes comparable, and facilitates peer learning. The course covered in this study was delivered over a 6 weeks period at a rate of 4 hours a week. The group of participants was composed of 21 students in pairs.

For the preliminary learning situation design, a methodology to teach and evaluate conceptual understanding is proposed. In this learning design, firstly a spatial model for parametric design is submitted by the student. Next, multiple parametric concepts are introduced to support the development of this model into a physically built design. Accordingly, the effectiveness of the learning design is measured by the improved conceptual understanding between the initial and the finalized model. For this preliminary test, visual observation, and student report analysis are used.

In order to introduce a two-directional teaching-learning approach, in the Preliminary Learning Situation for Model-Centered Parametric Design Education (PLMP) as presented in Figure 2, the design process is centered on physical models or form-studies. By using physical models, a medium is introduced that allows two-directional teaching and learning without dependency on digital specifics of coding and algorithm creation. As a result, the PLMP distinguishes the following seven phases.

1. Form Study Model: In the first phase, a model or form-study is provided in which the learner introduces their ambitions. The model is not meant for presentation but states ambitions in terms of geometry.

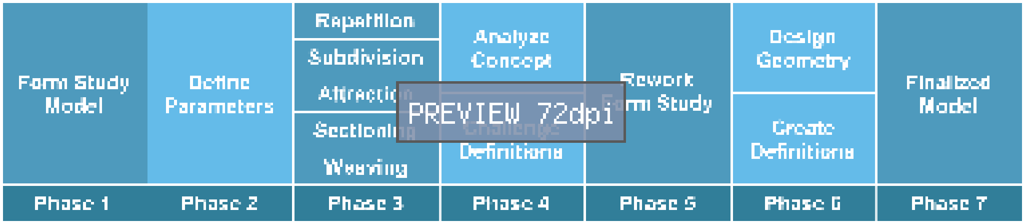


Figure 2
Preliminary Learning Situation Design for Model-Centred Parametric Design Education (PLMP)

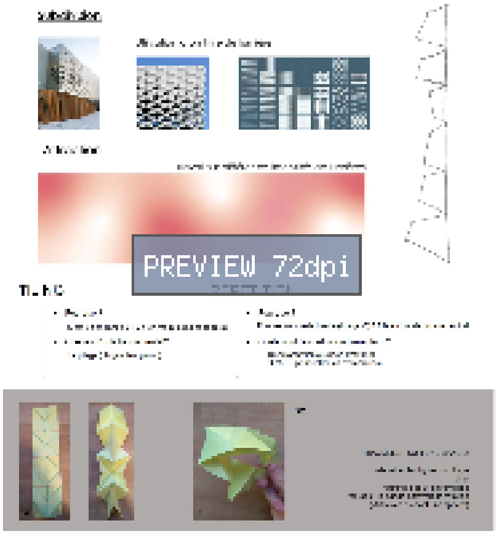
2. Parameter Definition: In the second phase, the model is analyzed in conversation with mentors and peers. As a result of this analysis, definition and enumeration of parameters to be considered are highlighted.
3. Parametric Concepts: In the third phase, the parameters as highlighted in phase 2 are reflected to a selection of five parametric concepts (i.e. Repetition, Subdivision, Attraction, Sectioning, and Weaving) as used by Jabi (2013). Then, these concepts are discussed, altered, and extended when needed. Finally, one concept is chosen by each group of students for further review.
4. Concept Analysis: In the fourth phase, parametric concept as chosen in phase 3 is studied and reviewed. Firstly, a small report is made to introduce the concept theoretically. Next, existing codes and definitions are collected and applied to simple geometries resembling the intended model.
5. Rework Model: In the fifth phase, the parametric concepts are defined, and opportunities and challenges are explored. Next, the initial physical model or form study is reworked. The purpose of this model is like phase 1 (i.e. communication of the geometrical ambitions). However, in this phase, the ambitions are refined, and novel insights are introduced.
6. Parametric Design: In the sixth phase, a digital geometry is created based on the parametric concepts and ambitions as studied in phases 4 and 5.
7. Final Model: In the seventh phase, a presentation model is produced using the digital geometry of phase 6. This model is made using CAD-CAM technologies such as laser-cutting, 3D printing, or milling. When the step from phase 6 to 7 is not easily completed as the result of the complexity of the model used, phase 5 and 6 are repeated to introduce intermediate models.

To illustrate each phase of the PLMP, the course "Digital Culture and Generative Processes of Form" is used. During each phase learning outcome and research observation are introduced.

During the first phase (i.e. form study model), the students were requested to look for references and ideas for the lamp design through web research, form-study, and sketching (Figure 3). At this point in the curriculum, the students are comfortable with this process. Since the students have limited experience with the parametric concepts as used, the students are encouraged to explore subjective interests through loose constraints. During this phase, we experienced no significant bias related to their digital ability. Due to this lack of experience, the students show having a hard time explaining exactly what they want to achieve, which required some degree of flexibility in the process.

Figure 3 "Form Study Model", example of two groups' research and presentation of ambitions.

Figure 5 "Concept Analysis", Example of two groups refocusing their form research according to Jabi's concepts through testing and further research.



During the second phase (i.e. parameter definition), parametric software was practiced. As a result, the learner formed an understanding of various concepts involved in parametric design. Based on this understanding, the students' conceptual knowledge improved, which enabled them to define the parameters to consider in their research and design. As presented in Figure 4L, with the development of the students' experience, their parametric design intentions became more specific.

During the third phase (i.e. parametric concepts), the students are introduced to five of Jabi's "parametric concepts". Regardless of their previous research and design intentions, the students are requested to pick one of the concepts and refocus their work. To support this shift of focus and avoid a stressful situation, the tutors ensured that the students' design intentions were kept ambiguous during the previous phases. By framing their designs, the students was motivated to reconsider their ambitions and define subsequent steps.

During the fourth phase (i.e. concept analysis), based on the constraint as introduced in phase 3, references from previous phases are refined, and models are tested through existing codes and definitions (Figure 4L). Based on their improved conceptual knowledge, the students show a capacity to solve design problems that occur, and visibly connect the aspects as introduced in the previous phases.

During the fifth phase (i.e. rework model), a contained trial-and-error approach is introduced. As presented in Figure 4R, the chosen parametric concept has been studied and tested, and the students have acquired sufficient experience to improve their design through an iterative process of experience, disruption, and evaluation. At this stage, each group works at its own pace and produces as many design iterations as requested for the design.

During the sixth phase (i.e. parametric design), the students reflect on the results of the previous phases and refine their model. As presented in Figure 6L, the final model must be described geometrically through each phase of the algorithm and show appropriate parametric flexibility.

For the seventh phase (i.e. final model), the students are requested to produce a physical output from the models as made during the sixth phase (Figure 6R). This phase serves to evaluate mainly two aspects. Firstly, the student is requested to present their control over the design as a whole, and secondly, the flexibility of the parametric model to adapt to the fabrication constraints. The latter is set by the tools and materials provided by the fablab the department partnered with for this project.

CONCLUSIONS AND FUTURE PROSPECTS

Over the past decades, various scholars have indicated that the development of new digital design tools requires a new kind of knowledge. However, a review of scientific literature shows the confusion of vocabulary when defining this knowledge, and therefore the difficulty to construct a relevant and common pedagogical program. In that regard, this study presents a preliminary learning situation for parametric design within the framework of a master's course in architecture. The suggested and tested methodology is based on the notion of conceptual knowledge. In order to integrate this notion, the design process is structured into seven phases.

Considering the experience of the authors in giving this course through a two-direction teaching-learning method, this suggested learning situation design proved effective based on the following preliminary findings of. Firstly, by using form-study and physical models as a primary medium, both teacher and student could communicate effectively, without being restricted by digital challenges. Secondly, during each phase of the design process, the learner visibly improved regarding specificity and understanding of parametric conceptual involved. With each phase of the preliminary learning situation design, the student was able to converge specify their design ambitions more specifically. Finally, the successful production of the lamps shows that the sequencing allows the students a coherent design by understanding the concept.

The preliminary learning situation presented will evolve based on the feedback from this conference. For future work, we suggest a complementary approach that could be integrated in order to (un)confirm our preliminary results and thus assess the learning curve of students with a more quantitative method. In order to test the learning effectiveness of the PLMP, we refer to a study by John Hattie (2012). This study contains a set of meta-analyses of many research articles and ranks teaching-learning approaches based on effect size. In our case, we suggest using pre- post-testing using quizzes as a measurement instrument.

REFERENCES

Anderson, JR 2015, *Cognitive psychology and its implications*, Worth Publishers, New York

European Commission, European Commission and Generaldirektion Beschäftigung, SuI 2018, *The European Qualifications Framework supporting learning, work and cross-border mobility: 10th anniversary*, European Commission

Cross, N 2011, *Design Thinking: Understanding How Designers Think and Work*, Bloomsbury Academic

Freire, P and Ramos, MB 2000, *Pedagogy of the Oppressed: 30th Anniversary Edition*, Continuum, New York

Gallas, MA, Jacquot, K, Jancart, S and Delvaux, F 2015 'Parametric Modeling: An Advanced Design Process for Architectural Education', *Real Time - Proceedings of the 33rd eCAADe Conference*, Vienna, Austria, p. 9

Hattie, J 2012, *Visible Learning for Teachers: Maximizing Impact on Learning*, Routledge, London ; New York

Hicks, MJ 2004, *Problem Solving and Decision Making*, Cengage Learning EMEA, London

Hooks, B 1994, *Teaching to Transgress: Education as the Practice of Freedom*, Routledge, New York

Illeris, K 2007, *How we learn: learning and non-learning in school and beyond*, Routledge, London ; New York

Jabi, W 2013, *Parametric Design for Architecture*, Laurence King Publishing, London

Jancart, S and Stals, A 2019 'A pedagogical introduction to parametric modeling as a formal research tool', *DeMset - Design and Modeling in Science, Education, and Technology*, Orlando, USA, p. 5

Karakiewicz, J 2020, 'Design is real, complex, inclusive, emergent and evil', *International Journal of Architectural Computing*, 18(1), pp. 5-19

Klausmeier, HJ 1973 'Overview of a Model of Conceptual Learning and Development.', *Annual Convention of the American Psychological Association*, Montreal,Canada

Kotnik, T 2010, 'Digital Architectural Design as Explo-

ration of Computable Functions', *International Journal of Architectural Computing*, 8(1), pp. 1-16
Krathwohl, DR 2002, 'A revision of Bloom's taxonomy: An overview', *Theory into practice*, 41(4), pp. 212-218
Oxman, R 2008, 'Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium', *Design Studies*, 29(2), pp. 99-120
Oxman, R 2017, 'Thinking difference: Theories and models of parametric design thinking', *Design Studies*, 52, pp. 4-39
Oxman, R and Gu, N 2015 'Theories and Models of Parametric Design Thinking', *Real Time - Proceedings of the 33rd eCAADe Conference*, Vienna, Austria, p. 6
Pottmann, H, Asperl, A, Hofer, M and Kilian, A 2007, *Architectural Geometry*, Bentley Institute Press, Exton, Pa
Simon, HA 1996, *The Sciences of the Artificial - 3rd Edition*, The MIT Press
Symeonidou, I 2016, 'Flexible matter: A real-time shape exploration employing analogue and digital form-finding of tensile structures', *International Journal of Architectural Computing*, 14(4), pp. 322-332
Tosello, ME and Bredanini, MG 2017, 'A personal space in the Web. Bases, processes and evaluation of a collaborative digital design experience for significant learning', *International Journal of Architectural Computing*, 15(3), pp. 230-245
Trilsbeck, M, Gardner, N, Fabbri, A, Haeusler, MH, Zavoleas, Y and Page, M 2019, 'Meeting in the middle: Hybrid clay three-dimensional fabrication processes for bio-reef structures', *International Journal of Architectural Computing*, 17(2), pp. 148-165
Varinlioglu, G, Basarir, L, Genca, O and Vaizoglu, Z 2017 'Challenges in Raising Digital Awareness in Architectural Curriculum', *Computer-Aided Architectural Design. Future Trajectories*, pp. 136-150
de Vasconselos, TB and Sperling, D 2017, 'From representational to parametric and algorithmic interactions: A panorama of Digital Architectural Design teaching in Latin America', *International Journal of Architectural Computing*, 15(3), pp. 215-229
Wankat, PC and Oreovicz, FS (eds) 2015, *Teaching Engineering, Second Edition*, Purdue University Press, West Lafayette, Indiana
Woodbury, R 2010, *Elements of Parametric Design*, Routledge, London ; New York, NY

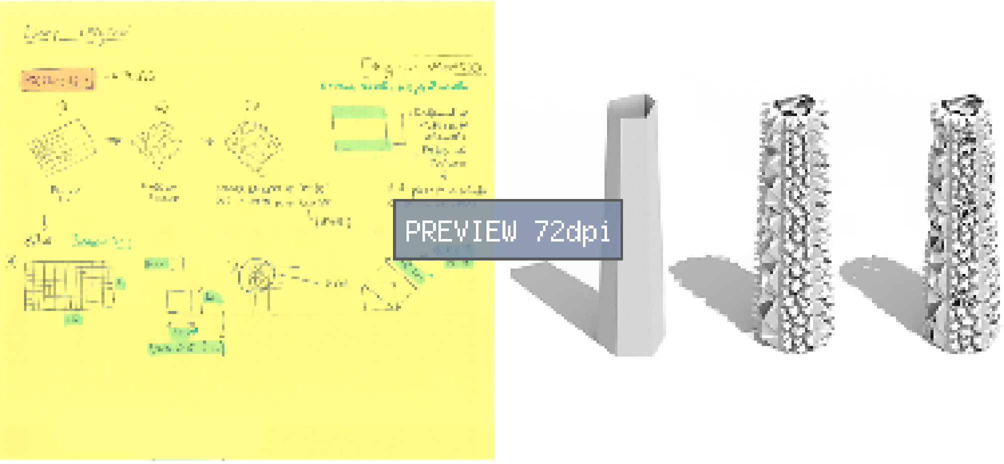


Figure 4
(L) "Parameter Definition", an example of a group of students starting to reflect on parameters. (R) Example of the "rework model" phase.

Figure 6
(L) Examples of phases of algorithm. (R) Some results of the "Final Model" phase, here as physical outputs.