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An Experimental Framework for Designing a Parametric Design Course

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Abstract

Architectural forms, architectural knowledge, design process, and design thinking are all changing with the use of computer-aided design programmes, and even traditional university architecture departments now wish to teach these programmes. However, it can be difficult to implement courses on such computer programmes because these departments have traditionally structured curricula. We developed a framework that can inform the design of a parametric design course which considers the university profile, the course profile, and the student profile. This framework evaluates the departments in three categories: 'open to new design approaches', 'supportive of CAD' and 'reject new design approaches'. A parametric design course in relation to the proposed framework was designed and implemented as a case study. The process and the results were discussed.

Keywords

Parametric Design, Design Education, Design Process, Architecture Curriculum.

Introduction

Change in architectural forms, architectural knowledge, design processes, and design thinking has occurred due to the use of various computer-aided design (CAD) tools in the architectural world. These changes are also reflected in architectural education. Especially in graduate programmes, expansions are being made and new methods are being tested. In particular, teaching methodologies for parametric design are being researched all over the world since there is a growing demand for computer programming logic in the field. At the undergraduate level, such knowledge is equally needed; however, it is still a challenge for both students and teachers to incorporate it into undergrad programmes, which are still rather more structured and traditional. For this reason, a framework is needed for designing parametric design courses. The framework is proposed to support the challenge of incorporating parametric design tools on programmes of study. The framework supports course instructor to build a parametric design teaching methodology by articulating the conditions or characteristics of individual programmes.

Paradigm Shift

In order to create a framework that can inform the design of a parametric design course, it is necessary to first examine the change caused by the effect of computer aided design tools on the architecture world. We can classify these changes as form-based change, change in architectural knowledge, change in design process, and change in design thinking. It is important to consider these changes which are reflected to a certain extent in parametric design education, depending on the scope of the course.

Complex geometries have begun to be created with the rapid development of computer-aided design tools. With today's tools, it is possible to not only create but also revise and refine these complex forms without the necessity of remodelling many sub-parts (Burry, 1999; Woodburry, 2010; Jabi, 2013). With developing technologies, such as 3D printers and robots, complex and unique forms can now be produced. The interest of architects naturally shifts to these complex forms. This, in turn, pushes research toward the development of new construction techniques and the search for new materials with which architects can extend these complex forms and satisfy their aesthetic understanding and vision (Kolarevic, 2003). The increased use of various design tools has also changed architecture as a discipline. New ideas also begin to emerge as novel conceptual structures arise in the field (Oxman, 2008). This suggests that architectural knowledge can change periodically.

The design process is becoming more holistic with the use of emerging technologies. New technologies allow designers to make more than one design decision in the early stages of design (e.g. using optimisation tools). For example, decisions about fabrication and the use of materials are now made at the beginning of the design process (Menges, 2008; Hensel and Menges, 2008; Hensel et al., 2011). This situation in turn increases interdisciplinary interaction and makes collaborative work more important, as the range of the parameters considered can increase and thus different fields may be included.

Unlike CAD tools, parametric design tools allow for the iterative process which is essential in sketching and designing. The parametric design tools do allow this type of process, showing a similarity between the pre-computer cognitive model of design thinking (Oxman, 2017). In the era of design with paper and pencil, the designer used conceptualization, modification and refinement (Cross, 1982; Cross, 2011), in addition to observation and visual documentation (Schon, 1983, Schon, 1987, Schon, 1988). They always employed iterative processes in the sketching process (Schon and Wiggins, 1992; Goel, 1995; Do et al., 2001; Suwa and Tversky, 2002, Goldschmidt and Smolkov, 2006), which is essential to developing design ideas, as design thinking is not a linear but a non-linear or 'ill-structured' process (Bhooshan, 2017). In addition, due to the re-editing feature of parametric design tools, surprises occur in the design process just as they do in manual design. Schon (1983) discusses the concept of 'surprise' in his creative design theory, which takes the designer away from the routine process and thus gives originality to the design project (Dorst and Cross, 2001). Early CAD tools do not allow such iterative processes, because they do not have re-editing features. A case study comparing CAD tools with manual sketching, conducted by Veisz et al. (2012), found that conceptual design requires a more human-centred process. This is probably because it is easy to make iterative movements with manual sketching.

Parametric Design Teaching Methodologies

The change of paradigms in the architectural world has affected architectural education, as noted above. Due to the emergence of computer-aided design tools and fabrication systems, the need to integrate digital design into architectural design education is becoming increasingly great. Today, graduate as well as undergraduate architecture programmes in many architectural schools are beginning to encourage an intensive use of computer-aided design tools.

Various parametric design teaching methodologies have been tried by researchers. For example, Headley (2013) and Lordanova et. al. (2009) conducted studies that integrated parametric design systems into the design studio in an undergraduate architecture programme. The study by Lima et. al (2020) included the use of shape grammars and parametric tools in the design studio. Schnabel (2013) implemented an integrated design studio method titled as a parametric design studio course, because he thought that the integration of digital media into design studio curricula prevented deep exploration in design. Nakapan and Onsuwan (2018) proposed a parametric design studio within the scope of a vertical studio. Agirbas (2018) used metaphors as the basis for a parametric design teaching methodology in an elective course.

For undergraduate design education, Aish and Hanna (2017) considered that different parametric design tools might have different effects on the parametric design thinking, compared three different parametric design tools (GenerativeComponents, Grasshopper and Dynamo) in terms of cognitive dimensions. This assessment can inform programmes development from a new user's perspective as well as programme choice by undergraduates based on which one they feel closest to in terms of both cognition (and thus in principle can use most productively) and the nature of the task at hand.

It should also be noted that, in general, many studies have explored the relationship between computer tools and design education. Many researchers have searched for cognitive effects of the computational approach on the design process in the educational context in order to model it within design theory (Oxman, 1999; Cuff, 2001; Knight and Stiny, 2001; Oxman, 2008; Oxman, 2017). Studies have also been carried out on students' attitude towards the use of computers in the design process (Hanna and Barber, 2001; Basa and Senyapili, 2005; Pektas and Erkip, 2006).

As Oxman (2008) said, 'Digital design theory has transformed the concept of form into the concept of formation'. Digital formation models are becoming conceptualization tools. The formation process becomes more interesting than the idea, and ambiguous effects can occur in this process (Zaero-Polo, 2001). Parametric design tools reveal topological variations in concepts, and different form configurations are associated with different parameter values. In addition, as mentioned above, in the process of using parametric design tools, the cognitive model of design thinking with its iterative process, advanced through conceptualization, modification, and refinement (Cross, 1982; Cross, 2011) or through observation and visual documentation (Schon, 1983; Schon, 1987, Schon, 1988), emerges as similar to the paper-based design process and different from CAD.

Most new experimental methods are usually implemented in the design studio. However, in many architectural schools around the world, design studios employ more traditional methods in architectural undergraduate education. The reasons could include unwillingness to change, inadequate knowledge of students by teachers for more innovative methods to be effectively applied, or the fact that people completing undergraduate programmes are often designated architects, with signoff authority on projects, so that directors of architecture programmes prefer to make sure more technical information is instilled, for safety and for the graduates' basic professional effectiveness. However, in some architectural undergraduate programmes, despite the traditional orientation, courses in computer-aided design tools have been added at students' demand, and better practice around the teaching of those tools is thus already needed.

As exemplified above, many parametric design teaching methods have been tried. However, to date, no studies suggesting a framework that can inform the design of a parametric design course exist in the literature. Such a proposal could be a guide for applying the parametric design teaching methodology, especially for traditional architecture departments.

A Framework for Designing a Parametric Design Course

In parametric design teaching, characteristics such as university profile, student profile, and course type should be considered when preparing a teaching methodology and/or design process scheme. In other words, parametric design teaching methodologies will vary according to these conditions. In this section, a framework that can inform the design of a parametric design course for an undergraduate architecture department is suggested (see Figure 1).

Considering the university profile, student profile, and course type helps the instructor create more accurate teaching methodology. Because there can be departments, student profiles or course profiles at many different levels.

Characteristics

Department profile. First of all, we should consider the curriculum of the undergraduate architecture department at the university where the programme will be implemented. The answers to the following questions should be sought in the curriculum. A key to the answers of these questions is provided in Table 1.

Are there courses that teach computer-aided design programmes? If so, the architecture department is to some degree open to helping its students learn computer-aided design programmes. Most architectural departments now seem to be open to computer-aided design programmes for reasons of accreditation and student demand.

If so, are these courses compulsory or elective? If it is a compulsory course, the architecture department is likely more supportive of learning computer-aided design programmes.

What computer-aided design programmes are taught in these compulsory or elective courses? In particular, are general programmes (such as AutoCAD) taught, or are the programmes (e.g. programmes that have script editors) that are taught more recent or lesser known ones? If the latter, the department is seemingly more open to new technology and new design approaches; if the former, it may be more traditional.

How many hours per week are these lessons? Especially where the teaching of computer-aided design programmes is not accompanied by a design studio course, more weekly hours and containing practices may show the importance the department ascribes to training in computer-aided design programmes.

Is there a difference between weekly hours of classes that teach different computer-aided design programmes? In particular, do the courses that contain content in regard to teaching programmes with script editors have fewer weekly hours than other CAD courses? For example, if both a CAD programme (like AutoCAD) and a parametric design programme are taught in the architecture department, but the CAD programme is taught for 4 hours and the parametric design programme for 2, the department of architecture seems to have given more importance to the teaching of the CAD program.

Are computer-aided design tools taught within the scope of the design studio? There is no clear-cut opinion as to whether computer-aided design tools are better taught within the design studio. However, the design studio course's hours and credits are usually higher than other courses. Considering this, integrating the tools into the design studio indicates that the department may find it important to teach with these tools. It is especially important to encourage the use of tools simultaneously during a specific project. For example, if this occurs in a design studio environment, there will be enough time for the student to learn and apply these tools, while simultaneously generating their own script for the direction of the project. In contrast, if learning is conducted in a separate lesson outside of a design studio, the process will be more difficult.

Does the design studio tutor comprehend the logic of computer-aided design tools? Can the design studio tutor use computer-aided design tools, or do they have an assistant who can? Evidently, such a tutor will better orient the design process in relation to the logic of the tools and ideally is experienced using them first-hand.

In the design studio, are alternatives to traditional methods tried? Testing alternative methods shows that the department is aware that computer-aided design tools change paradigms in the architectural world and intends to contribute to the understanding of effective practice in architectural education.

Table 1. Key to finding answers to the questions

Question	**Where to find the answer**
Are there courses that teach computer-aided design programmes?	Course list
If so, are these courses compulsory or elective?	Course list
What computer-aided design programmes are taught in these compulsory or elective courses? In particular, are general programmes (such as AutoCAD) taught, or are the programmes (e.g. programmes that have script editors) that are taught more recent or lesser known ones?	Course list Syllabus
How many hours per week are these lessons?	Course list
Is there a difference between weekly hours of classes that teach different computer-aided design programmes? In particular, do the courses that contain content in regard to teaching programmes with script editors have fewer weekly hours than other CAD courses?	Course list Syllabus
Are computer-aided design tools taught within the scope of the design studio?	Syllabus
Does the design studio tutor comprehend the logic of computer-aided design tools? Can the design studio tutor use computer-aided design tools, or do they have an assistant who can?	Background of the lecturers
In the design studio, are alternatives to traditional methods tried?	Syllabus

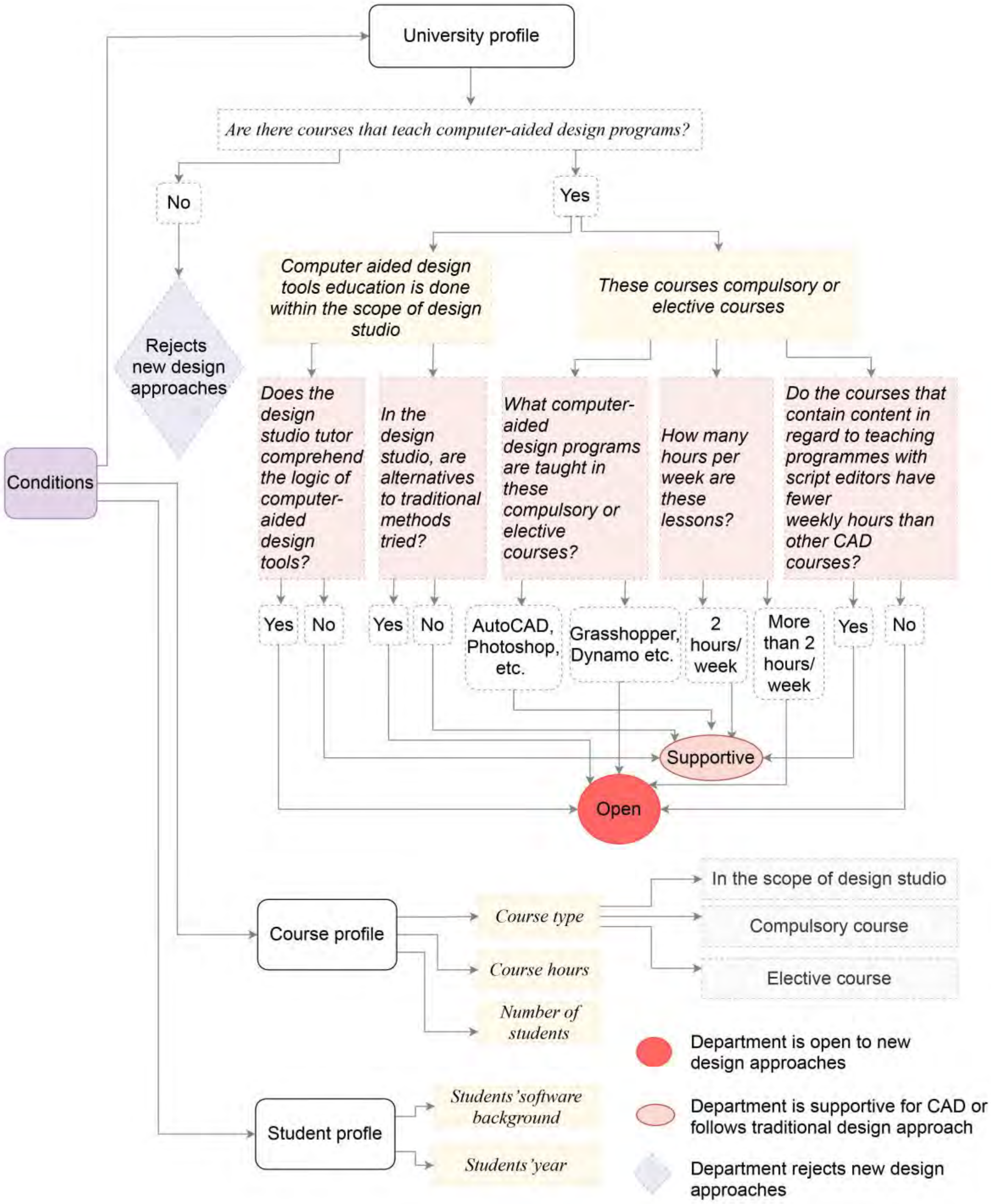

Figure 1. The proposed framework that will help programme designers

Course profile. It is necessary to do applied work for parametric design education in undergraduate architecture education. In carrying out this applied work, the following factors are important: course type, course hours, and number of students.

Course type: Whether parametric design tools are to be taught in a compulsory course, an elective course, or the design studio in architectural undergraduate education is an important criterion in determining the methodology to be followed. If parametric design tools are taught in the design studio, many alternative methods can be tried, whereas if it is taught in a compulsory course or elective course, it is difficult to make the application work because opportunities for application are lacking, though sometimes teaching can be split between these contexts, allowing applied work. In addition, students may put more effort into their compulsory courses in comparison to their elective ones. This is because students are required to repeat compulsory courses upon failure, which may lead to the loss of a semester.

Course hours: If the hours of a compulsory course or elective course dedicated to parametric design tools are sufficient, applied work can be done independent from the architectural design studio course. If course hours are limited, in contrast, this will be difficult. This is because, in this limited time period, the student is expected to develop a new project from scratch in order to perform the applied work.

Number of students: Another criterion is how many students are in the course, because it is difficult to do applied work in a class with many students. However, to combat this issue, group studies can be considered.

Student profile. In determining the methodology to be followed, it is useful to know what computer-aided design tools students can use and how many years students have studied architecture. Thus, the scope and method of teaching to be given can be determined more easily.

Students' software background: If students have prior knowledge of programming (e.g. the programmes with script editors that have re-editing features), the methodology to be followed will be different.

Students' year: The students' academic year in architectural education (e.g., first year, third year) can partially act as a proxy for their level of design knowledge and thus help determine the level of design work students will be asked to do.

Based on the answers to these questions, a computer-aided design tutor will comprehend the general orientation of the department toward computer-aided design. The template recognises three types of viewpoints in this regard: the department is open to new design approaches, it is supportive of CAD while following traditional design approaches, and it rejects new design approaches (Figure 1). New experimental methods can be applied for the departments in the 'Open' category. In the 'Supportive' category, based on the traditional teaching approaches infrastructure, new digital media can be included in the process and various studies can be performed.

Case study

To begin, the architecture department where the case study will be conducted has been analyzed according to Figure 1 and its characteristics determined. This study has been conducted in the department of architecture at Fatih Sultan Mehmet Vakif University. As discussed in detail below, the department falls into the 'supportive' category. A method for parametric design teaching was determined based upon these characteristics.

Student productions are included in this study. However, it is not discussed whether the parametric design teaching method applied here is a suitable method in parametric design education. To validate this, separate tests are needed.

Characteristics

When the university's curriculum, in which parametric design teaching is included, is examined, it is seen that some courses in computer-aided design education are compulsory and some are elective: Photoshop, AutoCAD and Revit are taught in the former, and 3Ds Max, ArchiCAD, Maya, Rhino and Grasshopper in the latter. The compulsory Revit course is 4 hours weekly, while the elective courses are 2 hours.

One of the answers to the question in the proposed framework (Question: Is there a difference between weekly hours of classes that teach different computer-aided design programs? In particular, do the courses that contain content in regard to teaching programs with script editors have fewer weekly hours than other CAD courses?) has been released as supportive. Therefore, this department was evaluated as supportive category.

Furthermore, it seems that in this department, computer-aided design education is given outside the architectural design studio, which itself is completely traditionally handled. Students' computational knowledge, learned in compulsory or elective courses in computer-aided design, is introduced into the studio only through their own initiative. However, studio instructors and their assistants support the use of computer-aided design tools. In this department, although the laser cutter is widely used in the studio, use of the 3D printer is very rare.

The department offers an elective course called 'Introduction to Parametric Design' on the programmes Rhino and Grasshopper. It is 2 hours a week. Consequently, the students have limited time to complete the work. The semester consists of 14 weeks. The course can be taken by students at any level. The section considered here had 15 students.

The students may have experience with 3D modelling programmes but do not have experience using parametric design tools based on a visual programming language. The method used to help the students understand the design-thinking logic of Grasshopper is explained below.

Methodology

After reviewing the characteristics, the methodology of the case study has been determined. Considering the university profile, course profile, and student profile, a methodology was determined as detailed below (Figure 2, Figure 3).

Since the students, who take the course covering parametric design education, do not have scripting knowledge, VPL (visual programming language) is first taught as a lecture. 3D modelling in Rhino and visual programming language basics (Grasshopper) are taught. Because the course has a limited time (two hours elective course), ready-made scripts are used. Later, in the traditional design studio context, the basic aim is to teach students the four changes (form-based change, change in architectural knowledge, change in design process, and change in design thinking) discussed in the paradigm shift section (Figure 2).

Students have general knowledge about traditional design methods since they learn these methods in the architectural design studio. It was thought best to find ways to utilise this basic knowledge of the students. Thus, a fully alternative approach to learning was avoided, and students used parametric design tools in close adherence to the logic of the design principles taught in the studio, focused on form creation (Figure 2). Conceptualization, modification and refinement, which are widely used in traditional design studio training, have been included in the process by playing with the script. At the same time, students have experienced the digital sketching process by observing changes on the basis of form through script configurations. With the form formation model, the goal is that students gain knowledge on form-based change and on change in architectural knowledge. In this strategy, students are required to eliminate the issues such as performative, structural, or sustainability issues in the limited period of time of the course. Therefore, the students focused on form formation only. This allowed the students to modify the ready-made script, that is, to make changes by playing with various parameters in the script at the form formation basis.

Students learn primarily the use of ready-made scripts according to the purpose, to understand the flow of the script in general, change the slider parameters according to the design, and if necessary, include other components to the script. With this learning style, the student can create and modify more comprehensive or complex forms in a shorter time. Therefore, the student can understand what parametric design tools will be useful in a real sense. In addition, while creating forms, the student can understand the relationship between the variations of the object and the script in different configurations and can refine the form with the slider parameters by observing it and therefore, can experience a design process related to the form. At this stage, the goal is for students try to establish a relationship between VPL and sketching and to gain knowledge about changes in design thinking.

Throughout the learning period, the student must be able to obtain information about what parametric design is and what will benefit from it. Otherwise, students at the undergraduate level may cease to continue learning the program, as they find they cannot test geometrical productions at a certain level of complexity with the program; especially in the early years of undergraduate education, learning the production of a few basic geometrical objects in the visual programming language is not enough to really see what parametric design tools can do. Therefore, design work that is performed with parametric design tools needs to reach a certain level of complexity in order for its value to become apparent. This factor should be included in the teaching methodology. In order to be able to see clearly what the parametric design tools can do, students need to create a design product, as noted; therefore, although time was limited, applied work was decided on.

Nowadays, since decisions about the choice of fabrication method and choice of materials are taken from the beginning of the design process, it was thought to be necessary in our course that digital fabrication should also be included in the design process. That is, at a certain stage of the formation process, students were directed to think about the form they had created in relation to the fabrication process. In this way, the aim was to provide students with information about change in the design process.

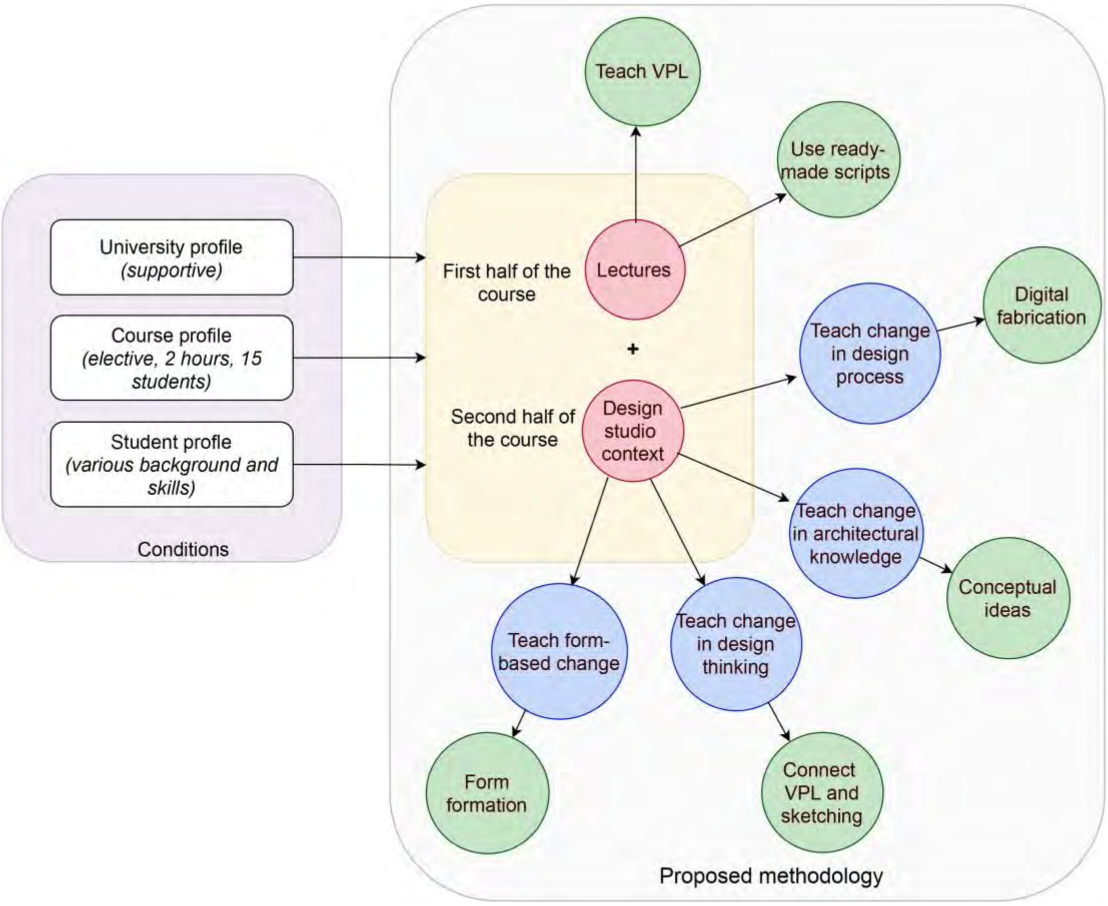

Figure 2. Proposed methodology for parametric design teaching in an architecture department in the 'supportive' category.

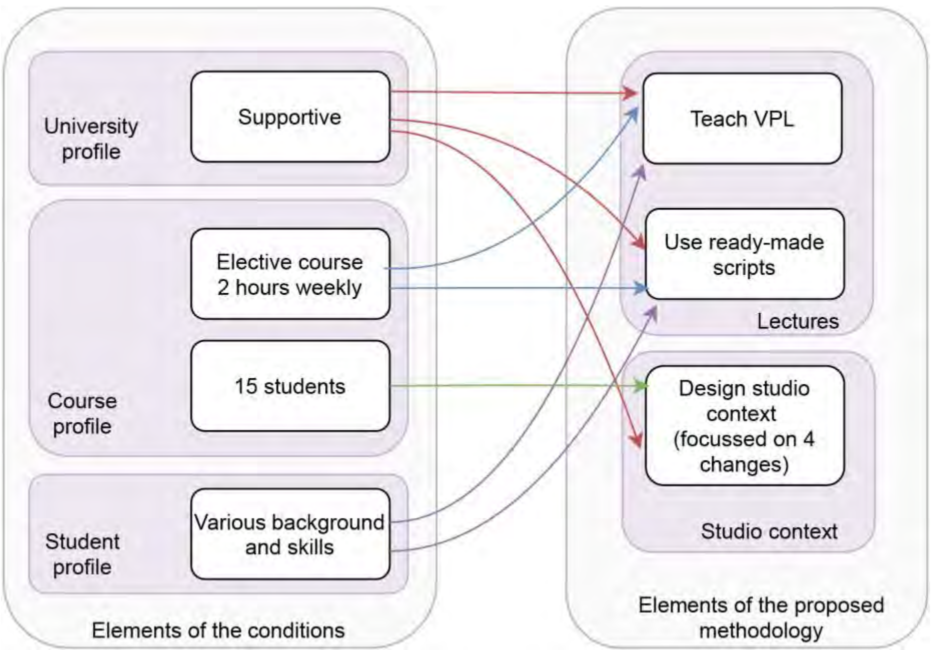

Figure 3. Proposed teaching methodology according to the conditions

Course Outcomes

The students came up with ideas from very large to small scale in their designs; for example, while some of them were designing skyscrapers (Figure 4, Figure 5), others preferred lamp design (Figure 6). Apart from this, there were no significant differences in the design quality of students' designs.

Each student first parametrically modified the given script (i.e. the ready-made Grasshopper code) by changing the sliders, which covered parameters such as width, length, and curvilinearity.

With the Morph component in the script, each student tested the placement of different units on the surfaces. Work related to the formation of different textures and bringing the different units together took place widely across the design process. For example, design experiments using different units can be seen in Figure 4 and Figure 5 (respectively).

Some students developed designs by combining the forms that they could produce using the script. For example, in Figure 7, the form was generated three times with the script, and the design was developed considering the three forms together, although they are independent from each other in the context of the script.

Although some students were not asked to set a relationship with the built environment, it was observed that they attempted to relate their forms to the built environment that they either chose or designed by themselves. For example, in Figure 8, the student preferred to place his form against an Egyptian pyramids visual, and established a metaphorical relationship in doing this. In Figure 9, the student preferred to model his bridge design to match its surroundings. Again, in Figure 5, the student preferred to contextualise his skyscraper design by placing other skyscrapers around it. It should be noted that, in their previous traditional architectural design studio course studies, the students had tried to relate their designs to the built environment.

It has been aimed to teach VPL in the lecture part of the teaching methodology. As observed in the form creation process, the students were able to play with the script and modify the script in a certain extent. When we consider the design process and evaluate the final products, it is seen that this methodology enabled students to understand the capacity of parametric design tools in a limited period of time.

In the design studio section of the course, we observed that students understood form-based change, change in architectural knowledge, change in design process, and change in design thinking to a certain extent. Students engaged in visual reasoning and often revised the parametric form. In this way, they were able to gain understanding of design thinking change in contemporary architecture. To better connect the changes in form-based knowledge to developments in the contemporary architectural world, the students focused on complex form production. Thus, the students were made more knowledgeable about changes in the basis of real architectural knowledge. Digital fabrication and material issues were included with instruction on the formation process, to help students understand changes in the design process.

In the experimental methodology followed in this study, students were meant to be able to apply their already acquired knowledge. At the end of the study, it was seen that students did employ the traditional design studio techniques that they had learned before. For example, they followed an iterative form revision process, usually applying this technique at the beginning of the paper-based design process using the forms that they created with parametric design tools.

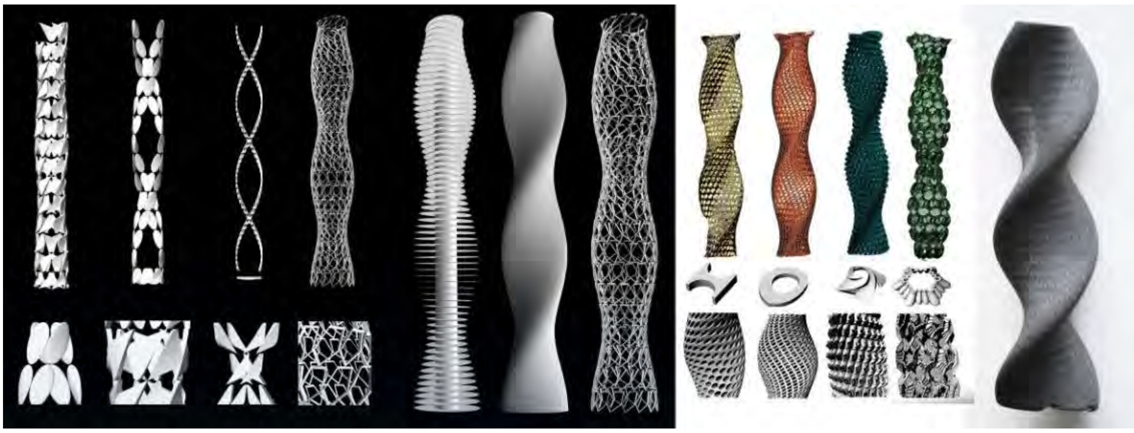

Figure 4. Student work (a skyscraper design study and its 3D print).

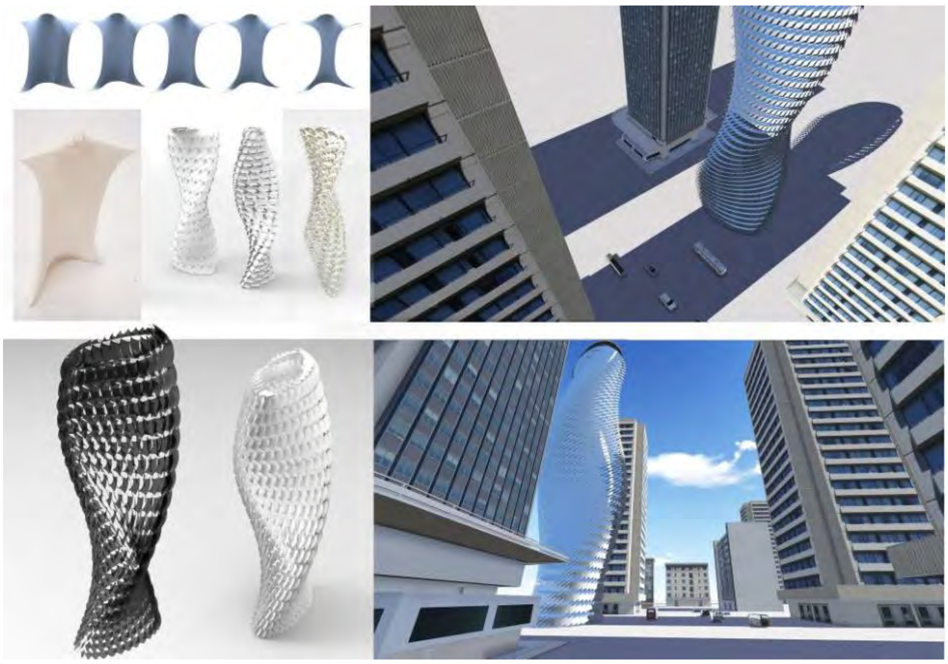

Figure 5. Student work (a skyscraper design study and its 3D print).

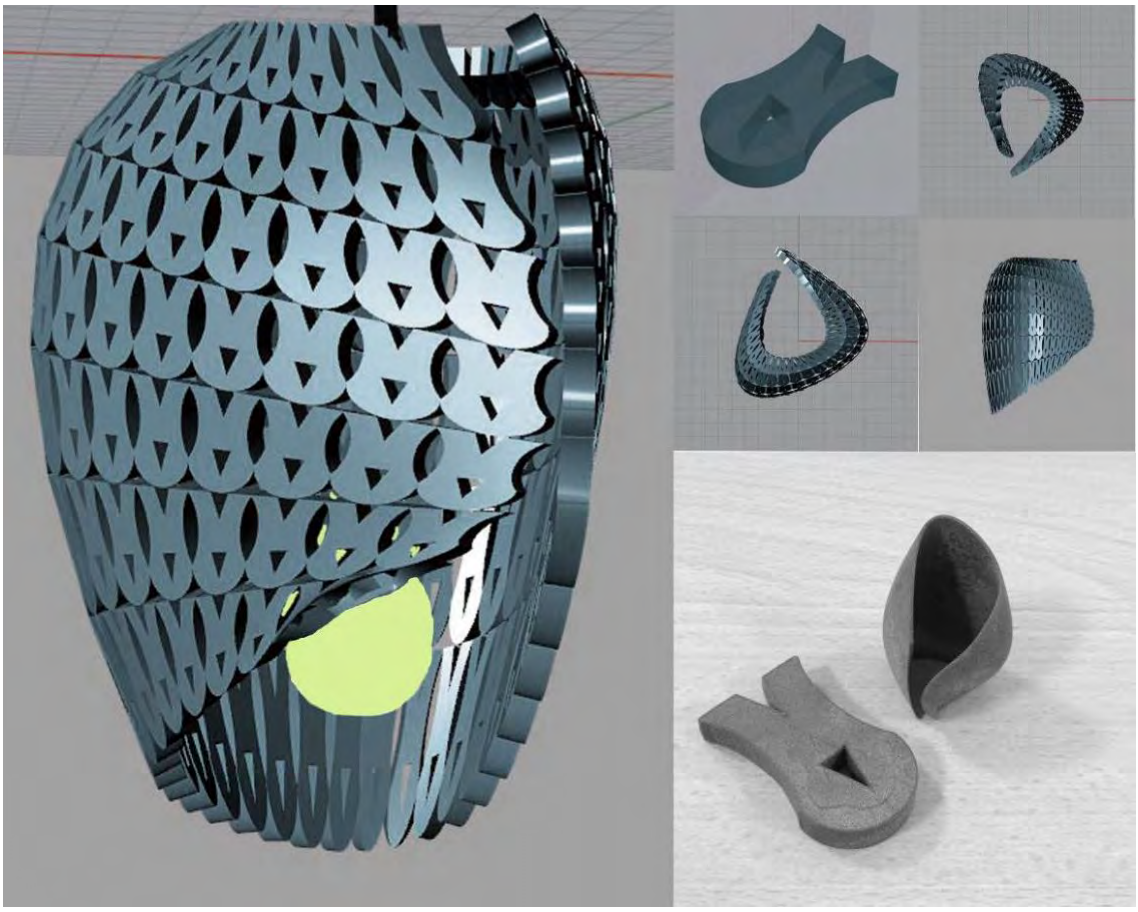

Figure 6. Student work (a lamp design study and its 3D print).

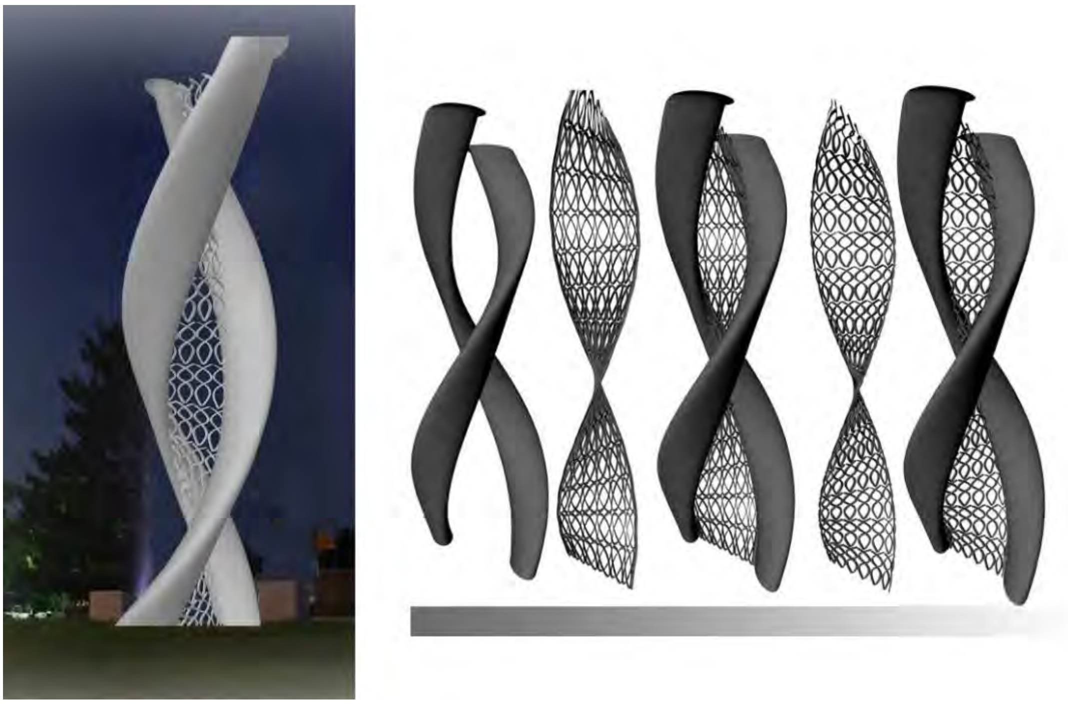

Figure 7. Student work (a memorial design study).

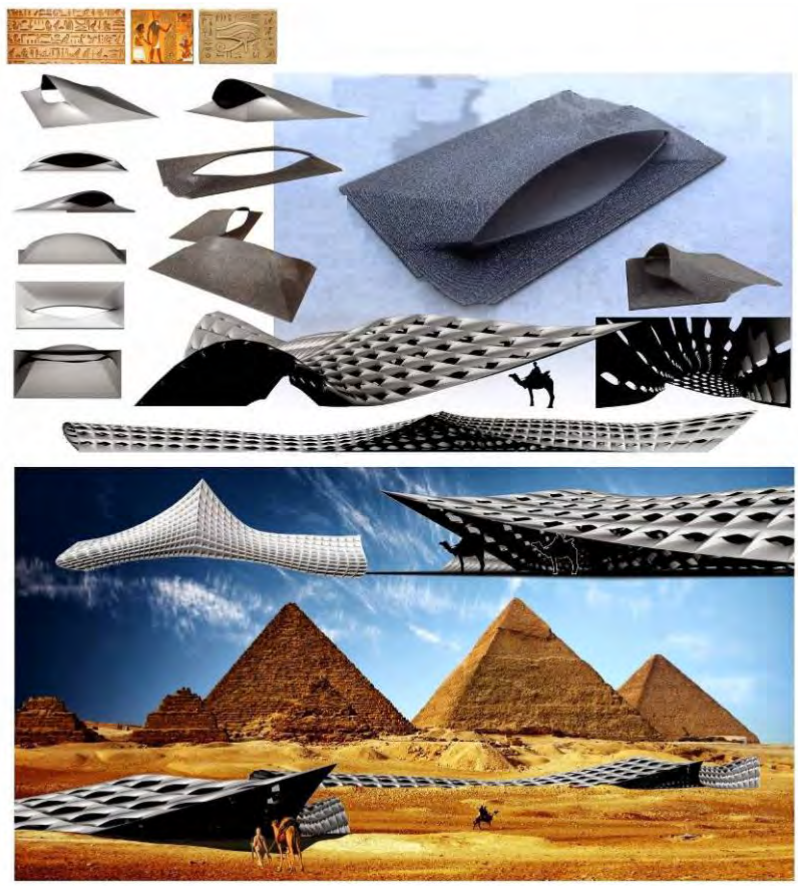

Figure 8. Student work (a science centre design study and its 3D print).

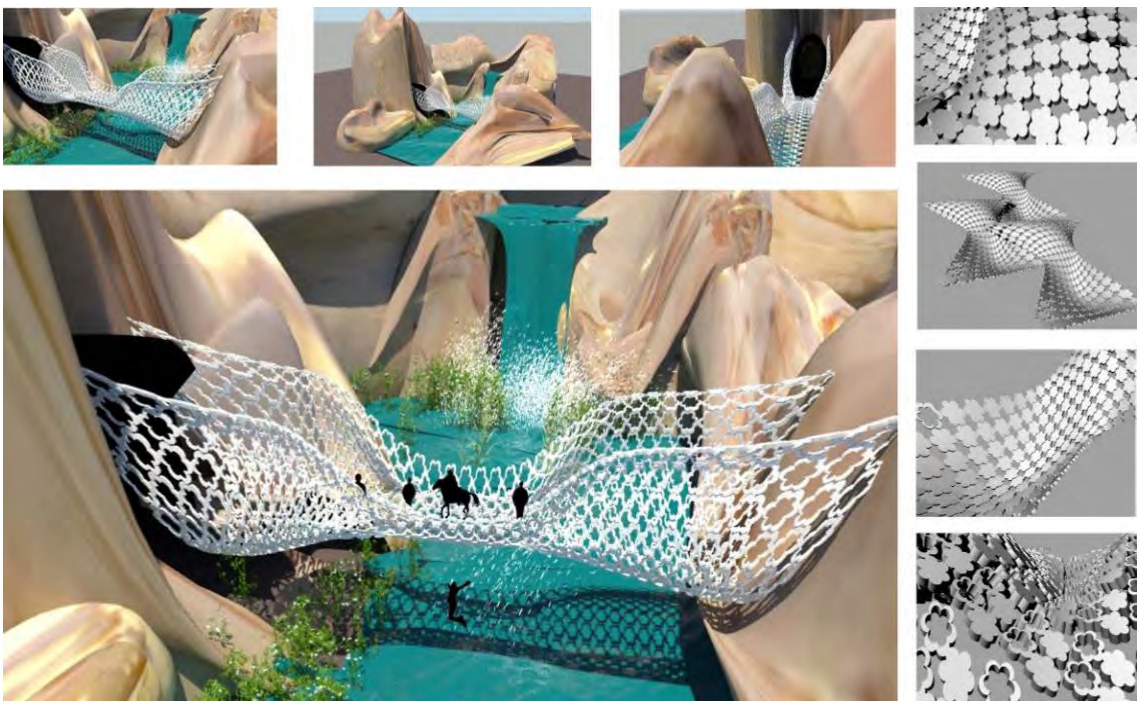

Figure 9. Student work (a bridge design study).

Conclusion

Digital design tools are constantly developing and becoming more complex. Therefore, it is necessary to educate the new generation of architects to use these tools. However, there are many different types of architecture departments. Before developing a parametric design teaching methodology, the characteristics of the different types of departments must be identified and the appropriate solutions determined. In this study, we developed a framework that can inform the design of a parametric design course, which considers the university profile, course profile, and student profile.

Within the scope of this study, it is suggested that the university profile, course profile and student profile should be considered when developing a framework for designing a parametric design. However, this method can be extended by adding other parameters.

The type of course in which parametric design education will be given is important in determining the instructional methodology, as parametric design education integrated into design studios and parametric design education given within compulsory or elective courses, will be very different. The parametric design instructor's understanding of and attention to the student profile, in particular their technical knowledge and their cognitive model of the design process, will also influence teaching methodology decisions. Once these conditions are known, decisions can be made about which method will be applied to parametric design teaching. For all these reasons, parametric design education methodology may vary greatly among schools.

A case study was also conducted in this study. Before starting the experimental work in this study, the conditions of the site undergraduate architecture department (university profile, course profile, student profile), where the teaching of parametric design tools was delivered, were examined. As a result, it was seen that the architecture department was open to the use of computer-aided design tools but was teaching architecture using traditional methods. According to our proposed framework, this department fell under the category of 'supportive'. Under these conditions, for teaching of parametric design programmes, a methodology was developed and applied in an elective course, in a limited timeframe. The evaluation of the success of the method discussed in the case study requires further and independent study.

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