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The Use of Metaphors as a Parametric Design Teaching Model: A Case Study

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Abstract

Teaching methodologies for parametric design are being researched all over the world, since there is a growing demand for computer programming logic and its fabrication process in architectural education. The computer programming courses in architectural education are usually done in a very short period of time, and so students have no chance to create their own designs. This paper describes a course in which metaphors are used as a teaching methodology in parametric design, in order to let students create their own designs and learn the basic elements of parametric programming language in a short period of time with deductive reasoning. In this course, it was intended to teach visual programming language to undergraduates. Advancing under the metaphor theoretical framework, the students obtained experience in achieving form-finding process for their projects in accord with the certain constraints. Using this methodology, the students, who experienced all design stages from 3D modeling to the digital fabrication, additionally were able to develop their ability for versatile thinking and the use of more than one tool in combination, in the early years of their architectural education.

Key words

metaphors; Parametric Design; Form-finding; Teaching Model; Architectural Education.

Introduction

When parametric design is referred to, two perspectives come to mind in architecture, as was noted by Stavric and Marina (2011). One of these is the architectural constructive parametric design, and the other is the architectural conceptual parametric design. In architectural constructive parametric design, focus is made upon the forms, which are easier to produce in real life, and the work is carried out using pre-drawn 3D objects: BIM programs (such as Revit and ArchiCAD) are used for this purpose. In the architectural conceptual parametric design, the creation of complex forms, which are difficult to produce in reality, is focused on and generally the Rhino and Maya programs, which have script editors, are used (Stavric and Marina, 2011). The experimental work in this article has been made on architectural conceptual parametric design.

Kolarevic (2003) states that ‘architects have always looked beyond the boundaries of their discipline, appropriating materials, methods and processes from other industries as needed'. Parametric operations which are based on a computer programming language, concern the modification of the declared values of constraints and parameters without transformation in the geometry or topology and the relations between them (Woodburry, 2010). This operation helps architects to generate a set of forms which are mostly complex in nature, curvilinear surfaces and non-Euclidean geometry that are difficult to manage via conventional methods (Burry, 2003; Lee et al., 2014). This type of complex form production with hand drawing or with an ordinary 3D modeling program is difficult since much effort and time are required. In addition, the lower levels of the model are required for each of the changes to be made in the main model; however, the parametric design program is itself able to make these changes, rather than it being necessary for the designer to do it (Burry, 1999; Jabi, 2013).

Since standardised forms with Euclidean geometry were easy to produce and the machines available were capable of creating many of them in a short period time, these forms emerged in many parts of the world following the industrial revolution. However, this progress brought a contrast approach that includes the use of avant-garde forms in architecture with non-Euclidean geometry. Today, such new types of fabrication tools as 3D printing and robotics have made the non-Euclidean geometries possible to produce, such that the demand for designing avant-garde forms has increased (Agirbas, 2015). Although the production of these forms has increased to the present day, some methods associated with the production of such form before the industrial revolution are also used. In the time before the computers were widely used in architecture, different experimental procedures were used in research on non-Euclidean geometry. For example, Gaudi (1852-1926), Isler (1926-2009), Otto (1925-2015) and Musmeci (1926-1981) carried out form-finding studies by examining self-formation processes in nature. These forms, which were found by making physical models, rather than drawings, were attempted to transfer to the architecture (Tedeschi, 2014). Pugnale (2014) goes further back in time, and states that the oldest form-finding method is 'the reverse hanging method' which is used to create shells, vaults and arches.

Today, it is obvious that types of computer software are employed directly in the designing process of non-Euclidean geometries. One approach to working with these types of geometries is to use various kinds of parametric architecture software as a tool which lets us to create a set of forms. However, there is no specific methodology available for their application to architecture and architectural education. Therefore, we have attempted to use metaphors in designing avant-garde forms with parametric architecture tools.

The Use of Metaphors in Architectural Design

Lakoff and Johnson (2003) claim that one of the aspects of imagination is seeing something in terms of another thing, and metaphorical thinking is understanding and experiencing one kind of thing in terms of another. Our perceptions can be differentiated by metaphors which alter our sense of reality. In other words, reality undergoes phases of metamorphosis through metaphors (Ricoeur, 1991; Schon, 1993; Lakoff, 1993). There is a constant use of metaphors in architectural design (Di Palma, 2006; Casakin, 2011; Goldschmidt and Sever, 2011; Caballero, 2013): thus, in the metamorphosis process of architectural design, the designer activates knowledge obtained previously, and in the light of this knowledge, establishes connections within the mind. In his late formulation of hermeneutics, Ricoeur (1988) explained this situation as being our negotiation between the *space of experience* and the *horizon of expectation*. Historical narratives uncover our *space of experience*, while fictional narratives relate to our *horizon of expectation* (Perez-Gomez, 1999). This process generally occurs via a holistic approach, in which the individual elements are created from the whole.

The use of metaphors in the architectural design process can be observed throughout history, and may vary across different periods of time. Dictums, technology, symbols, nature, biology and many other factors can be used as metaphors in the design process. For example, the dictum of the Modern Movement in architecture 'form follows function', (which means that the internal use of a building gives rise to the external appearance of the building), influenced a whole generation of architects (Colquhoun, 2002). As Casakin (2007) has noted, Frank Lloyd Wright is the best known architect who used this dictum as a metaphor in most of his works, e.g. the Robie House at Chicago, the Fricke House, the William Martin House, the Oscar Balch House, and the Unity Temple. He characterized his works with ‘additive simple volumes interlocking with relative freedom to each other in accordance to functional needs’. In addition, Mies van der Rohe's memorable metaphor 'less is more' brought a minimalistic approach to architecture during that same period of time (Casakin, 2007).

For a long time, architects used nature as a source of inspiration, and incorporated natural forms as metaphors in their buildings. As Knippers and Speck (2012) noted, ‘architects transferred the variety of natural shape and form directly into their work alternated with those of strict geometrical order’. For example, Buckminster Fuller used nature as a model for such inventions as the geodesic dome. Another example is the Notre-Dame du Haut Chapel building of Le Corbusier, which was built in 1954. Although the design of the chapel began with the idea of a crab, a viewer might interpret the building in terms of many other different forms, and there is no unique form that might be ascribed to it. This is the most important feature of a metaphor and it is this which differentiates it from an analogy. Similarly, we can see this in the Lyon-Satolas Station, which was designed by Calatrava (Tzonis and Lefaivre, 1995; Casakin, 2006), using the metaphor of a bird; in the Turning Torso building, which was designed by using the human body as a metaphor; in the Heinz-Galinski School building, designed by Zvi Hecker, using a sunflower as a metaphor (Oxman, 2002; Caballero, 2013); and in the Dancing House, designed by Frank Gehry, using the metaphor of dance.

In contemporary architecture, the working principles of nature are taken as metaphors for generative design practices. As noted by Janssen and others (2000), ‘evolutionary programs use biological evolution in nature as a source of inspiration, rather than a phenomenon to be accurately modelled’. Generative design techniques (Singh and Gu, 2012), such as Genetic Algorithms (Holland, 1992) (inspired by the natural evolutionary process and often used for optimization to find the most appropriate solution), L-systems (Lindenmayer, 1968) (reflecting the characteristics of biological growth by generating fractal-like forms with self-similarity) and the Swarm Intelligence (Camazine, 1991; Bonabeau et al., 1999) agent-based model (Reynolds, 1987; Dorigo et.al., 2000; Jacob and Von Mammen, 2007) (based on the social or collective behaviours in nature) use the formations in nature as metaphors.

Methodological Procedures

As observed by Oxman (2008), the digital architectural design era changed the paper-based traditional architectural design education model and led to a search for new methodologies for design education. CAD (computer-aided design) models were an imitation of the paper-based design model in terms of principles, theories and methods. Today, however, new softwares are still being developed and participate directly in the designing process. We have therefore attempted to use these new softwares with a methodology that aims to use metaphors to advance the progress of parametric design.

Parametric design, which enables the creation of non-Euclidean geometric forms, is a subject much in demand for the instruction of architecture students. Therefore, the parametric design course was held at the architecture faculty of the university. It is useful to discuss the teaching methodology of this course, which is based on the use of metaphors in parametric design, where, despite limited time, the students were able to complete fine projects in a collaborative working environment.

The present research work began with the question: "How can effective teaching of parametric design tools be done in a limited period of time?" Since the best way of learning about the computer aided design tools is to actually undertake application-oriented work, it was found appropriate to carry out an application task within the course with a chosen methodology. The other research question in this study was, "Is it possible to use metaphor in a methodological way within the system of parametric design education, which can guide the student in the design process?" The course on teaching the use of parametric design tools in the architecture department is in the “elective” category. The elective course occupies 2 hours a week during a 14 week long semester (this work was done in Spring 2017). This elective course is open to both students in the later period of their architectural education, or to architecture students in their earlier educational phase. However, in the present study, which involved 17 students, most of the students were in the 3rd or 4th years of their undergraduate education. During this study, one to one discussions with students about their designs were done for each course. The conclusions of this study are based on inferences about the process of using computer-aided design tools by students, and about the process of script development, and also inferences about the effect of metaphor on the design process, which were drawn from the observations and discussions in one to one meetings by the author. In addition, inferences about the use of metaphor in parametric design education were drawn from the author's evaluation of the students` final design products in the context of a parametric design-metaphor.

In contemporary architecture, architects are increasingly adopting non-Euclidean geometry as a means to achieve forms of differing type. Hence, the boundaries of the technology are defined, and new developments are enabled, such that architects are able to satisfy their aesthetic understanding, enforce the limits in production, and experience the opportunity to work with different materials (Kolarevic, 2003). However, although the computer programs, which allow us to create non-Euclidean geometric forms, are very effective, the creation of such forms with a high aesthetic value is very difficult unless specific restrictive elements are present, during the form-finding process. The creation of these aesthetic forms is normally particularly difficult for architecture students. For those form-finding studies, which do not have a particular restriction or do not advance via a specific methodological framework, the results are generally achieved in the form of a gum. Such gum type forms are those which lack aesthetic satisfaction due to an absence of certain characteristics. Therefore, the identification of metaphor as a restrictive element in form-finding studies in this course, helps students to redirect their attention to production of the forms.

In those undergraduate elective courses which employ computer-aided design, the biggest problem that the students generally find is the practical implementation of classroom theory to an actual project. This is due to the fact that the classroom teaching is done outside of the architectural design studios, and there is little time to learn how to integrate the two aspects. However, the most efficient way of learning in architecture is to implement a project on the basis of which was learned in class. In this way, students learn to consolidate their knowledge from the course and how to use this in the architectural design process. Therefore, in the limited hours of the elective course given by the author, an experimental study on the production of the projects was carried out. In this way, the students were able to experience the coding in parametric design and all the processes, beginning with a virtual model, up to the digital fabrication stage. This systematic progression was achieved by means of the theoretical framework of the use of metaphor in architectural design.

Although most of the students were familiar with the use of some softwares before the course, they had no experience of Rhinoceros and Grasshopper which were the main softwares that were used in the course. The basics of Rhinoceros, which was used as the base for parametric design platform with Grasshopper, was explained in a series of lectures. Since most of the students had previously experienced other 3D modeling environments like SketchUp or 3DsMax, it was easy for them to assimilate the basics of Rhinoceros.

Afterwards, we covered the basics of parametric design and the use of Grasshopper. The students who had no experience with this type of visual programming language, were naturally anxious. Lectures on Grasshopper scripts were given, and despite the fact that the students were initially concerned about the new working environment, they began to enjoy using the program when they saw the outcomes of the scripts. For the work, which the students will carry out within the scope of this lesson, a base script was written in the class by the instructor, who explained the details of the operation of the script to them. In this script, an ellipse is created and this is arrayed on the Z-axis. This ellipse set, formed along the Z-axis, is rotated according to the range parameter, to determine the proportional rotation of each ellipse in the ellipse set. Later, the Loft command is added to the script, which creates a surface that surrounds the ellipse set, which is rotated. The resulting surface is transformed into 3 dimensions, and divided both vertically and horizontally. Finally, the Morph command, which permits the assignment of an object according to each unit in the divided surface, is added to the script. Hence, an object with any form produced in Rhino can easily be added to these units. With the script, the added object can be shaped according to the different forms of the units in the created surface (Figure 1). After the students had performed the operation of this script, they began to play with the script by changing sliders and adding different components. At this point, they were actually in the form-finding phase and started to make digital sketches.

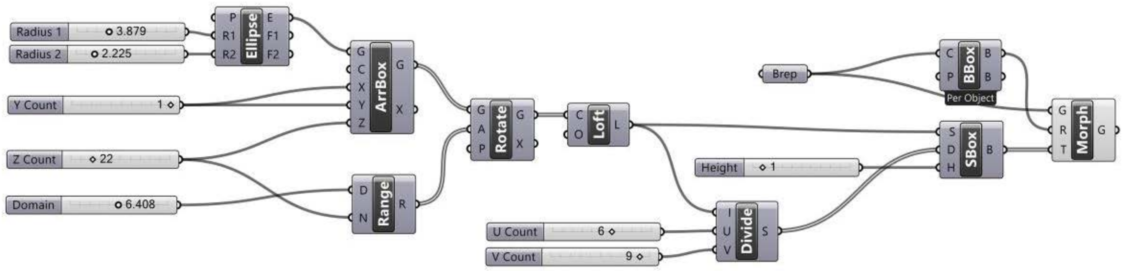


Figure 4. A script developed for the students to use as a base model in their designs

Meanwhile, presentations were made to the students in connection with metaphors, which were chosen to relate to their use in architecture. Projects designed by architects such as Frank Gehry, Santiago Calatrava and Zvi Hecker were shown to students, who were then asked to interpret them. The students likened the projects to various different objects, and by means of these different interpretations, the use of metaphor was focused on as the initial step from which to achieve different designs rather than to determine the exact forms.

The students determined the particular design issues for their own designs. After they decided what to design, they were asked to find a metaphor for their form of design, and continue to design on an architectural scale. At this stage, the use of metaphors in the designing process had been started. This process allows students to manage the form-finding progress more efficiently. The methodology worked quite well and the students continued to work in an interactive environment.

In order for them to undertake the design process, the students were informed in advance about the necessity of them knowing details of the digital fabrication machines to be used during the digital fabrication. This enabled the students to make 3D models that were compatible with the 3D printer. As Kolarevic (2008) said: ‘knowing the production capabilities and availability of particular digitally-driven fabrication equipment enables designers to design specifically for the capabilities of those machines.’ The students were also told how long it would take to achieve the digital fabrication, thus enabling them to make adequate time management regarding digital fabrication process.

Results

Some of the products made by the students during the course are shown in Figures 2-7. In Figure 2, the student took a snake as a metaphor which helped him in the form-finding process of his design, while thinking and observing the morphology, skin and positioning of the creature according to its environment. In Figure 3, the student took the body movements of Sufi-whirling (which is a physically active meditation method), as a metaphor for his minaret design, and thought about the shapes that the body movements make. He also added an octagonal star which is known as a Seljuk star, as a symbolic metaphor to his minaret design. In Figure 4, the student considered flames as a metaphor for her design. After modeling the form of flames, she started to aggregate the prototypes together in order to create a multi-function port. In Figure 5, the student took Chidori toys as a metaphor, and developed the idea on an architectural scale using the parametric design tools. He created non-standard spaces, as inspired by Chidori toys, which are actually in Euclidean geometries. The student took the DNA helix as a metaphor in order to create a bridge, as shown in Figure 6, and another student took erythrocyte as a metaphor in order to create a façade of a skyscraper as shown in Figure 7.

The students were at liberty to design any type of building and to use any metaphors for their forms of designs. Some of them used a metaphor for each unit of the gridally divided surface (Figure 4, Figure 5,Figure 7), while some of them used metaphors for the geometry of the entire form (Figure 2, Figure 3, Figure 4, Figure 5,Figure 6). One of the students used a particular metaphor for the general form of his design and a related but different metaphor for each unit of the surfaces (Figure 3). As can be seen from the figures, the metaphors that they selected were inspiring sources for the designs rather than just copying the forms of them.

In the form-finding process, the relationship between the configurations of the script and the created forms began to be understood more clearly. Hence, the students gradually started to connect what they saw on the screen, with the related parts in the script that they wished to refine, and therefore either changed some of the parameters in the script, or added new components. For example, in Figure 2, the student wanted to fit the form onto a curved landscape in a harmonious manner. Accordingly, he wanted to use a 2D surface instead of the cylindrical surface created from the ellipses in the first script. For this, he retained the partitioning part of the first script with its Morph components, but instead of a cylindrical surface being created by the ellipses, he generated a new surface with the help of the curves. Thus, by refining the script he could experience parametric design thinking (Oxman, 2017). Similarly, in Figures 5 and 9, the students wanted to duplicate a holistic single object that could be produced by the first script, and to achieve this, they could make copy-based additions to the script.

The designer advances his design using conceptualization, modification, refinement (Cross, 1982; Cross, 2006; Cross, 2011), or with observation and visual documentation (Schon, 1983, Schon, 1987, Schon, 1988), during the phase dominated by the use of paper-based tools. However, the cognitive model of design thinking using iterative processes became non-applicable in the period that was dominated by the first use of CAD tools, because they did not have a re-editing feature (Oxman, 2017). Currently, with the use of non-algorithmic modeling tools, particularly, the example of digital sketch is achieved in a given period of time in the design process. However, after a certain period of time has been occupied by the design process, re-editing becomes very difficult and thus design thinking related to the iterative process becomes impossible. Therefore, such modeling tools are now generally used only for presentation purposes. On the other hand, algorithmic modeling tools are seen to be included increasingly in design processes. Thus, as this study shows, by means of parametric design models, the designer can provide reconfiguration, re-editing and modification according to his individual mode of thinking (Oxman, 2017). Hence, there appears to be a similarity between the first cognitive model of design thinking (Cross, 1982; Schon, 1983), which emerged during the use of paper-based tools, and the design thinking of the period that is characterized by the use of algorithmic-based digital tools.

During the design for digital fabrication, the students were careful to prepare their 3D models in a suitable form for 3D printing (watertight). However, the tissue of the forms, which some of the students produced, became quite complex, and it was found simpler to neglect the tissue type in order to avoid spending a long time over making it compatible with a 3D printing (Figure 8). Such knowledge obtained during the early years of their undergraduate education will urge the students to consider the relationship of their complex forms with 3D print in the earlier design-stages for future projects. Other students attempted to make the 3D print in different pieces for the digital fabrication stage (Figure 9), according to the scale of the print, which could be accommodated by the 3D printer. Accordingly, the students were able to learn to develop their design in with the context of the capacity of the machine, which they used to create the actual, final object.

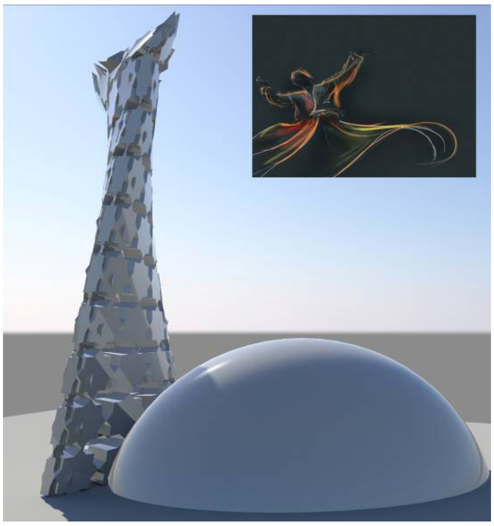
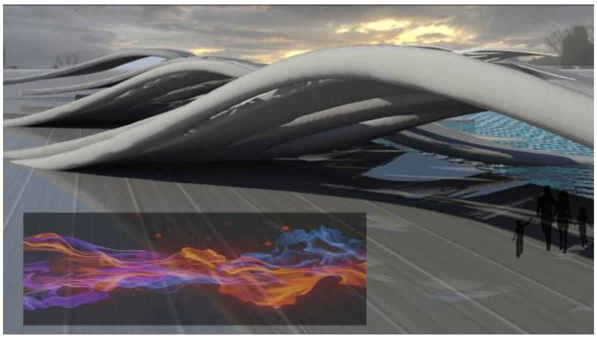


Figure 5. Use of nature/biology as a metaphor (Work of a student)

Figure 6. Use of a symbol as a metaphor (Work of a student)



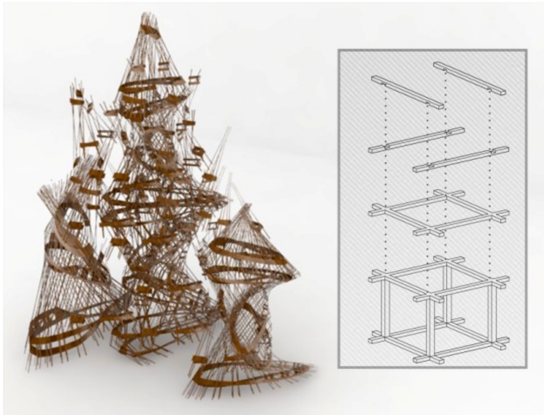
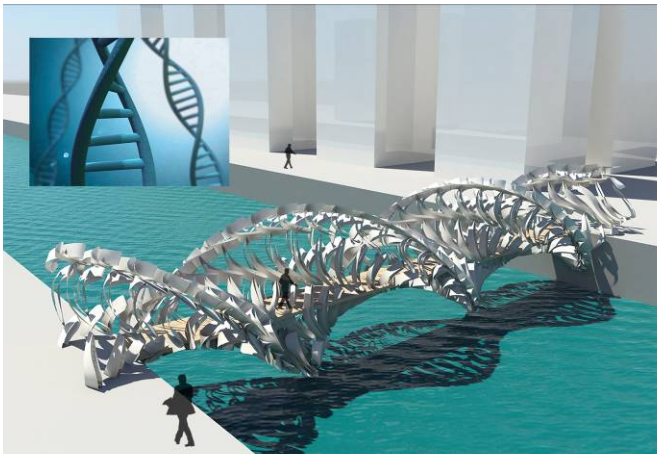


Figure 7. Use of nature as a metaphor (Work of a student)

Figure 8. Use of a symbol as a metaphor (Work of a student)



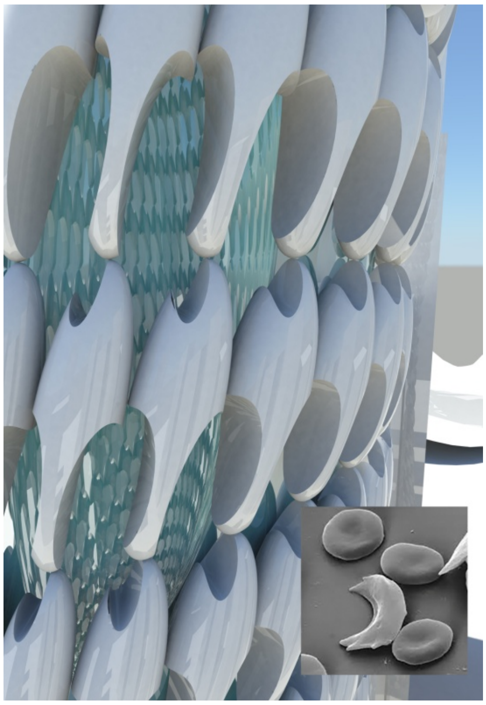


Figure 9. Use of nature/biology as a metaphor (Work of a student)

Figure 10. Use of nature/biology as a metaphor (Work of a student)

Figure 11. The work of a student and its 3D print.

Figure 12. The work of a student and its 3D print.

Conclusion

The advent of the digital era changed the paper-based tradition in architecture and design, and accordingly, the nature of design education has also changed, with the use of many computer-aided design tools being included in the design process. Parametric design tools, which are based on visual programming languages, recently became popular, and are now a feature of many undergraduate education programs. Hence, the use of these tools has increasingly influenced the design process. Therefore, although the present case study was made specifically in the field of architecture, its inferences on both the design process and design thinking, as related to the use of parametric design tools, will also be of interest to other fields of design.

The students found metaphors that can lead to the development of their designs on an architectural scale. In this way (by placing the course under the metaphor theoretical framework), the students developed their projects at the form-finding stage, using certain constraints and at the same time, were able to learned the visual programming language, which was the purpose of this elective course. Parametric design provided them with many forming options that they could choose one from; however, the use of metaphor methodology led them to limit the parameters. Since they focused on the shape or the concept of their metaphors, they started to neglect some of the parameters that are offered by parametric design tools. Also, the use of metaphors in the parametric architectural design process allowed them to control avant-garde forms easily since the forms have no limitations, in contrast to those with Euclidean geometries.

The students learned versatile thinking and how to use different tools in combination, since they experienced simultaneously the use of codes, to prepare 3D models that are compatible with digital fabrication, material based thinking and how to undertake effective time management. These are all important aspects of the use of the technology that is widely used in contemporary architecture. It is this rapidly developing technology which offers many different alternatives to architects, who may choose it for use in accordance with the intended design (such as materials, machinery, software) and to use selected different tools together. Therefore, it is important that students are able to experience the benefits of using a combination of different tools during their education, prior to becoming practicing professional architects.

The deductive process was followed so that the students could obtain a clear understanding of those circumstances where parametric design tools are useful and of the relationship between object and script configurations, and therefore of the cognitive model of design thinking for parametric design. As a result of the experimental study, the students were observed to understand the logic behind the parametric design tool. Furthermore, those students who wanted to make some refinements to a form basis, could modify the form in the direction indicated by the relation between the script configurations and the form of the object, which shows that they experienced the process of parametric design thinking.

At the university, traditional architectural design learning (which mostly depends on the Modern Movement in architecture), leads bachelor of architecture students to create bubble diagrams that shape the buildings according to their functional needs. In other words, we may describe it as a 'form follows function' based methodology, which mostly depends on an inductive reasoning process of form generation. Contrarily, in this course, the students were free to design in a bottom-up mode, which will influence their future project work. They started to consider both form and function in their designs by making reiterative movements within the architectural design process. This new cognition is partly influenced by the 3D modeling environment that students designed directly via a 3D image, rather than designing within a 2D environment, such as a plan or section. We may therefore conclude that courses with different teaching methodologies can allow architecture students to benefit from both processes of inductive and deductive reasoning.
The above described teaching methodology permits the students to create their own designs rapidly. The time to create their designs is further reduced by the fact that the methodology limits some parameters that are offered by the programming language. Although this methodology seems beneficial for elective courses, since it allows students to learn the basics of computer programming languages and also to create forms simultaneously, it may not be beneficial for longer term design projects since the students

need to consider additional parameters to make appropriate progress. However, for form-finding processes on a short timescale, the use of metaphors in parametric design can be useful and can be considered as an additional parameter to the script that limits forming options.

The study, which was carried out as part of the content of this elective course, was limited to the issue of form-finding. However, other parameters such as context, function, intention, program and structure, which are within the scope of the architectural design studio course, can be added to the content of this applied method, such that later experimental studies can be made, and the results of these can be evaluated.

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