The Use of Digital Fabrication as a Sketching Tool in the Architectural Design Process

A Case Study

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Computer-aided manufacturing (CAM) technologies including computer numerically controlled (CNC) milling, laser cutting and 3D printing are becoming cheaper and globally more accessible. Accordingly, many design professionals, academics and students have been able to experience the benefits and challenges of using digital fabrication in their designs. The use of digital fabrication in the education of architecture students has become normal in many schools of architecture, and there is a growing demand for computer-aided manufacturing (CAM) logic and fabrication knowledge in student learning. Clearly, architecture students are acquiring material base-thinking, time management, production methods and various software skills through this digital fabrication. However, it appears to be the case that architecture students use digital fabrication mainly in the final stage of their design or in their finishing work. In this study, computer-aided manufacturing (CAM) technologies have been used as a sketch tool rather than simply for fabricating a final product in the architectural design process and the advantages of this educational practice are demonstrated.

Keywords: *Digital fabrication, Teaching methodology, Sketching*

INTRODUCTION

Designers' sketches can be traditional concept drawings on paper, traditional handmade models, concept drawings in modelling software or CAM products. All of these media can be thought as sketching methods because they have common features that prompt designers to visualise the drawings and reinterpret them, so to produce new ideas, which helps them to shape their thoughts and accordingly to produce new designs.

Since CAD/CAM technologies became widespread, digital sketches and new technologies began to replace those freehand sketches and traditional handmade models which had formerly proved essential for developing new design ideas. During the process of drawing sketches and interpreting them, designers become aware of new relations and characteristics which suggest ways to refine and revise their ideas (Schon, 1983; Schon and Wiggins, 1992; Garner, 1992; Goel, 1995). According to Suwa and Tversky (1996), "seeing different types of information in sketches" is the driving force in revising design ideas, and sketches make apparent to designers not only perceptual features but also inherently non-visual functional relations.

Today, sketching process started to be done by digital 3D modelling tools which are preferred over the traditional sketching methods. CAM technology can actually be a supporting sketching model tool for designers as indicated by Cheng and Hegre (2009) who state that: "we can use digital fabrication as a catalyst for design instead of just a means of production". Hence, digital fabrication techniques can provide a creative design process (Hemsath, 2012), and the use of CAM technologies as a sketching tool leads designers to explore forms in real-time models which play an important role in architectural design. However, it is mainly in the manufacture of final products that these techniques are presently being used.

As a legacy of the Euclidean geometry building tradition, architects had used straight lines and circles for a long time. During the industrial revolution, the effects of standardization gave rise to fast, easy and economic constructions which influenced improvements in the design and manufacture of machines. Kolarevic (2003) has said that: "knowing the production capabilities and availability of particular digitally-driven fabrication equipment enables architects to design specifically for the capabilities of those machines". In the modern, digital age, integrating CAD with CAM redefines the relationship between designing and producing. Therefore, non-standard forms become easier to fabricate, which eliminates traditional drawing and production methods (Mitchell and McCullough, 1995). To include new CAM technologies in the sketching phase of designs would lead architects to learn how to use the machine and to reshape their designs according to its technological capabilities. In addition, actual products (objects) which could encourage architects to become aware of new relations and features, would allow them to make serendipitous discoveries. There are, accordingly, a number of advantages in incorporating the new CAM technologies as a sketching tool within the overall architectural design process.

The CAM technologies should also be used as a sketching tool in the educational process, so that students of architecture can gain familiarity with the machines and learn how to reshape their designs accordingly. This point is highlighted in the present paper, which discusses the use of digital fabrication in the architectural design process as a sketching tool, in reference to an architecture course that sought to educate students in CAD/CAM technologies, parametric modelling and digital fabrication, in architectural design, by creating waffle models which are mostly based on non-Euclidean architectural forms produced through laser cutting methods.

TEACHING METHODOLOGY OF THE COURSE

Since undergraduate courses with large class sizes have students who do not have adequate knowledge about CAD/CAM, and major transitions are difficult for traditional institutions, most of the courses that include contemporary and experimental techniques in architecture are given within graduate programs with small groups of students who already have some knowledge of digital architecture. However, it is necessary to include such courses in bachelor of architecture curricula since it has been noted that: "early adoption of digital fabrication exposes students to the process- and material-based thinking of contemporary architecture at a time when they form lasting attitudes to designing" (Roudavski and Walsh, 2011).

We included new courses related to CAD/CAM in the fall semester of the 2014 undergraduate program at the departments of architecture, Mimar Sinan Fine Arts University and Fatih Sultan Mehmet Vakif University, Istanbul. Although the courses were electives for bachelor of architecture students, the teaching was done as architectural design studio studies, and supported by lectures on modelling and scripting. The students were required to submit small-scale design projects which helped them to practice 3D modelling skills, which was one of the course objectives. The students were free to work either as individuals or in a group.

The courses began by teaching the fundamentals of 3D modelling in Rhino where students had to design a model with a waffle technique, and then continued with teaching parametric modelling, using Grasshopper. In this way, the students gained some experience in creating non-standard forms and had the opportunity to learn about digital fabrication tools. They learned how to use a laser cutter for the first time in their architectural education, and discovered the potential for its use in architecture. It thus became apparent to them that they should design their model on a computer screen along with considering how it might be fabricated by means of laser cutting, CNC milling or 3D printing processes.

The students had a free choice in their design object, while creating a waffle model, and were supposed to deform a plane surface along with rebuilding it. They were then expected to contour the non-Euclidean geometry that they had created. By then extruding the contours and booleaning the surfaces helped them in forming a model using a waffle technique. The objects chosen by most of the students to create for their initial laser cutting included a chair, a pavilion and a bridge. By using the waffle technique to model these forms, the students are able to develop their designs and to improve their 3D modelling computer skills. Their next task was to decide upon the materials that they wanted to use for laser cutting, which was the point at which they began to learn material base thinking. Having made this choice, then they returned to their designs and revised their models according to the properties of the particular material. Such properties as thickness and size affected the students' design models directly as was commented on by Oxman (2007), who wrote that: "integration of material and techniques together in earlier design phase causes fluent design process". Moreover, such properties of the material as color, texture and smell led the students to make additional unintended discoveries, and hence we may infer that they were already in the sketching process.

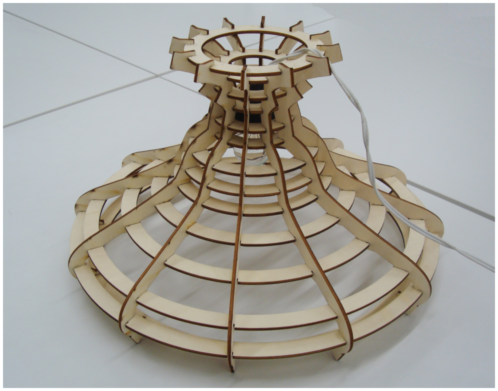

Figure 1
Work of Ogulcan Unesi, MSFAU

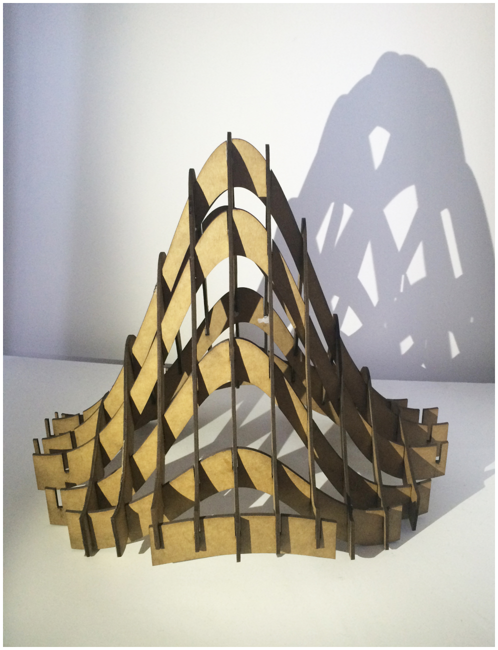

Figure 2
Work of Aysegul Yalman, Beyza Bengul and Beyza Karakus, FSMVU

DIGITAL FABRICATION PROCESS

It became clear that the students were still thinking of ways to improve their designs after their first laser cutting experience. Since some students were still considering making changes to some of the parts of their models, it was obvious that they were still in the design phase.

After the digital fabrication, some of the students said that they realized that the ribs (contours) in their models were very sparsely distributed, but this was not obvious from the model on the computer screen (Figures 1, 2). Since some of the students had used 3D modelling software for the first time, it is possible that they might not have controlled all the different views fully via the computer, and thus the model would appear different from the actual fabricated object. One student said that he was imagining the model from the perspective of the ground level while modelling on the computer screen; however, after production of the actual object, he attempted to change his model by partially removing it from the ground level and saw that the design can still remain physically stable (Figure 3). He then created multiple versions of the model and fabricated some of them again, and, at this stage, realized that he didn't achieve a balance of the surface deformation with the number of the contours. In contrast, some of the students were able to control their designs on the computer screen more carefully (Figures 4 - 7).

Some of the students neglected to give numbers to waffle ribs in Rhino or AutoCAD before proceeding with the laser cutting, but then realized that the numbering process was critical in arranging the ordering of the ribs following fabrication, because of the similarity in their appearance, such that it was difficult to order them correctly without numbering. They also discovered that rearranging the ribs carefully in 2D before final fabrication meant that less material was wasted, thus increasing the cost-effectiveness of the process.

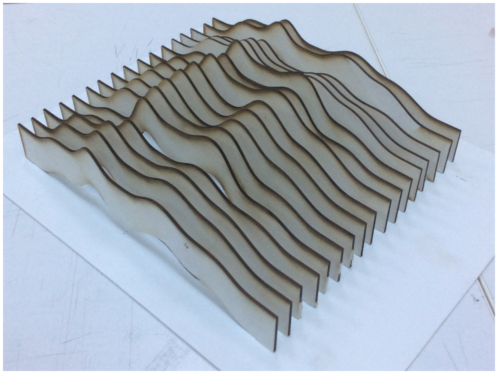

Figure 3
Work of Hamza Turanli, FSMVU

Figure 4
Work of Omer Unlusoy and Enes Duzli, FSMVU

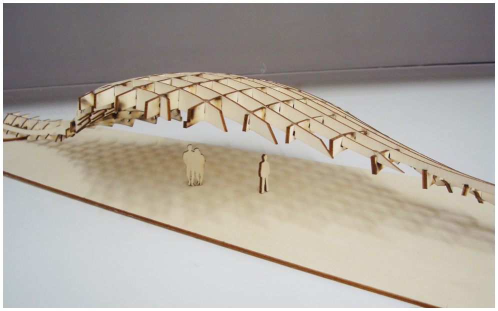

Figure 5
Work of Esra Oktay, MSFAU

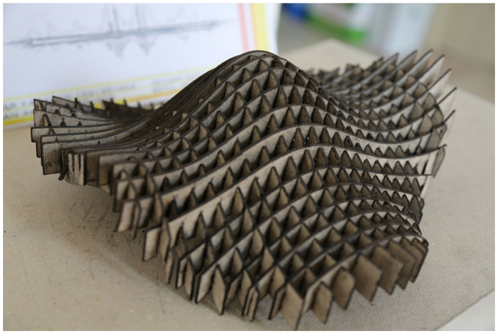

Figure 6
Work of Ceylan Akis, Huda Sarac, FSMVU

Figure 7
Work of Caglar Karahan, Betul Eres and Behiyye Yilmaz, FSMVU

Some of the students were disappointed by the materials that they chose for laser cutting, in particular those which melted during the laser cutting, or which took a long time to cut by the laser (Figure 8). Nonetheless, it is clear that to gain experience in the use of materials and their properties is very effective in the learning process for teaching students about architectural design. While some of the students found problems in fitting parts of the waffle ribs together, after their fabrication, because they had not determined the voids according to the material thickness, others made a very careful determination of them, and concluded that the fit would be better fit if fractionally more space was left between two crossing ribs to minimize the frictional force between them (Figures 9, 10).

CONCLUSION

The teaching method described can be applied throughout the course, thus enabling its students to: develop both their designs and computer skills, search for new materials, manage their time, learn material base thinking and how to use the laser cutter. Then, after producing physical models (objects) by laser cutting, the students can reexamine the first stage of their designs for further development. At this stage, they are actually engaged in the design process, and begin to reevaluate their ideas in terms of the possibilities and advantages of the digital fabrication that they have themselves created. As a result of using real materials, seeing actual color and modelling in precise dimensions, students learn to develop their designs. Thus, digital fabrication may be regarded as an integral part of the design process and can be defined as a kind of sketching method with applications for developing ideas and concepts in architectural design.

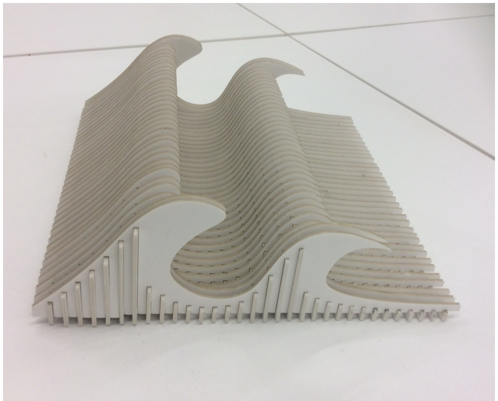

Figure 8
Work of Hilal Cumhur, MSFAU

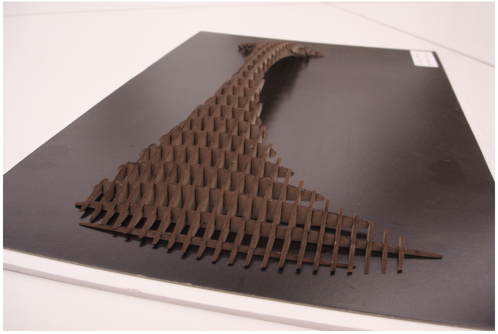

Figure 9
Work of Loran Ozdemir, MSFAU

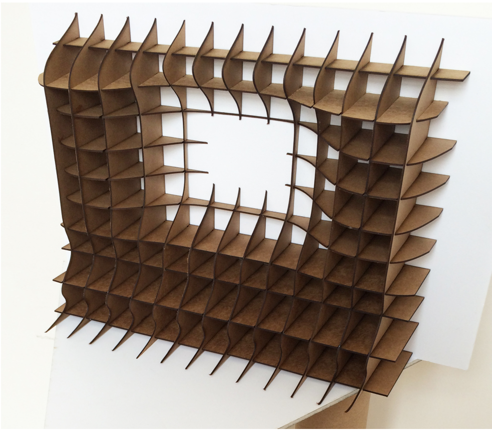

Figure 10
Work of Huseyin Sogukpinar, Yusuf Yucesoy, Busra Tasyuz and Adnan Gunes, FSMVU

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