1st International Conference on Frontiers in Academic Research

https://www.icfarconf.com/

February 18-21, 2023, Konya, Turkey

Application of 3D Printing for the Parametric Models Fabrication in the Architectural Education

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Abstract – Model making is one of the most important visualization skills, which architecture students learn during their education. The recent development and wide accessibility of the digital fabrication technologies allows students to use the CNC machines for the production of the scaled building models. Digital fabrication techniques allows to produce models, which are more presized, accurate, uniform in material and free of human errors, but at the same time it requires the understanding of the technology limitations and an additional efforts at the file preparation stage. This paper is focused on the evaluation of the 3D printing technique by the group of architectural students. During the lesson they were asked to design a tower using the parametric modeling tools, to prepare the files for printing and to evaluate the result. Students compared the 3D printing with the conventional manual model making and expressed their expectations, concerns and disappointments by the rapid prototyping technology. Based on the student survey, the advantages and disadvantages of the additive manufacturing are evaluated. Further, its applicability for architectural education and limitations at the current stage of development are discussed.

Keywords – 3D Printing, Digital Fabrication, Parametric Modeling, Architectural Education

I. INTRODUCTION

Digital fabrication technologies, such as rapid prototyping, CNC milling and laser cutting, are the dynamic and rapidly developing part of the industrial manufacturing processes. Additive manufacturing techniques were introduced in 1987 with the construction of the first stereolitography 3D printer [1]. After 20 years the 3D printers passed from the experimental stage and became available at the commercial market and affordable for the larger groups of people [2]. 3D printing (3DP) industry is rapidly developing, and the technology have been applied in different areas and at different scales of production, helping to produce on-site the presized and customizable objects, to reduce labour and transportation expenses, to decrease waste and to use the wide range of materials including the locally-sourced ones [3]. Small 3D printers and the DIY kits are suitable for the home use. 3DP does not require professional training since the software for the 3D printer and the printing process itself are intuitively understandable even by non-technical users [4]. The 3D printers at home are used mainly for the replication and customisation of the existing objects and also for the production of new ones [5].

3D printers have been introduced in education at all the levels, starting from the elementary schools till the colleges and universities. The introduction of 3DP technologies in the elementary school contributes to the development of the creative skills of the schoolchildren [6]. It motivates them them study, helps to understand theories, and improves the drawing abilities [7]. 3DP includes three innovative concepts of learning, which are active learning, learning by doing, and knowledge building [8]. Novak summarises four main directions in application of the 3DP in education, such as introduction of the design projects, which are based on the design, 3D modelling and further 3DP of the objects; introduction of the theoretical background of the 3DP technology and its application in the industry; direct 3DP of the small prototypes of the biological objects and chemical elements; and production of artefacts, which help to assist the students with limited abilities [9]. Inclusion of the 3D modelling into the curriculum of the visual arts study program resulted to the overall improvement of the creative process satisfaction and to the rise of the creative thinking, abstraction level and the spatial imagination of students [10]. Demonstration of 3DP raises the students' interest in STEM-related fields of study [11]. The production of printed models makes the students of engineering students to understand the three-dimensional composition of their prototypes and to improve the overall quality of the design [12]. Chun notes the development of the problem-solving skills as well as the ability to cooperate the design process with the other group members [13]. Lin et al. [14] notes, that students, who use 3DP, perform better feasibility analysis and concept explanation in comparison with the other students. Male students express their interest in the analytical fields of STEM, female students tend to work on the empathetic areas [15], and all students demonstrate the increased interest in mathematics [16]. The use of various teaching and learning techniques stimulates the students' research for the use and application of new technologies. The innovative approach using 3DP shifts the educational approach towards 'blended learning', when students find themselves the recent developments in the field of 3D modelling and production [17]. 3DP can be used as a tool, which helps the non-specialists to understand and to interpret the scientific concepts [18].

In architectural education, 3DP allows students to better understand the spatial and volumetric qualities of the designed objects and to visualise and interpret complicated forms and details [19]. 3DP is applied widely in the fast construction of the houses and settlements [20], therefore the students are prepared for the future large-scale application of the technology. Digital fabrication can be used to illustrate the structural problems [21]. In the landscape design course, students were able better refine their concepts, to understand the dimensions, to get clear ideas and to avoid possible mistakes [22]. Lorenzo adds the rise of the self-confidence as an important output of the use of digital fabrication technologies [23]. Students are more focused on the design development process than on the result [24]. They develop better research skills, the ability to evaluate the current step of the concept, and to modify it according to the technological limitations. Architecture students better understand the output of their project, develop design skills, and enhance creativity after using 3DP for their projects [25]. It stimulates teamwork and allows to improve the communication between group members with different academic backgrounds and professional experience [26]. In addition, large-scale on-site 3DP of buildings is an emerging area field of construction technologies, therefore, students become familiar with the basic principles and limitations of the additive manufacturing processes. They change the approach towards the design thinking and construction process aiming the project to be applicable for the on-site fabrication [27].

Inexpensive open-source 3D printers are the most suitable for educational purposes. Students can be involved into all stages of the fabrication process starting from the assembly of the 3D printer, replication of the parts, setting out the printing process and exploring the specificities of it. The important parameters that affect the productivity of the 3D printer are the accuracy, printing volume, printing speed, material cost, and the general maintenance [28]. Aslan and Celik state, that time and cost are the main limitations for the use of the 3DP in education [29]. Nemorin mentions the necessity of mathematical calculations and software restrictions, which are required for the printing of the physical prototype compared to the virtual model [30]. Nevertheless, 3DP techniques are affordable for students in terms of skills, cost, and time and can be used in the most efficient way for the fabrication of the architectural models with complex geometry.

II. METHODOLOGY

The research starts from the introduction of the digital fabrication principles to fourth-year architecture students. At this stage the students have a good experience in model making using the conventional techniques, such as cutting, gluing, forming and bending. Some of them could learn the basics of laser cutting or 3D printing on demand, but the majority do not have any systematic knowledge. During the “Research on Fabrication” course the students learn the basics of the parametric modelling and the specificity of the additive manufacturing, contouring and slicing techniques.

Students start from the development of the concept of simple parametric object, such as the twisting tower. They produce sketches that define the height, shape of the floor, and rotation angle of the building and propose the modular facade design. Students are free to develop their own design or to select the case study and explore the way in which it can be modelled. During the exercise, they learn the basic commands of Grasshopper such as Move, Rotate, and Scale, and later learn the quick ways of the application of the modular facades using the Lunchbox plugin. In the end, students produce the small-scale model of the building which is ready for 3d printing. To facilitate the process and to focus entirely of the design issue, the Grasshopper script (Figure 1) is delivered to the group.

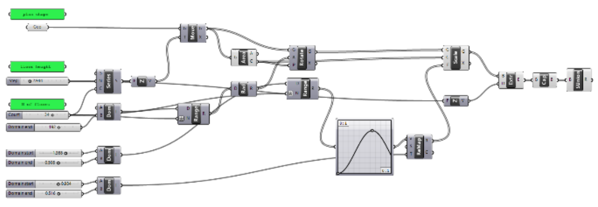

Fig. 1 Grasshopper script of the twisting tower

The student teams are asked to prepare the whole set of materials, such as concept poster, production files and drawings, to print the small scale models, to present them in class (Figure 2) and to explain the specific problems and issues occurred during the fabrication process.

During the study process, three surveys are conducted in order to understand the experience in conventional modelling, their expectation of digital fabrication tools, and their opinion regarding the practical application of 3D printing.

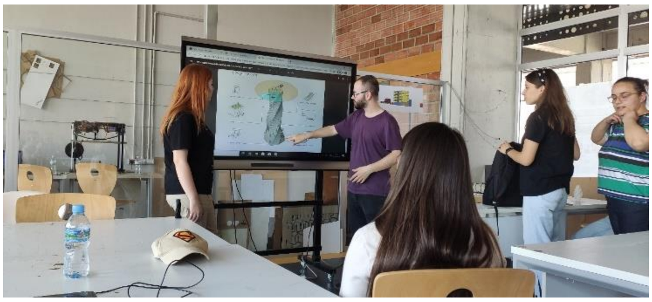

Fig. 2 Students’ team presenting the work

III. Results

A. Fabrication experience.

Production of the model is a part of the study program curriculum from the first year of education, therefore all surveyed students of architecture have the four years of experience in conventional model making. They are familiar with different production techniques, such as Cutting, Folding, Carving, Slicing, Texturing and Filling (Figure 3).

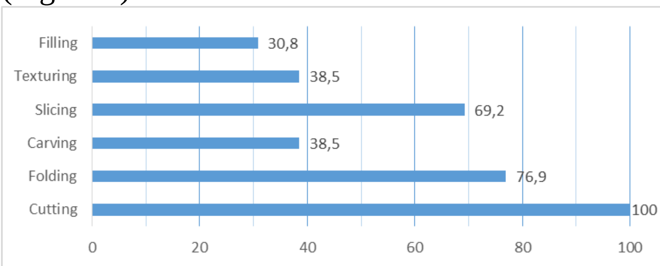

Fig. 3 Students’ experience in modelling techniques (%)

The students shared their problems in conventional model making. The most common are the production and assembly of parts and parts uniformity. Such problems can be easily solved by the application of digital fabrication tools. The next group of concerns, such as form generation, concept development and its adaptation for the manual fabrication are rather the design-related, then production-related problems.

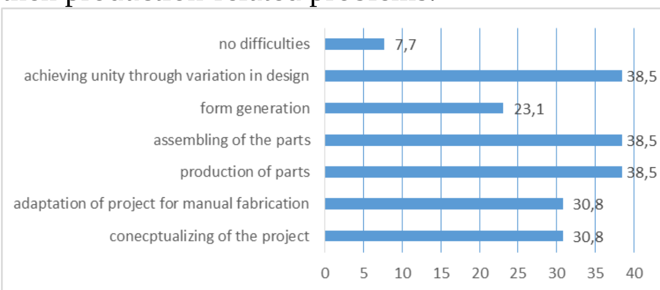

Fig. 4 Difficulties in manual modelling (%)

83.3% have used Digital Fabrication tools for the architectural models production, and out of them 91% used Laser Cutting. Rhinoceros and particularly Grasshopper is the most common software used for the model preparation. As secondary programmes, the students used AutoCAD, Sketchup, and Rewit. Figure 5 shows the difficulties occurring during the digital fabrication using the 3D printer. 50% of them is associated with the printing process, which is technology related. One third of the students experienced also design-related problems, which occurred due to the technological limitations of the additive manufacturing process.

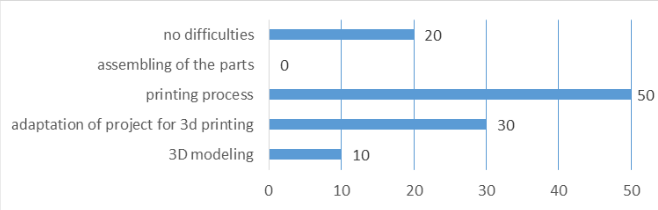

Fig. 5 Difficulties in 3D printing (%)

B. *Fabrication process*

At the next section of the survey the students were asked to express their opinion regarding the manual fabrication process, to show their expectations from the digital fabrication 3D printer and to share their experience when then printing process was completed. Figure 6 shows the comparison between the three stages of evaluation. Students demonstrate neutral to slightly positive evaluation of the manual model making and they are mostly satisfied by the 3D printing.

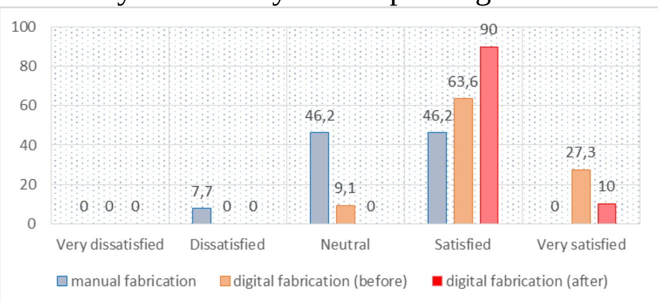

Fig. 6 Evaluation of the fabrication process (%)

C. *Fabrication time*

Students' reflections regarding the time needed to produce the model using conventional tools, their expectations of 3D printing and the real time consumed by digital manufacturing, are given in Figure 7. Manual model making is evaluated as rather time-consuming process. Students have high expectations for the speed of digital fabrication; however, in reality, 3D printing required a lot of time, which increased the number of dissatisfied students.

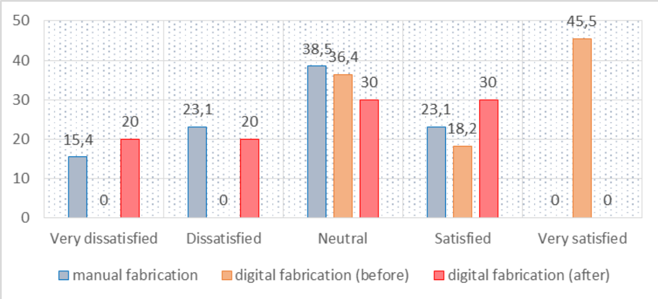

Fig. 7 Evaluation of the time spent on the fabrication (%)

D. *Model assembly*

The assembly of the model using the smaller parts and its post-elaboration is an important part of the model-making process. Figure 8 shows, that students are mainly satisfied by the manual model assembly as well as by its digital manufacturing. The answers are contradictory since the 3D printed object is a completed product and does not require any post-elaboration besides cleaning of the improperly laid filament.

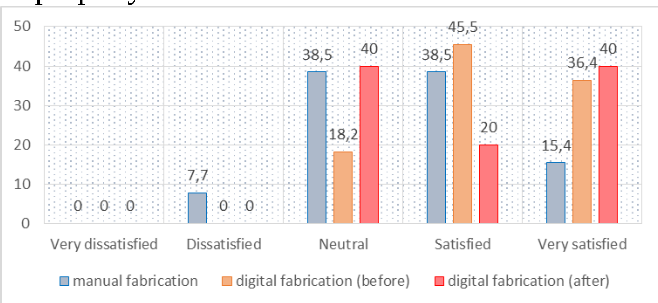

Fig. 8 Evaluation of the model assembly and post-elaboration process (%)

E. *Aesthetical quality*

The evaluation of the overall aesthetical quality of the model is given in Figure 9. Students are rather neutral in relation to their manually produced models. They have very high expectations towards the digital fabrication; however, the final quality of the 3D printed models is still high, but a bit lower than expected.

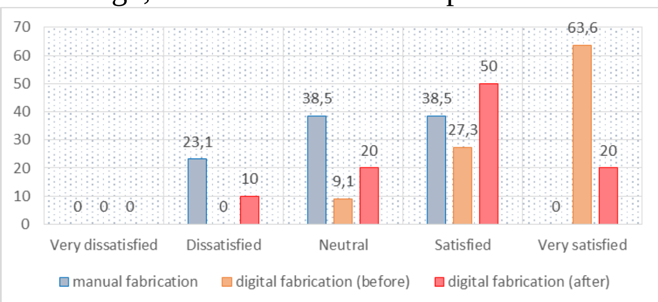

Fig. 9 The aesthetic quality of the model (%)

F. *Precision quality*

The evaluation of the precision quality of the model is shown in Figure 10. The precision of the manually produced models is not high. The expectation towards the digital fabrication is high, but the final product is affected by the technological limitation of the 3D printed, such as filament thickness and model size. For the small-scale intricate models it was not possible to represent all minor details of the design.

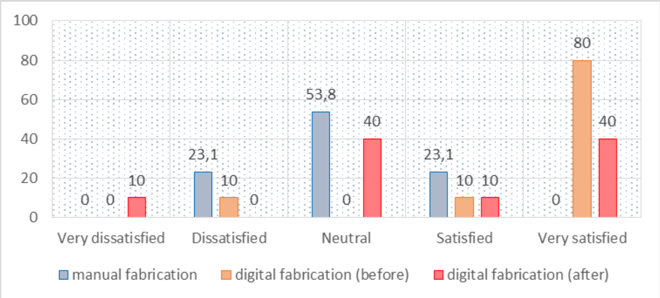

Fig. 10 Precision quality of the model (%)

G. *Model steadiness*

The steadiness of the model is affected by the selected materials and the way, how the parts are assembled. Figure 11 shows, that students evaluate the steadiness of the manually produced model as neutral, while this quality is significantly higher in case of 3D printing.

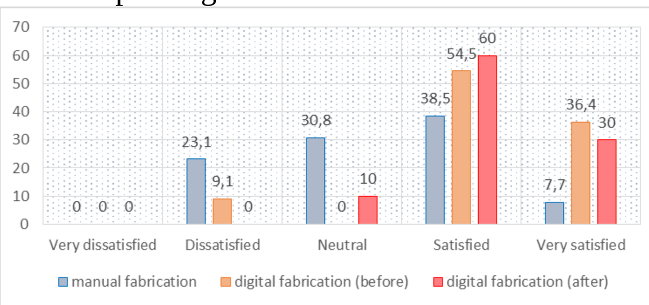

Fig. 11 Evaluation of model steadiness (%)

H. *Model price*

Material cost is an important issue for architectural students. Figure 12 shows that the price of the 3D printed model is generally higher than the conventional model.

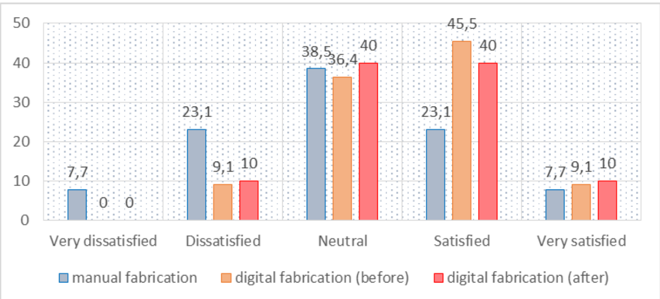

Fig. 12 Evaluation of model price (%)

IV. DISCUSSION

The overall comparison of the students' evaluation of the 3D printing process in comparison with the manual manufacturing is given in the Table 1. All students have the same four-year experience in the model making; however, they evaluate the process of manual fabrication neutrally or rather negatively. The expectations towards the 3D printing process are generally higher, then its evaluation after the try-outs. The time required for the layer-by-layer additive manufacturing process is too large for small-scale models and it increases with the introduction of large number of the intricate façade details. The printer itself sometimes does not work in a proper way, and the complex structures require printing the supports, which was not expected by the students. Additional difficulty was the adaptation of the 3D model according to the 3D printing requirements, such as joining of all the surfaces, closing the holes, alignment of the surfaces, and uniting the multiple volumes in one.

Table 1. Comparison of manual and digital fabrication

Param.	**Manual fabrication**	**Digital fabrication**	
		Expectation	**Experience**
Process	Neutral	Positive	Positive
Time	Rather negative	Positive	Rather negative
Model assembly	Neutral	Positive	Positive
Aesthetic quality	Neutral	Positive	Rather positive
Precision	Neutral	Positive	Rather positive
Steadiness	Neutral	Rather positive	Rather positive
Price	Rather negative	Rather positive	Rather positive

During the exercise, the students faced all the difficulties typical for the 3D printing, such as long printing time [29], material limitations and low precision, technical problems [28] and software restrictions [30]. Such problems can be easily resolved by the organisation of the study process with the emphasis on the learning of the presized 3D modelling; increase of the number of 3D printers in the digital fabrication laboratory; use of the recent advanced 3D printers with higher precision and bigger printing volume; slicing of digital model and parallel printing of its parts.

V. CONCLUSION

3D printing is a technology, which is widely used for the educational purposes due to its affordability, easiness in use and low technical requirements. 3D printers for education are used mainly for the demonstration of small-scale prototypes. The introduction of additive manufacturing for students and their inclusion into the architectural curriculum allows them to merge both the creative and technological approach in one project and helps the students to understand the spatial and volumetrical composition of their designs. This paper focuses on the evaluation of the 3D printing technology by the students of architecture after their first experience in its application. They get familiar with all stages of design and fabrication process, which start from the writing of the modelling algorithm, concept development, form finding, digital model making, and its production. However, the technological limitations caused by the equipment slow down the fabrication stage of the project, which students perceive as the main disadvantage. The 3D printing is a constantly advancing field of engineering, and the drawbacks of the current low-cost equipment can be easily overpassed. Use of the new technology makes the students more innovative since with the use of 3D printing they overpass the limitations of the complex form production, and deliberate their design skills.

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