Furniture Design with Digital Media

A participative educational experiment of digital craftsmanship

Ioanna Symeonidou

Department of Architecture, University of Thessaly & MSc in Strategic Product Design, School of Technology, International Hellenic University

i.symeonidou@ihu.edu.gr

The paper discusses the methodology, educational process and design outcome of the studio course “Furniture Design with Digital Media: From Design To Production” which took place at International Hellenic University in Thessaloniki, Greece. 20 students and young professionals participated in the course working in teams to produce a series of models which would later develop into a full-scale furniture piece. The workshop aimed to offer an experiential learning opportunity, showcasing the entire digital workflow employed for furniture design, from design to production. The design methodology employed digital design strategies, linked with material constraints, optimization and adaptation of the design for digital fabrication equipment. This educational experiment led to the production of a full-scale furniture prototype which was digitally fabricated and is currently on exhibit at the premises of the International Hellenic University in Thessaloniki.

Keywords: furniture design, parametric design, digital fabrication, experiential learning, CNC milling

INTRODUCTION

The studio “Furniture Design with Digital Media: From Design To Production” was organized by the Strategic Product Design program and the Life-long learning cluster of the International Hellenic University and it took place at International Hellenic University in Thessaloniki, Greece. The participants were a mixture of people with completely different backgrounds, ranging from architecture, to mechanical engineering, wood technology and automation. Some of them had a previous working knowledge of 3D modeling in Rhino, very few of them had previous experiences with parametric modelling in Grasshopper and a small percentage of the participants had fluency in the use of CNC machinery and other woodworking equipment. The workshop aspired to offer a short but intense experience of the entire digital workflow employed for furniture, from design to production. The intensive hands-on workshop was structured over two consecutive weekends, dedicating the first weekend to the design and prototyping with the use of digital media, while the second weekend was reserved for the full-scale fabrication of the furniture piece. After a brief introduction to furniture de-
sign, ergonomics and anthropometrics, the students received a basic tutorial of Rhino 3D and immediately jumped into the digital design of their furniture piece in the digital environment. At this stage most of the students worked individually or in small teams of two to produce furniture proposals which they would later fabricate as scaled models. The aim was to address the multidisciplinary aspect of furniture design with digital media, encouraging the participation of the interdisciplinary team of students and young professionals, introducing digital methodologies for the design to production workflow, engage in digital fabrication and physical testing of scaled prototypes and eventually designing in detail a full-scale prototype that would be assembled on the last day of the studio. The workshop aimed to explore a new hybrid design methodology where “the investigation of ideas is fully engaged with the tactile, physical nature of architecture and building processes” (Sheil, 2005).

ON CONSTRUCTING NEW KNOWLEDGE
The Concept of Mind and Learning by Making

In his seminal work “The Concept of Mind” (Ryle and Dennett, 2000), British philosopher Gilbert Ryle, objects to the Cartesian duality of body and mind. He suggests that mental processes cannot be isolated from physical processes and places special emphasis on the distinction between “knowing how” and “knowing that”, which is of great importance for design education. The physical act of model building for instance directly relates to the above, as the student physically engages in the activity. With regards to teaching, Ryle explains that “we are much more concerned with people’s competences than with their cognitive repertoires, with the operations than with the truths that they learn” (Ryle and Dennett, 2000).

During the last decades, in particular with the rise of digital technologies, there is a growing acceptance of learning-by-making within design education, it is understood that knowledge is a consequence of experience and that the role of technology is significant in the construction of knowledge (Stager, 2014). The school of thought of learning-by-making goes back to great historical figures such as Leonardo da Vinci who is considered to be among the greatest makers of all time. Within the same lines, Pestalozzi (1746-1827), inspired by Rousseau, advocated that learning resulted from the learner’s first-hand experiences and self-activity, favouring things and deeds over words (Martinez and Stager, 2013). Taking this theory one step further, Seymour Papert from MIT Media Lab, being one of the leading figures of active learning, was a supporter of the idea of learning by actively constructing knowledge through the process of making and sharing both the artefact and the knowledge. (Papert, 1994, 1993).

Project Based Learning

Project based learning has been established over the years as the main approach in architectural education (Dutton, 1991; Hejduk, 1991; Kuhn, 2001; Pearce and Toy, 1995; Salama and Wilkinson, 2007; Spiller and Clear, 2014). For architecture and more generally for design disciplines the biggest portion of the curriculum is studio based, with students learning through the development of a design project. Collaborative design workshops are structured as an interactive bottom-up process where the educator is present and constantly alert and ready to “seize the teachable moment”. It is about shifting agency to the learner, rather than correcting during the learning process. Particularly for experimental teaching studios, which often fall outside the students’ comfort zone, outcomes are not as expected - surprises, uncertainty or fabrication constraints occur. Within this realm students need to “reflect” on their actions, on the spot, so they can still have an impact on the outcome. Depending on the circumstances students are trained to develop their “reflection-in-action” (Schon, 1984) taking into consideration a multiplicity of factors (digital and physical) ranging from computational constraints and algorithms to actual material performance and construction workflow.

The experimental furniture design studio that is presented in this paper combines principles from the
active learning and project based approach. The students work in groups, they learn to work independently and build the necessary skills for completing the project, in this case the design and construction of the furniture piece. While the task of design is an open-ended question, the fact the design proposal needs to be constructed poses a series of new problems that relate to fabrication strategies, efficient use of material, and structural performance among others. Therefore the students are presented with central problem of “how to make it stand” that of course can be solved in several different ways.

The Experiential Learning Theory Model

One of the most relevant learning models that has been extensively used to understand and evaluate this participatory educational experiment is Kolb’s Experiential Learning Theory (ELT) model. Also known as Kolb’s Cycle (Figure 1), this model acted as a reference methodology to ensure that the student experience would lead to the acquisition of new knowledge. Only experience that is reflected upon can yield new knowledge, according to Kolb, “Learning is the process whereby knowledge is created through the transformation of experience” (Kolb, 1984). The famous model developed by Kolb and Fry comprises of 4 elements: concrete experience, observation and reflection, the formation of abstract concepts and testing in new situations. This model is widely known as the Experiential Learning Cycle. As Kolb explains “The ELT model portrays two dialectically related modes of grasping experience-Concrete Experience (CE) and Abstract Conceptualization (AC) – and two dialectically related modes of transforming experience-Reflective Observation (RO) and Active Experimentation (AE)” (Kolb, 2009).

This scheme should be seen as a conceptual spiral, a feedback loop, where each stage influences the other. However, the process of learning often commences with a particular action whose effect is the regarded within the given situation (CE). The next stage would be to comprehend this effect in the specific instance with the aim to be able to anticipate what would follow from an action if that would take place in the same circumstances (RO). In this fashion the following step would be the conceptualization and discovery of the general principle under which the particular instance falls (AC). When the general principle is understood by the learner, the following stage, according to Kolb, would be its application through a new action in a new circumstance (AE), therefore generalizing the knowledge gained; the four stages could be summarized in a sequence of actions: “Do-Observe-Think-Plan”. After several iterations of the 4 stages (Jabi et al., 2013) of the Experiential Learning Cycle, the learner is able to anticipate the possible effects of the actions taken within a given context. Kolb’s model is still very topical, several researchers of architectural education refer to Kolb’s cycle of experiential learning for the teaching of architecture (Sara, 2011; Tucker, 2008). Particularly for construction experiments, Kolb’s model proves to be a great reference both for setting up the educational process as well as for evaluating its efficacy.

WORKSHOP METHODOLOGY

**CAD-CAM processes and the production of scaled models**

After a series of introductory lectures on furniture design by a team of design experts in the field of furniture design, the participants embarked in a hands-on exploratory design phase, where digital and ana-
logue sketches coupled with physical modelmaking counter informed the design proposals. This initial design charrette led to the generation of seven furniture design proposals that took into consideration a number of different design parameters, such as ergonomics, aesthetics, functionality, material use, CAD-CAM processes among others. As the design proposal was to be fabricated in full scale, already from early design stages the logistics and design requirements relating to the fabrication equipment, the assembly and joinery were present in the sketches. For this first phase of the workshop, the students produced scaled prototypes in 1:10 or 1:5 of the furniture pieces they designed (Figure 2). As Iwamoto effectively explains in the book Digital Fabrications, “decisions as to which machine and method to use must marry design intent with machine capability” (Iwamoto, 2013).

The production of scaled prototypes offered an insight into material properties, structural performance and technology, assembly sequence and the logistics of construction, which are key factors that would influence construction during the later stage of 1:1 production. The design proposals were examined with regards to their aesthetic value, functionality and constructability and the final design of the furniture piece emerged within the group in a bottom-up process by combining design ideas found in the scaled models and incorporating then into a free-form parametric model. This collective design process led to an architectural artefact that embedded multiple hierarchies of design decisions within one continuous furniture piece incorporating local mutations and differentiations of the form to respond to ergonomics and afford multiple habitation scenarios.

Design of the final piece and CNC fabrication of the components

The geometry that emerged through this participatory design process was parametrically defined and optimized for CNC fabrication, aiming at minimum material waste, maximizing the volume and sitting area while remaining within the budget constraints that were set by the university and construction partners. The feedback loop of design modifications, analysis and optimization was an empirical process where students and educator would collectively suggest and discard design decisions, offering a very
valuable educational opportunity for design rationalization based on multiple parameters.

The parametric model embedded all construction parameters, the sourcing and processing of different materials (timber, steel rod reinforcement, washers, connectors) taking into consideration the available sizes and quantities, the CNC milling time required for each piece, and a comprehensive alphanumerical tagging of both timber and steel parts to facilitate the assembly process aiming at the reduction of possible mistakes. 66 timber components in total and approximately 250 spacers were to be CNC milled and sanded. These were to be assembled together with the use of steel rods which were precut to size according to the Rod Inventory directly extracted from the parametric definition.

The design and construction of the furniture piece proved to be a highly participatory activity; there was knowledge exchange and interdisciplinarity, which enriched the CAD/CAM workflow of this design experiment with practical advice and ad hoc solutions. For the CNC milling, due to the restriction that CNC bed had only lateral grips and no vacuum table (Figure 5), an ad hoc solution was adopted to avoid the movement of pieces. The CNC mill would not cut through the entire perimeter of each piece, but the cutting pattern modified so as to leave some “bridges” which would be cut half-depth to hold the piece in place during milling. The bridges would then be removed manually and thoroughly sanded. This decision was fed into the parametric model and automatically updated the nested cutting pattern saving time and ensuring the stability of the pieces. Similarly for the spacers, another CNC milling strategy was adopted. The hole and outline of the spacer was not cut through to the complete depth (21mm) but carved the wood up to a depth of 20mm, leaving one millimeter of “skin” to hold the pieces together. The pieces were then secured with polyethylene tape and passed into an automatic sanding machine that would eliminate the remaining “skin” producing ready-made sanded spacers. In the absence of the aforementioned ad hoc arrangements, the CNC milling would not had been cost and time effective, the cut pieces would jump out of the machine and the participants would have spent a significantly increased amount of time for the manual finishing of the pieces.

**Assembly of the full-scale furniture piece**

The assembly of the final piece took around 3 hours. Each of the 66 wood components was numbered and stacked in groups of ten and each of the 22 threaded steel rods were cut to size according to the Rod Inventory extracted from the parametric definition in grasshopper (Figure 6). The systematization of pieces prior to assembly saved a lot of construction time and further facilitated the assembly logistics to avoid mistakes. The assembly started from left to right according to the sequence that was also followed for the 1:10 test model (Figures 3-4). The 3D model was consulted during the assembly in order to locate each numbered rod to go through specific numbered components (Figure 7). The end of each rod was secured with a double bolt. In between the components round plywood spacers would regulate the distance among components and would hide the steel rods.

The multidisciplinary background of the workshop participants was extremely useful for this collective design to production process. In particular students with engineering background would offer their expertise with regards to the reinforcement of
the furniture piece with rods, to ensure stability as well as the relevant distances. The engineering input was also very important during the actual assembly, as the components were settling into position due to the fastening of the bolts. Some of the bolts were more fastened than others to permit movement during the assembly and all of them were fully fastened when the construction process was over. The wood specialist among the team offered their expertise about wood processing in general throughout the entire process and offered crucial remarks about areas that a wooden piece might fail, how to protect the wood from the distortion induced by the fastened bolts and how to assure the endurance and visual aspect of the finished piece. As a general remark we could say that decision making and the actual workflow would not have been so efficient without the participatory approach and multidisciplinary input on each stage of the design to production workflow.

**Evaluation of the workshop**

The evaluation of the workshop was based on one hand on the systematic observation of the students and their learning process and on the other hand on an anonymous questionnaire that the participating students have answered upon completion of the aforementioned courses. Each of the above methods would evaluate different aspects of the process, encompassing both quantitative and qualitative data. The observation confirmed the hypothesis that students are more engaged than usual when hands-on exercises take place. From an educator’s point of view, one would say that they were during most of the time in the “Flow Zone” which propelled their creativity giving rise to innovative designs. The students were actively engaged in the course asking questions and experimenting. The observation of their day-to-day progress revealed great progress in their design thinking capabilities as well as mastery of the necessary digital tools. Most students had experienced a phase of confusion in the beginning of the creative process, coupled with the difficulty of familiarization with new digital media. Later phases of the workshop were much more fluid and productive.

The anonymous questionnaires that were filled up by the participants at the end of the workshop aimed to address additional issues and gather information that was not easy to obtain from mere observation, and also reconfirm some of the observations by directly asking the students about their experience with digital and physical media. The questions were formed based on the methodology suggested by researchers engaged in the Scholarship of Teaching and Learning (Bishop-Clark and Dietz-Uhler, 2012). In order to identify successful practice, the questionnaire, apart from rating certain aspects of the workshops using the Likert rating scale, asked students to pinpoint which particular features were important to the learning (Bishop-Clark and Dietz-Uhler, 2012). It was therefore possible to gain an insight into the students’ point of view, confirming initial hypothesis that active involvement and actual making enhances the knowledge and creativity. When students were asked to identify which features of the course were most important to their learning, most of them pointed out the combination of digital and physical media. This confirmed
the initial hypothesis that students learn more effectively when they are able to connect knowledge and methods. In particular they rated as very positive the use of hands-on exercises highlighting the importance of tacit knowledge which becomes of particular significance in the ever evolving computational design scene. Students affirmed that software tutorials would help them overcome initial difficulties, however the self-discovery of concepts through guided exercises and tasks would help them assimilate the new knowledge.

CONCLUSIONS
Participative construction experiments, like the aforementioned furniture piece (Figures 8-9), aspire to offer multiple learning opportunities, they encourage the shift from passive listening to active learning, with the aim to produce new knowledge through active engagement in a broad spectrum of mental and physical activities. The workflow employed and the constant input of the participants is in accordance with the current trend in design disciplines which rejects the role of the architect as solitary genius, and encourages the contemporary idea of collaborator. William Carpenter in his book *Learning by Building* (Carpenter, 1997) highlights the importance of craft in architectural education. He claims that this type of experiences inspire architects and artists to see construction as a creative act and draws upon examples from the work of renowned artists such as Richard Serra and Donald Judd.

The furniture design studio was a bottom-up participatory process which promoted discovery praising the belief that self-guided learning pedagogies
are of a very high educational value (Kolb, 1984). The experimental and collaborative character of the digital furniture studio reconfirmed once again the value of experiential learning and project-based learning for design education. By observing at the entire workflow for the design and construction of the furniture piece, we can strongly affirm that decision making and the design of the process would not have been so efficient without the participatory approach and multidisciplinary input on each stage of the design to production workflow.

The educational experiment has addressed both procedural (knowing-how) and declarative (knowing-that) models of knowledge acquisition, as students proceeded in developing their test models, they would gain an insight on how to make a structure stable, what parameters they need to consider, how they can achieve a seamless transfer between the design and construction process. What was of particular interest was the fact that the initial scaled models brought up all issues of material processing, labelling, joinery, economy and assembly. Therefore when designing the full scale prototype, students were already aware of the critical points that should be fulfilled by their design in order to produce a feasible concept and proceed to its actual fabrication.

During the teaching process Kolb’s experiential teaching methodology was used as a means of validating the experiential teaching strategy. During the design and construction of the furniture piece there were several iterations of Concrete Experience (CE) Reflective Observation (RO) Abstract Conceptualization (AC) and Active Experimentation (AE) (Kolb, 1984). As it involved a mixture of digital and manual activity, the participants had the chance to obtain tacit knowledge about wood and construction, while in several critical points they would take design decisions while “reflecting-in-action”. The multidisciplinarity among the team members also proved of great value, as the participatory character of the exercise was further enhanced by the diversity of skills and expertise, in agreement with Robinson’s assertion that “most great learning happens in groups” and that “collaboration is the stuff of growth” (Robinson, 2010). With regards to the digital media used for the design and construction of the furniture piece, it was seen that once again three-dimensional computer modeling and digital fabrication have energized design thinking and expanded the boundaries of architectural form and construction. As Iwamoto explains “The projects center on a mode of inquiry whose method of making ultimately forms the design aesthetic” (Iwamoto, 2013). The educational experiment on furniture design with digital media gave overall successful results with regards to the project and learning process within the aforementioned digital-analogue set-up. Several of the hypothesis concerning hands-on learning approaches have been confirmed yet there is still a long way to go with great opportunities for improvement and cross fertilization among thinking, making, teaching and designing.

**ACKNOWLEDGEMENTS**

The author would like to acknowledge the support of colleagues and faculty at the International Hellenic University and the contribution of the workshop participants: Apostolos Voulgarakis, Georgios Danelis, Stavros Emmanouilidis, Giannis Efthivoulidis, Vasilis Karamanolis, Xenia Komliki, Avraam Kourtidis, Niki Margaritoglou, Dimitrios Messis, Stamatoula Bozardeni, Kostas Nikolaidis, Marika Kyriakidou, Stefanos Sideroglou, Kostas Tsavdaroglou, Evaggelia Tsiaousi, Athanasios Tsiggos, Theoni Tsot-
sona, Charoula Tyri. Special thanks goes to designer Athanasios Babalis for offering an initial session on Introduction to Furniture design, to the Company Xylogliptiki that sponsored the CNC cutting and to Charalampos Oikonomidis and Dimitris Avramidis for assisting during the Computer Aided Manufacturing.

REFERENCES
Ryle, G and Dennett, DC 2000, *The Concept of Mind*, University Of Chicago Press, Chicago