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Teaching Numeric Control through a Hybrid Device

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FlexiMold: Teaching Numeric Control through a Hybrid Device

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This proceeding presents the process and outputs of a collaborative workshop which was held between Yaşar University in Turkey and Delft University of Technology in the Netherlands. The aim of the workshop was to observe the educational potentials of a custom-made formwork device towards teaching CAD/CAM to architecture students. This flexible formwork, which we call FlexiMold, is a hybrid device that is used manually by following computerized numeric information. The students designed an architectural object which has a complex shape and used this formwork to fabricate it in actual scale. We present the workshop objectives, process and outcomes in this proceeding.

Keywords: *CAAD Education, Human-Numeric Control, Flexible Formwork, Double-Curved Surfaces*

INTRODUCTION

The aim of this proceeding is to present the experience and outputs of a collaborative workshop which was held between the Faculty of Architecture at Yaşar University (YU) in Turkey and the Faculty of Architecture and Built Environment at Delft University of Technology (TUDelft) in the Netherlands. The workshop was held in April 2015 with the participation of the bachelor students of the Architecture and Interior Architecture and Environmental Design departments of YU and the master's students of the Design Informatics chair of TUDelft.

The content of the workshop was focused on teaching the use of Computer Aided Design and Manufacturing (CAD/CAM) techniques for designing and fabricating architectural objects which consist of double-curved surfaces. To this end, we have developed a custom made flexible formwork device which we call FlexiMold. FlexiMold is a hybrid device which is operated manually by following the data sets which are derived from a digital model. The overall aim of the workshop was to explore the benefits and drawbacks of such a hybrid approach towards teaching CAD/CAM to architecture students. We propose that hybrid media, which enable and encourage the students to engage with the design and fabrication information both cognitively and bodily, enable a more efficient learning environment. The workshop had provided us a set-up in which we could empirically observe and analyse the validity of this proposal.

In addition to introducing skills and know-how within CAD/CAM, the workshop aimed at familiarizing the students with the collaborative aspects of design and fabrication as well as assisting them towards developing insight on the tight relationships between fabrication techniques and design thinking. The workshop setup was structured towards achieving these objectives. The first phase of the workshop was based on distant collaboration in which the students of both universities worked in parallel; while the students of TUDelft were developing the design, the students of YU were developing the fabrication system and examining its potentials and constraints in order to communicate with the design team. After the design proposal is completed, all of the students have gathered in Izmir for a five days' hands-on workshop in order to fabricate the design object. The workshop was funded by the Scientific Research Project Fund of Yaşar University, TUDelft Design Informatics Chair and Polkima Plastic Solutions.

THE DEVICE

FlexiMold is a flexible formwork device which was developed at TUDelft Design Informatics master's program in the previous semesters at the elective course that is titled Technoledge. It is developed by upgrading its precedents such as the Zero Waste Formwork (Oesterle et al. 2012), Flexible Mould for Precast Concrete Elements (Raun et al. 2010) and Formwork Table (Spuybroek 2004).

FlexiMold is constructed on a 70*70 cm wooden base. It has 49 steel rods, each of which can be independently moved up and down manually. These rods are placed in the base on a grid of 10*10 cm. The formwork is shaped by adjusting all of the rods, and then, placing a flexible polyethylene sheet on top of them. The sheet is able to perform -almost- any double-curved surface thanks to the grid pattern which was CNC milled on both sides of the sheet (see Figure 1).

The user receives a data set from the digital model for shaping the formwork in order to cast each surface. The data set consists of 49 numbers, each of which refers to the position of each single rod. The user adjusts all of the rods by following this information. Once all the rods are set in correct positions and the polyethylene sheet is firmly placed on the rods, the formwork is ready for casting the material. Therefore, we propose that this device is a hybrid medium, which is operated using both computerized numeric information and manual labour. Our hypothetical statement of Human-Numeric Control (HNC) is rooted on this hybrid situation.

Figure 1
FlexiMold Flexible Formwork Device.

HUMAN-NUMERIC CONTROL

Cross claims that design has its own distinct 'things to know, ways of knowing them, and ways of finding out about them' which remain largely tacit (Cross 1982). This indicates one of the critical challenges faced in teaching CAD to design students, as CAD mostly requires to communicate explicit information which do not mostly overlap with the implicit realms of design knowledge. Therefore, we need to develop educational tools and methods which enable the students to experience the digital workflows of CAD practices through implicit, tacit and intuitive means.

Latour and Yaneva (2008) claims that an architect has to be equipped with diverse tools which are the aids of imagination and instruments of thinking tied to the body. This concept is rooted on the phenomenological perspective of Merleau-Ponty (1962), who have defined the concept of embodied perception towards illustrating the instruments which are the extensions of one's bodily range and the bodily synthesis. Within our hypothesis, FlexiMold is an instrument of thinking tied to the body which supports imagination and it performs as the extension of the student's bodily range and synthesis towards enabling an embodied perception of the digital information.

Norman (1994) introduces the concept of soft technology in order to refer to compliant and yielding systems that acknowledge the initiative and flexibility of the person; whereas hard technology refers to those systems that put technology first, with inflexible, hard and rigid requirements for the human. In this sense, FlexiMold addresses the concept of soft technology as it is a compliant and yielding system which allows initiatives and flexibility. Instead of constraining the human with rigid requirements, it integrates with him/her while sustaining his/her intuitive skills. This is where our statement of HNC is rooted on. Unlike a complete Computer Numeric Control (CNC) process with which the human cannot interfere, the human undertakes a core role in an HNC process. The user of the FlexiMold receives data from the computer, understands and interprets it, then operates the device manually in order to complete the process (see Figure 2). Therefore, it is a hybrid situation between CNC and manual machining.

Figure 2
Human-Numeric Control (Photo credit: Yaman Umut Bilir).

The bodily and cognitive interaction of the human with the system in this hybrid situation provides potentials for reframing the fabrication process towards capturing the tacit dimensions of design knowledge. By this means, it can lead to several experiments even where fabrication becomes a creative performance. In our particular case, the educational potentials of this performance were the most significant ones. First of all, it enables the students to fully comprehend how a CNC machining process operates. Also, it helps them to directly observe the relations between numeric data and form. We even had the chance to observe that, they were most of the time able to fix the problems on the formwork itself when there is a mistake related with the datasheet which is received from the digital model. And all of these are performed through intuitive and simple acts.

This mode of intuitive interaction with the device corresponds with certain fundamental notions of Human-Computer Interaction (HCI) research even though our study is not directly related with HCI. Namely, the theory of affordances and the synchronization of action and perception are key to understand the potentials that rise on the interaction between the human and FlexiMold. These two are key concepts in Implicit Human-Computer Interaction (iHCI) studies, which address the so-called third-wave in HCI research. Gibsons's (1977) theory of affordances was introduced into design by Norman (1990) in order to address the relationship between a physical object and a person -or for that matter, any interacting agent, whether animal or human, or even machines and robots-. Just like argued by him, FlexiMold affords its user towards determining how it is possibly used, and therefore provides a steep learning curve. On the other hand, FlexiMold enables the natural synchronization of the perception and action spaces, which is argued as being a factor that enables us to perform complex tasks by Sutphen et al (2000). Eventually, FlexiMold is an HNC medium which enables direct and organic interaction with numeric information rather than through consecutive lines of text or, referring to Ishii and Ullmer (1997), painted bits. It introduces the qualities of traditional and typical craftsmanship into our relationships with numeric information.

WORKSHOP SETUP

The workshop was applied as a part of regular semester courses in both universities. The participants from TUDelft were the 32 students which were enrolled in the Technoledge course which is offered at the first year of the Design Informatics master's program. This elective course which runs for 10 weeks focuses on the design and fabrication of a non-standard architectural object. The course requires the students to work in teams by using CAD applications. Pre-rationalization of the design is one of the core learning objectives of the course. The participants from YU were the 17 students who enrolled in the CAD/CAM and Rapid Prototyping course which is offered by the Faculty of Architecture for the third and fourth year bachelor students of the Architecture and the Interior Architecture and Environmental Design departments. The objective of this elective course is to introduce the students the uses of CAD/-CAM techniques in spatial applications.

After completing the design, all 49 students have gathered in Izmir for 5 days for the hands-on fabrication phase. The workshop was coordinated by Serdar Aşut and Winfried Meijer and it was applied with the supports of Peter Eigenraam and Thijs Welman from TUDelft, Bilge Göktoğan from YU and Mark Giraud from Polkima Plastic Solutions. The infrastructure which was necessary for the fabrication was provided by yumak (Yaşar University MakerLab).

DESIGN AND PRE-RATIONALIZATION

The students of TUDelft were given the task to design an architectural object which has a complex shape, can self-stand and provides spatial qualities while considering the qualities and constraints of FlexiMold and fiberglass. The design brief challenged the students to model a complex shape by using parametric tools. Also, they were asked to consider the qualities of fiberglass and the limitations of the formwork (such as its dimensions or its capabilities to bend) starting with the early phases of the design process and pre-rationalize the design decisions accordingly. At the first phase, the students worked as 8 teams for 2 weeks and presented a draft proposal. One of these proposals was selected to be detailed further. The selection was based on the aesthetic qualities of the object and its producibility in this workshop. Then, the students worked on detailing the proposal and preparing it for the fabrication for 4 weeks. Eventually, they developed a design in the form of a mobius stripe which consists of 59 unique panels that has double-curved surfaces (see Figure 3). The object was approximately 2.30 in height and 4 meters in diameter. The panels had hexagonal shapes. The size of each hexagon was limited in a boundary of 60*60 cm due to the dimensions of the FlexiMold.

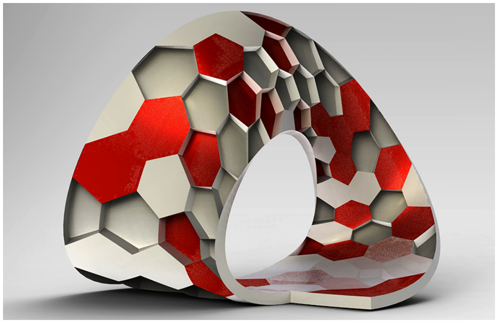

Figure 3
The design model.

The course of the YU students started only after the TUDelft students completed the design proposals and selected the one to be fabricated due to the schedule differences between the two universities. At this stage, the YU students were asked to produce 3 FlexiMolds, understand how to use these devices as flexible formwork, test its opportunities and limitations for the fabrication and guide the design team accordingly. The students worked with the formworks for 4 weeks in order to determine the most feasible techniques for outputting the datasets from the parametric model and shaping the formwork using them. They communicated these decisions with the design team and prepared manuals to be used on the site during the fabrication.

The students of TUDelft have developed the parametric model using Grasshopper and Rhino 3D. The model served as an assistant to be used for generating variations of the design and the necessary information for the fabrication. Eventually, the model was able to output charts which contain the numeric data sets and CAD drawings with 2D and 3D drawings of the panels.

FABRICATION

The students of both universities gathered in Izmir in order to fabricate the design object at the campus of YU. They formed three mixed teams each of which worked on a separate FlexiMold. So, each team was responsible for producing approximately 20 panels and finishing the assembly in five days.

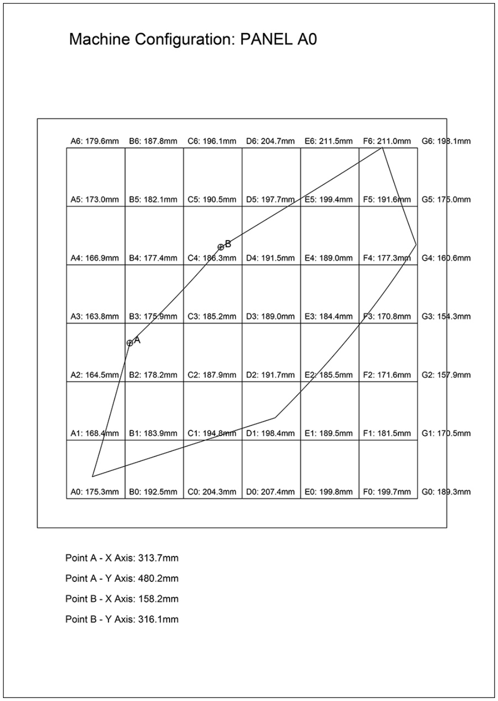

Figure 4
A sample chart containing the numeric data set.

The information regarding the fabrication process was derived from the parametric model which was completed using Grasshopper before the fabrication week. This model first analyses the surface geometry of the whole object, then divides it into unique hexagonal panels. It analyses the shape of each panel surface and generates output in the form of charts (see Figure 4) which contain numeric data sets that correspond to the positions of each adjustable rod of the formwork. Also, it produces flanges which enclose these panels and output drawings which represent the shape of these flanges.

The panel surfaces were made by using fiberglass. The reason for using fiberglass was that it can perform well with curved surfaces, it is lightweight and that it is fairly easy to learn how to cast it. The flanges were produced by laser cutting mdf boards which has 3 mm thickness. The flanges, which are cut and assembled in the form of frames, define the boundary of each panel. Also, they provide surfaces for connecting each panel with its neighboring panels. Moreover, they perform as a structural skeleton for the whole object when assembled. These mdf flanges provided proper stability to the structure while they were able to perform slight bends when necessary during the assembly.

Figure 5
Students positioning the rods on the formwork.

The panel fabrication process was simply done in three sequential steps such as; adjusting the formwork, casting the fiberglass and finishing the panel. In order to adjust the formwork, the students used the charts with numeric data sets for positioning the 49 rods manually (see Figure 5). After all of the rods were positioned precisely, they firmly placed the flexible polyethylene sheet on top of them. Then, they positioned the flange frame considering the reference points. After that, they started casting 3 layers of fiberglass mat inside the frame and applied the resin on it. After the panel was cured and removed from the formwork, a group of students started to work on panel finishing (such as sanding, smoothing

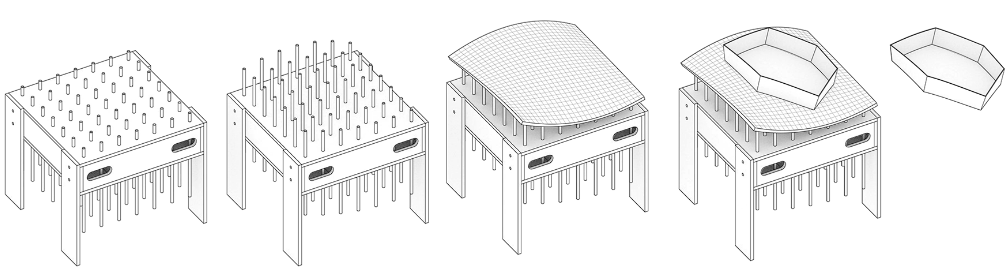

Figure 6
The steps for preparing a panel on FlexiMold.

and polishing), while another group starts to adjust the formwork for a new panel. By this means, the students were able to produce one panel in down to 45 minutes (see Figure 6). Finally, they assembled all of the panels by using bolts on the flanges and built the whole structure. Despite the complex shape of the object and its panels, only moderate force was needed to make all the panels fit together precisely.

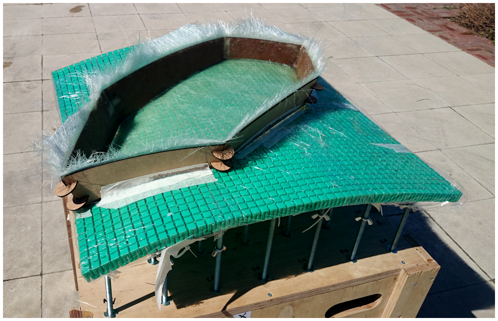

Figure 7
The panel being cured on the formwork.

One of the most important difficulties which was faced during the fabrication was caused by the mismatch between the shape of the hexagonal panels and the square shape of the formwork. Each panel had to fit on a different group of rods. However, it was necessary to calculate the position of all 49 rods in order to achieve the curve continuities on the surface. This difficulty was overcome by the parametric model. For each panel, the model created ghost extensions to the surfaces so that the boundary of its projection onto the formwork was as same as the boundary of the formwork surface. Hence, it was possible to calculate the positions of all 49 rods. Then, a corner of the panel was matched with a reference point on the formwork surface so that the panel fits on the surface with correct location and orientation (see Figure 7).

CONCLUSION

The workshop was concluded with a successfully completed product (see Figure 8). On the other hand, its process was more important for us than the object itself. After this first collaborative teaching experience which we practiced together, it is fair to claim that the workshop process within the learning objectives was way more efficient than we expected it to be. We were able to observe that certain learning outcomes were achieved during and at the end of the workshop process. Also, it was able to provide us input towards improving our strategies in teaching CAD/CAM.

The broadest thing is that design is highly related with making; therefore, such hands-on experiences in which the students are invited to build architectural objects in actual scale need to take place more common in architecture education. They encourage personal involvement for the students -which is a key aspect in learning. This experience has provided them opportunities to comprehend the strong relationships between design thinking and the fabrication and material systems.

Another learning outcome is that the students had the chance to understand the complex organization of the labour which is necessary for both designing and building. Even our scale was much smaller than an actual building design and construction, we tried to introduce as much complexity as possible regarding the design and fabrication management. We asked the students to form different groups to practice different tasks and to communicate with each other all along the process. We also tried to re-mix these groups for each time as much as we could so that each of them had the chance to work with different people on each phase of the project. Eventually, they practised close and distant collaboration to solve a variety of problems with different people each of the time.

The particular learning outcome of this workshop was that the students had the chance to fully comprehend how a CNC machining process works by integrating their own selves bodily and cognitively into the process. This is achieved through a hybrid device in the form of an HNC system. Even the students with the least knowledge on CAD/CAM were able to understand the fundamentals of numeric control easily by the help of this hybrid system. After a quick warm-up process, all of the students were able to develop an understanding on the relationships between data and form seamlessly. Because, such a hybrid device minimizes the need for explicit instructions as being an instrument of thinking tied to the body. It enables an embodied perception of the fabrication information by introducing intuitiveness and bodily interactions.

Besides being a good tool for learning, this hybrid fabrication device performed as an efficient communication interface between the students. Considering that the group was fairly diverse, it was necessary to encourage the participation of all in each phase of the process. In our case it simplified the communication between the students who

Figure 8
The built object.

come from different countries, have different educational backgrounds and focus (from structural engineering to interior design), have different skills (from Grasshopper experts to the ones who have met it for the first time in this workshop) are studying in different levels (bachelors and masters') and have different language skills; and enabled them to easily collaborate on complex tasks.

We have applied two more follow-up workshops in the following semesters with new students. Each of these workshops focused on developing a certain aspect of our first experience. For example, the main issue which we have tried to elaborate in the second workshop was the diversity of the students' profiles and the organization of design and fabrication management between them. The third workshop, which was applied by not flexible but stable formworks, focused on developing the distant collaboration phase. We are planning to present these studies in future proceedings.

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