EXPERIMENTAL METHODS ON UNIFYING COMPUTATIONAL AND MANUFACTURE WORKFLOWS.

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ABSTRACT

This paper examines the evolution of a teaching methodology and agenda of a series of intense workshops deployed and evolved with master students of architectural school. Especially, having the objective of digital manufacturing, merging in one single workflow, designing, materials and CNC methods; Milling, 3D printing and laser cutting. By simulating multiple aspects of developed processes with a bottom up approach the goal was to achieve the establishment of a unique panel based on the knowledge of the tool. The geometrical configurations require also to take in account tolerances together with machine procedures and material behaviour. The adopted approach implements material and tool intuition into a learning by doing process to steer the design based on material and fabrication methods.

KEYWORDS:

Workshop Workflows, Digital Fabrication, Learn by Doing, Approach Design Simulation, Tools.

INTRODUCTION

Current design to production processes do not take into account the machines to use on the fabrication. Design procedures have to be aware of the fabrication methods, such as CNC milling, 3D printing and laser cutting, which are mostly used nowadays in architecture and design. These workflows need to be combined and performed in a seamless process in order to process data without any noise. Merging digital manufacturing methods have the advantage of understanding the machines' working area and the permissible range of variation in the projects dimension, besides understanding the importance of preparing geometry for different fabrication methods. (Baquero and Orciuoli 2016)

> "Design has a symbiotic relationship with geometry... This is the shape I have sketched, but how to I formally describe it" versus "This is the formal shape description system I am using, how do I harness and control this system to create the shape I like". (AISH, 2005)

In our case, the 'system to hardness and control' are the fabrication and assembly procedures, in other words, 'to create the shape we like' we investigate how to challenge the machine restrictions. For this reason, the goal of these workshops was to design through the machine's limitations, and for that, it was necessary to provide some basic knowledge for preparing and sending files to the machines.

In addition, students were invited to collaborate and improve the materialization process, construction logic and connectivity by building prototypes. The theoretical framework speculated processes and paradigms which implement manufacturing knowledge inside computational design systems. Through the proposed experiments, the intention was to teach how to combine design and manufacturing workflows through three fabrication methods using three different materials.

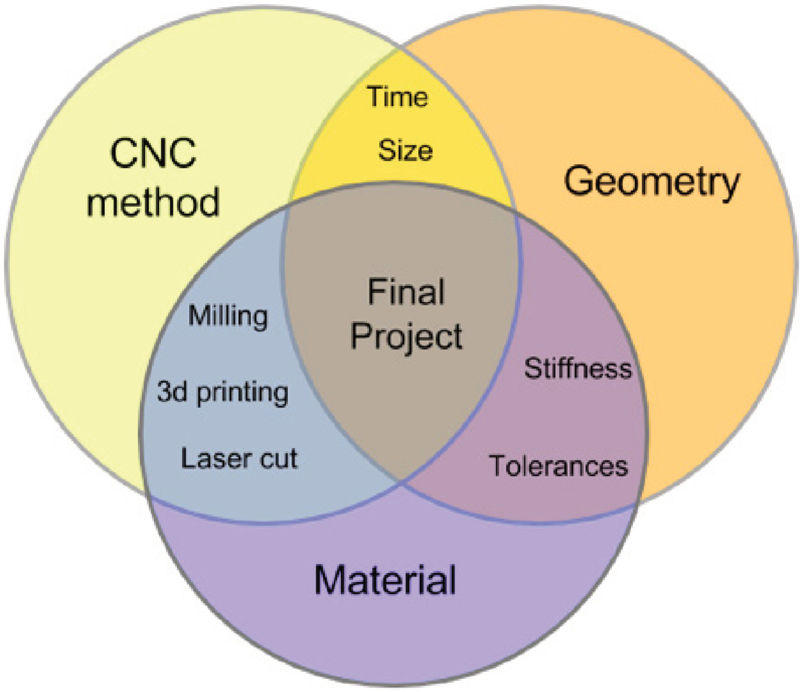

Figure 1. Parameters taken into account on the theoretical framework .

METHODOLOGY

Based on Sennett's (2009) assumption that in the learning process both techniques- considered as a cultural issue rather than as a mindless procedure - and their applications come hand to hand, apprentice is in fact a learning through doing process. Following this direction, teaching process was enhanced, giving the opportunity to learn by applying and solving problems instead of just learning the tool (software) itself. This method gave the possibility of implementing intuition inside the design procedure.

In addition to this experimental process, the exercises were intentionally developed in such a way that could promote collaboration between groups. Thus, each group was responsible for solving issues of a specific part of the project, at the same time, required understanding and implementing parts to the whole. This way, the groups had the opportunity to work in parallel, from bottom - up as individuals, collaborating with others, and from top - bottom, building shared 3d models, to advance the project, altogether as a team. The role of the professors became more like of the coach and coordinator, guiding students, with an intuitive approach, so they could perform and solve problems better by themselves, from simple to complex. Therefore, the intention was to teach how to formulate questions in an adequate way and not to give ready made answers.

The teaching agenda, as part of the Master in Biodigital Architecture, was strategically organized in the beginning to the middle of the program, so there should be already some knowledge of the software tools (Rhino3D, Grasshopper graphical algorithmic editor and plug-ins). All workshop projects were previously prepared by the tutors, with few design features allowing modifications and adjustments. This way, more importance was given to the experience of programing and manipulation of the machines.

DEVELOPED PROCESS

The main focus was given in the ability of the project to be executed with the use of three digital manufacturing technologies from conception to completion. To achieve this, the developed projects consisted of a milled panel of polyurethane foam (200x100x50cm), laser cutted pieces of polypropylene sheets and 3D printed components of PLA filament. The workshops agenda was organized as follow:

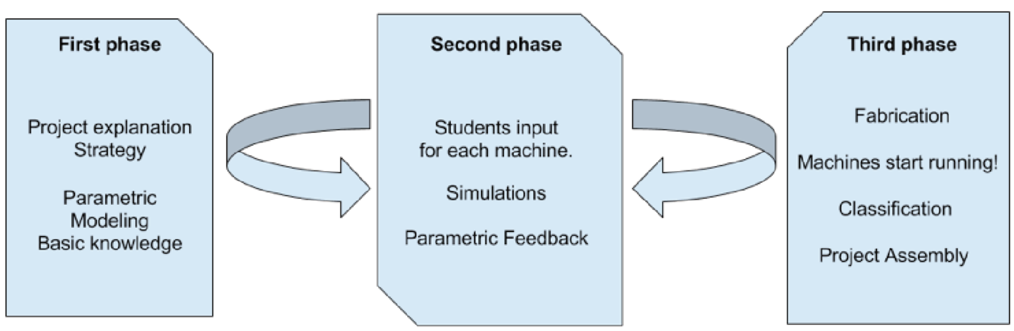

Figure 2. Parametric workflow used on each workshop.

- During the first day, the task was to introduce the parametric definition and the fabrication strategies to be used.

- The second day was dedicated to having a closer look on the machines and their corresponding software for simulation and preparation of the production parts. Additionally, was to mention topics like safety rules, tolerances, material properties, time optimization as parameters to take into account when designing for production.

- The third day, students were separated into groups, to be responsible for each fabrication technique, (milling, cutting, 3D printing) and intervene with different design alternatives for optimization and simulation of the fabrication process. RhinoCam and Repetier were introduced.

- The Fourth day was for the materialization, and each team, responsible for each fabrication technique, had to consider times and send G-Code from Repetier and G-Code from RhinoCam, to start the machine up and running.

- The Fifth day all the pieces from the CNC, laser cutter and 3D printer were organized and assembled in a specific order previously planned and discussed. This process students were mostly enjoyed.

CASE STUDIES

Each of the following case studies, examine the workshops workflow for specific project, they focusing on how the materials are merged together and how three machines are connected on the same process.

- **Voronoi 2D Connectivity**

The first project was done 2014 with the Biodigital Master students. The design was made of 72 cones on points on a Voronoi pattern using different milling machine operations. Each student created a specific G-code and accompanied the process of mechanization on their own area. There were 12 laser cutted pieces of polypropylene were arranged in 5 different heights which fit precisely in their respective cones, given freedom to define openings (circles) for the connections. 110 pieces of different heights, as 5 types of anchors (designed for 3D printing, but finally laser cutted for time issues), clamp sheets in the head to anchor were assembled and added by inserting to the foam in the bottom. (Figure 3) Each student analyzed the position of the sheet component within the general context and thus parametrically defined the necessary heights (Orciuoli and Baquero, 2015).

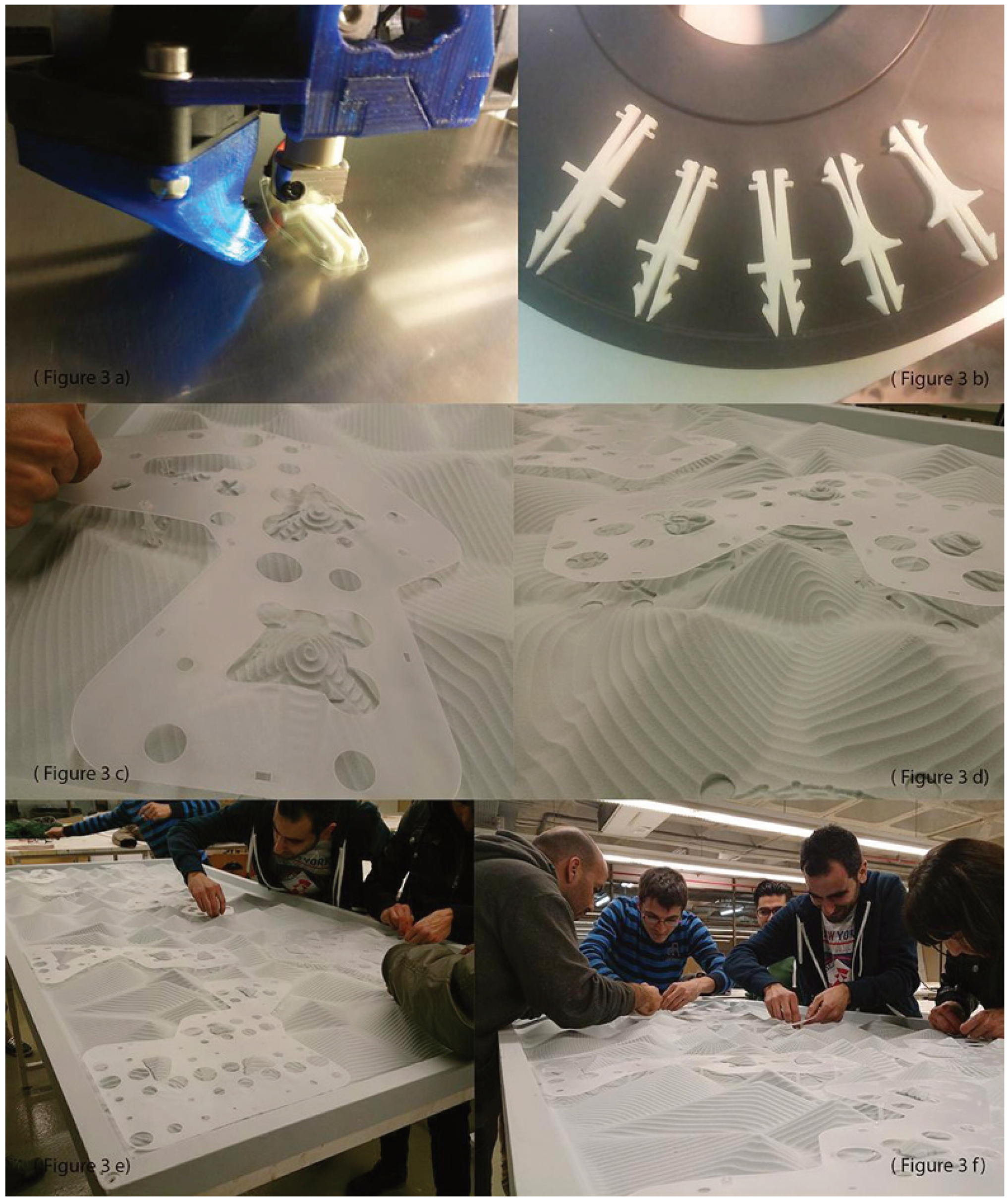

Figure 3. Voronoi 2D Connectivity , BioDigital Panel, 2014.

- **Voronoi 3D Connectivity**

The main idea of the 2016 workshop was to introduce students to 3D printing basic techniques, using parametric modelling tools. One of the crucial concepts of the design was taking into account the type of connectivity which was constrained to each joint, based on the proximity to each other and the quantity of connections. (Figure 2) Other 3D printing key issues explored in all workshops, include the relation of geometry with the printer's capacities, like which possible geometries we can do with different kinds of 3D printers and with which filament type. In this project, since the connections were all different, 3D printing was chosen as the only adequate method to fabricate them.

The 3D voronoi space frames, by means of different materials and geometric solutions were prototyped. The groups assessed the suitability of each design variation and adjusted key parameters. One main design difficulty of the connection parts was to be able to have a flat surface on them to add a number for each aluminum bar IDs connected on them. It was also important to organize and orient the 3D printed parts on the machine bed size and to be able to locate them spatially during the assembly process. Flexible material filament was selected to adjust fitting the first to the last of the aluminum bars and for smaller tolerances. Spatial cells that came out of the 3D voronoi have always planar faces but some bars became very short that those joints geometrically collided. For this reason, we applied a logarithm that merged vertices that are closer than double the size of the connection parts. (Baquero and Orciuoli, 2016)

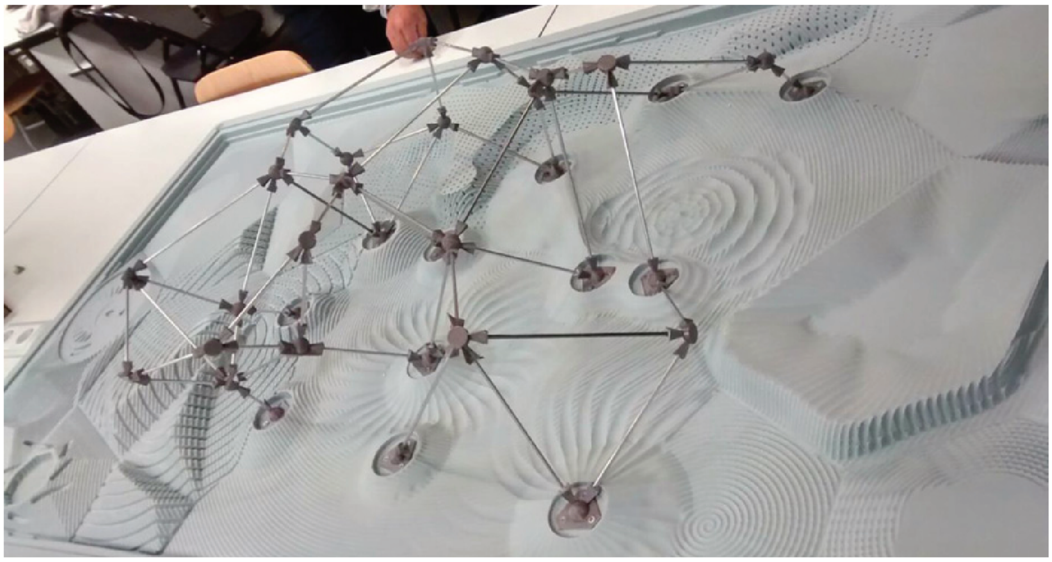

Figure 4. Voronoi 3D Connectivity, BioDigital Panel, 2016.

- **3D Pattern Connectivity**

The main focus of the 2017 workshop was in the patterning logic of connectivity. The experiment was to apply pattern formations of stripes, as ruled surfaces. The stripes were unrolled based on two valence nodes meshes and tested as structural elements of a self supporting skin without the need of connection parts. (Figure 3)

The project had as a reference biological morphogenesis of zebrafish stripe formations and the Turing mathematical model of reaction-diffusion algorithm.

The idea was to investigate possible algorithms matching stripe formations to be used as a construction logic and fabrication technique for laser cutting polypropylene sheets. In the first stage of the design form finding, the physics engine of Kangaroo plug-in inside GH was applied for the mesh relaxation of the structural skin and landscape. According to that, the relaxation of the skin served as space frame for a self supporting structure. In a second stage, IVY plug-in inside GH and the Kruskal Algorithm on a 2 valences mesh was used for the generation of fabrication stripes and for milling the landscape pattern. This method manifested close resemblance of a reaction-diffusion system. Students participated in three groups and each group was responsible to deliver G-code for one machine and to finalize the design of the parts and connections. The fabrication of the prototype required full coordination of all groups and a specific assembly plan. The biggest challenge for improvement was the tolerances of stripes connectivity in relation with the geometry, the material and structural performance.

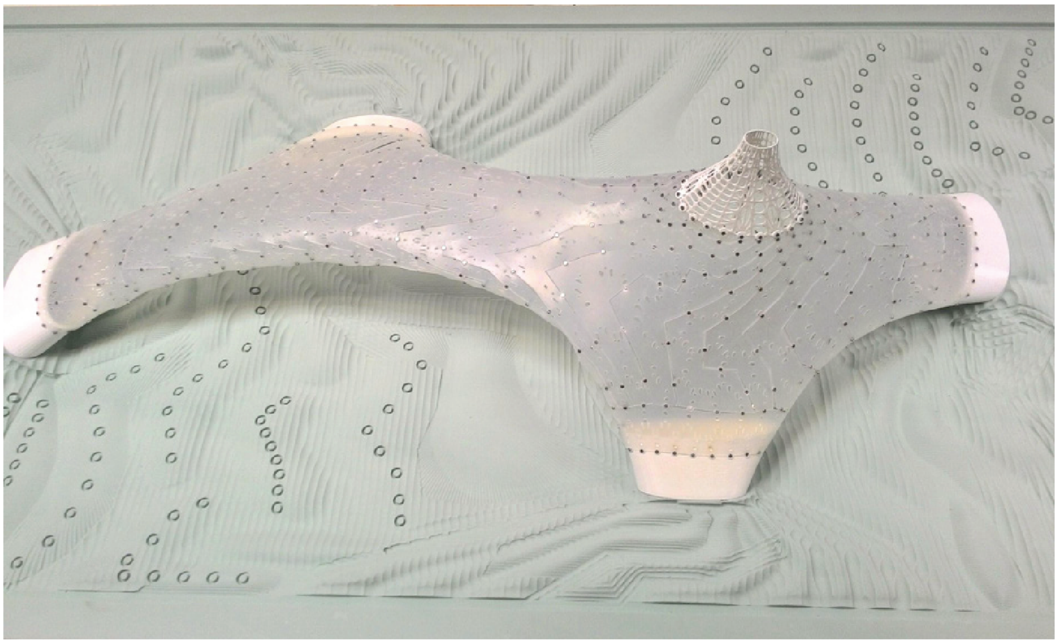

Figure 5. 3D Pattern Connectivity, BioDigital Panel, 2017.

CONCLUSIONS

Some programing languages, normally available to students are usually classified in two main paradigms: imperative and declarative programming (Davis 2013) as Davis argues the imperative language is more suitable for learning. We have also considered by experience that Grasshopper, as an imperative language, is more acceptable for architectural students, since is a node based graphic program.

In the last years, computational methods have been settled to design with equilibrium, Kilian was the first who developed a virtual interactive and real-time hanging strings modeling environment, using particle spring systems adopted from the computer graphics industry. His approach emphasized the exploration experience, but had challenges to steer the design in a controlled manner. Most recently, several interactive tools allowing for real time explorations of funicular networks have been developed (Piker 2013). According to that, workshop projects had evolved to use simulation tools (physics engine) to steer the design based on material and fabrication methods.

This article examined how three workshop projects have evolved as part of a teaching methodology, from the design to fabrication process, investigating the connectivity performance for a voronoi 2D, a voronoi 3D and a skin pattern prototype. As a conclusion, merging fabrication techniques require more time to understand deeply the potentials and application for prototyping. The combination of three materials with different geometrical aspects of connectivity for each and three manufacturing techniques add more complexity to the process. In order not to multiply errors, geometrical configurations require to take in account tolerances together with machine procedures and material behaviour, such as polypropylene material expansion. By experience, this could be arranged also independently, as part of programming the machine and optimizing software capacities instead of adjusting the design itself. For instance, some parts of the computational process inside the Grasshopper definition need to be debugged for the fabrication process and each machine. It is always very useful making preliminary material testing to adjust precisely the tolerances for the selected fabrication method. By experience also, we realized how important is to consider and plan the method and order of pieces assembly in advance. For a successful outcome, this could be realized by adjustments on the design, or even by using simulations of the assembling process to site plans.

As Philippa Lyon mentions we noted the tendency within higher education to move towards "constructivist" models of learning: approaches that plays an emphasis on the learners role… all these have in common the aspiration to move away from the idea of a teacher simple passing knowledge to the student and toward a focus on the learner as active participant in the learning. (Lyon, 2011). As in Sennet's craftsman learning by doing, we approach teaching design as a digital fabrication experiment.

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