Workflows from design to fabrication:  
Parametric explorations in fabrication workshops

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The key aim is to investigate the workflow from concept design to digital fabrication as a method of teaching that encourages innovation in the architectural field and challenge how we approach the process from design to production. This article explains the teaching strategies used to merge parametric design tools and digital manufacturing methods in one workflow: modeling-fabrication-assembling, realized as part of a series of workshop seminars, developing experiments, prototypes and real scaled self-supporting structures.

\textbf{Keywords:} Teaching, Simulation, Parametric, Digital Fabrication, CNC Milling, laser-cutting.

1. Background

The workshops run as a platform for architectural experimentation focusing on the parametric logic and computational tools for digital fabrication techniques. “Based on the concept of in-vivo, in-silico, in-vitro architecture, the use of in-silico tools challenges the philosophical concept of “HomoFaber” which refers to humans controlling the environment with tools”, as part of an extreme wish to cultivate artificial environments for people that have emerged from open platform studies, cloud storage, open source software and compromised on local materialities and therefore on the tectonics. In architecture, are the studying techniques and methods for testing with real materials (in-vivo), geometrical configurations (in-silico) and computer simulations (in-vitro). Ramsgaard and Tamke (2012), in their discussion of the term “digital crafting” examine how “the maturing of interfaces between the design space of the architect and the production space of the manufacturer is leading to the shape of a new material practice in architecture.” Considering the evolution from the craft of making to computational materialization, we can now combine them to speculate, control and predict multiple and more complexly designed objects.
2. Area of research

Computational methods allow high-level integration and manipulation of the geometry through the use of a series of algorithmic strategies to explore the creative potentials of emerging and dynamic phenomena. However, there is a lack of tangibility in the experience with materials for fabrication, specifically taking into account material thicknesses and properties for different scales.

The aim of the workshops has been to investigate a practical design methodology which challenges the traditional perception of the object, raising an open framework for thinking about design as the accumulation of different possibilities, employing simulation as a generative design tool. “Challenges in performance driven design methodologies is the way that designers can effectively integrate simulation and optimization techniques with parametric design procedures” (Oxman, 2008).

The workshops explore how the design intentions and strategies can be embedded deeply through a set of local operations, geometrical and material systems for simulation and design optimization, and to demonstrate how parametric design and digital manufacture, as in the case of CNC (computer numerical control) machines, is providing an effective connection between design and production in real scale.

The agenda is organized to be within 40 hours, oriented toward participants to professionals and students from design disciplines with basic computer knowledge. They have the opportunity to design and construct prototypes through experimentation, a unique set of components that negotiate a range of material property variations across different field and surface conditions, to achieve the materialization of a complex geometry to a prototype that can be translated in any scale object and referred to in architecture as construction logic.

“The most compelling shifts in design occur when new technologies and fabrication capabilities are made available and interpreted in new ways”.

Being more critical, Karl Chu has once mentioned in social media that “New techniques of design and fabrication have to be accompanied by new conceptual frames ... if not, they run the risk of merely repeating the old paradigm (of architecture) but couched in the emperor's new clothes...”

3. Workshop objectives

The workshops are trying to establish an interdisciplinary collaboration, in a teaching environment, combining technological precision and creativity; connecting with and networking architects with local industries and companies which provide the material and machinery, by raising questions, sharing and exchanging knowledge (techniques, processes and terminology).

A parallel goal is to demonstrate how this work favors a material architecture, a conviction that architectural ideas and materials are inextricably intertwined.
Architecture has a physical substance and the point of conceptualization is to figure out how to treat that material. Inspired by the material and CNC machine industry advances, the intention is to integrate them into the design process for novel ways of construction and to optimize the workflow process parametrically, from design to fabrication, integrating the computational logic of design with physical testing and construction.

Additionally, the goal is to control that workflow of information and critically the generative geometry, allowing to analyze, various necessary solutions on the project development.

And understanding concepts, design strategies, and material constraints, in order to transform complex 3D geometries and structures into fabrication element; exploring how materials can affect and cooperate under external forces and obtaining a sense of fabrication time and material costs depending on complexity.

4. Methodology

“The computational tools require not only ways of doing but ways of thinking” - Mitchel Resnick. The main idea has been to introduce new thinking methods about design for production, using digital tools and emerging manufacturing methods. In order to organize the design for the construction process, the teaching agenda is usually arranged in three main phases: concept modeling, fabricating, assembling.

“We shape our tools and thereafter our tools shape us” - Marshall McLuhan. To understand methods from computation to materialization, in real context, throughout the workshop agenda, various architects have been invited for an online lecture, to explain computational methods and fabrication processes inside their professional practice.

Behavior-based and knowledge-based strategies have significant differences in how information is structured for the progression from abstraction to precision that is inherent in any design process. The primary difference between these two approaches is that one is based upon the determination and self-organization of fundamental properties by which global behavior (or form) emerges, while the other is a structure for the re-organization of mostly pre-specified information made applicable through interpretation (Mark E. 2008). These strategies on behavior-based models have been taken into account inside the workshops with different collaborations with local fabrication industries operating with metallic materials, and exchanging their experience on the creation of digital objects from ideas and its constraints to physical fabrication.

Learning from parametric workflows, the knowledge-based strategies, has benefit to move from form-finding technique to preparation for digital manufacturing, automation of drawings for fabrication and assembly guiding material.

The theoretical lessons are given as a computational open framework, with many possibilities for designing, to initiate individual or group projects. As a primary
workflow of design, students are given a set of exercises that serve as a scaffolding to start with their explorations. Depending on the intentions of each participant, the projects have been developed through each phase.

5. Parametric Modeling

The workshops are introducing primary logics of design to fabrication, by explaining some real constructed references and their fabrication processes, as case studies, showing an area of production, within architecture, which ranges from experimental and speculative prototypes to completed projects and the shift of the office to an experimental studio.

Fundamental concepts of parametric modeling are explained, like data tree manipulations, transformation patterns and attractor influences. Some recommendations of Rhino to adapt the modeling process, is useful to allow better manipulation of the parametric logics of Grasshopper components.

Similar to computational functions of programing languages, as inputs and outputs, Grasshopper has the possibility of cluster components. With the use of clusters, the canvas should have better organized based on structure and geometrical relationships. At the same time with the break of bigger definitions and essential algorithmic structure, it is important when sharing a cluster definition; for instance, while the necessary inputs to orient or unroll pieces, the cluster outputs should continue to be linked with the rest of the definition to update streamed data.

During the early stages of design, a structure and connection system have to be defined geometrically, as a method of assembling and fabricating the construct, as well as to define it according to possible materials to be used.

The purpose of the project studies in this phase was to simulate how a structure would respond to geometry, material stiffness and loads incurred in real scale. Looking at nature for inspiration, dynamic systems for the form-finding are explored in common. Some projects had explored catenary systems based on springs from lines and gravity, as main inputs for the physics engine. The intention of those projects was to investigate particle-spring systems (Kilian A. and Ochsendorf J, 2005) behavior with real time simulation, using Kangaroo plug-in for the form-finding and surface relaxation as architects/engineers Frei Otto and Antoni Gaudi have used and Robert Hooke discovered.

6. Digital Manufacturing

In this workflow, we introduce participants to the production process by testing different digital manufacturing techniques. Participants were introduced to various types of CNC machines including a punching machine, large laser-cutting, bending machine, and experience with many materials like steel, aluminium [fig. 1].
Furthermore, the theoretical classes include parametric methods to orientate 3d geometry for the production of CAD drawings. Those methods include unrolling curved surfaces, bending stripes, folding elements and orienting components onto 2d material sheets. Those strategies are always related with the connection system. The most challenging part usually is to understand parametrically how to find the intersections and geometry numbering that would serve as of the connection and assembly order.

During this phase we usually visit various local industries or invite them to lecture in order to take advantage of their knowledge and expertise, to optimize our designs related to the cost and possibilities. During previous workshops we have visited: Elval (Oct. 2014), the biggest aluminium manufacturing company in Greece, Elval Colour (Oct, 2014), a company specialized in ACP production, Veta S.A, a company providing CNC services especially for metal, Etem, specialized in aluminium profiles extrusion, Metalso, a company specialized in metal products and smaller ones that provide CNC services.

7. Automate cutting drawings for fabrication

The preparation of the cutting drawing parametrically is important to update latest adjustment and elements overall the need to be labeled using a numerical system, while still in 3d and then based on the geometry and design technique used, to be oriented or unrolled with their number onto the specific dimension of each material sheet. Sometimes this system tells us how to develop the connection system. For example, it could be stripes with tabs (ears) or components connected with screws and bulbs, rivets or cutting lines.

At the same time, the connection technique or independent element has to be taken into consideration depending upon the material properties and tolerances already chosen. Sometimes, the joint is designed, either as a tab, or ear, slit or holes, after the parts are unrolled and oriented; however, the decision is already made from the beginning, based on the design intention.
Nesting in fabrication is a crucial process to follow after having all elements oriented. This process permits a precise knowledge of the amount of material to be used, based on the material specifications that the industry provides. We try to use open source software for this process, but in some cases the work is done manually.

Together with the material, it is also necessary for the machine to be specified (CNC routing, punching, laser cutter) based on the material chosen and the design technique. Some trials are using the same design technique but with a different manufacturing method, or different material choice, in order to make decisions for the design and reduce fabrication costs.

Various materials like wood, polypropylene, Plexiglas, aluminium, and paper have been tested with the laser-cutting technique, allowing design feedback of the connection system and tolerance.

Drawings are parametrically designed so that all processes are automated. The production drawings, including the smallest details, take into account material cost, cutting machine time and the assembly process. The fact that all pieces are different always adds extra difficulty and complexity in the whole process.

8. Organizing for the assembly processes

From the projects that students had designed parametrically, there have been quite a few componential organizations, for the drawings to be sent for fabrication, but the order in which they have to be assembled is critical, taking into account the weight of the structure and the tolerances of the construction. Some constructs require material folding in different angles, where, according design, they need to be closed with screws or joints, before they are located in the main structure [Fig. 2].

Figure 2. A Pieces set up at TheBox and B,C participants assembling Calycas, Athens.
It is also useful to have 2d printed assembly order diagrams with a numbering code system and the 3d model in front, to understand the location of each component in 3d space.

Most important during this assembly phase is the coordination, especially if there is a time limit to come up with solutions in a practical way, to resolve various issues related to the design, order of assembly, scale, forces, and necessary tools. Here, we understand how important it is to have a prototype previously, to have the reaction of the whole assembly process.

9. Selection of constructed student projects

Some constructs serve as case studies of different workflows, which used either parts or combinations of the exercises and have been applied to constructed projects.

This section selects some case studies based on their design process, strategies used and particular interests, developed from 2012 to 2014.

Some projects evolving from applying series of transformations, “Transforming and waffle morphologies”, with the idea of sectioning, contouring and intersecting profiles with the purpose of making a bookshelf or a plexiglas table [fig.3].

Figure 3. A. Christianis, library, mdf. B. Moutsokou, Chatzouli, Kanetsou, table, plexiglass.

Other students’ projects are based on a pre-defined component propagated into a twisted box applied to a surface subdivided, “Propagating bi-dimensional components”, even though it does not perform very accurately nor does it have control of the geometry, but it’s a quick way to construct a component propagation into a surface with flexible material[fig. 4].
Also based on doubly-curved surfaces “Diagrid structures and tridimensional component propagation” projects had adopted parametrically one or more components propagated along a surface in U and V directions, according to each face vertex, its normal and a propagation pattern [fig.5-6].
Projects based on “Mathematical functions” like metaballs, voronoi, vector attractors, and magnetic fields, are using group distances and sets of points to lines. The challenge of these projects has been the translation to material fabrication [fig.7].

Figure 7. A-B. Valsamidou, table, mdf. C. Leonidou, light, paper.

Several projects are relaying in two processes explorations of “Dynamic relaxation and stripes morphologies”. First, in the dynamic relaxation of quadrangular meshes, as a method for form-finding the final shape parametrically, with the main objective of separating it is in vertical and horizontal stripes, and second to design a pattern that would serve both for connecting the stripes and for the design [fig. 8].

Figure 8. A. Eleftheriadou, Giouri, light, paper. B. Valsamidou, Pallis, Papasotiriou, light, polypropylene. C. Makriyiannis, light, polypropylene.

The latest exploration on “Dynamic relaxation and components” in contrast to the previous projects, followed a different workflow, because the project was a pavillion scale and all participants contributed to the materialization. The process combined 3d components propagation over a catenary system. The objective was to emphasize in the design process a vault structure based on three systems: A self-supporting triangular grid with structural rigidity made of aluminium profiles, a connection element, joint or disc made of ACPs and a hexagonal folded component made of ACPs [fig. 9].
In this project, the collaboration with the engineering company was effective, considering the characteristics and performance of aluminium and ACP and the distribution of forces and loads along the joints.

10. Discussions

Experiments in the workshops can be enhanced introducing various methods of structural and environmental analyses to inform the design, in terms of form-finding and understanding where the structure needs less or additional material. The workflow of design for digital fabrication can be optimized in terms of time and cost and enriched with inputs from different interdisciplinary collaboration.

In the previous workshops, we had experienced two teaching methods, team projects and one project for all the students. We have identified that people working in teams or independently, like to spend more time in the design and parametric process and less in making the fabrication drawings parametric as well, which in fact is the most challenging part. On the other hand, when working with one single project, the workflow is more fluid since there has been previous coordination with the cutting machines to be able to make the fabrication files also parametric and have a feedback of cost and cutting time analysis.

The final comments are made at the exhibition. At the end of each workshop we organize an open presentation of the last and previous workshop projects in a gallery. The students show a presentation for each project to explain the design process, fabrication and assembly technique used. The exhibition permits comments between invited architects, teachers, industry, and professionals, around the table to critique each project in terms of how the project could be mass produced and to what degree the fabrication methods could be customized.
Another purpose of the exhibition is to encourage the students to network with possible clients and projects. Finally, project images were uploaded in the workshop’s website so they can have them as links to their own portfolio.

Manufacturing industries in general are open to a degree to collaboration, experimentation and exchange of knowledge. However, the cad-cam software standards differ among companies due to their machines programs, causing delays and extra work. There is a need for further communication of exchanging drawings to make the process more productive and efficient.

To master the parametric workflow for design to digital fabrication requires a level of skill. As Bob Sheil mentions “If architectural designers do not grasp the center of building production by taking command of the art and craft of construction, when now they are offered the chance, who will”? (Sheil, 2005).
1 Notes

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