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Experimentation, Prototyping and Digital Technologies towards 1:1 in architectural education

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Abstract

Within education, and in relation to the physical-digital dialogue, we can observe the emergence of new tools, or tool sets, that facilitate experimentation in architectural education, among these, the Fab Lab movement, where 1:1 scale prototyping in construction become more accessible. The Institute for Advanced Architecture of Catalonia, considered the frontrunners in the integration of this mission within their architectural and construction based educational programs, bring materialising design to the centre of their educational methodology. Based on this, IAAC educational programs explore and produce a large series of experiments and prototypes, aiming to propose a different paradigm to the current productive system. This paper analyses series of projects co-developed by students, staff and industry collaborators with this aim. Through a design/build methodology the paper exhibits the importance of this approach to not only envision the future habitat of our society, but also to build it in the present.

Keywords: *technology, ICT tools, active methodologies, design/build, digital fabrication.*

Fig. 1 Iaac students prototyping with robotic fabrication. Source: Iaac OTF, Open Thesis Fabrication (2017)

Introduction

Throughout the course of History we can observe that each technological evolution, impacting a deep change in the way we produce things and our relationship to what we are producing, comes a societal revolution, responding to this change. From the Industrial revolution - incrementing production and lowering costs -, which brought with it the profound change moving towards linear production systems, based on an extractive approach, the foundation for the consumer based society, we can observe the response through the counterculture Hippie movement. The Hippie movement broke away from the time's societal and organizational codes, laying out the foundation for a new form of cohabitation, that aimed to liberate the people from the oppressive societal expectations, giving them a space to manifest vitality through playful acts. With this movement, came a series of new age learning environments which were profoundly influenced by the concept of experimentation in the architectural realm, from materials to new forms of living, to name a few, Arcosanti in Arizona, the chilean Ciudad Abierta, ICSID in Ibiza, bringing a highly experimental approach into a field of education, and inviting us to question the methods and approaches of architectural education on a whole. All these experiments came across the basic idea of 1:1 prototypes that fostered an existencial, symbolic hybrid laboratory.

Similarly, with the digital revolution, we can observe the emergence of an information society, driven by Information and Communication Technologies and the consequent "information explosion" - a substantial increase in the amount of data and information published, and the consequent increment in its accessibility to the broader public - which has profoundly impacted societal organization in all its realms, including that of education. From the experimental approaches in the physical and material world brought forth with the Hippie movement, with the information society, we see this response transpose from the physical realm to the digital one, each feeding the other, and entering an experimental dialogue.

In the specific framework of education, and in relation to the physical-digital dialogue, we can observe the emergence of new tools, or tool sets, that further facilitate this approach of experimentation in architectural education, among these open source software and the Fab Lab movement, creating a scenario where prototyping and 1:1 scale construction become more accessible to a broader range of people. The fab lab mission, based on a global network of fabrication laboratories, offers access to tools and knowledge to educate, innovate and invent using technology and digital fabrication to allow anyone to make (almost) anything.

Within this framework, and in the European context, the Institute for Advanced Architecture of Catalonia, home to the first Fab Lab in EU (Fab Lab Barcelona), are considered the frontrunners, in the integration of the Fab Lab mission within their architectural and construction based educational programs, bringing the aim of materialising design - prototyping - to the centre of their educational methodology. This in turn is associated to a central agenda for the Institute around the topic of Self-Sufficiency, explored through diverse scales of operation, and with the aim of empowering people to make real change in/for/with a performative habitat, evolving towards a positive future.

IAAC educational methodology approach is based on the following five pillars:

1. SYSTEMIC DESIGN based in research and system theory that work in multi-disciplinary and multi-scalar design context.
2. LEARNING BY DOING in collaboration with the industry, allowing students to work with real case studies and to explore and practice with existing data, technologies and materials in a hands-on approach.
3. SHARING INFORMATION, to support a multidirectional and multispatial pedagogical learning based in the circulation and exchange of data. Educational formats are globally connected through networks of communication that engage with both local and international programs and projects.
4. ADAPTABILITY of the research and educational programs, to fit the constantly evolving context of society and technology. Students learn to adapt and evolve in a dynamic environment offered by the school.
5. HORIZONTAL STRUCTURE. Prototyping requires massive interaction and active methodologies. All the actors of this process, from students to academics, become researchers who learn together.

Based on this methodology, IAAC has explored and produced a large series of experiments and prototypes within its educational programs, always with the goal to propose a different paradigm to the current productive system. This paper analyses in detail a series of projects based on 1:1 prototypes co-developed by students, staff and industry collaborators with this aim, among these:

1. **“Nomad Folding Flax Pavilion”** (2017, Nowhere Festival, Desert de los Monegros).
2. **“Digital Adobe”** (2018, Valldaura Lab, Collserola Park).
3. **“Urban Orchard”** (2016, Barcelona).

Analysing the methodology of these projects and comparing these with teaching experiments of the past century, this paper explores the issues and best practices, focussing on the IAAC approaches to prototyping with students. Through a design/build methodology the paper exhibits the opportunity and importance of this approach to not only envision the future habitat of our society, but also to build it in the present.

1. Nomad Folding Flax Pavilion

Fig. 2 Nomad Folding Flax Pavilion erected in the desert of Monegros, Zaragoza. Photo by Ji Won Jun, (2017)

Nomad Folding Flax Pavilion (NFFP) explores the agency and new potentials of natural materials developing a digitally manufactured bio-composite for lightweight construction. Here, robotic fabrication and bio-composite materials, have been used as an experimental basis to develop novel fabrication protocols for performative architecture. Beginning with 1:1 scale probes and material tests, NFFP's journey culminated with its erection and use as a public and community space during five days in the desert of Monegros.

A team of 18 students and 2 tutors, with the aid of digital, structural and biosynthetic experts developed the design during a period of 9 weeks. The tasks at hand were divided thematically, each one under the responsibility of 2-3 students: shape, structure, construction details, selection and production of biosynthetic materials, digital production, transportation, and budget management. Each week the whole team met and discussed the progress of the full pavilion, addressing problems, making decisions and programming next week objectives.

The NFFP design model was developed around the structural value of origami shapes. Rather that aiming towards a specific shape, the innate structure of folding has been used to generate the form. The purpose of the pavilion is to create a light weight bio-composite structure, meaning that organic materials are to be used to generate a structural form that can be made, fabricated and manoeuvred by people. By creating this pavilion in a series of repeated sections, the form can be moved and constructed with ease.

The structural issues revolve largely around the transportation of the pavilion from the Fab Lab to the ultimate location in the desert. Beyond the limits put on the scale of the pavilion by the fabrication machine, the size is also restricted by truck transporting the pieces. While it is ideal to fabricate as many fixed joints as possible at IaaC's Fab Lab, these restrictions have led to alternative construction details to be made, in order to give this flexibility.

The optimisation of the structure came from increasing the depth of folds in relation to maximising the usable floor plate. The deeper the bends, the greater the inherent strength of the piece. Using grasshopper, these relationships have been able to be digitally tested and perfected.

The bio-composite is achieved through the combination of timber frames, jute fibres and resin.

The material used for the resin in the pavilion is Colofono, which is a combination of pine resin and olive oil. The pine resin itself is too brittle to work with on its own, therefore, olive oil has been added in order to plasticise the composition. The olive oil has high oleic acid, which helps to make the material malleable.

Tests were conducted to establish the optimum combination of materials. A recipe of 90% pine resin to 10% olive oil has been established to be the best blend for the fabrication process, to apply to the jute and fly fibres; it is strong and the brittleness of the material is lowered.

This was tested to work best with the Kuka tool, which is necessary for the weaving of the jute thread. The robotic arm has 6 points of rotation to have 360 degree access to the timber base. Working in X, Y + Z axis, this tool has greater flexibility than common place fabrication tools such as a CNC machine, as well as being more efficient than manual processes. For this project, the robotic arm is used to weave the jute thread based on a computationally generated pattern. These threads are to be sandwiched between wooden panels to give the structure the ability to fold and hold.

NFFP not only protected us from 40ºC temperature, stormy rains and burning sun, but most importantly, built a community. Students worked together in a horizontal structure with intensive interaction. It resulted in great engagement with the course and built strong relations between all the actors of the process that is still present. NFFP allowed students to engage with issues they would then go on to encounter in their professional development, such as transportation, accessibility, material constraints, etc, yet engaging with these in the safety of a research and education environment, allowing them to troubleshoot and learn from each other, as well as the professional figures interacting in the project.

2. Digital Adobe

Fig. 3 Digital Adobe final prototype at Valldaura Labs, Bcn. Source: Iaac OTF, Open Thesis Fabrication (2018)

Digital Adobe is a research on earth 3D printing for performative habitat. The additive manufacturing technology developed at IAAC, enables to customize the form of a building on multiple scales, from the global form, to the resolution of the section of the wall. Such freedom of details allows for the creation of highly performative structural and passive/climatic behavior. The research was concluded with the construction of a 1:1 prototype of a performative wall 5m tall that adapt its morphology to localized structural and climatic needs.

The research has been developed by 8 students, 5 faculty and 5 partners within the Open Thesis Fabrication (OTF) 2017-18, a 6 month long program focused on 3D Printing Architecture. The opportunity to have students focused so long and on such a clear research topic allows to bring the students further into research and innovation, beyond the reproduction of existing knowledge and into the creation of new one.

Students are introduced to technical topics (such as structural performance, climatic performance, 3D Printing parameters, Matter, etc..) in a series of hands-on workshops, each one of a week long dedicated to only one topic, where students are driven in a series of simple exercises that evidence the importance of each parameters in regard to the final performance. For example students are driven to explore how geometry influence structural performance by 3dprinting a large series of shapes until collapse and to then analyse the relation between mode of failure and geometrical inertia.

In parallel, students are driven to develop their own research agenda based on physical experimentation at 1:1 scale. Combining Rapid prototyping (3d printing) and quick evaluation methods (thermal camera, open source sensor, etc…), the experimental setup allows for fast cycle of iteration and exploration backed by reliable data.

In a third line of research, students are driven to develop their own architectural design within a more classic studio course of architecture, but oriented to discover design methodology specific to 3D printing.

Towards the end of the course, the work developed in each research line is brought together in a common project that is then materialize as a single prototype that can demonstrate the validity of all previous developed work.

This course structure where students are initially dispersed between different scales and topics, to finally be driven to channel their efforts into one construction, have proven to be a strong vector of innovation that are demonstrated with large scale prototype. On the other side, students can become lost and confused in the process, thus requiring faculty to have a very clear agenda with goals that need to be repeated often. It also requires a lot of flexibility from faculty and the institution to handle unexpected outcomes, challenges and social cohesion within the group of students. In this regard digital construction and digital management help faculty to coordinate better students and control the outcome before and during the construction process.

3. Urban Orchard

Fig. 4 Urban Orchard final prototype. Source: Iaac OTF, Open Thesis Fabrication (2016)

The pavilion is the prototype of a new form of urban agriculture based on aquaponics: a symbiotic system where breeding fish is combined with the soilless cultivation of plants and vegetables.

The pavilion demonstrates a concept in which soilless aquaponic system could be cultivated over building roofs as a habitable space in itself by growing the plants on top of the structure. Compared to traditional green houses, the plantation area increased tremendously by using the surface area of the structure and the production rate increased manifold by introducing aquaponic system.

Water is distributed to all parts of pavilion consuming little energy as gravitational forces assist the designed slopes to naturally distribute the water to all parts of the structure. Connection to an overhead water tank in building can transform this into an almost zero energy concept. This system could be implemented as a whole or as independent self contained module.

The design of the pavilion has been optimized in order to maximize the solar exposition of the plants, both on the surface and in the interior of the pavilion.

The form has been developed following wind and solar analysis. The design of the wooden structure allows the mounting of the aquaponic systems allowing the flow of water along the flow of lines in the structure. The facets of the wooden structure are designed to capture the ideal solar radiation suited for winters and summers. Play of shadows through the wooden structure avoids the excess radiation onto the plants during summers. Scattered wooden members on the top of the pavilion allow solar radiation to evenly reach the plants grown on the pavilion.

The pavilion is divided into three major components: aquaponic system, silicon skin and wooden structure. Each perform a primary function and form the framework for the other component to function.

The realization of the Digital Urban Orchard involved computational methods and robotic fabrication tools. Hence the implementation of a 1:1 scale prototype allowing to test techniques and materials on real scale. The resulting form was manageable to fabricate, realized using sticks of Redwood of Flanders (45×45 mm). The Pavilion's design combines solar/wind shape optimization, structural logics, the robotic fabrication constraints together with the in-situ manual assembly. This last step splits the structure in 12 different bow-shaped sections: they are pulled together and manually screwed in position.

This cocoon-shape hidden in between a misleading undifferentiated amount of wooden slats manifold structural purposes and functional ones. The sticks are distinguished in main trusses, structural stiffeners, plants supports, skin holders, furniture supports and platform beams.

In the light of the previous experience of the Fusta Robòtica Pavilion 2015, the IAAC researchers improved the final robotic manufacturing process and they succeed to optimize the production process, mainly reducing the scrap's length, using the most part of the material. Each wooden stick is handled throughout one single robotic fabrication loop: picking, cutting and dropping. According to the respective final sticks positions and functions, they are selected from one out of the three starting sticks, provided by the custom made wood-feeder. They are then cut into various and always different lengths and their end edges are shaped with different 3-dimensional angled cuts. Thus each stick, varying each time the fabrication loop, informs the robotic fabrication code.

The first phase of construction consisted of the robotic fabrication of the structure out of 1680 sticks of wood during 60 hours of robotic fabrication.

During the following phases of the construction, the pavilion will be complemented by a transparent protective skin self responding to the internal and external environmental conditions and the integration of the farming products with plants and fish. This membrane on top of the wooden structure controls the ventilation air inside the pavilion. Sensors with the help of arduino control the temperature and humidity by initiating the active inflation and deflation mechanism in the skin to maintain optimum temperature needed for the growth of the plants on the pavilion.

A simple network of pipes mounted on the wooden structure allows the plants to grow. Water from the aquaculture system in the fish tank is fed to the hydroponic system mounted on the structure, where the by-products are broken down by nitrification bacteria into nitrates and nitrites, which are utilized by the plants as nutrients, and the water is then recirculated back to the aquaculture system in the fish tank.

4. Conclusions

In the light of these three educational experiences, based on the construction of 1:1 scale prototypes, all in fact digital pavilions, we can see the emergence of a series of pointers underlining the importance in an educational scenario, to work with this scale. The IaaC Master students fundamentally have the opportunity to build their first - in most cases - built structure, in the sense that they take on the challenge of each related phase of this process, developing a comprehensive understanding, learning by doing, of what the construction sector in fact deals with as a whole. Furthermore, this opportunity is put forth to them in an educational and research environment, which allows them not only to explore the above complexities in a “safe” environment, but also allows them to explore this field without limiting their actuation in relation to established processes.

The pillars of these experiences are outlined as follows:

Innovation in Academia: Working in an academic environment liberate students and faculty from legal barriers and many other constraints encountered in professional project, allowing a suitable freedom to be creative, to discover, to propose, to test, to fail, to learn and finally to innovate.

Prototyping at 1:1: Working at 1:1 scale with material, machines, budget and schedules, allows students to design architecture with real conditions usually not found in student’s project. Prototyping can be use to demonstrate innovative ideas viability.

Digital Production: Digital design, simulation and fabrication allows for fast cycle of prototyping, accelerating innovation and validation phase.

Inspiration and Support: Teacher to guide; guests to inspire and assistant to support the creative process of the student.

Evangelism: Students often embrace the innovative prototype as a manifest for a new architecture in line with our contemporary respect of the planet resources and human community. Empowered students continue after the class to promote the same idea. sometimes becoming the next teacher of those concepts.

Stimulating environment: Exposed to different cultures (multinational), different professionals (teachers, researchers, practitioners. industry, users, etc...), and different disciplines (architecture, engineering, crafts, material science, etc…) students are exposed to a stimulating environment for innovation.

Collaboration between students and Industry: Is great for students to get in contact with the real world and good for industry to explore new technology and innovate without costly investment. But often there is a discrepancy between industry expectations and students work ethics that have to be very well managed and planned by the faculty, requiring a longer timeline for construction and the possibility to get external support from the rest of the institution to actually deliver if students fails to do so.

Community: The work in group and the self-organisation of students within the project are also key learning aspect of the experience, generator of a specific bounds between students, seeds for a new community.

Fab Construction: DIY and maker spirit linked to Circular design applied to the construction sector, where inhabitants would build their own construction with local material and global digital knowledge. A vernacular architecture reinvented in the digital era.

To conclude, it is important to understand the broader impacts of this process, where we professors become fellow researchers, all learning from the same experiences in a community and sharing our experiences with the next generation of architects, finally shaping together the future of the discipline as a whole.

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