Sensitive Shelters: Poetics of Interaction

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This paper describes and reflects about a workshop activity in the field of Digital Manufacturing technologies to build responsive shelters that interact with their users and the environment. It addresses a teaching strategy intended to overcome tooling or the simple use of instruments and proposes instead to frame the production of objects using a new language, or a new operative strategy, directly linked to the production of the objects. It addresses a teaching strategy behind the workshop two main levels: first, by the development of technical skills by means of an operative action directly linked to the production of the object, and not apart from the action of making it (as in learning first and applying later). And second - and no less important -, it helped foster the maturation of critical thinking arising from the creation of a dynamic object of architecture - with moving parts and programmed to respond to its users.

Keywords: Digital Fabrication, Parametric Design, Responsive Architecture, Sensitive Shelters

INTRODUCTION

Digital simulation and fabrication tools can empower architects to regain awareness of how things are built, understanding the architectural modes of production. Traditional design process using analogue methods seldom the person who designs manufactures and builds the project is the same. With the digital integration (Kolarevic 2003), processes can have a wider interference in project. Indeed, visual programming itself, commonly present in parametric design, with its intensive use of diagrams, helps shift emphasis from form to process (just as diagrams in contemporary architecture discourse so often do). This workshop, therefore, was not about teaching how to operate software or how to use digital cutting tools or 3D printers. To overcome a simple and empty technical discourse implies the search for new languages, in order to explore the new operational possibilities of the new tools, maybe most notably the embodiment of processes in architectural spaces. A Flusserian approach of meddling with the "black box" is used to subvert its "program" and re-appropriate the technology from the artist's point of view (Flusser 2011).

The increased use of parametric design and digital fabrication technologies is not intrinsically bound to produce any specific result - as with any technology, it depends on how we choose to use them.
Although new technologies can support the current architectural production, that still oscillates between narrative fragmentation and super-modern compactness (Moneo 1999); they may also become a major tool in the service of bland real estate developments. The workshop intended to explore new techniques searching for new paradigms to change (or at the very least challenge) the current architectural discourse. These tools can modify the modes of representation, the use of the materials, the production process and finally the very understanding of architectural form. The idea to couple visual abstract concepts (diagrams) with construction, results that these processes somehow subvert the Albertian separation of notation and construction that once was essential to the profession of Architecture (Carpo 2011). They therefore place the current critical systems in a crisis situation and provide a new path about Architectural processes and the language associate with them.

**DIGITAL DESIGN AND FABRICATION PROCEDURES**

When LAMO - Laboratório Modelos e Fabricação Digital (Laboratory of Fabrication and Modeling) acquired the first digital manufacturing machines, learning parametric design would appear to solve any problem regarding the production of innovative contemporary architecture. However, after a while we realized - with a feeling of déjà vu - that this discussion was very similar to the one that started some 30 years ago when the computer aided design (CAD) was introduced in professional practice and academia. Now, as then, the simple use of more technologically advanced tools does not mean that the discipline has absorbed the specificity of the new technologies.

The ability to automate design procedures to respond to environmental demands also does not mean by itself a better design. Exploring new methods to improve quality, social justice or the forefront of thought require, in addition to proficiency, a methodological review of the act of design that makes the practice. The new digital processes allow the exploration of parametric solutions that surpass the traditional sequential logic of Problem> Project> Building resulting in a single solution. The traditional mode of design, based on paper documentation produced by someone that is later used by another one to fabricate the parts and eventually the object is built by a third person, induces communication and learning gaps that can successfully be overcome with digital integration (Kolarevic 2013). Moreover, as Carpo notices (2011, 44-45), digital fabrication challenges the Albertian principle of separation between notation and building, as architects design and build at the same time. As Dollens (2002, 106) notes, in this scenario conceptual design and digital fabrication originate in the same intellectual and representational gesture, as exemplified by the architecture explorations in digital fabrication and algorithms of Bernard Cache’s Objectile.

Parametric design can generate families of solutions using new logics of modeling and modifying the design sequence (De Landa 2011). Parametrization fosters new logics of modeling, thus modifying the sequence of design with the use of mathematical-geometric functions replacing notations based on the identity between object and description; proposing instead the development of series of objects with parameter-controlled variations between them (Carpo 2011). At the same time, tinkering with functions and their parameters may be seen as an externalized black box, helping to develop the (meta) design feedback procedure proposed by Jones (1972), as reported by Barki (2006, 95), and thus help shed some light at design heuristics in general. It is also affiliated to the concept of "reflection-in-action", developed by Schön (1983), as commented by Barki (2006, 113), in the sense that those external representations made by the designer, such as drawings and models, will be reincorporated as images feeding new design alternatives - only now we can also add functions and algorithms as proto-imagetastic material. Not only they generate several new images, but they also allow some degree of randomness to be carefully introduced in the whole process, increasing the chances
of serendipitous findings.

It should be stressed that the possibility of creating an automated, optimal response of the form to external demands does not necessarily imply in a better design. Computation can also be used in passive forms of optimization - like finding a specific shape that can profit more from solar orientation, for instance. In the end, the exploration of new methods that promote building quality, social justice or an avant-garde design requires, apart from immediate knowledge about the use of tools, the ability to think critically about the whole design process. It is possible to relate this, along with the relative instability of form that can be found in parametric design and the diagrammatic expression of visual programming languages, to the multiplication of signifying processes characteristic of Somol’s “diagrammatic practice” (2010, 90). According to Somol, "the role of the architect in this model is dissipated, as he or she becomes an organizer and channeller of information”, from vertical forces (gravity, for instance) to horizontal ones (social, political, cultural and economic).

Starting from these premises, uncertainty arises on how to teach parametric design and digital fabrication in order to promote a significant paradigm shift in the architectural production, and the present research aims to improve the discourse and the method of design including these new tools and procedures. Using the CAD to emulate a manual draft is not considered a paradigm shift, as it is also no paradigm shift to simply substitute the utility
knife for a laser-cutting machine. In order to have a paradigm shift it is necessary to incorporate a discourse that legitimizes the interventions. The poetic of architecture is present in the strategy used to develop project, incorporating in the learning process the tools and digital processes. The project strategy to find design solutions requires the participants to establish an 'image as a synthesis' of project (Cache and Bergson). That image must be developed from a diagram of a mechanism provided at the beginning of the workshop. The participants are encouraged to develop a design idea from these diagrams. Participants should therefore seek, instead of a priori solutions, for solutions that derive from the use of new tools and processes taught. In this sense a theoretical and practical search that is analogue-digital incorporates new knowledge in the design process (Dolens 2002). In this sense, the culture of project instead of generic solution of generic exercises is one of the strategies used to overcome the pure instrumentalization and to go beyond exercises alien from the design context.

At the "Universidade Federal Rio de Janeiro", as in most Brazilian universities there is little awareness of the importance of the integration between digital design and manufacturing (Henriques and Bueno 2009). The training that exists is usually based on uncritical learning of software without the actual reinterpretation of design processes. Instead new tools are used in the framework of traditional processes, only aiming to improve the speed and efficiency of project development.

THE WORKSHOP PRODUCTION

The demand for a discourse or a legitimate narrative of the production is undoubtedly better than the technical option. Only this understanding would allow perceiving the change that these new instruments can bring to the project, expanding the previous possibilities. In this sense, the workshop was proposed and conducted with the intention to overcome the stage of pure exploration of digital design and manufacturing tools, and induce the search for a new conceptual method. The choice of the workshop format answered our needs to have less hierarchical relationships among participants, an intensive participation over a short time frame, and to foster quick, iterative responses from the students.

The workshop became an annual joint activity among three laboratories, LAMO, LAURD - Laboratório de Análise Urbana e Representação Digital (Laboratory of Urban Analysis and Digital Representation) and NANO - Núcleo de Arte e Novos Organismos (Nucleus of Art and New Organisms). The first two are part of the Program of Post-Graduation in Urbanism of the School of Architecture, and the latter from the School of Fine Arts, all from the Federal University of Rio de Janeiro.

The intention is to incorporate contributions from different fields such as architecture, digital arts and sciences. These different areas are exploring the new possibilities of digital to integrate in their practice. Because they possess different specificities, they find different solutions of how to incorporate the digital, therefore making it crucial to share experiences and techniques. By including these different areas, the intention is to mingle different modus operandi on the use of digital processes and instruments, thus helping redefine the design research. Apart from the variations that accompany parametric design, the workshop brought also the multiplicity of states of interactive systems to the designers' tables. From the architects' point of view, dealing with interactive structures increases the need for hands-on experimentation; but it also adds a new layer of meaning to the design. The structures not only change over time, but they have a behavior, and interact with users, forcing the participants to develop the conceptual apparatus and aesthetic vocabulary needed to design shapes, structures, feedback loops and (meaningful) movements. The underlying (diagrammatic) system must also possess a phenomenological presence, capable of triggering subjective responses from viewers. Relative to the traditional method such processes and instruments allow intervening in all project phases in an asynchronous...
sequence, unlike some previous (more traditional) methods in which the characteristics of the medium themselves favored more sequential and unidirectional design processes (Duarte et al. 2011; Oxman 2006).

The workshop targets participants with minor experience in digital design. Its public mixes undergraduate students, Master and PhD candidates and even professors, thus creating very interesting interactions in each team. It was necessary to reintroduce the concept of ‘computer aided design’, along with notions of associative and parametric design, digital fabrication and new media like Arduino, creating a different - and expanded - mindset for the participants. Arduino is responsible for making accessible the production of responsive mechanisms - and therefore the responsive shelters that ought to be designed within the 2014 edition workshop. The tutorial sessions included digital modeling with Rhinoceros and basic visual programming with Grasshopper, including various plug-ins to generate multiple design alternatives. The advantage of computer-aided manufacturing, that is, the digital integration among these programs in order to digitally control the production of physical objects, was quickly perceived by the participants after some training in the operation of the laser cutting machine and the 3d printer, as well as some basic training in carpentry techniques, metalwork and some experience with product assembly. In this context, the act of design was experienced as a digital continuum, which also influences the project itself and the sequence of operations used. The moment a line in the design is no longer just a representation, but also happens to be an actual cut line in a subsequent operation, the integrated operation acquires a new meaning.

However the starting point of the design exercise is conceptual in nature. Certain primary responsive mechanisms were suggested and the participants should - within a short but intensive period - conceive, fabricate, and assemble the solution. The design should include automated moving parts, what is only possible manufacturing and testing solutions with physical models. Thus the teaching of these different areas promotes not only the reflection during the learning and use of these new processes and tools but also requires the definition of a concept. This method originates multiple proposals that are perfected by trial and error, giving participants a valuable learning feedback. This experience can be used in the future for the student to design, cut and manufacture their projects. The participants of the exercise should develop interactive spatial sculptures or ‘follies’ (for lack of a more precise denomination) from five suggested primary responsive mechanisms, essentially names and diagrams: curtain, octopus, shell, Chinese lantern and fuchsia flower (“brinco-de-princesa", in Brazil).

The workshop was immersive - and intensive; it lasted for nine days, starting on a Saturday and finishing on the next week’s Sunday. The first four days had lectures in the morning sessions and software tutorials in the afternoon ones. Participants were divided in five teams of six people. Each group was installed in one of the working tables of LAMO, with enough space for sketchbooks, laptops and the many parts that constituted each prototype. Four teachers were responsible for the workshop, three also acting as instructors during the tutorial phase. Fifteen laboratory monitors took part in the workshop to help operate the machinery (digital and analogical) and were also responsible for the daily organization of the workshop itself. Undergraduate and graduate students showed up and worked as volunteers as well. One Lab monitor was designated for each group. The more experienced with parametric design were constantly rotating among the groups helping them as difficulties came along.

The undergraduate students participation as monitors cannot be underestimated when considering a workshop based on new technologies. Their experience arises from the daily operation of the Lab, which gives them basic skills to safely operate with different materials and techniques such as laser cutters, 3D printing, CNC routers as well as traditional
modelling hardware and tools. Besides, most of them are enthusiastic - and usually self-taught - explorers of parametric design.

The workshop also used several instructors for the tutorials on parametric design and electronics. Most of these instructors were recently graduated - with a few holding a MA degree. Apart from the software tutorials, they also gave lectures about their works and the theoretical approach they were using. The tutorials of Victor Sardenberg, Orion Campos and Verônica Natividade discussed parametric issues using Rhinoceros + Grasshopper. On the electronics sessions with Arduino and motion sensors, Lucas de Sordi was in charge of robotic tutorials (Arduino and sensors) and Marlus Araújo was responsible for addressing 3D printing and rapid prototyping. The only lecturer with Doctoral Degree was Gonçalo Henriques - who also was a tutor. He shared his practical experience highlighting the importance of computation, fabrication processes and digital integration, paving the way for new directions in future workshops. Professor Guto Nóbrega, NANO coordinator, introduced the issues of hybridization through interactivity with living organisms. Professors Andrés Passaro and Arthur Lara also presented their lectures.

We would like to consider a small digression here, in order to illustrate issues typical of new technologies - at least in the digital age. This particular type of knowledge is more widely spread among those recently graduated (or even undergraduate students) than tenured professors, for instance. There is not, at least in Rio de Janeiro, a considerable number of academic researchers that master digital fabrication and parametric design techniques yet. This handicap leads to the situation where instructional sessions have to be conducted by those recently graduated. While it does not pose a problem for those directly involved (on the contrary, it is healthy to invert the roles of teachers and students from time to time), it is not easy to have research agencies to fund transportation and hotel costs for people that possess a knowledge highly specialized but not formally acknowledged. That may indicate that those official financing and supporting channels have not yet constituted mechanisms to deal with this kind of demand linked to new technologies and, perhaps, the very spirit of fabrication and the "maker revolution".

In short, in the first days, instructors conducted basic tutorials on parametric design and digital fabrication with the participants, who also received basic training in the use of the laser cutter and the 3D printer. We presented five primary devices (curtain; octopus; shell; Chinese lantern; fuchsia flower), that served as an inspiration for five responsive designs. From the fourth day of the workshop on, at the end of each day, there as a small seminar where each team would present updated information on their concepts, ideas, mechanisms and shapes. This schedule revealed itself paramount to the proper development of each design, among other things because daily presentations demanded carefully elaborated concepts, overcoming the illusionary charm of techniques and tools. The results embodied both the knowledge and the trial and error of the workshop, going beyond the dichotomy shape-tooling.

WORKSHOP CHALLENGES: CONCEPTS, ART AND TECHNIQUES

During the workshop five propositions were developed around the theme of "sensitive shelters", that is, shelters composed of movable parts that should embody a concept in the interaction with the human presence, either with a mechanism of actuation or in the underlying geometrical explorations. Each team designed and built working mock-up prototypes.

The basic idea to go beyond basic and avoid strict sequential design thinking (from idea to shape to form, for instance) was the stimulation of integrated action in several moments of the creative process. The device - and its supporting concept - should work beyond the rhetorical level, because it had to be prototyped, that is, its parts should work properly, turning design concepts into matter. The design thus got scale and movement, and a narrative associated that should include mechanical, sensorial and algo-
Figure 2
The "Ephyra" design development (left). Design development of the "Origami" (right).

The design system comprises digital fabrication (CAM) on top of the simulation of the mechanisms (CAE) and the design conception (CAAD), simultaneously dealing with the parts and the whole.

Each design was conceived using algorithms written in visual language (Grasshopper software was used), taking into account the sensor's interfaces that would trigger associated re-actions. Light and presence sensors were used to capture data from the environment so an Arduino-based interface could transmit this data and processes the date in the CPU. The algorithm here is understood as a "soft" interface controlling the relationship between geometries and their becoming, while transmitting actions to Arduino. From this moment on, Arduino reports instructions as a "hard" interface to activate engines that spin cogs in charge of the movements of the shelter. At first, the geometry resided only in the CPU and was affected via mouse (simulating data from the environment); later the mouse was suppressed in order to have actual readings from the sensors trigger the responses on the computer screen. Finally, when the models were built, the computer's role was reduced to convert data from the environment in instructions for the actual engines, operating on a physical model, becoming thus an intermediate operator in a responsive product.

The workshop lectures reinforced the constructive issues and possibilities of built projects, connecting architectural theory and practice, showing the generation, simulation, fabrication and (responsive) interaction of project from the physical and technological point of view of the maker. Each team then tried to enhance their experiences with those solid references acquired with the lectures, and the result was a growing enthusiasm of the participants, even among those that did not master the mouse nor
the pliers. More than becoming proficient with new tools, they dealt with new ideas reconfiguring themselves from an empirical process of trial and error.

Instructors encouraged symbiotic actions between physical and digital modes of creation and production, while advising each workgroup. Each team proposed new solutions and developments and reviewed the results at a very fast pace as designs were rapidly materialized thanks to digital fabrication.

**DESIGN DISCUSSION: 5 DIAGRAMS, 5 MECHANISMS**

The core strategy of the workshop derived from the five diagrams and derived mechanisms. The five diagrams presented were also named. As Picon (2004, 118) stated, diagrams, in fact, are "inseparable from courses of action" throughout "the world appears as a field in which forces are manifest rather than static geography"; and the workshop presented the challenge of designing the object as a re-action to the environment, as a kind of "live" diagram. The result therefore should appear as an interaction between the physical and digital worlds - and they even happened to extrapolate the original diagrams at times.

**G1** - The ÉFIRA ("Ephyra"; Figure 2 Left) is a mechanism with a vertical axis in which dishes on both ends rotate in opposite directions. This movement creates a torsion in the exterior skin formed by stripes connecting the dishes. An Arduino presence sensor triggers the motion-controlling algorithm that activates the rotation engine in reverse directions at each extreme of the axis. The proximity of the user therefore causes the skin of the object to rotate and open up so he or she can enter.

**G2** - The ORIGAMI (Figure 2, right) describes a movement of simultaneous expansion from the center to the four borders in the face of a transparent cube. A leap motion potentiometer detects human presence and makes the folds open up using pulleys and cables activated by an engine. The system is mediated by an Arduino board that manages communication between sensors and the controlling algorithm.

**G3** - XTENSÃO ("Xtension"; Figure 3, left) is based...
on tensegrity structures, that is, a combination of bars and cables forming a net of continuous tension. Five pairs of bars and cables are grouped around a circle; the bars in each module stay up and are arranged in a polar array. The movement of contraction and retraction of the bars towards the center of the circle reconfigures the whole structure. Human movement and vegetable-generated impulses trigger responses from the algorithm through the Arduino board, activating a rotating engine in the center. This engine is connected to five pulleys placed along the circumference, that contract and retract the cables, thus reordering the tension - and shape - of the whole structure, since bars are pushed towards the center or the border. In the absence of stimulus, the structure returns to its initial rest state.

G4 - The CATERPILLAR (Figure 3, right) is constituted by longitudinal stripes that rest on the soil. They are sensitive to human proximity and bend themselves like a shell to welcome the visitor. The stripes modify themselves according to the distance of the stimulus. They contract or expand from the borders to the center, becoming arches. Human presence triggers a motion sensor that transmits the signal via Arduino to the algorithm, where it operates the four fuse engines that bend or stretch the stripes. As people approach the stripes, they progressively bend, relaxing as people go away.

G5 - The MUSCIPULLUS (Figure 4) emulates a carnivore plant: this shelter opens up as the visitor arrives. The shape derives from a set of vertical poles arranged in a polar array. Each pole is part of a panel, and the synchronized movement of the five panels opens up the surface when visitors arrive and close it as a trap when visitors reach the inside. The interaction of sensors and information processing are similar to the previous cases. The algorithm commands Arduino to start a central rotational engine, which, through levers, transmits movement to each of the five poles, making the carnivore plant open or close in interaction with the visitor.

The emphasis on constructive signal-processing issues in this section should not lead one to underestimate the role of the diagrams in the whole system. Either as the work was an explanatory synthesis of complex design situations or a visual rhetoric argumentative device that helped developing the designs. We should also mention the contribution of visual programming languages with the use of Grasshopper to the very possibility of designing and fabricating the shelters. They make computation with algorithms more accessible to architects, for instance, but they also make them understand form as a product of visual thinking and diagrams.

The daily observation of the rhetoric of each group to describe their designs, even when talking about their concepts, still reinforced the technological aspects. They could only stray away from those aspects as they mastered the technology. Therefore, as the workshop progressed, instead of teaching new tools, we focused on the research for new types of mimeses, developing a discourse around the concepts of bio-shapes and morphogenesis, based on proto-mechanics, sensorial algorithms.
CONCLUSIONS

The Sensitive Shelters workshop is just the starting point of a broader discussion. In broad strokes, its format tried to recover conceptual devices applied to design, integrating procedures and technologies connected to the act of building.

The intention was to overcome the mere training on the use of new tools; it was not about doing the same things with new tools, but about researching new possibilities brought by new instruments. From a Flusserian perspective (Flusser 2011), we could say that, in order to subvert the programming of the device, the programming had to be rewritten, even if using the device’s own language.

This discussion ensues that training and tutorials, and the new instruments themselves, do not automatically imply meaningful changes in architecture designs. The workshop focused in the perceived need to find a novel narrative for those new instruments, less literal and with stronger conceptual backbones to legitimate or effect an imminent paradigm shift. If the results described sound more as curiosities than revolutions, albeit interesting curiosities, it is because they indeed do not introduce enough elements to justify such shift. However, each proposition sets solid grounds for their conceptual discourse, and overcomes not only the mere “re-drafting” but also the empty yet mesmerizing hedonistic formal games.

Throughout two intense weeks, participants acquired basic proficiency in algorithmic design and digital fabrication, as well as conceived, fabricated and assembled a reduced scale prototype of their chosen design. Prototypes included mechanic parts and electronic sensors in order to allow experimentation (and troubleshooting) with actual movement and motion and presence detection, refining the design through fabrication. More than promote the use of digital tools or the reflection upon the design concept, the procedure allowed the participants of the workshop to understand how both systems can work together, fostering new modes of enquiry based on a deeper understanding of the algorithmic logic within architecture design. Apart from yet another digital tool, the process induces working with multiple empirical propositions, enhancing the usual trial and error of architecture design, something students can later employ in their designs. The feedback from the students, showing the importance of the design decisions they had to face, helps corroborate the whole experience, as demonstrated in this video recorded in the end of the workshop [1].

The results, apart from questioning traditional training as a matter of learning new tools, reinforce the need to embed a critical approach and the articulation of techniques and concepts within these systems, bringing new areas of knowledge to the architecture practice. This type of learning goes against specialized, compartmentalized knowledge: in the workshop, design solutions were tested through their construction, integrating digital and analogical practices as a single continuum, without the artificial divide that is usually imposed upon those domains.

As a challenge, we can define this workshop as a work in progress that creates the conditions for us to explore other ways of architectural production and design. In LAMO, the laser cutter was first an improved utility knife, but we soon realized that understand it that way as a conceptual mistake. The technology was to be understood as an opportunity to think differently, drawing upon the specificities of the instrument to enrich the design process.

The workshop successfully produced a critical discourse in this sense, gathering from the reunion of several practitioners and thinkers under the same roof, involved in a practical activity while bringing and refining their own reflections upon this practice. Participants were exposed to discussions from parametric design to hybridization of living organisms, including robotics and 3D printing, at the same time with the notion that these themes are all interrelated, and that each of them has possible contributions to the design of architectural objects.

This window of opportunity is in fact a network that is woven little by little, through the acquisition of technology and equipment as well as the slow yet
progressive development of knowledge and a huge will to do so. This account reminds us Benjamin’s "Angel of History" (2012 [1940]), in the sense that, as we look back, we perceive several modes of production becoming obsolete. Ours is a less nihilist point of view than Benjamin’s, our Angel not looking back in dismay but looking forward with enchantment.

(Note: cross-reference original text Angel of History: "A Klee painting named Angelus Novus shows an angel looking as though he is about to move away from something he is fixedly contemplating. His eyes are staring, his mouth is open, his wings are spread. This is how one pictures the angel of history. His face is turned toward the past. Where we perceive a chain of events, he sees one single catastrophe which keeps piling wreckage upon wreckage and hurls it in front of his feet. The angel would like to stay, awaken the dead, and make whole what has been smashed. But a storm is blowing from Paradise; it has got caught in his wings with such violence that the angel can no longer close them. The storm irresistibly propels him into the future to which his back is turned, while the pile of debris before him grows skyward. This storm is what we call progress." (Benjamin 1969)

**Future Work**

This workshop is part of a series that aims to improve upon previous experiences and further refine the theoretical and technical framework along with practical constraints of time and materials. It has already been followed by another workshop, called "Defying Gravity" (Henriques and Passaro 2016). New experiences should address more focused concepts, allowing faster response time (and more experimentation with algorithms and fabrication) from participants. Other themes include temporary interventions and tactical urbanism.
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