Toward optimization and performance: Assessing architectural design through microcontrollers

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ABSTRACT: This paper addresses responsiveness and the integration of microprocessors as a real-time assessment tool by investigating the work completed in Responsive Prototyping [RP], a design/craft studio, which was oriented toward the interface of simple interactive prototypes developed to test and assess data relative to the designs produced. Accordingly, and in order to define its pedagogical framework, students were asked to address two focal research/design questions: how do we define the concepts of "responsiveness and optimization" in architecture? And, how do we apply them in specific design studio subsets characterized by a craft component? Within this pedagogical outline, and through the use of parametric interfaces, real-time data was collected, parsed, filtered and used to provide feedback to the project delivery system via the production of responsive architectural prototypes.

KEYWORDS: Responsiveness, Optimization, Microcontrollers, Parametric.

INTRODUCTION

> "From the eye to the skin: such is the architectural itinerary proposed here. We tend to think of buildings as forms frozen in the retina or on photographic paper; but architecture appeals as much to touch as to sight. The incursion of energy into that still, crystalline picture defrosts architecture, blurring its hermetic profile and giving it a place in the world of processes and life." – Luis Fernandez-Galiano (Fernandez-Galliano, 2000; vi)

One of the essential roles of architecture is to create and build structures that holistically and systemically interact with the physical environment. Recent developments and experimentations with microprocessor technologies seem to support a type of architectural production closer to concepts such as adaptability, intelligence, and responsiveness. Yet, while those ideas have been associated to speculative parametric scenarios typically characterized by the excessive use of digi-bio-techno ornamental models, they have hardly been implemented in pedagogical subsets described by the actual physical and prototypical integration of both human and environmental agents (Fox, 2009).

While addressing basic issues of design agency, this paper primarily investigates strategies aimed to build simple interactive prototypes that can provide a preliminary environmental assessment of the design processes via the responsive analysis of the quantitative and qualitative data collected. As another integrative system that assimilates the idea of computing as a design method, interactive prototyping has the potential of becoming one of the main strategies in design research that can be effectively used as a critical and analytical design tool. In fact, the use of microcontrollers can sense the environment by receiving inputs from a variety of sensors, and consequently interact with its surroundings by controlling specific actuators. Certainly, their pedagogical use in architecture can provide to both faculty and students an opportunity to construct and test interactive prototypes in continuous feedback with the designed (Fox, 2009).

Yet, the idea of responsiveness in architectural design is not new territory. In fact, Le Corbusier and Iannis Xenakis' Philips Electronic Company Pavilion at the Brussels Expo of 1958 had been designed as a multimedia interactive architectural installation that integrated visual imagery with sound in order to create a physical and sensorial interaction with its visitors. Corbusier's intention was to "…make an Electronic Poem and a vessel containing light, color, image, rhythm and sound joined together in an organic synthesis" (Lopez, 2011). The Philips Pavilion certainly represented a valid proposal that addressed issues of architectural interaction via responsiveness, and interestingly enough this methodological and ideological framework was successively consolidated by the rise of cybernetic thinking as well as the assimilation of computational strategies applied to architecture both explored by Nicholas Negroponte at MIT. Indeed, those moments represented a true point of departure for what is now a well-established architectural methodology of applied digital technologies (Hensel, 2010).

1.0 TOWARD A PERFORMANCE ORIENTED ARCHITECTURE

> "The altered environmental conditions of today can no longer be mastered with the architectural resources of the past...Though architecture today does not fulfill its task, it is nevertheless the only decidedly peaceful profession in which synthetic thinking can be exercised on a large project without hindrance.... The relationship between biology and building is now in need of clarification due to real and practical exigencies. The problem of environment has never before been such a threat to existence. In effect, it is a biological problem." – Frei Otto (Otto, 1971; 7)

Certainly, computational and synthetic design thinking has allowed us to investigate and address some of the issues originally recognized by Frei Otto in 1971, creating a new sense of interdisciplinary, which seems to be finalized toward the creation of responsive interfaces. In fact, rather than generating a process dictated by its mere technological and technical delivery (mostly software based), computational approaches put the emphasis on the systemic and dynamic relationship between parts (Hensel, 2013). They also address research and experimentation by generating creative explorations that operate within a virtual environment controlled by algorithmic definitions. As a highly systemic methodology, computation is a technique that is symbiotically integrated with design; it is not about form, but it focuses on data driven processes that can lead to a particular mathematically controlled form. This brings up the idea of "context-derived data" that has to be understood both quantitatively and qualitatively. Yet, as in any algorithmic process, the data collected has to be filtered through specific rules open only to one specific interpretation (if…then). It is a machinic process that uses quantitative data to generate a framework characterized by elements in constant feedback to one another as well as with external stimuli (Hensel, 2010). This seemingly intelligent/responsive framework is certainly defined by spatial conditions, which use algorithms to enhance and control its overall performance reveling what criteria are met and how buildings function. Yet, before addressing the idiosyncrasies of such a methodology and its intrinsic pedagogical subsets, I believe that it is appropriate to delineate and understand the concept of performance, and the role of active agents, human and non-human.

> "The environment must be organized so that its own regeneration and reconstruction does not constantly disrupt its performance." – Christopher Alexander (Alexander, 1964; 3)

While Alexander's proposition is relevant toward an understanding of the dynamic relationships existing between morpho-tectonic conditions and performance, it does not quantify nor qualify parameters and benchmarks that may define the level of disruption within the system. Those elements have to be quantified numerically and mathematically so that a specific value can be assigned in order to define performance-based standards. However, while the idea of performance can be addressed both formally and analytically via the integration of particular software-based interfaces such as Rhino 3D, what becomes crucial is the recognition of those "active external" agents that have the potential to disrupt or facilitate particular performative outcomes. Andrew Pickering, a sociologist, philosopher and historian of science stated that:

> "One can start from the idea that the world is filled not, in the first instance with facts and observations, but with agency. The world, I want to say, is continually doing things, things that bear upon us not as observation statements upon disembodied intellects but as forces upon material beings. Think of the weather. Winds, storms, droughts, floods, heat and cold – all of these engage with our bodies as well as our minds ... Much of everyday life, I would say, has this character of coping with material agency, agency that comes at us from outside the human realm and that cannot be reduced to anything within that realm." – Andrew Pickering (Pickering 1995, 6-7)

It is clear that architecture in its physical representation needs to be understood as a systemic, spatial and material organization in constant interaction with external agents where its morphological condition is always controlled by contextual forces, which can be characterized by incredible heterogeneity. Thus, performance-oriented strategies have to address the uncertainty and variability of active external agents, which can only be controlled via complex parametric techniques so that form, or the idea of it, follows the data contextually collected. Within this framework, it is important to orient our discipline toward a new methodological and pedagogical model that more accurately takes into consideration shifts in computational production, especially as they relate to issues of interconnection and intelligent adaptation (Tedeschi, 2014). This can only happen if our understating of performance and optimization is not statically defined by checklists or tables, but it is derived by evolving external environmental parameters that can only be collected by using real-time feedback technologies. Architectural production in an age defined by computational design thinking must arrive at approaches that address transforming systems and bio-systemic interaction.

2.0 PEDAGOCIAL SUBSET: RESPONSIVE PROTOTYPING

> "It becomes possible to coordinate the operation of different systems to achieve significant efficiencies and sustainability benefits. In designing smart products, buildings, and urban systems we simultaneously consider both their synchronic and diachronic aspects." – Bill Mitchell (Kemp, 2000; 5)

In order to address and investigate both concepts of prototyping/fabrication and design agency, the pedagogical module Responsive Prototyping [RP] proposed a mediated pedagogical praxis based on the integration and use of 3D softwares such as Rhino/Grasshopper with microcontrollers, sensors, and actuators to provide students an understanding and ability to design, develop and test interactive architectural ideas in an environment characterized by heterogeneity. The course was organized around two major research questions: how do we define the concepts of "responsiveness and optimization" in architecture? And, how do we materially and tectonically apply the same conceptual frameworks in specific design studios characterized by a craft component?

Therefore, and to frame the domain and content defined by of the first question, students were asked to research specific case studies that addressed issues of architectural fabrication, responsiveness and optimization via the use of microcontroller devices capable of collecting real time data to outline specific external benchmarks. Students were also introduced, via weekly seminars, to basic concepts of electronics as well as to specific technological tools used to understand issues related to the use of microcontrollers, physical computing, scripting, and debugging to collect, monitor, and control the data recorded in Rhino/Grasshopper via Firefly. Firefly is ”a set of comprehensive software tools dedicated to bridging the gap between Grasshopper - a free plug-in for Rhino - microcontrollers and other input/output devices like web cams, mobile phones, game controllers and more. It allows near real-time data flow between the digital and physical worlds – enabling the possibility to explore virtual and physical prototypes with unprecedented fluidity.” Essentially, it enables users to graphically manipulate the data recorded by a microcontroller device so that the same data can be used to generate 3D interactive objects or devices.

Microcontrollers (Figure 1) are essentially small computers that contains processors and pin connections with input/output functions and various sensors that can interact with the physical world so that the objects designed can sense and respond to touch, position, sound, heat, and light. Because of its relative affordability and open-source nature, Responsive Prototyping studio used the Arduino Uno, a microcontroller system based on the ATMega series of chips, which allows it to be programmed via a serial connection such as a USB (Margolis, 2011). While they are designed to be relatively easy to use for people that have little to no electronic experience, its interface is primarily controlled via codes and scripts that require a basic understanding of Processing and C or C++ language.

The first step required the students to identify what they wanted to measure (light, sound, movements, humidity, etc.). Consequently, they had to get the specific sensor connected to the Arduino, upload the Processing code relative to the sensor used to make the measurements automatically. With this setup, the microcontroller provided real-time data measurements every 100 milliseconds printing the values onto the screen. Data was then copied and pasted in the row of values into Excel eventually creating line graphs needed to assess optimal benchmarks based on specific regional data sets analysis. In order to bridge the gap between the digital and the physical, Grasshopper and Firefly were used to create interactive digital environments by connecting set of components such as light sensor, LED or servos motors (servos have integrated gears and a shaft that can be precisely controlled by the microprocessor).

Figure 1: Arduino Uno Microprocessor with Sensors Kit. Source: Arduino.com

Based on the generative application of parametric design and various scripting techniques, Responsive Prototyping [RP] also explored the integrative use of parametric modeling to generate differentiated geometrical and formal solutions derived from external agents and other heterogeneous parameters (Tedeschi, 2014). This methodology allowed for a better understanding of incremental values related to both environmental and morphological relationships in a way that the students could eventually craft and activate the interdependencies between new forms in an iterative, indeterminate, complex, continuously evolving process. Indeed, computational models promoted complex interrelations between form, material, structure, space and their systems’ behavior and performance (Hensel, 2010). The scripted and parametrically defined surface structures were constituted of material and aesthetic performativity and were all controlled in Rhino 3D. Most importantly, this pedagogical framework ended up generating work that questioned, via the interpolation of large subsets of data, the relationship between form and space, and between the envelope and the content.

3.0 RESPONSIVE INTERFACES

In order to explore and investigate different strategies characterized by the use of interactive and responsive prototypes applied to particular design frameworks, students had to individually explore both fabrication and computational issues. While the two projects analyzed in this paper looked at recording and collecting traditional data values relative to motion and light intensity, their conceptual design articulation ended up being primarily based on experiential elements of human interaction (not necessary quantifiable qualitatively speaking), creating prototypical architectural installations that would respond to the interior environment while also creating a unique “phenomenological” experience for its occupants.

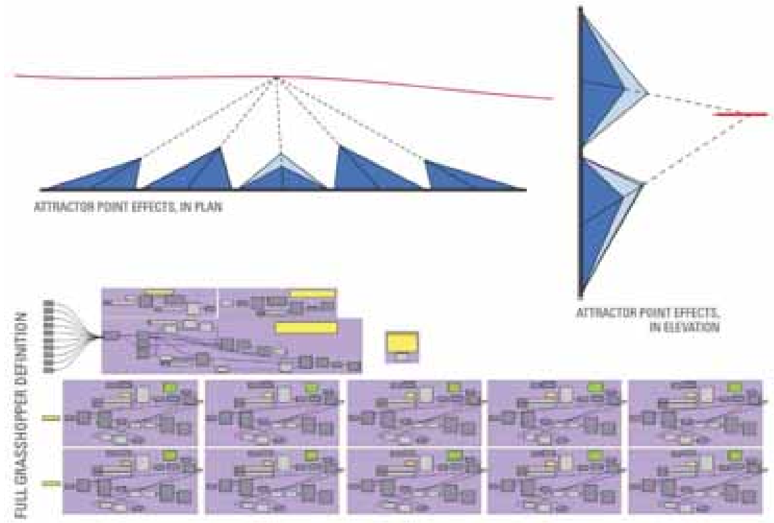

Figure 2: Reactive Architecture by Chis McLean. Source: (De Paola 2013)

Reactive Architecture (Figure 2) aimed to challenge the idea that buildings are, once built, entirely immobile and unchangeable entities in our environment that provide little to no interaction with their users. Though primarily a consequence of technology and economy (that is, the capability to change and the ability to afford it), the project analyzed the lack of meaningful alteration in our environments, which tends to produce an experience that, over time, becomes increasingly jaded. Installations and buildings that address the issue of immobility are normally unable to produce a meaningful change in the interactions they provide. They typically rely upon entirely passive methods (e.g. solar activity at Jean Nouvel’s Arab Institute), counting upon the (unreliable) actions of people to drive their actions. Even if successful, passive experiences still become jaded over time. Particularly, Reactive Architecture proposed the design of an architectural component, a wall panel, that is active and sourced specifically to the individual that uses it and that must be adaptable, such that alterations in its environment, and in the persons experiencing it in visible and variable ways.

In order to sense and measure movement, two motion sensors that detect distance were connected with the Arduino: an infrared proximity sensor and an ultrasonic range finder. Those two output components essentially sense any sort of movements and communicate numerical data back to the microcontrollers; the same data can be evaluated in Firefly via particular data components that analyze its hierarchical nature by using tree-chart components. Additionally, an infrared proximity sensor was also used to indicate the distance of interaction with the reactive surface. In fact, the sensor has both a light source (visual indicator) and a sensor; the light source bounces infrared light off objects and back to the sensor, and the time it takes the light to return is measured to indicate how far away an object is. An ultrasonic range finder fires out high frequency sound waves and listens for an echo when they hit a solid surface. By measuring the time that it takes a signal to bounce back, the ultrasonic range finder can determine the distance travelled and communicate that to the architectural prototype designed, which in return responds to the users (Margolis, 2011; 65). Rather than rely upon the initiative and curiosity of random passers-by, Reactive Architecture reaches out and engage its surroundings actively and aggressively. The design created a flexible architectural skin that stretched around areas that recorded a high presence of social gathering/motion. Additionally, low voltage LED lighting was also used to map movement in order to provide a “graphic and visual” representation of the levels of active interaction. Designed after Studio Luz’s Diva Lounge, Reactive Architecture essentially emphasized the idea that architecture could and should create opportunities for social interactions while also recording and possibly promoting a desired mood.

The Wave Wall (Figure 3) is a responsive façade that functions to provide an optimal set amount of daylight into a building located in very harsh sunlight conditions. In order to define the initial architectural and technological domain, the student analyzed the responsive facade system of Al Bahar Towers in Abu Dhabi where temperatures are steadily above 100 degrees Fahrenheit. These towers, while conventionally and programmatically organized, are shaded by a secondary lattice device that opens and closes in response to sun exposure. Thus, in order to similarly sense light and measure its intensity, the student developed a closed circuit system in which an Arduino microprocessor was connected to a photocell and a light dependent resistor called LDR (Light Dependent Resistor). This output component essentially acts just like a resistor while its resistance changes in response to how much light is collected by the photocell. In order to convert the values collected in Grasshopper via Firefly, a fixed resistor was also connected to the Arduino board to translate the analog numbers into a voltage. Thus, to design the mechanical apparatus that measured and translated the same data into a responsive device, the student had to put together a microcontroller unit based also on a 10K resistor, a breadboard, 3-4 wires used to connect the breadboard to the Arduino Uno, and a USB cable to upload a code for serial communication of external data. One of the major issues with this setup was based on the complexity of the script needed. In fact, the student had to measure both minimum and maximum range of light intensity from the photosensor and consequently map values that were either too high or too low. In order to keep the range consistent, Processing scripting was used to determine the true numerical range (average value), allowing the sensor and the Arduino to discard values not included in the same range.

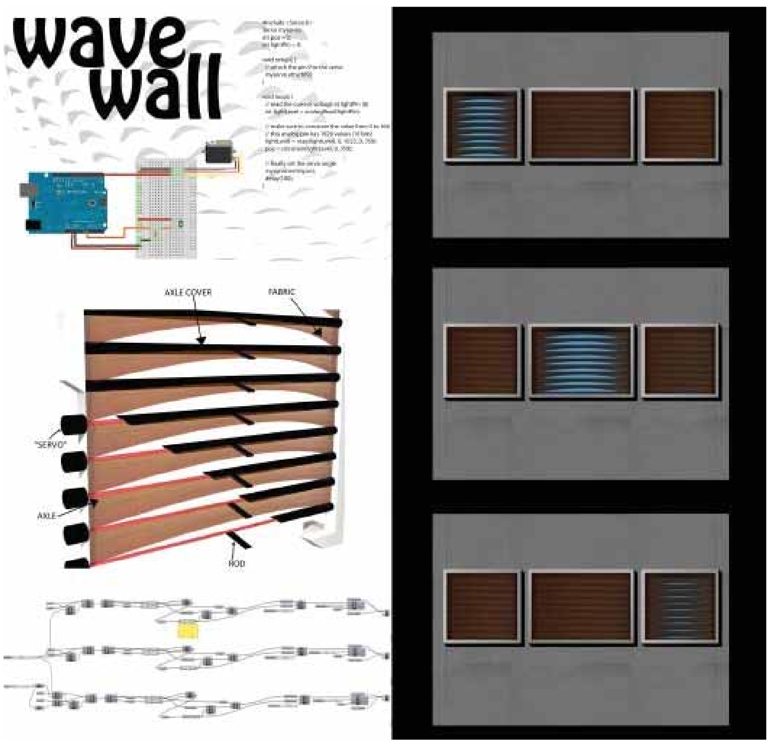

Figure 3: Wave-Wall by Will Doss. Source: (De Paola, 2013)

Again, the Arduino board uses a USB cable to send serial communication to and from a computer. When data from the Arduino is printed to the serial port via a Generic Serial Read component, Grasshopper and Firefly open the connection and read the data into a buffer and communicate it back to Grasshopper and Rhino. The Generic Serial Read component essentially returns any data being sent over the serial port. As explained before, Arduino components are specifically tailored for using Firefly Firmata outputs, which are basically sets of instructions loaded onto the board that tell all of the pins how to exchange data with Grasshopper. The data collected was then used to develop a different script that would communicate inputs and outputs to a servo motor, which basically handled the high torque rotation of the device designed to respond to light intensity. Servos are essentially small voltage motors that have an integrated gear system and shaft that can be controlled via scripting on a variance of 0 to 180 degrees. Thus, based on user-defined variables typical of particular regional comfort levels (North Louisiana in this case), the responsive prototype would open and close individual flaps to permit or deny light or potentially respond to the ambient temperature inside the building. This responsive façade was designed via integration of both microprocessors and light sensors in order to track sunlight, shading the interior spaces and also preserve views of the outdoors. Again, sensor data was collected and stored via Arduino and Firefly, and it was then processed and interpreted according to the various modes of behavior explored in Rhino/Grasshopper.

CONCLUSION

> "This makes it clear that a synergetic understanding and approach is required to unlock these complex interactions for the purpose of an instrumental approach to architectural design. It is evident that the articulation of architectures and the built environment can absorb and satisfy multi-functional and aesthetic criteria and preferences and that partitioning of space and modulation of environment are both consequences of material practice." – Michael Hensel (Hensel, 2010; 55)

In his book *Performance-Oriented Architecture*, Michael Hensel states that architecture, environment and inhabitants all perform and interact in relation to a particular active agency, which can consequently define certain morphogenetic qualities of the architectural artifacts itself (Hensel, 2013). Thus, this paper investigated strategies aimed to build simple interactive prototypes through the use of small microcontrollers to verify and test the idea of external agency and its effects on the design of small architectural prototypes. In order to effectively investigate issues of design agency, students had to develop additional technical skills like scripting and parametric modeling via plug-ins like Grasshopper and Firefly to generate viable digital and physical solution that showed different levels of adaptability and responsiveness. Conceptually speaking, computational design strategies, understood as systemic and methodological paradigms, provided a framework of complexity that linked form, function and structure and that also allowed for all of them to morphologically respond to external stimuli. Interestingly enough, the vast majority of those algorithmic models look at the self-referential organizational complexity of bio-analogues systems, whose form adaptation appears to be in constant feedback with external agents.

Yet, when we look at current pedagogical models based on computational strategies, formal analysis seems to be more important than optimization and performance. Thanks to current advancements in digital and microcontroller technologies, we have now the ability to design and create interactive environments responsive to active agents. The projects undertaken in Responsive Prototyping [RP], while characterized by a perhaps simplistic and repetitive tectonic and performative agenda are particularly important because they represent a step toward a pedagogy more open to responsiveness while addressing heterogeneity and external instabilities. Thanks to technology, architecture's ideological and conceptual playground has noticeably changed; it is now time to investigate systemic heterogeneity and performance-oriented approaches where buildings are actually "doing something" rather than merely representing it.

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