Rapid Craft

MATERIAL EXPERIMENTS TOWARDS AN INTEGRATED SENSING SKIN SYSTEM

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The distinction between matter (mechanics) and information (electronics) in the context of responsive building skins has promoted unique design protocols for integrating sensor technologies into material components. Such a distinction results in applications of remote sensing after the process of material fabrication. Sensors are commonly perceived as electronic patches which initiate mechanical output with response to electrical input. This work seeks to establish a novel approach to the application of electronics in building skins, which prioritizes material selection, behavior, and fabrication technology in relation to the required task, over post-production sensor integration. The term "Rapid Craft" is proposed to describe such design protocols which couple material behavior and fabrication in the design of responsive skins. Rapid Craft is a designation for the incorporation of craft materialization knowledge within the framework of CNC processes of fabrication. A light-sensing inflatable skin system is developed as a working prototype, which demonstrates such an approach.

1. INTRODUCTION

1.1 BACKGROUND

The classic and desired state of architectural-environmental interactive relationships is that of the sealed building envelope in a condition of little or no exchange with its environment. Recent initiatives capitalize upon sensor technologies and computational control systems that break down the received theories of static design of the building envelope. Such initiatives maximize the design potential for a more responsive approach to the building in an interactive relationship with its environment. Buildings, particularly large-scale building systems, are beginning to be seen from the point of view of establishing a responsive relationship with environmental and physical impacts (Bullivant 2005).

This paper aims at demonstrating such notions of responsiveness in building skins that possess sensate capabilities relative to climatic and other potential forces affecting their physical environment. It suggests that by departing from the conception of buildings as static products we may begin to think of buildings as organic, living entities. This re-conceptualization brings with it certain potential benefits, as well as certain complexities.

Through the development of a working prototype, this paper demonstrates how such integration may present itself through rapid and strategic digital and physical tool-customizing processes, which prioritize dynamic material behavior over electronic integration. Beyond "proof of concept" the prototype itself is treated as a "pilot experiment" for the demonstration of a "rapid craft" as a novel design methodology which unites material performance with sensate technologies, often lacking in contemporary so-called "responsive environments." For the building industry and the design disciplines this rationalization may indeed provide a dominant paradigm for production, promoting a subtle yet significant sensibility towards material and structural integrity in the process of production, fabrication and assembly. Significant, as such awareness may prove to be both more effective and efficient with regards to the way in which a building (or any artifact for that matter) may respond to its environment.

1.2 PROBLEM DEFINITION AND THEORETICAL FOUNDATIONS

1.2.1 Factory to file

In the words of David Pye, technology is "the study and extension of technique" (Pye 1968). Technique denotes a specific approach for accomplishing a given task or function by way of perceiving and putting into use material integrity and processing methods. A hierarchical approach tends to prevail where fabrication methods and material considerations are only brought into the design process as final functional solutions, rather than offering design explorations, which are generative in nature.

However, the material and technique in which a natural artifact has been formed is directly linked to its behavior (McQuaid 2005). So, ways of making things are inextricably linked to what and how they serve as final artifacts. The work of the craftsman involves the knowledge and skill-set of particular practical arts. Craft has promoted the skill and knowledge of "know-how;" it has elevated the notion of "technique" to a method of

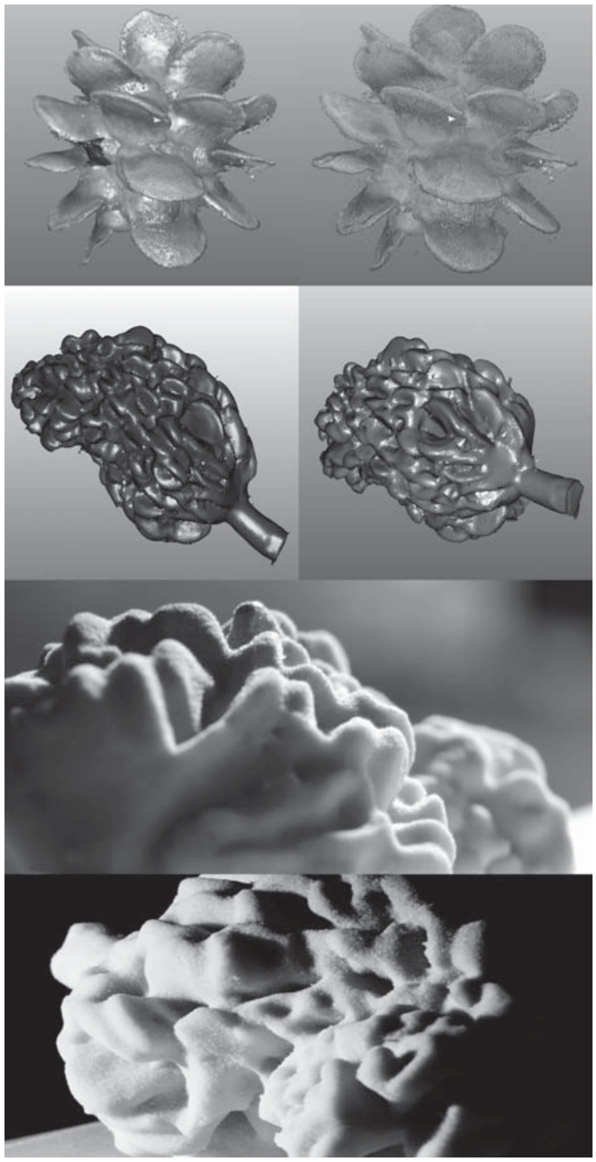

FIGURE 1 3-D scanned cones: Two types of cones were scanned in order to create a 3-D reconstruction of the natural artifacts. These reconstructions were then analyzed aiming at understanding the relation between performance and geometrical attributes.

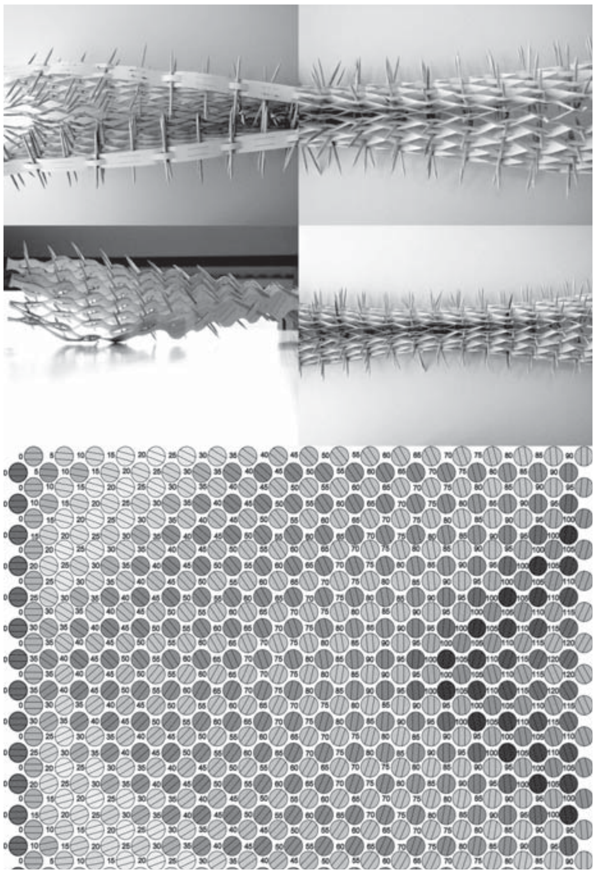

FIGURE 2 Differentiated Distribution of Assembly Slots: In this experiment, the slots used to assemble the strips are placed at different angles, such that for every slot on a given strip the angle increases gradually (from 0 to 120 degrees with a 5 degree increment). This slot layout, when the structure was assembled and extended (stretched) in one direction, resulted in a flexible doubly-curved surface. Thus, by purely controlling the slot-angle which connects the strips together, using different configuration each time, one could control the curvature of the global surface. The bottom image illustrates the slot-angle layout as a continuous map of the registered angles, color-coded from small (red-yellow) to large (purple-blue) angles. For a 180 degree difference across the length of the surface, the structure rotates from vertical to horizontal configurations.

production informed by task and function (Sheil 2005). However, in many ways it was always considered a secret-practice, a legacy. A craft of any kind that embodies the skill set and techniques of selecting and processing material is inherently apparent in the final object.

Today, rapid prototyping technologies offer this knowledge to the people. But there is obviously more to the notion of a rapid craft than simply hitting the power switch. Machining is by convention a form of execution, a final phase. "File to Factory" protocols have indeed pushed ahead our vision as designers with regards to efficient CAD/CAM/CAE processes (Schodek et al. 2005) and yet an opposite approach: "factory to file," has never been considered. In other words, machine execution should not merely be regarded simply as a service tool for materializing design but rather an *opportunity* to inform the design process as one that integrates machine-logic across all scales of production. Material choice and fabrication methods are not innocent decisions, but are rather pre-determined factors which guide the design with respect to both artifact and process from start to finish.

1.2.2 The *"PHYSYDIGI"* and the notion of ubiquitous sensing

An intelligent wall or a responsive skin is, at its simplest, an environmental manifestation of technology that is already being appropriated (Bullivant 2006). However, in much of the work generated recently which falls under the umbrella of "responsive environments" there still exists a separation, both in process and authorship, between "what" a building senses and "how" it does so.

Electronics are mostly embedded into the artifact after its production rather than considering the association between the sensors and the sensing elements of the building. In most of the work shown here, the *digital presence* (or any proof of CAD) is in most cases absent: complex geometrical form is fabricated in physical matter, and sensors are embedded within it as potentially seamless and ubiquitous elements enhancing material response to local stimuli. One of the crucial ideas that this work seeks to portray is that of *integrated electronics*. Simply put, this means that instead of "adding-on" sensors to the artifact, material choice and processing are targeted towards, and guided by, an understanding of the mechanical properties which initiate dynamic behavior.

1.2.3 Master Craftsman: Matter Craftsman

In his writings, David Pye distinguishes between "regulated" and "free" craftsmanship, the latter as he claims provides for creativity in the process of making (Pye 1968). Inherent to this distinction is the idea that craft promotes the ability to recreate and reinvent the association between tool, material and application beyond it serving as a form of execution. In this light, the rapid infiltration of technology into literally every bit of our existence has made us think twice before we write the software, or so it should. In the process of designing a sensate-responsive skin, this work integrates a wide range of skills and applications, from wood milling to the electronic programming of sensor-integrated circuits, in order to promote a holistic and integrative approach promoting a "rapid-craft."

1.2.4 Architecture and the Extended Organism

In his essay, "The gadget lover, Narcissus as Narcosis," Marshall McLuhan defined the relation between

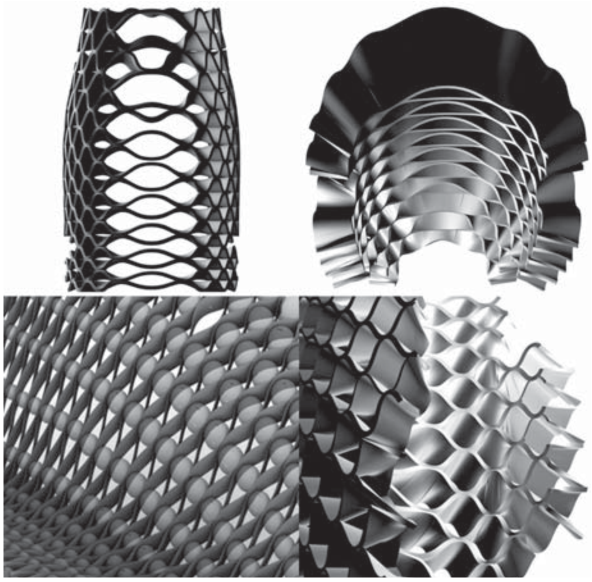

FIGURE 3 Digital Modeling of Surface Behavior: The model was generated using a parametric software package, where small sphere-like elements increase and decrease volume parametrically to allow for the simulated "stretch" effect of the surface.

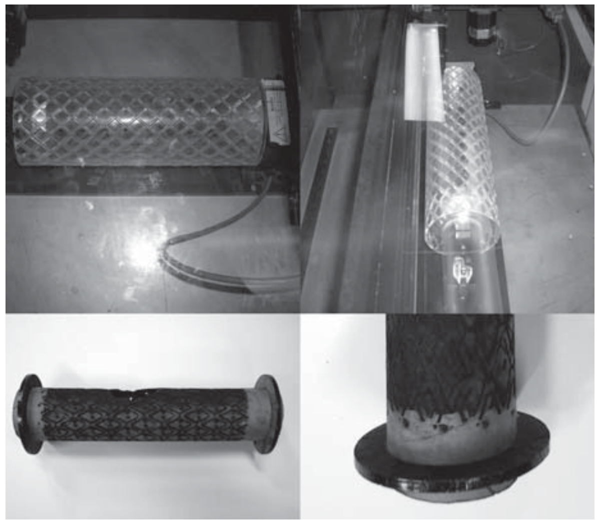

FIGURE 4 Scale Support Structure Image illustrates the cylindrically cut acrylic piece that was cut and assembled with the scale pieces.

media and self as an amalgam of tools and bodily extensions seamlessly at work (McLuhan 1964). The "servomechanism" is an adaptation of the self to its technological extensions such that a closed system is created whereby the detection of such extensions as individual entities is unattainable. In this light, the designed artifact may be perceived as an entity weighted with commensurate "extensions." The tool, technique, or technology applied for production has as much value and meaning as the artifact itself, inherently promoting explicit effects which are the result of a non-innocent affinity between machine and material.

Such affinity may extend to include behavioral attributes with regards to the environment in which such a design (whether a building or building-element) may be situated. The built environment may be perceived as a multi-faceted expression of our affinity for, and instrumentalization of, its natural resources by means of appropriation. Much has been said and written about the metaphor of the extended organism. For instance, that the edifices constructed by animals are properly extended organs of physiology (Turner 2000), or that primitive architectures are the outcome of spontaneous and intuitive local knowledge of one's own environment (Rudofsky 1964). Craft, in general, represents such an affinity between the maker and its immediate context, the environment, which is to contain the object of desire. As such, beyond its traditional description or meaning, craftsmanship may be reinterpreted as a set of instructions combining knowledge and application, matter and tools. An operational framework for processing and re-organizing material constructs. Thus, a craft of any kind may potentially serve as a guiding instruction-set, a formalism, which merges knowledge of application with an instrumentality of material organization.

1.3 AIMS AND OBJECTIVES

The aim was to construct a working prototype for a sensing building-skin which modulates its surface response to light. All mechanical and electrical elements of the prototype were designed as integrated parts, each of which was programmed and/or fabricated to fit its structural behavior and potentially control its environmental performance.

1.4 ORGANIZATION

The fabrication process of this exploration included a range of tasks and tool-customization processes which may promote a new sensibility to the integration between material, behavior and machining modes that has been termed by the author a "rapid craft." Such processes include the devising of add-on tools and the usage of multiple machining modes such as cutting, etching and scoring. Following the introductory statements which seek to establish some theoretical foundations for "rapid craft," the paper demonstrates the processes and tools used to design and fabricate the model. The second section unfolds tool customization and electronic integration processes by presenting the design-aim and the corresponding tools (CNC machines were used for that purpose). Section 3 demonstrates the final prototype, followed by a summary and conclusions.

2. PROCESS DEMONSTRATION: CNC/RP TOOLS CUSTOMIZATION AND ELECTRONIC INTEGRATION

2.1 CNC/RP DESIGN GENERATION

2.1.1 Environmental Cartographies: Analysis of Natural Artifacts [*3D Scanning and Printing*]

The project commenced as an attempt to understand how certain natural structures operate within their environment. In search for a "breathing skin" model, i.e. surface structure which would allow for global and local modulation of its parts with response to environmental stimuli, natural pinecones, which use light energy to induce motion - were 3-D scanned and modeled.

Laser scanning is accomplished by using a laser device that collects range data across a given field of registration. Active optical triangulation is one of the most common methods for acquiring range data and allows, at the same time, to generate a 3-D reconstruction out of the scanned image. Range data is produced by placing a depth value on a regular sampling lattice from the surface of the object. Then, by connecting triangular elements with the nearest neighbors, a range image is created. Figure 1 illustrates the point-cloud generated after registration.

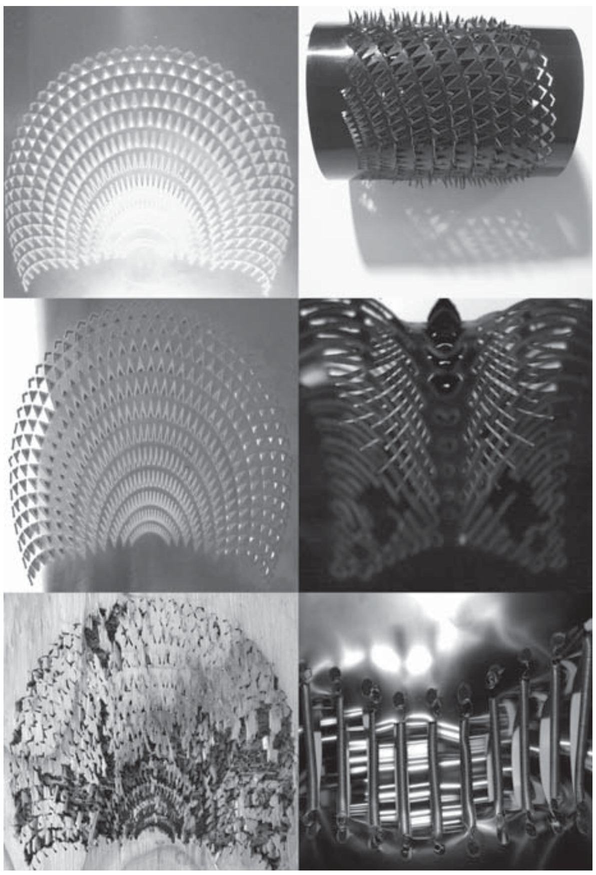

FIGURE 5 Parallel and nested etching patters in flexure structures (stainless steel and cut shim stock using the WJC)

2.1.2 Inherent Tectonics: Surface Dynamic Behavior [*Laser Cutting (LC)*]

The notion of an *inherent tectonic* implies that certain characteristics of the system at hand, which describe its construction, may be brought into consideration in the fabrication process itself. Once fabricated, the system presents a range of behaviors which have been accounted for in the fabrication and assembly process. This notion is particularly relevant when designing adaptive systems which introduce a high degree of complexity into the design. Establishing the range, increments, and limits of adaptability may be accounted for by coupling the fabrication technique with material behavior and its geometrical characteristics. The following experiments demonstrate such a notion by introducing a specific logic of cuts into the paper and stainless steel models (Figures 2 and 3), the geometry of which allows for a unique local and global structural behavior to emerge. For example, these images demonstrate how a 180 degree rotation of cut lines which connect adjacent strips, allows for the generation of curvature in the surface upon introduction of stretch.

2.1.3 Parasite Tooling by Add-On(s): Generation of Cylindrical Structure [*LC Rotary Station*]

The cylindrical structure was designed to support scale-like elements and allow for sufficient room for the inflatable bladder to be installed inside it. In order to cut the structure (fabricated from acrylic), a mandrill structure was constructed to support the acrylic tube to be cut (Figure 4). The diamond-like engravings of the surface indicate the laser registration of the tool-path as it rotates the tube in constant motion. The Rotary Station is an add-on tool which may be placed on the laser-cutter bed to allow for rotary-cutting. The gear-driven CNC Rotary Axis permits cutting profiles or tubes in different diameters. Instead of an X and a Y-axis, the laser beam is calibrated to the circumference of the tube as its Y-axis. The Rotary Station is plugged into the LC bed with a serial connection, converting all geometrical information from planar to tubular format. The cutting pattern is then unfolded in digital form to allow for the cutting process to occur (Figure 4).

2.1.4 Multiple Craft (Machining) Modes: Construction of Flexure Structure [*Water-Jet Cut/Etch (WJC/E)*]

The ability to process material in a multitude of machining modes (such as cutting, scoring, etching, etc.) allows one to achieve certain material behaviors when the material is being stretched, folded etc. In this case, stainless steel sheets were cut and etched using the water jet cutter to allow for a scale-structure which behaves like a flexure.

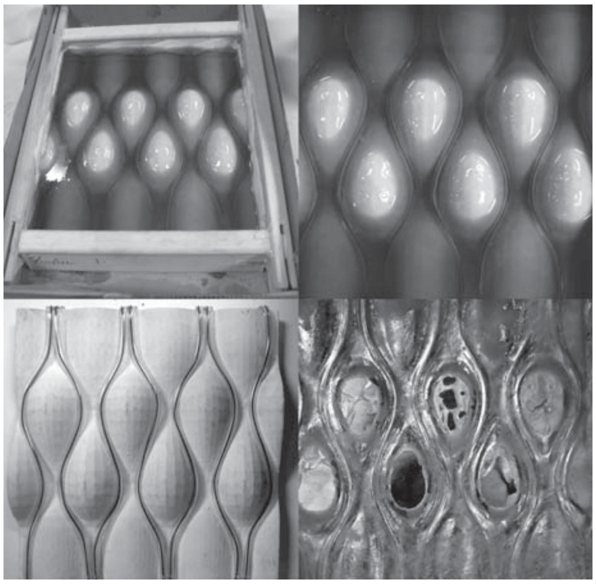

FIGURE 6 3-D printed mold with wires (inserted in plastic tubing) The composite structure allows for the incorporation of the structural elements (bent wires) within the skin (rubber), which was designed to allow for inflation "pocket" members.

Flexure structures are structures which present a large range of motion when load is applied (bending deformation, i.e., deformation by increasing curvature), and have minimal (or no) joints. In that sense, a flexure behaves much like a fabric, or a continuous mesh, allowing for local loads to propagate across its entire surface. Such structures were explored for the flexible scale surface which would deform with response to light. The initial exploration demonstrates the ability to achieve a three-dimensional structure from a two-dimensional pattern. The cut components are all identical in topology but differentiate relative to their location in the pattern, thus, initiating curvature upon folding the sheet-material itself. In addition, the sheet behaves as a flexure initially by flipping the direction of the cuts from side to side upon folding internally or externally (figure 5). Potentially, one could imagine a force-flow through those cuts which determines their orientation locally, as componentized flexure elements. This exploration seeks to devise the nesting of cuts (etched, no cut-outs) as a method for generating flexures. The material used here is shim stock (a type of plastic), which is as thin as a sheet of paper but isotropic.

2.1.5 Inherent Tectonics 2: Air Bladder Construction [*Molding / Vacuum Forming*]

The aim was to generate an interstitial skin which would consist of a semi-structural mesh and a system of inflatable bladders (Figure 6). From bottom to top the different layers consist of the following materials to form a composite fabric: (1) 3-D printed mold, modeled in 3-D and printed in the Z-Corp. (2) Flexible wires inserted in plastic tubing to form the structural elements. (3) Polyurethane mold. The process of applying the liquid plastics was repeated twice so as to allow for a double layer to be produced. Once filled with air, the inflated structure was held by the wires in the seam lines positioned in the mold.

2.2 ELECTRONICS DESIGN INTEGRATION

2.2.1 Material Stimulus (SENSE INPUT): Light Sensor Circuit Design [*Microcontroller Programming*]

The prototype was designed to convert light energy into mechanical motion. A circuit board which reads visible light levels as input data and converts them into voltage was designed (Figure 7). Voltage levels are then converted into mechanical motion (air inflation initiating skin movement) as output. An Infra-Red (IR) Phototransistor was used and a Graphic User Interface (GUI) was programmed to illustrate the step-response cycle, the curvature of which indicates capacitance value per one step (1 2 3 4 framing) over time. An additional interface was developed which converts voltage units to candelas (approximating the 1 to 5 volt range to the IR wavelength). The Processing (JAVA based software) serial library allows for the easy reading and writing of data to and from external machines. It allows two computers to send and receive data and give back the flexibility to communicate with custom microcontroller devices, using them as the input or output to the Java based *Processing* program.

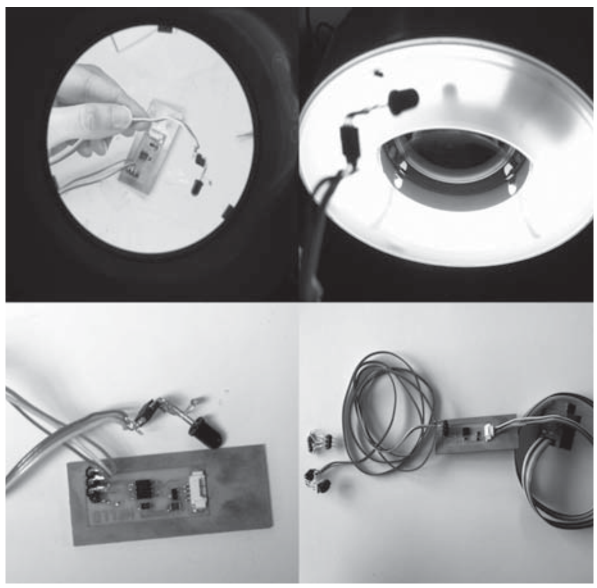

FIGURE 7 Circuit board and light sensor integration: The circuit was designed to read light levels and convert them into voltage, which in turn would allow for the inflation of bladders within the structure.

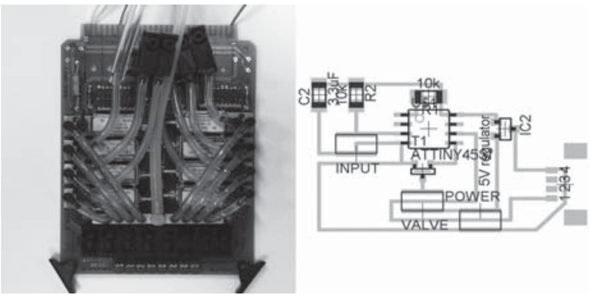

FIGURE 8 LIGHT-AIR Conversion Protocol: Image shows the solenoid valve board and the circuit board schematics.

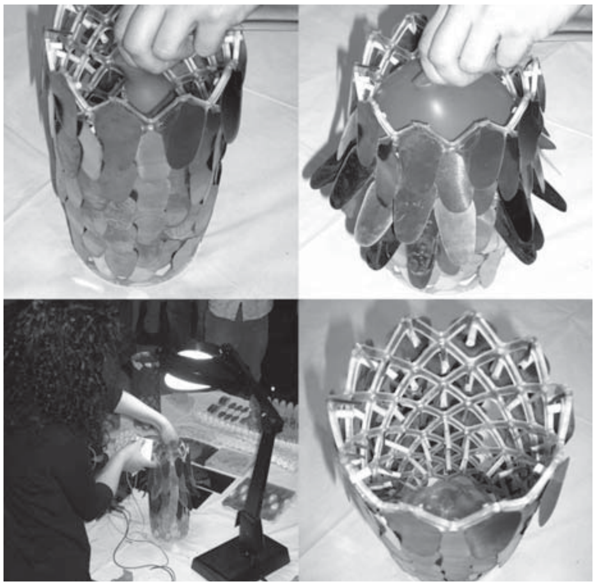

FIGURE 9 Digitally generated parametric models showing the scale elements and the nested cutting pattern for the Water Jet Cutter (WJC). The global surface was rationalized to a ruled (cylindrical surface) out of which the scales were cut and assembled.

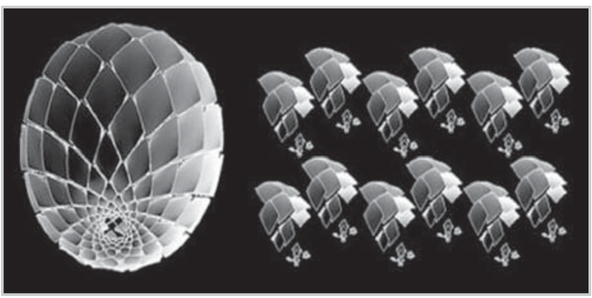

FIGURE 10 Final prototype demonstrating scale in motion with response to the changing light levels. The images illustrate closed and open states of the final model, incorporating scale geometry and material behavior as the parameters establishing the final form.

2.2.2 Material Excitation (RESONSE OUTPUT): Motor Integration [*Microcontroller Programming*]

Prior to integrating the light sensor with a motor which would allow for air-pumping into the structure, this exploration looks at a much simpler problem: the actuation of a motor and a fan to blow up a sealed plastic bladder connected to it.

2.2.3 SENSE-RESPONSE Integration: Light-Air Conversion Protocol [*Microcontroller Programming*]

The circuit-board schematics (Figure 8) illustrate the general layout in which the light sensor and motor are integrated. The INPUT header to the right of the image indicates the connection to the light-sensor which will extend ideally to each scale element in the skin. The VALVE at the bottom left indicates the position of the motor, which is actually a solenoid valve—which simply acts like a gate that targets the air from the pump to the bladder. The gate opens with response to light: beyond a given light level, the gate opens, and air is pumped to a local bladder attached to a scale component on the skin structure. The circuit board itself is comprised of the INPUT header (light-sensor), the OUPUT header (valve), the Microcontroller, and a bunch of resistors, a capacitor, and a transistor (Figure 8).

3. PROTOTYPE DEMONSTRATION

The structural skin is made up of a cylindrical diagonal grid support-structure to which are attached the light-sensing scales. The scales are made of stainless steel sheets, custom cut to fit the cylindrical mesh (Figures 9 and 10). Each scale is designed to accommodate a light sensor within its surface area, and a structural peg-like element attached to its interior surface which would allow for effective inflation of the local component. Preceding from the cylindrical construction generation the goal was to design an interstitial skin which would act as air bladders for each scale on the skin.

The general aim was to generate an in-between skin which would consist of a semi-structural mesh and a system of inflatable bladders which would inflate locally. The skin is made of stainless steel scales, placed on a cylindrical structure, which tilt in response to light in a localized manner such that the tilt degree is directly informed by light levels. In this prototype an inflatable skin allows for the reconfiguration of its local members.

4. SUMMARY AND CONCLUSIONS

In his seminal work, "The Work of Art in the Age of Mechanical Reproduction," Walter Benjamin poses the assumption that the very nature of art is defined (among other things) by the way in which it has been produced and perceived (Benjamin 1968). Such supposition may inspire us to revisit the association between "art" and "production" in the context of "design" and "digital technologies" respectively. The notion of *rapid craft* seeks to demonstrate such connections by emphasizing the significant role of rapid fabrication and manufacturing techniques in the generative phases of the design process.

This work attempts to establish *rapid craft* protocols for a light-sensing inflatable skin system. By developing a working prototype which incorporates material and electrical behaviors and properties (Gordon 2006) through the use of a range of rapid prototyping and CNC tools (Silver 2006), this exploration demonstrates design's ability to integrate physical and digital media as scaled constructions and performance-driven architectures, beyond their traditional role as representation and simulation media. Moreover, beyond the demonstration of a working prototype, the description of *design through fabrication* may support such material sensibility in design. Each exploratory phase aims at establishing a conceptual framework which may promote such novel interpretations of digital design tools, techniques and technologies.

Finally, the notion of a *Rapid Craft* is manifested in this work as a *design method* which promotes the creation of novel structural systems through processes of digital fabrication and assembly. Sensors, and other applied electronics, become ubiquitous in that they are part of the material system at hand, and at the same time, define its behavior.

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