MORPHOSIS

A responsive membrane

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Abstract. In this paper, we introduce *Morphosis*: A Responsive Membrane, which physically responds to movement, light and sound interacting spatially and temporally with the environment and their inhabitants. The fundamental hypothesis is to create architectural systems as living, evolving materials. The dynamic of the material is produced by dozens of actuators made by Shape Memory Alloys (SMAs) and LED's which react in real time to change the behavior of the membrane. The system is controlled by a genetic algorithm in an attempt to develop a technological approach to performance skins that possess adaptive and evolutionary personality relative to changing phenomena of the environment of buildings.

1. Introduction

We consider that digital technology and kinetic structures should be implanted in the physical materials of architecture. As part of our ongoing research we developed a prototype interface titled *Morphosis* (Figures 5-6) a reconfigurable and visual system, based in our previous work (Diniz 2006),

A Dong, A Vande Moere & JS Gero (eds), CAADFutures'07, 489–498.

and inspired by the manner in which an organism, or any of its parts, evolve and change form in a short lapse of time, triggered by some combination of external stimuli in the ever changing surrounding environment. This paper proposes the *Morphosis* prototype as a model that is suitable for execution of a responsive architecture material and that enables the development of transformable architectural surfaces that have the ability to act in a responsive way, thus communicating and constantly reshaping our perception. The paper is structured as follows. In the Section 2, we examine related work in the artistic and architectural domains, focusing in the investigations in kinetic surfaces and aiming at understanding the objectives and design processes, proposed by their creators. In Sections 3 and 4, we describe the *Morphosis* prototype: its objectives, system design and implementation. In the later sections, the outcome results (Section 5) and future work directions (Section 6) are discussed.

2. Related Work

A direct relation between the human activity and the manifestation of surfaces; in this fusion between body and machine has been demonstrated by numerous systems which act as physical networks of a digital information landscape. Highly influenced by cybernetic thinkers, including Norbert Wiener (Wiener 1967), John von Neumann (von Neumann 1966), and Gordon Pask (Pask 1969) during the 1960's and 1970's, architects were encouraged to think of buildings as feedback systems rather static objects. Later, John Frazer at the Architectural Association (between the end of the 1980's and beginning of the 1990's) created a whole new lexicon towards an evolutionary architecture with many experimental projects with his students (Frazer 1995). He investigated fundamental form-generating processes, paralleling a wider scientific search for a theory of "morphogenesis" in the natural world. Gordon Pask describes it like this: "The role of the architect, I think, is not so much to design a building as to catalyze it; to act that they may evolve" (Frazer 1995).

Cedric Price was one of the first architects who actually formulated this model into a project becoming famous on the radicalism of his un-built ideas. His project, "The Fun Palace", although never built, was one of his most influential projects to a generation of architects. The idea central to Price's practice was the belief that through the correct use of new technology the public could have unprecedented control over their environment, resulting in a building which could be responsive to visitors' needs and the many activities intended to take place there. The building constitutes an open framework into which modular, pre-fabricated elements can be inserted and removed as required according to need. For Price, time was the fourth spatial dimension: length, width and height being the other three.

Kas Oosterhuis (1995) published the article "*Liquid Architecture*" describing the design of a pair of buildings known as the "*Salt-Water*" and "*Fresh-water*" pavilions, respectively designed by his firm Oosterhuis and the architectural firm Nox. These buildings incorporated numerous electronic sensors into their designs to gather information about both interior and exterior changes. Although the changes were mere virtual projections, the incorporation of computer sensing and display technology in the design of the buildings was a touchstone in the architectural discourse of computationally enhanced environments in which the building is loosely defined as an *Interface*.

Mark Goulthourpe's system "*Aegis Hypo-Surface*" built in 2001 is perhaps the world's first interactive wall. The piece is a triangle metallic surface that has potential to deform physically in response to electronic stimuli from the environment (movement, sound, light, etc). Driven by a bed of 896 pneumatic pistons, the effects are generated as real-time calculations. This project has potential for information to literally translate into form, it offers an entirely new medium, digitally dynamic yet materially tactile. Any digital input (microphone, keyboard, movement sensor) can trigger any physical output (a wave or pattern or word). In this *Aegis* has potential beyond that of a screen to being a fully 'architectural' (i.e. social, physical) interface, where activity (sound, movement, etc) translates into form (Leach 2002).

Very recently a variety of designers using shape memory alloys as actuators in kinetic architecture and computer-controlled projects allowed form to represent dynamic change in original ways ranging from aesthetic like "Implant Matrix" to functional approaches like "Pixel Skin".

"*Implant Matrix*" is described by the authors as "A network of mechanisms that reacts to human occupants as erotic prey". It represents an interactive geotextile similar to a natural system and aesthetically it displays a very sensual and delicate appeal. The piece is composed of "purpose programmed micro-controlled sensors and actuators that provide a mechanical response to user stimuli". Implant Matrix is organized as a lightweight large organic array of shape memory alloy arrays, sensors and distributed microprocessors that open and close as people touch the matrix to achieve a responding performance producing waves of motion. The matrix is capable of mechanical empathy, it responds to human presence with "subtle grasping and sucking motions" (Beesley 2006).

"*Pixel Skin*" (Anshuman 2004) is a heterogeneous smart surface that could be used to generate low resolution images, low refresh rate videos or graphical patterns. The interactive facade uses shape memory alloys to actuate each of the 4 triangular panels. Depending on the opening coefficient each set of 4 panels acts as a pixel (255 states between fully open to fully closed). The simulation controls the pattern type in response to live weather prediction for the day. This project deals with finding a solution to contemporary architectural surfaces; where conventional windows have to compromise between providing a natural light source and climate protection versus facilitating advertising and information display.

3. Objectives

The *Morphosis* prototype, borrows its design logic from ubiquitous electronic technology, artificial life, robotics, and human computer interaction (HCI) models as integral components of the design system, Figure 1. Its objectives are to explore the potential of architecture to communicate, respond and perform for its inhabitants. *Morphosis* aims also at developing an affordable artifact that combines architecture in form and function; and proposes a selected mix of technologies as a way to really augment the physical capabilities of architecture, by sensing the environment and responding to stimulus and analog inputs, and by evolving and achieving a symbiotic behavior, that are characteristics of the natural environment.

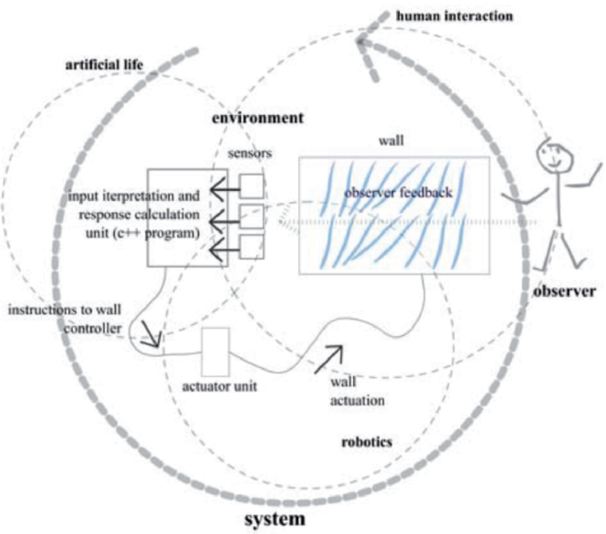

Figure 1. Morphosis Design Control Logic

3.1. A FUNCTIONAL RESPONSIVE SKIN

The abundance of sensing devices now available means that designers have a whole range of new possibilities for adaptive systems. We sought after to develop a smart structure that is light, strong and able of make extensive shape changes that minimizes the consumption of energy. Complex building structures now incorporate sensors, displays, and a range of mechanical functions. Many of our actions trigger automatic responses in our environment. Buildings contain innumerable sensors already, which detect temperature, humidity, light, fire and many other parameters relevant to the operation of the facility and the safety and comfort of their occupants. Sensing devices are becoming ubiquitous. The manufacture of these sensing devices for high volume commercial use has provided access to artists and scientists who want to create interactive systems responding to movement, light, touch, heat, acceleration, and position. Because these devices are increasingly inexpensive, it becomes possible to use them in experiments without commercial purposes. We have followed this approach in the *Morphosis* system design.

4. System Description and Design

The *Morphosis* system, Figure 2, consists of a physical structure with an embedded dynamic kinetic membrane, measuring 0.8 meters tall by 0.5 meters wide. Its objective is to create a human sized, sensitive, interactive (Figure 7) and multimodal, scalable structure that can be used as an architectural material. After analyzing the background work and presenting a critical review of the state-of-the-art, we introduce the system design of our prototype (Figure 5 and 6). This comprises a tactile and visual wall using an array of individual shape memory alloys (SMA), to actuate electric "muscles" that are anchored to an elastic skin, controlled by a microprocessor. For each muscle wire, we attach a LED that lights proportionally to the strength applied by the muscle. A stressed muscle will make an illuminated bump on the skin; a relaxed muscle will leave the skin dark at its neutral position. Additionally, this LED matrix can also constitute a low resolution image display, to transmit messages or design patterns.

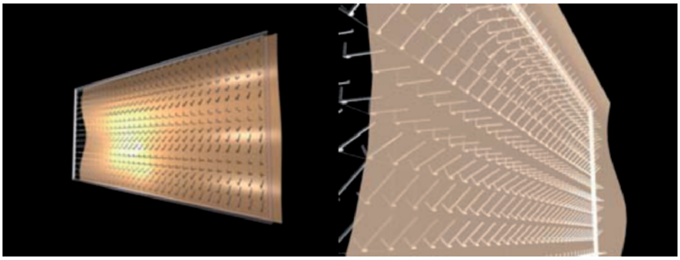

Figure 2. Morphosis conceptual design depicted as a virtual prototype

4.1. TECHNICAL HARDWARE/SOFTWARE IMPLEMENTATION

The scheme behind the project requires a computer controlling an array of physical levers in real time. To make this possible the computer has to physically connect the Flexinol® SMA, and control the electrical power going through it at any given time (Figure 3 and 4). The chosen interface was the Phidget 64 LED controller that connects to the computer USB port. A C++ library is supplied so it is possible to write a C++ program to drive each individual LED (in 256 different intensities). This program can read the sensor inputs (web cam, vibration sensor, ambient light sensor) and decide which LEDs output to activate and thus the corresponding lever. A key component of the system software, detailed in Section 5, is the Genetic Algorithm.

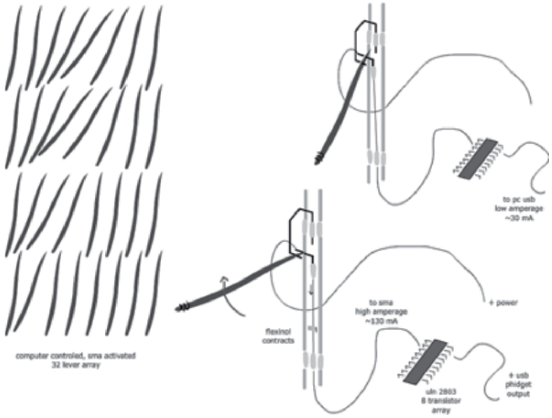

Figure 3. Views of the levers setup.

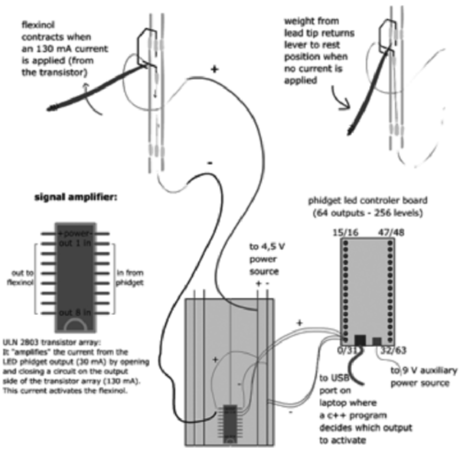

Figure 4. Diagram of Morphosis hardware setup

The system software, written in C++, launches an individual thread for each LED output. These are activated in power bursts, with the following characteristics: 2000 ms to activate the Flexinol®, plus 10 sequences of power (100 ms)/no power (200 ms) to maintain the Flexinol® contracted.

When the lever is to return to its default configuration, no power is applied and the lead weight at the tip of the lever, under the influence of gravity, brings the Flexinol® to the rest position.

Figure 5. Morphosis prototype without membrane and its SMA levers

Figure 6. Morphosis prototype with a latex membrane and its actuated systems changing its shape. This prototype was produced by the authors in January 2007

Figure 7. Changes in shape and lighting through proximity interactions by a user. The prototype was produced by the authors in August 2006

4.2. REAL-TIME DESIGN PROCESS

In this project most of the design process in non-CAD. The geometric form is crafted in the traditional model-making *modus operandi*. Form is fabricated with steel, latex, PVC, wires, and electronics are embedded within it, catalyzing material response to the external inputs. This way, a "performance based design" takes place, promoting a design approach which integrates form, structure and behavior as equal elements of the design process as a whole.

In our system, the process used of mounting surface modules connected to a computer via a standard, off the shelf USB controller, allows for the repetition and assemblage of several wall modules with no significant extra cost. This also brings the advantage of controlling several walls in an integrated fashion, sharing inputs and responding as a single structure.

Interlocked *Morphosis* modules could begin to design and export behaviors (wall/lever configurations) to structures (with variations from the simple rest form), depending on multiple variables: the time of day, temperature, ambient light levels, exceptional events and human response to it. Therefore, the modules have "memory, processing power and connection to the network" enabling a designer to give indications not only spatially but also temporally. Effectively, authors are designing systems in space and in time, hence in 4 dimensions.

5. Results and Discussion: Morphosis in Use

5.1. A STEP TOWARDS PHYSICAL AUGMENTED-ARCHITECTURE

We have developed *Morphosis*, in part, to investigate how the learning qualities of a material could be used to improve communication between buildings and its inhabitants.

The prototype behavior is the result of a complex system composed by sensors, actuators and a Genetic Algorithm (GA) component. From the literature, we know that GA is computational technique that roughly simulates biologic genetics (Mitchell 1998). A GA involves a "genotype" which is a string of code specifying a "phenotype".

In *Morphosis*, our "phenotype" is the shape of the membrane and the behavior of the levers and LED's. The input actions of the users and the environment are inputs for the genetic variations. Three input devices inform the computer of the status of the surrounding environment: a vibration sensor, a proximity sensor and a light sensor. These sensors are unobtrusively included in the wall and "feel" the environment informing the wall:

- Whether loud music is playing or someone is walking, for example, on a wooden floor (vibration sensor).
- If there is a rapid change in the ambient light levels (light sensor).
- If someone approaches the wall in a touching distance (proximity sensor).

These inputs change the behavior of the *Morphosis* in shape, trigger motion and light and can create random patterns on the surface, making the wall a responsive part of space, a lighting element, a functional architectural element and a performance piece.

The wall should respond to empathy and repulsion of the people present around the wall: their needs being coded as a measure of how a spectator is keeping herself/himself near the wall and their dislikes being coded as an evaluation of how a spectator is approaching the wall and leaving soon after. A wide range of possible phenotypes can be generated, and are evaluated for their "fitness", based on some formally specified criteria. The wall begins its learning phase, by running a random set of behaviors (raising and lowering levers to form patterns), and will try to adapt its effect sequences to get the maximum "empathy" responses. The wall also registers the environment with the aid of the vibration and light sensors, to detect which environment variables and effects are most liked. This way the wall tries to maximize the enjoyment of the people around it at all times and conditions. We think this kind of functionality may be included in outdoors as well as indoors structures, combining a structural functionality (facades, walls, lighting) with an artistic and empathic purpose.

The programmed GA works like this:
There are 3 different types of wall behaviors (effects): (1) Horizontal waves (left to right and right to left); (2) Vertical waves (top to bottom and bottom to top); (3) Random bumps.

There are 2 types of human responses to the wall:

- Empathy: the human approaches the wall and stays close (< 100 cm) to the wall for 2 minutes or more
- Dislike: the human approaches the wall and leaves the proximity of the wall, close to the wall (< 100 cm) for less than 2 minutes

The behaviors are randomly triggered and the wall waits for someone to approach the wall (detected by the proximity sensor or a web cam). The computer will register the particular effect combination being displayed at the times a viewer likes or dislikes it, and the circumstances (environment): time of day, luminosity and activity around the wall (measured by the vibration sensor). The wall will then try to exhibit the behaviors most liked at any given environmental conditions.

6. Future Work and Conclusions

The concepts described in this paper result from work carried out by the authors to build a functional and responsive surface (measuring 0.7 meters tall by 0.6 meters wide), actuated by shape memory alloys. Each actuator is controlled by a mixture of distributed, embedded, digital, and analog circuitry. Our prototype development was both satisfying and awe-inspiring; testing upon the aesthetic possibilities and technical opportunities of our model has allowed us to conceptualize more fully functional applications. Nevertheless, much more work, formal testing and usability evaluation with a set of selected subjects, following international standards, remains to be done.

One of the interesting developments is to make the surface more sensitive to the sound level, by introducing a Genetic Algorithm to make the wall react to undesirable sound conditions, and by re-arranging it in order to reduce the ambient noise; this is achievable using the computer microphone. As an example, a set-up like this could be used as an active feature in public spaces where low sound levels are required. A spiked wall could soften the ambient noise in large empty halls. Such spikes could be produced with the bumps made by the handles. In another example, when in situations of crowded spaces, the wall could fallback to other behaviors.

We will soon be extending the work to produce, test and evaluate a large-scale structure (measuring 1.4 meters tall by 2 meters wide). The prototype will be built from aluminum, rubber and steel components making it more robust and efficient. From its conception, *Morphosis* was intended to be a scalable multimodal material to be used on an architectural scale, rather than just “yet another interactive device”, that could transmit meaning through functional and visual movement. For the future results we envisage not only incorporating interactivity within the physical nature of the material with performance and aesthetic nature, but also adding levels of functionality for Architecture purposes.

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