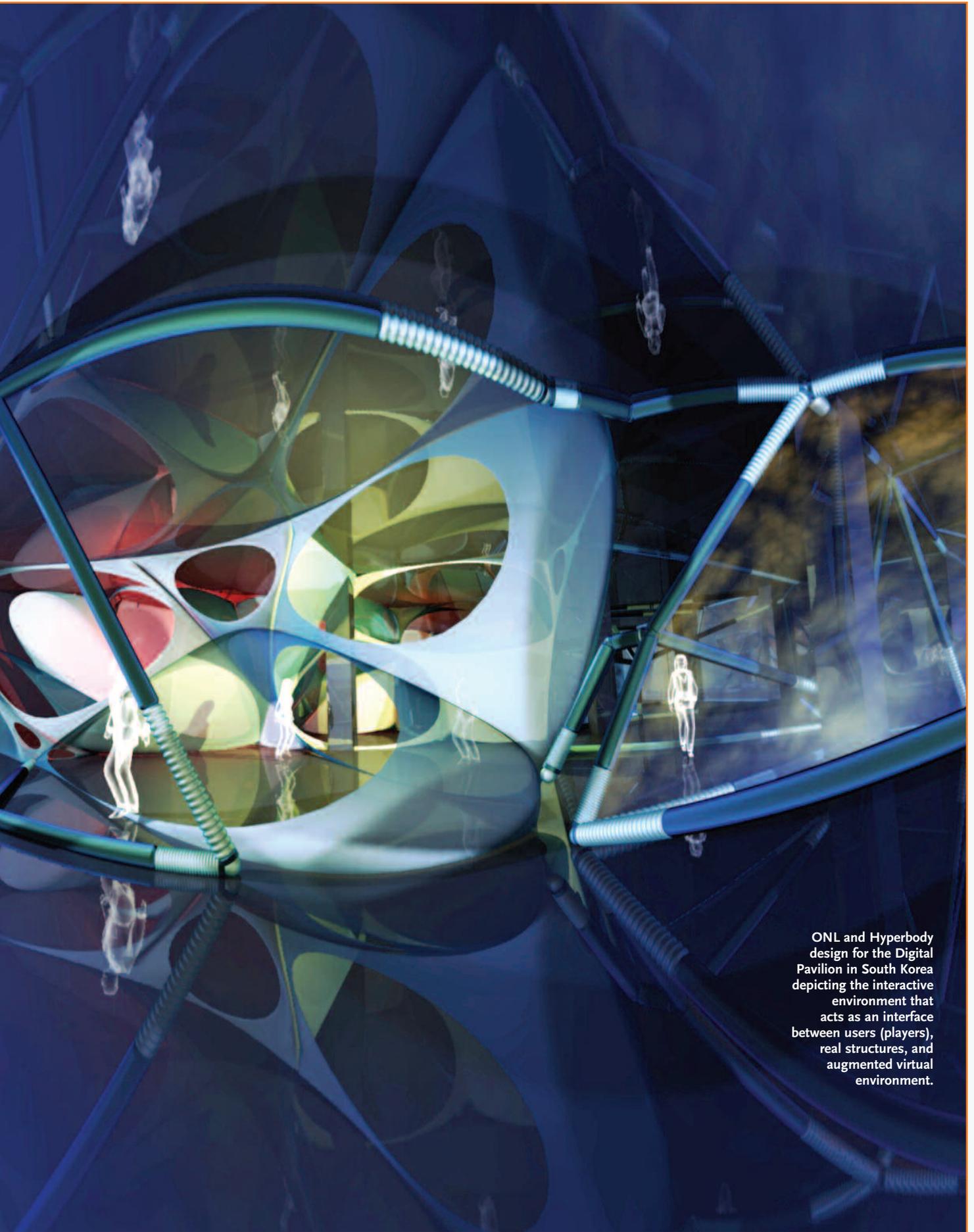


INTERACTIONS WITH PROACTIVE ARCHITECTURAL SPACES: THE MUSCLE PROJECTS

Developing structures as flexible networked information processors.

BY KAS OOSTERHUIS AND NIMISH BILORIA

Modernist architecture, from Le Corbusier to Herzog de Meuron, is based on an outdated aesthetic, one that leans heavily on that of mass production. In architecture, however, we can no longer celebrate the beauty of repetition of similar elements. Although critics may think differently, even current deconstructivists, like Morphosis and Gehry, base their aesthetic essentially on ideas of mass production: they start from series of mass-produced components, for which they subsequently make many exceptions. They create holes in volumes, they cut off, they chamfer and twist, they superimpose, they collage: they build in conflicts as they try to individualize components.



ONL and Hyperbody design for the Digital Pavilion in South Korea depicting the interactive environment that acts as an interface between users (players), real structures, and augmented virtual environment.

At ONL, an architectural design firm in Rotterdam, The Netherlands, and the Hyperbody Research Group at the TU Delft in The Netherlands, we have been designing an entirely new aesthetic, one based on the principles of customization. Mass customization of buildings means that all produced building components have a unique identity and are individuals that can be addressed independently. Each building component is different, and fits only in one place. The structure that is built becomes a giant 3D puzzle, where each piece fits exactly in one location, and the unique ID of each component is comparable to an IP address of a computer linked to the Internet. This new generation of Pro-active Architecture (ProA) is based on customization that respects the individuality of each component, building up a completely new aesthetic. ProA buildings are responsive to the individuals that live inside them, and to their environment. In the ProA concept, buildings are organic, ever-changing vehicles for processing and displaying information. They exhibit independent real-time behaviors, like adjustments in shape in response to changing environmental circumstances such as wind direction.

At Hyperbody, we have instigated a series of interactive prototypes to study the design of such buildings. For the NSA exhibition in Centre Pompidou in 2003, we were invited by the curators to build a first installation, NSA Muscle. NSA Muscle is a proactive inflated space, its surface populated with a mesh of 72 muscles, all of which were addressed individually. In the installation, the muscles cooperated as a swarm of muscular actuators, so as to behave in real time. The NSA Muscle danced, hopped, twisted, contracted, and responded with subtle movements to sensor input coming from visitors touching particular locations on the nodes of the muscular mesh. The paradigm of ProA was created, appearing on the cover of the French daily newspaper *Libération*.

Our first truly interactive environment was the Saltwaterpavilion, realized in 1997. A weather station positioned at the North Sea sent data to a computer running Max/MSP, which informed a mixing table to produce a soothing massage of light and sound that refreshed every 20 seconds. The public could interact with this dynamic environment using a sensorboard, pushing and pulling lights and sound toward both extremes of the interior space (see Figure 1). Interactivity and architecture were designed from scratch with similar high budgets and at the same scale. Interactivity formed an integral part of the architecture for the first time in the history of architecture. Imagine if we could produce a swarm of such Waterpavilions, all

Figure 1. Sensorboard in Saltwaterpavilion.

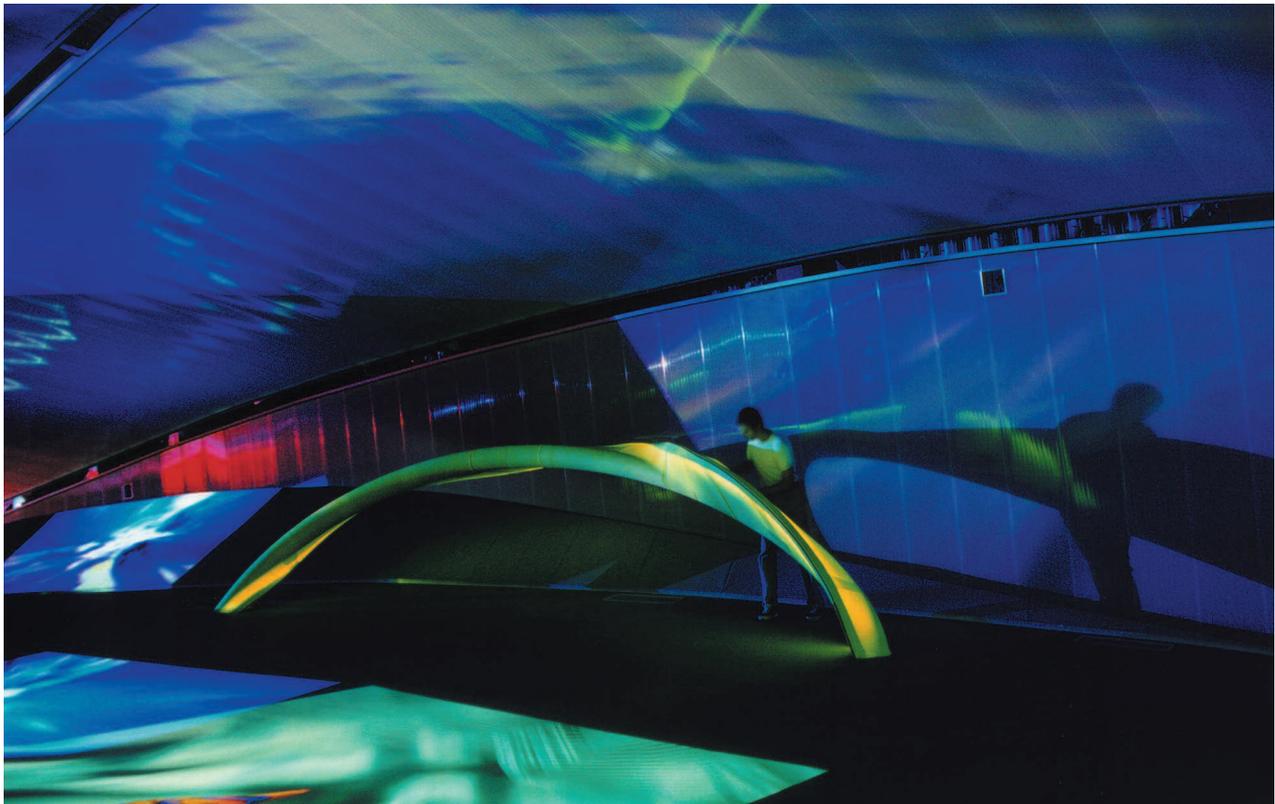




Figure 2. Hylite panels actuated by embedded fluidic Festo Muscles.

placed on different locations around the globe, all exchanging information with each other, with their local environment, their local users, and with their global directives. What would these ProA buildings tell each other, and what sort of information would they exchange?

THE MUSCLE PROJECTS

With the Muscle projects, our first prototypes of ProA, we tried to emphasize the real-time actuated spatial response that a building or architectural space might provide. The prototypes were conceived of as

a collection of 3D spatial strips, programmed to respond to their occupants through proximity and touch sensors, processors, and actuating fluidic muscles made by Festo (see Figure 2). Each strip is made out of Hylite panels, a sandwich material with combined properties of aluminum and plastic that is bendable. Two fluidic muscles produce compression power that transforms the otherwise hard-edged strip into soft luxuriant undulations.

In the Muscle project, the cumulative coupling of basic units gives rise to three distinct elements: a responsive floor, a ceiling, and walls joined together in a closed 3D loop. These elements are linked in space in a highly interdependent manner, constantly exchanging information (such as air pressure varia-

By introducing interactivity, we wanted to break the stereotype of the facade of a building as a barrier separating the interior from the external environment.



Figure 3. Muscle Tower 1.

tions), yet behaving as a collective whole to attain certain spatial reconfigurations.

THE MUSCLE TOWER 1

The Muscle Tower is a working prototype (model scale 1:20) for a building's structure that responds to external stimuli (the weather) and internal conditions (the users) (see Figure 3). This programmable structure is seen as a process relating to other running processes (people, the environment) that displays real-time behavior. It was first shown at the Aandrijftechniek exhibition, part of the Industrial Week (a meeting point for Dutch industry), at the



Figure 4. The Muscle Tower 2.

Jaarbeurs Utrecht. This exhibition informed visitors about many of the latest innovations, developments, and ideas in the fields of power transmission, factory automation, and motion control in one brain-stimulating visit. Some possible practical applications of a real-time adaptive structure like the Muscle Tower include:

- Adaptive Facade: Adapting to changing external environmental conditions and internal usage patterns.
- Responsive Roof: Responding to changes in solar radiation.

The potential importance of interactivity through organic reshaping of buildings as computers, and as computer displays, has become apparent.

Figure 5. The Muscle Body.

- Pro-active Space: The building morphology augments itself in real time to suggest and provoke the possibilities of engaging with a space.
- Balancing Structure: Dynamically resisting external forces, making a skyscraper stand perfectly upright when enduring strong winds.

THE MUSCLE TOWER 2

The second Muscle Tower prototype was an interactive advertising billboard structure with built-in behaviors for reacting to its environment, through bending and rotation of its elements. The tower consists of a network of aluminum rods, connected flexibly to each other and to pneumatic muscles by means of hollow iron spherical nodes (see Figure 4).

Each spherical node attaches to one end of a fluidic muscle and two aluminum rods that create 3D framed sections (of variable dimensions), which are stacked upon each other to build up the entire tower.



This positioning of the muscles allows the 3D frame to be bent, twisted, and deformed while maintaining a sense of balance of the entire tower, thus preventing it from toppling over. A cumulative stacking and

attaching of subsequent frames allows for a higher degree of movement. The tower is programmed using Virtools, which obtains data about the presence of people by means of a sensing field with motion sensors laid out in the periphery of the tower (see the sidebar). The tower can elegantly bend, twist, and turn toward the sensed spatial coordinates of people around it in order to attract attention to an advertisement displayed on the tower's surface.

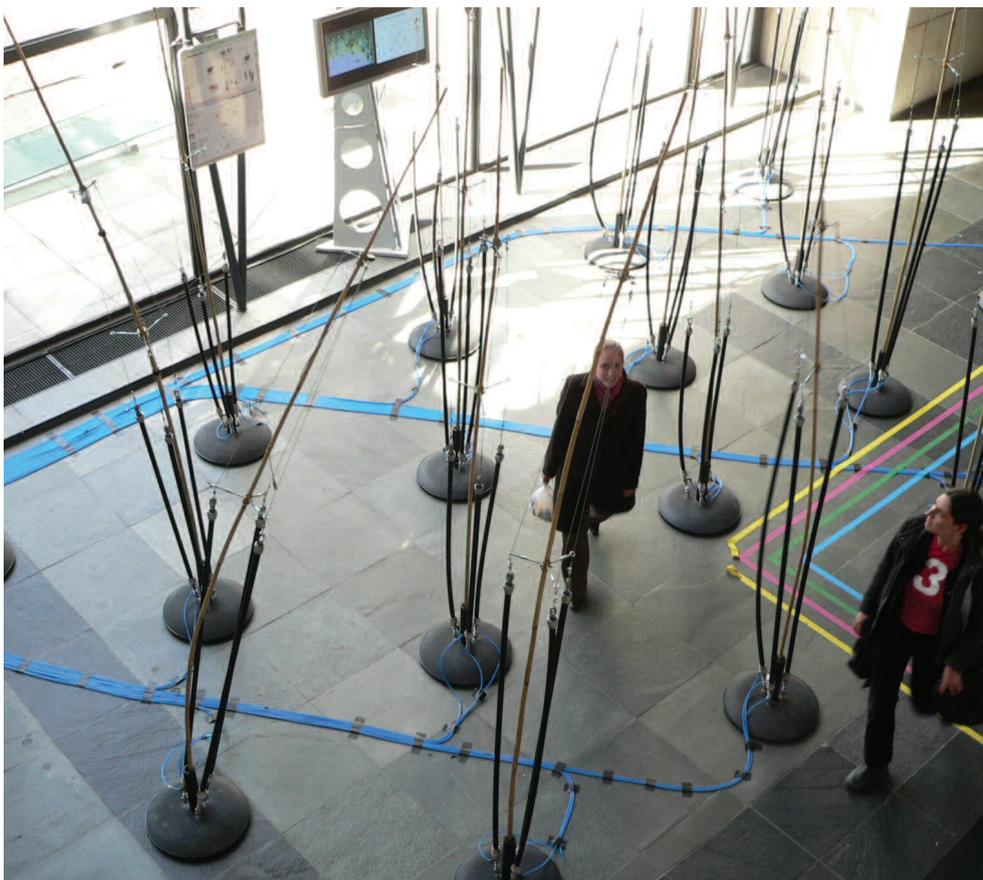


Figure 6. A Bamboostic forest.



Figure 7. The Muscle Space.

of coupling three pneumatic muscles utilized for actuation with a central mast of bamboo specifically chosen for its flexibility. Steel strings, interconnected with three pneumatic muscles on the central bamboo post were woven through clamps and connected to the rigid base. Actuation of each individual muscle produced the conceptualized movement of the bamboo in predefined directions. After successfully

THE MUSCLE BODY

The Muscle Body is a fully kinetic and interactive prototype of an interior space. The project is an architectural body constituting a continuous Lycra skin that makes no categorical distinctions between floor, wall, ceiling, or doors (see Figure 5). This continuous skin is structurally supported by a spiraling 3D PVC tube framework, thus endowing it with flexibility and stiffness. A total of 26 Festo muscles are integrated into this spiraling structure to control the physical movement. Using these materials, the Muscle Body can change its shape, its degrees of transparency, and the sound it generates in real time as it interacts with people who enter it. The translucency of its Lycra fabric varies according to the degree of stretching induced by this shape augmentation. The thin strips of light mounted between the tubing and the skin, in combination with the altering translucency of the fabric results in an intriguing play of light upon activation. There are also a number of speakers integrated into the skin that generate sound from several sound samples combined and transformed according to the actions, proximity, and movement of the people inside the Muscle Body.

THE BAMBOOSTIC

The Bamboostic installation is another example of an interactive architectural space (see Figure 6). It operates as an interactive forest that could be placed in a public space like a square, and is composed of a series of mechanical trees. These trees are the result

building and testing one prototype, a series of trees was created and grouped together to create an organized forest of kinetic bamboo structures. The kinetic behavior is regulated in accordance with the proximity of people near each individual bamboo structure. Proximity is tracked in real time via a tracking system developed at Hyperbody using Virtools. The tree nearest to a tracked individual bends toward him or her, and its movement is replicated in a decreasing extent by surrounding trees. This produces a rather natural landscape feel via a set of mechanized entities.

THE MUSCLE SPACE

Figure 7 shows the Muscle Space project, an interactive passage space that interacts with passersby in a proactive manner. The structural profile chosen for the Muscle Space consists of double-curved surfaces that are actuated by pneumatic muscles woven into a grid of PVC tubes. The kinetic behavior displayed by this dynamic structure is a complex combination of scissoring, folding, bending, and falling movements. The floor surface of this interactive passage has embedded pressure sensors that register the movement of people passing by. These movement patterns are communicated to a set of behavioral algorithms which, in turn, coordinate the actuation of pneumatic muscles and ambient sound along the length of the passage. Passersby thus become passengers within an architectural body that is communicative and seemingly alive.

ACTUATED BUILDING TECHNOLOGIES

Pneumatic Entities: Fluidic Muscle Type MAS (provided by Festo):

A flexible tube with reinforcing fibers in the form of a lattice structure for up to 10x higher initial force compared to a cylinder of identical diameter. The muscles tend to contract 20% of their initial length with the induction of air pressure, hence making it act as an actuating device to alter the node positions of the prototype.

Properties: Diameters 10mm, 20mm, and 40mm, rating length 30mm–9,000mm, no stick-slip effect, low weight, hermetically sealed.

Application: Actuating devices connecting the Hylite plates into a singular networked whole.

The Black Box (by ONL and HRG with Festo air valves and switching components):

A hard-edged box housing the switching mechanisms: I/O boards connected to the 72 valves controlling the air pressure lock of the fluidic muscles. The box has provisions to attach the compressed air intake pipes through distribution channels; houses the CPU and power back-up mechanisms.

Application: Used as a secure container, housing the brain of the installation through which the fluidic muscles are instructed to attain the contraction or relaxation modes.

Flexible Skins:

Hylite panels: Hylite is a sandwich sheet comprising two thin aluminium layers with a plastic core in between. It was developed for car body parts. It integrates high flexural stiffness and extreme lightness. Compared to sheet steel with the same flexural stiffness (0.74 mm) and aluminium (1.0 mm), Hylite is 65% and approximately 30% lighter respectively. These results have been obtained by combining the best properties of aluminium and plastic in a single material. The Hylite panels were specifically selected for the skin of the prototype due to the flexibility criterion and the ease involved in its handling.

Lycra-based fabric: Lycra is a stretchable fabric often used for sports clothing. The translucency of the fabric varies according to the degree of stretching.

Application: Spatial envelope, interactive furniture surface, projection surface.

Control System: Sensing devices used to enrich the activity recognition criterion of the prototype. The selection of the sensors involved two basic distinctions in the manner in which we wanted data to be sensed: the global level—dealing with proximity of users with respect to the prototype; and the local level—dealing with finer adjustments made to the panels by means of individual inputs through touch sensors, hence providing partial control by the user.

Sensors: Proximity sensors for sensing the distance of the occupant from the installation and touch sensors for sensing the amount of pressure exerted upon a surface.

Software: Virtools Dev 3.0, software is used for developing an inherent connectivity between the sensed data and the expected behavior output from the prototype (by means of programming output rules for the system). The software is used as the main computation tool that receives inputs from the MIDI device (sensed data), processes data in accordance with the scripted behaviors programmed into it and sends output digital signals via PCI cards device, which are directly linked with actuating mechanisms.

The graphical scripts are systematically composed to communicate dynamic data, related with proximity of users (through sensors) to a set of arrays built into the software file, which act as the interface between the real and the virtual worlds. These arrays are constantly updated via the 'sensor reading script' developed at the HRG, which primarily utilize MIDI inputs for this purpose. Apart from this script, a parallel operation that concerns the status of each system unit (a component attached with the muscle) is tracked constantly in real time by means of updating the corresponding valve status linked with the pistons. These two operations formulate the so-called first-level operations of the scripts, which are aimed at capturing the context within which the prototype is embedded. The second level involves a 'data processing' script to check in parallel with the previously acquired information: the Status and the Sensor reading scripts, hence abstracting the change in context by means of reading the updated array and the current position status of each system unit. This information is gathered by means of compiling it in the form of genotypic numeric strings, which are forwarded to the Smart lab PCI cards.

The PCI cards, as mentioned earlier, further relate these numeric strings in correspondence with the airlock valves status and runs re-checks for any updated arrays in parallel to create a phenotype string, which involves a long numeric string equivalent to the number of pneumatic muscles in the prototype and represents the new on, off status commands by means of numeric 1 and 2 codes. This processed data directly communicates with the airlock valves and results in the opening and closing of valves corresponding with the numeric data delivered to the black box, hence actuating specific sets of pneumatic muscles to produce an appropriate system response. **C**

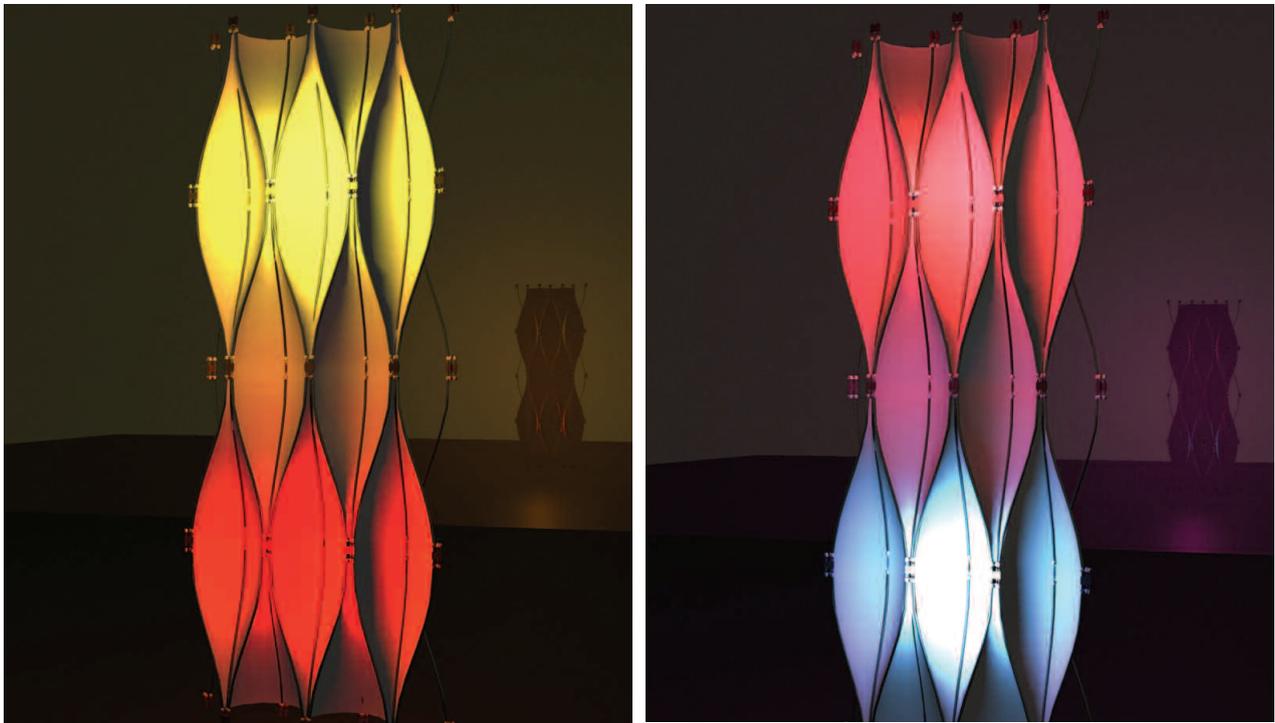


Figure 8. Muscle Facades.

THE MUSCLE FACADE

By introducing interactivity, we wanted to break the stereotype of the facade of a building as a barrier separating the interior from the external environment. The Muscle Facade (see Figure 8) moves and changes its visual appearance in accordance with fluctuating contextual conditions, such as the weather. The facade registers contextual information through a multitude of sensors and connectivity to global media (such as weather forecasts). This incoming data is processed by Virtools, and the Muscle Facade manifests its response by changing its own shape, the color of images projected on its surface, and the augmentation with sound.

CONCLUSION

Through the examples and experimentation described here, the potential importance of interactivity through organic reshaping of buildings as computers, and as computer displays, has become apparent. We realized that if we develop our buildings as flexible networked information processors, they become vehicles that can receive and transmit information to and from each other. Just like cars on the highway form a population of interacting moving bodies, just like houses in the city form populations, these interactive architectural bodies will form a network of live entities. All would feed on data produced by other buildings and elements, all would behave in real time, all would tell the others what

they did, and all would become a self-learning entity. Self-learning capacity will only arise if the architectural body will be part of a swarm, if it can communicate with peers. Then they may start building up a body of knowledge, perhaps not unlike its human inhabitants. Our minds are completely helpless and uninformed if we do not communicate with peers. Our body of knowledge does not reside in any one brain, but is embedded and distributed across a network of brains and bodies. It will be no different with these architectural bodies, the brains of which will feed on meaningful data from the Internet and other wirelessly transmitted semantic signals beyond the electricity used for metabolic operation. **C**

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