SURFACE CHANGE

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Over the past decade, there has been an increasing interest in exploring the capacity of built spaces to respond dynamically and adapt to changes in the external and internal environments. Such explorations are technologically and socially motivated, in response to recent technological and cultural developments. Advances in embedded computation, material design, and kinetics on the technological side, and increasing concerns about sustainability, social and urban changes on the cultural side, provide a background for responsive/interactive architectural solutions that have started to emerge.

This paper presents an ongoing design research project driven by an interest in adaptive systems in nature and a desire to explore the capacity of built spaces to respond dynamically. The paper underlines architecture's inseparable link to technology and projects a vision of architecture that, through its capacity to change and adapt, becomes an integrated, responsive, adaptive and productive participant within larger ecologies.

Thanks to current technological achievements, broadening of scientific knowledge, and understanding of the underlying processes that govern metabolisms of natural world, we are able to see deep connections between the made and natural worlds. With such an expansive context comes an ability to effectively and productively integrate new knowledge, information, methods and techniques back into the design and production of architecture. Confluence of various technologies and their assimilation is altering the way we perform, organize and distribute our activities and materials. We now expect more from architecture. We expect buildings not only to house and facilitate various modes of human activity but also to adapt to, behave, respond, and accommodate the flow of energy and information. The conceptual model of architecture is changing.

Behavior, adaptation and responsiveness are characteristics of live organisms; architecture on the other hand is structurally, materially and functionally constructed. But the influence of the "organic paradigm" is changing attitudes towards architectural adaptation, behavior and performance and altering the system of reference we use for design conception.[1] Recent thinking in science is bringing down the traditional concept of nature as a closed system governed by static rules, recognizing that everything in nature operates within dynamic and open systems.[2] This presents a potent context for rethinking the conceptual model of architecture. Recent attitudes towards materialization and material processes (Achim Menges, Neri Oxman, Rachel Armstrong), architectural assembly and its construction (Skylar Tibbits), as well as localized control of the interior environment (Michelle Addington) remind us that processes of building and consuming architecture could be seen and practiced as life sustaining metabolic processes. This ambition to view architecture as a form of artificial life is fueled on one hand by "material shifts occurring in the domains of energy, resources, and technology"[3] and on the other by grasping a deeper connection between biological and cultural systems. In a world of depleting resources these developments might hold a key for establishing a holistic relationship between made and natural worlds; these approaches that liken architecture to a living organism propose fundamentally different attitudes towards materialization, form, performance and construction of the built environment. New content for architecture is being formulated that relies on the integration of dynamics/change into architecture – dynamics that don't address kinetic movement only but include flows of energies, material and information.

CHANGE I EXCHANGE I FLOW

Thinking in terms of exchange, dynamics, energy, and flow and not in terms of assembled elements affects the way we think about matter/material that makes architecture. Rayner Banham reminds us that two basic ways of controlling environment was by hiding under the tree/tent/roof (in other words, by building a shelter) or by mediating local environment by campfire. He points out that "a campfire has many unique qualities which architecture cannot hope to equal, above all, its freedom and variability."[4] (The freedom and variability of a phenomena stands opposed to architectural form and it is clear that Banham is not interested in the later.) This is not a nostalgic note but rather an observation that hints at an unexplored potential to re-conceptualize the environmental control. By shifting a discourse from form to system Banham locates architecture's agility not in its formal and structural expression but in the realm of building systems/technology[5] emphasizing that architecture's relationship to technology must intensify in order for architecture to stay relevant. He alludes to technology's capacity to deliver a radically different way of living as well as frame future architectural discourse and experimentation. This predicates the most recent attitudes about environmental control that mediate conditions locally not globally and in relation to a body not space – relying on a material that does not need thermal mass but regulates the heat exchange within a thin zone of a few millimeters[6]. Furthermore, "campfire" as a source of heat and light is localized and specific to its placement within the space, but if we think about it beyond its traditional form and in relation to energy exchange we can imagine it as a distributed system that can be activated locally and intelligently only where needed; campfire becomes an intelligent surface.

Similarly to Banham's focus on building systems, Gordon Pask emphasizes architecture's "operational" capacity (and its "intimate relationship" to cybernetics) by pointing out that "architects are first and foremost system designers"[7]. The focus on architectural systems from the organizational and operational aspects extends Bahnam's idea of the flow of energy to include the idea of the flow of information. Several projects/ideas that developed in the late 60's and early 70's such as Cedric Price's *Fun Palace*, Negroponte's *Soft Architecture Machines*, Eastman's concept of "adaptive-conditional architecture" began to explore "intelligence" and programmability of architecture's processes and spaces in order to form a two way relationship between spaces and users.

Current technological achievements as well as expansion of our understanding of the underlying processes in nature brought about a new generation of projects exploring deep connections between made and natural worlds. In 2003 Kas Oosterhuis and his Hyperbody research group designed and constructed the *Muscle*, a working prototype of a "programmable building that can reconfigure itself". The *Muscle* is the first in a series of Pro-active Architecture (*ProA*) projects that study design of responsive buildings that exhibit real-time behaviors and adjust shape in response to changing environmental circumstances. The *Muscle* is a pressurized soft volume, wrapped in a mesh of tensile Festo "muscles," which can change their own length and, thus, the overall shape of the prototype. The public connects to the prototype by sensors and quickly learns how the *Muscle* reacts to their actions; the *Muscle*, however, is programmed making the outcomes of interactions unpredictable. The *ProA* projects test capacity of buildings to respond in real time and explore a range of enclosures and programmatic situations. They demonstrate that responsive and kinetic architectural systems are not so techno-utopian and that spaces that move, transmit information, or adjust to a feedback could perhaps become a reality of our inhabitation in the future. They offer a promise of a "total" environment that could be inhabited, touched, moved into action and above all responsive. Surfaces/spaces like these could be at the same time architectural spaces and have a capacity to adjust to a productive role of harvesting or distributing energy or information. According to engineer Guy Nordenson, building's structural mass could be cut in half if it was designed like a body, with a system of bones, muscles and tendons and ability to change its posture, tighten its muscles, and brace itself against wind.[8] The ProA projects test a structure/skin construct that is so instrumental in architecture and suggest that the way in which it is currently conceived could give way to a more organic concept of tissue/tendon/bone transitions where joints allow for certain adaptability and accommodation of changing shape.

SURFACE CHANGE PROJECT

Buildings that change in real time can be many things: they can change their functionality, perform several functions at the same time, change form and physical location, harvest and distribute energy. The *Surface Change* project is an ongoing design research project focused on the integration of information, matter and environment. The ambition is to develop technological/tectonic solutions that can provide buildings with a (biologically inspired) capacity to transform and adapt. A fully developed project will result in a system by which responsive dynamic structure/skin will be capable of altering its shape or its regions based on environmental conditions and the nature of use. At the same time the system would address questions of energy capture and energy harvesting. The goal is to develop technologies and designs capable of transforming static building components into active responsive surfaces that produce added functionalities in architectural and urban environments and enable architecture to become a productive participant within larger ecologies.

The ambition of this phase of the project is to explore a material system that would make movement and adaptation possible without employing mechanical components. The *SKiN* project, presented here, consists of small scale prototypes of an adaptive kinetic surface capable of spatial modulation and response to environmental stimuli by using shape memory alloy (SMA) as an actuator. The presented work focuses on the layering of material system and studies of its movement.

Matter: Material System Actuation and Layering

Material systems in nature don't distinguish between material and structure and in order to achieve adaptation and responsiveness they involve movement.[9] This movement is both local and global resulting in a complex pattern produced by accumulation of the local movement effects. Furthermore, material systems in nature don't distinguish between structural and functional material instead, variation of material properties determines and fosters certain behaviors that result in change of form, shape or location. Information travels through integrated material layers and functional needs inform material and structural distribution. It is still difficult to imbue synthetic matter/material with this kind of "intelligence" and manufacture materials that would recognize changes and adapt in an organic way. The shift from programming bits and bytes to programming mechanical properties of objects offers possibilities to re-define the relationship between structure, skin and function of a material system. For example, recent research from Harvard Microrobotics Lab and MIT proposes a way to preprogram a sheet of material to change its shape. This preprogrammed sheet material can fold itself into a boat or airplane origami shape. The thin resin-fiberglass composite sheet, divided into triangular segments, has heat sensitive connections that fold into a particular shape depending on the program used. This concept could one day produce objects or surfaces that can shift shape or transform into a number of useful objects.[10]

The *Soft Kinetic Network* (*SKiN*) project began by making "V" shaped SMA wire (heat sensitive) joints and embedding them into a silicon tubing diagrid in order to make a surface that can move and thus change its shape. This experiment examined SMA wire capacity to act as a *point source of actuation* of the surface. To better understand the gradient of movement of the actuated grid, the grid was restricted by anchoring joint points to a flat surface in a variety of configurations. Depending on the configuration, the behavior ranged from expanding cells to vertical movements of the grid's regions. The vertical movement was surprisingly agile and pronounced. It reached its maximum when end points of the grid were anchored (Figure 1).

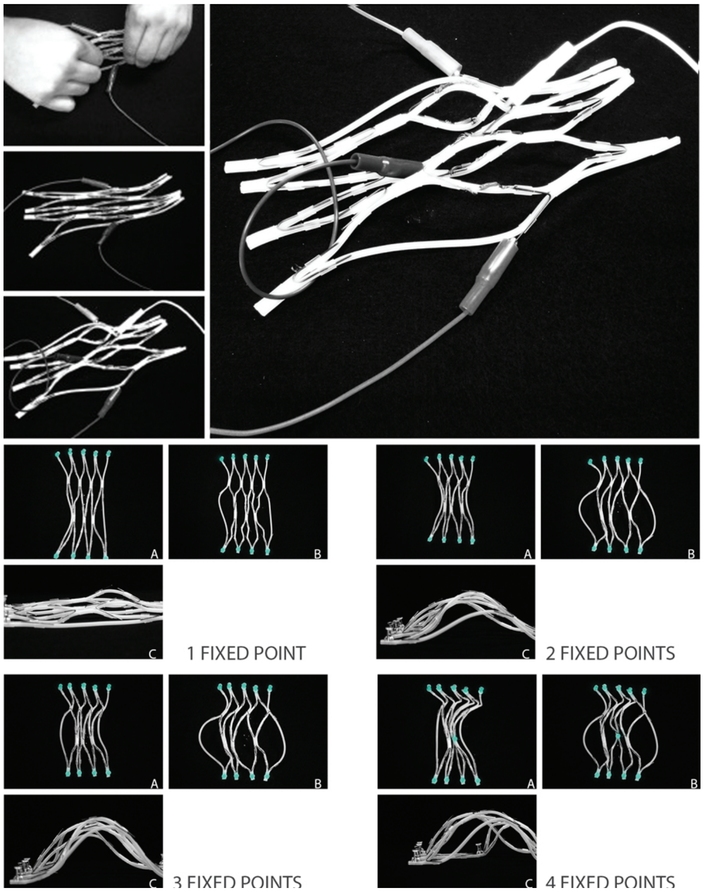

Figure 1. Point actuation using "V" joints and fixed point test showing the grid deformation

While we found the movement of the grid, especially in the vertical direction, very promising, the grid with the "V" shaped joints had several challenges. The number of connections between the SMA joints and conducting wire resulted in a loss of power over the length of the wire between joints. Also, once the joints changed their shape they had to be pulled back to the original shape by hand. Joint movement was one-directional and we were interested in finding a way to make a system that would return the wire into non-stimulated shape through its own movement.

The fixed point tests revealed a great degree of sensitivity in the relationship between the fixed points and the orientation of the actuation joints. Even subtle changes in any of these variables produced substantial differences in the type of movement. This made apparent a complexity of the task and a difficulty in tracking the complex global movement of the grid produced by discrete local movements. We also explored the integration of the "V" joint grid with the surface by adding in one iteration individual components to the grid and in the other imbedding the grid into a silicone surface substrate. In some of these experiments the silicone itself became the link between the grid cells, opening the possibilities of combining the regularity of the grid with the potential variability of the silicone surface.

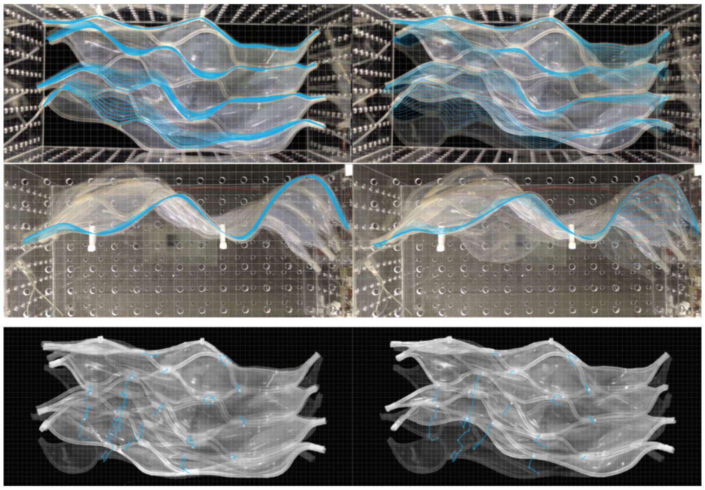

Figure 2. Using motion tracking to map the movement of the diagrid points

The second phase of the *SKiN* project examined SMA wire capacity to act as a *linear source of actuation* of the surface. This phase was defined by the introduction of 'long' (45cm) lengths of SMA wire baked into large amplitude (15cm) waves and treaded through silicone tubing. While technically challenging, this new method of using the wire enabled easier control and more dramatic movement results. To create a dynamic material system we continued our explorations of integrating the grid and the surface. The system relied on material fusion whereby silicone tubing with treaded SMA wire was fused with silicon cells creating a structural yet flexible surface. This material system achieved a certain level of material equilibrium: the SMA wire pulled the surface into a particular shape while silicone layer contained in the cells of the grid pulled the material system back close to its original shape. Still, the accumulation of the local movements resulted in a complex global movement where each shift of a cell depended on the movement of adjacent cells or regions. To better understand and analyze the deformations we filmed the motion and used motion tracking to map the movements (Figure 2).

Both ways of actuation have positive and negative aspects. Point actuation facilitated greater variety of movement. Continually reversed joints could produce twisted movement. Linear actuation produced more dramatic movement. This movement was limited by the baked shape of the wire. However the SMA wire could be baked in any shape. Powering the long string of SMA wire was technically more challenging but reduced the number of connections between the electrical wire and the SMA.

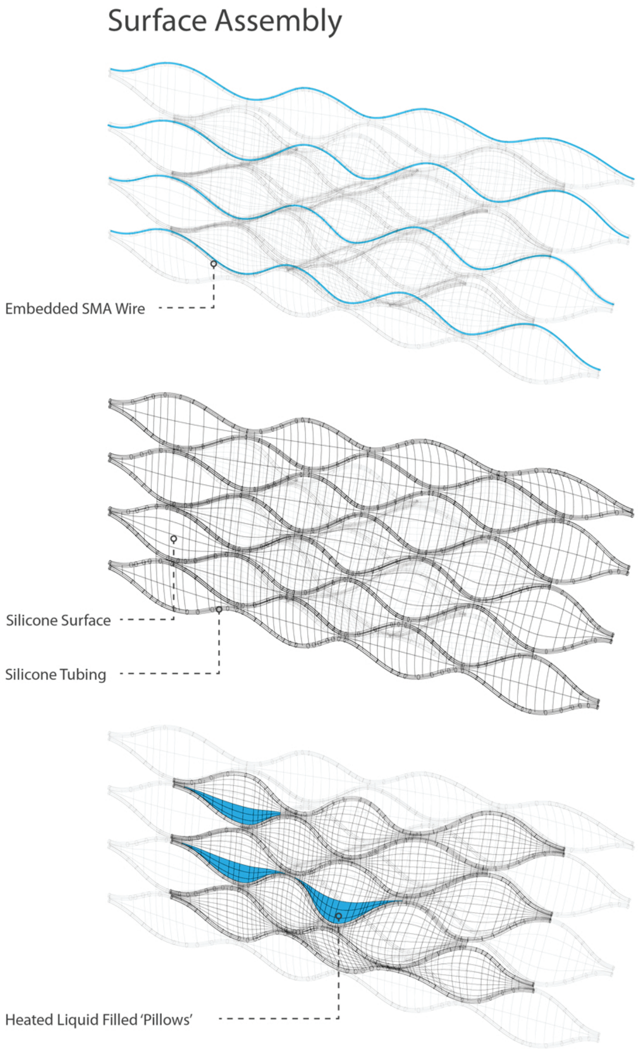

Figure 3. Assembly of the surface with "heat storage pillows"

In the course of these experiments we became interested in the material variability of the surface. We expected that variability in the material system will enable it to behave differently within surface regions; to vary the speed and degree of movement and to vary surface transparency. Material variability, geometry and material hierarchies would help reinforce dynamics of the surface; this combined with pre-tensioning and variation of pressure or swelling of cells would produce movement similar to what is observed in biodynamics.[11] These experiments in material variability resulted in our current preoccupation with making pillows that would hold heat storage material and facilitate heat transfer through the surface. We are currently working on this aspect of the project. (Figure 3)

The pillows have a two-fold role: to store the heat and participate in the movement/deformation of the surface by changing the volume of the diagrid cell. The change of the volume of the cell would exert pressure on its walls and create a tension that would result in the deformation of the entire surface. Our goal is to design elements, structure, surface and performance of the kinetic material system as integrated layers that make up a "tissue" capable of accommodating movement related to human occupation, energy harvesting and different external/environmental influences, reinforcing the capacity of the system to establish a two way relationship not only with users but with the environment as well.

Information and Matter

Parallel to the physical prototypes we developed a series of *Grasshopper* scripts in an attempt to visualize and simulate geometric behavior of the system. The very first technique focusing on single cell geometry and its distribution across a surface helped us understand geometry shifts and surface effects this would produce.

The implementation of a physics engine was also an important part of our digital explorations. Using *Kangaroo*, physics plug-in for *Grasshopper*, we explored how to replicate physical qualities within our digital models and were able to visualize how effecting geometry in one region could produce global changes to the entire surface system. As we moved towards linear actuation in our physical prototypes, the *Grasshopper* definitions attempted to replicate the movement of an actuated string of SMA wire. The intent was to understand, simulate and implement the physical properties of our actual system and superimpose these qualities onto a digital model. The final definition uses simple mathematical functions to represent dimensional changes in overall string length, wavelength and amplitude of the wave formation we embedded into our system. Actual systems were calibrated (measured) and accurately represented by dividing geometry and moving it along its predetermined trajectory. Discrepancies arose when comparing actual movement to virtual ones; the digital model assumes infinitely consistent movement and a perfect return to an "original" formation, whereas the amplitude of movement in the actual material can potentially degenerate over time and will almost never consistently return to exactly the same formation. This exploration was valuable in demonstrating basic movement and the complexity of the actual system of multiple strings acting within an intricately organized web of silicone. The current definition is using the string to simulate variety of movements within the surface in two ways: one where string follows the existing diagrid and the other where string acts diagonally across the diagrid. The next stage will explore variety of other geometric configurations and combinations in which the strings don’t cover entire length of the surface but are integrated with the geometry of the diagrid in a different way so that regions of different behavior could be formed (Figure 4).

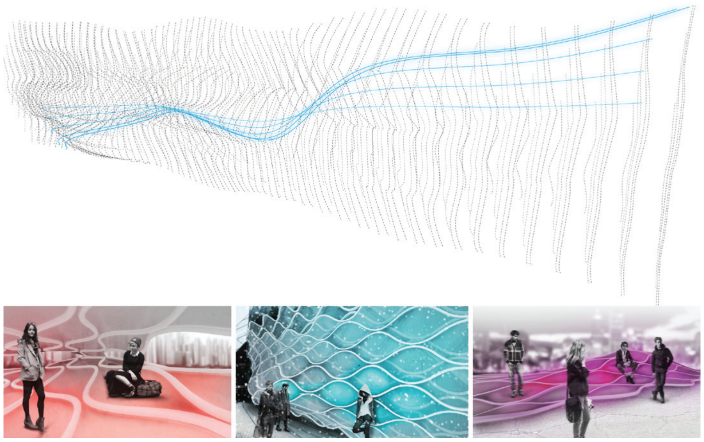

Figure 4. Mapping the movement with regions of different behavior; possible use based on these regions.

Information, Matter and Environment

Our goal to design an integrated, “tissue” like material system that has a two way relationship with users and the environment required integration of sensory input and other kinds of external and internal data. We used *Arduino* microcontroller platform to explore these possibilities. *Arduino* was used to control the application of power to the SMA string as well as to incorporate sensory input and other external information. *Firefly* plug-in bridged the gap between *Grasshopper* and *Arduino* and was used among other things to integrate local historical weather data as an input that would allow for our surface to respond to dynamic patterns. Movement of the surface became an abstract representation of changes in temperature. The prototype was also equipped with photo sensors that would react to the change in light level. These sensors were only a place holder for a more sophisticated setup that would include temperature and humidity sensors capable of collecting a real time weather data and influencing the movement of the surface in real time.

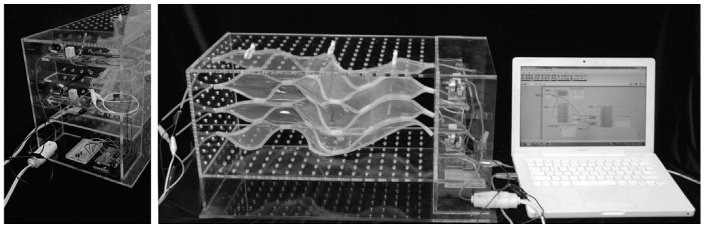

Figure 5. Integration of sensory input and other external and internal data.

Bringing in historical weather data enabled us to actuate our system by bringing in external information in order to explore the connection between spatial modulation and environmental input. We achieved our goal of implementing dynamic data patterns and yielding dynamic geometric responses (Figure 5).

We also explored another way to actuate the system by using a *Bluetooth* detection method to register the number of cell phones/ people in the immediate area of the surface. Using *Processing* and *Grasshopper* scripts we were able to detect phones in the vicinity of the prototype surface and to use this information to manipulate the geometry of the grasshopper surface definition.

Next iteration of this exploration will address direct relationship between the environmental input and specific spatial configuration. In other words, the particular input should be able to produce specific formation of the surface that is related to the functional requirements.

CONCLUSION

In summary, the *Soft Kinetic Network* (*SKiN*) surface is organized around the network of embedded “muscle” wires that change shape under electric current. The network of wires provides for a range of motions and facilitates surface transformations through soft and muscle-like movement. The material system developed around the wire network is variable and changes its thickness, stiffness, or permeability within its continuous composite structure. The variability in the material system enables it to (a) behave differently within surface regions; (b) vary the speed and degree of movement; (c) vary surface transparency; and (d) provide other levels of performance such as capture of heat produced by the muscle wire and distribution of heat within the surface regions. The main idea is that variability of the material system and its capacity to adapt can bring us closer to the seamless material integration and greater environmental responsiveness found in biological organisms.

The first series of prototypes allowed for the exploration of actuation using SMA, digital simulation, sensor integration and external input experimentation. Attempts were made towards mapping and understanding complex movement trajectories in order to choreograph the movement of the surfaces. Material variability was also explored as a way to further influence the movement of the surface. Simulation of the surface change using *Grasshopper* and *Kangaroo* was used to further understand the movement of the surface. Due to the limitation in size and scale of the prototypes precise patterns of movement could not be predicted with a satisfying degree of accuracy.

In the next phase of the project the focus will be placed on scaling up of the material system, further pursuit of seamless integration of the SMA (and other smart materials) and development of a more robust micro-controlling and sensing system.

Working with smart materials presents a significant challenge especially on the scale of an architectural element or surface. Traditionally architectural components are assembled using several different material layers and every one of them has its specific role and material properties. Smart materials, on the other hand, are not artifacts; they are technologies of motion, energy, and exchange. Their integration in architecture offers an opportunity to re-calibrate materialization of architectural components and surfaces. It is no longer a material that determines a design but it is a design of phenomena that determines the design of a material.[12] The challenge is to build architectural assemblies that integrate and fully utilize the capacities and properties of smart materials. The functional qualities of smart materials/technologies that transfer energy and/or information would have to achieve a full overlap and integration with structural functions of a material system that are necessary for architectural applications. In this way the change of scale, currently one of the greatest challenges in the projects of this kind, would be more effectively addressed. Experimenting with fuller integration of SMA was one of the aims of our project. The next phase of the project will take this further by changing the scale of the system and attempting to capitalize on discrete and local movements to produce larger global effect on the surface.

The focus on seamless material integration and capturing of emitted energy is related to our broader goal that architectural intervention should find a more productive place within larger ecologies. We are very much interested in suspending a challenge of finding a non-permeable and clearly defined boundary between inside and outside in exchange for a surface that fosters constant flow of information, matter and energy.

This project is situated between several disciplinary territories. By exploring theories, techniques and tools of architecture, engineering, material science and cybernetics the goal is to develop technologies and designs that are capable of transforming static building components into active responsive surfaces that produce added functionalities in architectural and urban environments.

If we were to accept change as a fundamental contextual condition, architecture could then begin to truly mediate between the built environment, the people who occupy it and the larger context. As Ed van Hinte notes, "instead of being merely the producer of a unique three-dimensional product, architects should see themselves as programmers of a process of spatial change." The principal task for architects is to create "a field of change and modification" that would generate possibilities instead of fixed conditions.[13]

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