Shutters: A Permeable Surface for Environmental Control and Communication

Marcelo Coelho
MIT Media Lab
20 Ames St., E15-322
marcelo@media.mit.edu
+1 (617) 452-5695

Pattie Maes
MIT Media Lab
20 Ames St., E15-322
pattie@media.mit.edu
+1 (617) 452-5695

ABSTRACT
Surfaces capable of modulating permeability have long been used in architecture for environmental control, but have remained largely unexplored as information displays. The advent of new shape changing materials and construction techniques promises to change this. In this paper, we describe *Shutters*: a curtain composed of actuated louvers that can be individually addressed for precise control of ventilation, daylight incidence and information display. We discuss related work, the underlying design principles behind *Shutters*, engineering details and application scenarios in architecture and fashion. We conclude with a comparative visual study for the use of permeability in kinetic and shadow displays and provide directions for future work.

Keywords
Shape change, transformation, kinetic, soft mechanics, permeability, architecture, façade, textile, soft computation.

INTRODUCTION
Textiles and architecture have a long intersecting history. Archaeologists date the first permanent construction and the first evidence of constructed textiles to circa 5,000 B.C., and believe that the first building materials were textiles based on the form of wattle-and-thatch construction [4]. This intrinsic relationship highlights the overlapping roles that clothing and buildings have played in providing privacy, protecting the body from exposure to the elements, and serving as conduits for aesthetic and personal expression.

To create living spaces that are habitable and pleasant for its residents, a building needs to regulate and balance the exchanges between its internal and external environments, while efficiently using a variety of technologies to insulate and maintain an adequate temperature and quality of air.

Figure 1. *Shutters*' louvers are controlled with a circuit board concealed in the wooden panel. The *Shutters* on the right has its louvers arranged to display the letter 'A'.

By carefully selecting materials and structures that can mediate the daylight intake and ventilation flow, it is possible to maintain, for instance, the building environment at a desired temperature range (usually based around human thermal comfort) throughout the sun's daily and annual cycles, while supporting lighting scenarios which are adequate for different activities. However, people's use of space is complex and changes frequently, raising the need for an environmental control system which is equally flexible, and capable of adapting to its users.

In an attempt to address this issue, we have developed *Shutters*, a curtain composed of shape memory alloy (SMA) actuated louvers (or shutters) that can be individually addressed for precise control of ventilation, daylight incidence and information display. By creating a shape changing permeable surface that can support a range of different uses, *Shutters* improves upon previous façade systems and proposes a novel alternative for the deployment of ubiquitous information displays. *Shutters* is silent, non-emissive and can ultimately create living environments and work spaces that are more controllable and adaptable, while also providing information to its users in a subtle and nonintrusive way.

In this paper we describe the evolution of *Shutters'* design and elucidate how controllable permeable surfaces can expand the ways in which we create, deploy and use pervasive displays.

RELATED WORK

Most buildings present some form of adjustable sun-shading element or technique (also referred to as 'brise-soleil, from French, "sun break"). These can range from traditional methods, such as lattices, pierced screens or blinds (see figure 2), to more elaborate smart surfaces that can filter out lighting and control ventilation at varying degrees with preprogrammed computerized behaviors.

The façade of L'Institut du Monde Arabe (Paris, 1987), (see figure 2) designed by the architect Jean Nouvel, is an example of a structure carrying several motorized apertures that act as a brise-soleil to control the light entering the building according to the weather conditions and season of the year.

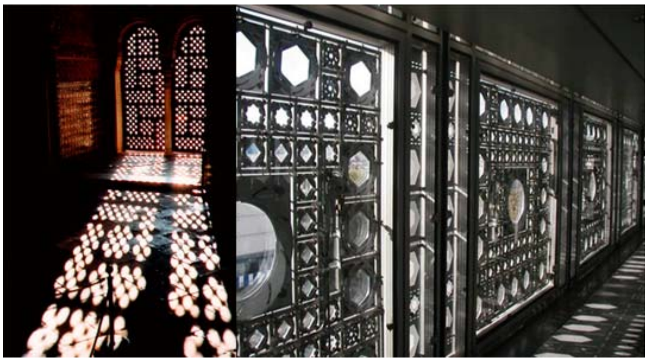

Figure 2. Left: Alhambra palace in Granada, Spain, provides an example of a traditional brise-soleil. Right: Jean Nouvel's L'Institut du Monde Arabe in Paris, France. The mechanical irises open and close in response to different light conditions over the course of the day. Image by David Merrill.

In spite of their functionality and striking design, these façade panels are noisy, tend to break easily and do not provide a very scalable solution that can be easily integrated into other buildings or easily replaceable when they fail. Most importantly, they are fully automated, not allowing residents in the building to have a high granularity of control over their own space.

The world of textiles is another area where precise and directional control of permeability is critical. For instance, high performance materials, such as Gore-Tex, can selectively let sweat and heat out of the body, while protecting a wearer from rain or snow. Moreover, shape-changing textiles have also already been successfully implemented. Kukkia and Vilkas, for instance, are two kinetic garments based on the use SMAs which use shape change to develop an almost whimsical relationship with their wearers [1]. Borrowing ideas from the worlds of textile and architecture, we have developed a soft kinetic surface that can be electronically controlled to regulate exchanges in a space and to communicate.

DESIGN PRINCIPLES AND MOTIVATIONS

Shutters is motivated by several design principles and is part of a larger research effort to develop transformable interactive surfaces for human-computer interaction.

These transformable surfaces are based on a design approach we call *soft mechanics*, where kinesis is generated by materials which transition through different shape memories and elasticity states, rather than traditional hard mechanical joints. Previous instantiations of this technology include *Surflex*, a composite that uses active and passive shape-changing materials to undergo large topological deformations [3], and *Sprout I/O*, a surface that combines small shape deformations and co-located input/output at the surface boundary to create a dynamic texture for communication [2].

In the case of *Shutters*, the focus was placed on shape-changing permeability where the goal was to create apertures for controlling the visual and environmental exchanges between two spaces, rather than just modulate their spatial relationships.

Architecture provides a compelling need for a permeable surface that can physically transform itself to simultaneously accommodate multiple conditions and functionalities. Spaces are deeply affected by their exposure to the elements, which vary continuously, and 'one size fits all' louver approaches usually turn out to be inefficient or inadequate for individually regulating ventilation, daylight, or visual privacy.

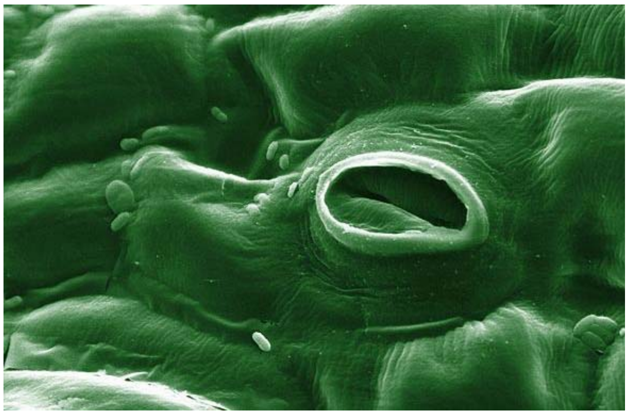

Figure 3. Electron microscope image of a stoma on the leaf of a tomato plant.

A comparable source of inspiration for the design of controllable louvers is a stoma (see figure 3). Found mostly on the underside epidermis of a leaf, stomata are pores which regulate the exchange of gases and water vapor between the outside air and the interior of a plant. The pore's aperture is controlled by a pair of specialized cells which elongate to open and close during the daytime in response to changing conditions, such as light intensity, humidity, and carbon dioxide concentration.

Finally, as a result of daylight control, *Shutters* can also affect changes in external surfaces by casting shadows which can be controlled like a regular display. Shadows have long been used as a technique for projecting images and providing information. Shadow puppetry is an example of a still common form of storytelling that uses paper cutouts to cast shadows on an illuminated backdrop.

Further in this paper, we examine how certain permeability properties, such as the pore's shape and its surface density, can affect the fidelity with which a permeable surface can display images and cast shadows.

ENGINEERING SHUTTERS

Shutters has gone through three design iterations. The first two implementations addressed technical concerns, while the third iteration focused on improving its appearance, scalability, and construction techniques. In this section, we discuss some of the main engineering challenges and how they were addressed.

Mechanical Design

Shutters is a fabric kinetic surface composed of a grid of actuated louvers, which can be individually controlled to move inwards and outwards.

Shutters is constructed out of fabric so as to be flexible and easy to manipulate, while still embodying some of the functionality of external façade elements. In its first design iteration, *Shuters* was constructed of fire retardant 100% wool felt, which is ideal for laser cutting and the integration of electronics, conductive threads and shape memory alloy (SMA) strands. Nonetheless, felt favors the use of traditional craft techniques and, in the last design iteration, was replaced with Gore-Tex, a waterproof fabric, and the use of high performance construction techniques which are more efficient, reproducible and appropriate for *Shutters* application.

Laser cutting is a technique which is becoming increasingly more common in textiles: it helps prevent fraying since the fibers fuse together when cut by the laser beam; it is computer controlled making the design and cutting of unique and complex patterns more efficient and customizable; and, in the case of a textile actuator, laser cutting makes it possible to score hinges in the material to create precise points of actuation. In tandem with laser cutting, we opted for ultrasonic welded seams over traditional sewing techniques, since they are faster to assemble and remove the need of perforating the textile, which lets water in and weakens its overall structure.

The mechanism for *Shutters* is based on the electronically controlled actuation of two strands of SMA per louver – for inward and outward movement – and through resistive heating, it is possible to electronically control the temperature of an SMA strand and generate the actuation to control the aperture angle of every louver.

The use of SMAs in *Shutters* is unique in that the SMA is shape set and optimized specifically for a two-way actuation and that it can lay flat against the felt, not requiring any extra physical space to move, as a conventional helical shaped SMA actuator would.

Another innovation is that previous SMA and textile composites require an external actuator, such as gravity, the wearer's interaction, or the rigidity of the material to provide a counter movement to the SMA's actuation [1][5]. *Shutters*, on the other hand, combines the states of two different SMA strands to get a gradual shape change, largely increasing the possibilities for electronic control and the scope of possible applications for this alloy in interactive systems. Additionally, since there are no hard, moving parts, *Shutters* is a completely silent kinetic display.

The louvers are shaped as 3.5 cm x 3.5 cm squares but can also be scaled to much smaller sizes or present curvilinear shapes, since the only limitation is in the practicality of physically assembling and securing hard components to the soft fabric, a common challenge in the development of electronic textiles [6]. One of the greatest mechanical hurdles in *Shutters* was to devise a technique for attaching together the SMA, fabric, diodes, and wires for power delivery. The solution found was to use the actual SMA to create mechanical loops from which to attach it to the textile, preventing the alloy from moving and speeding fabrication (see figure 4).

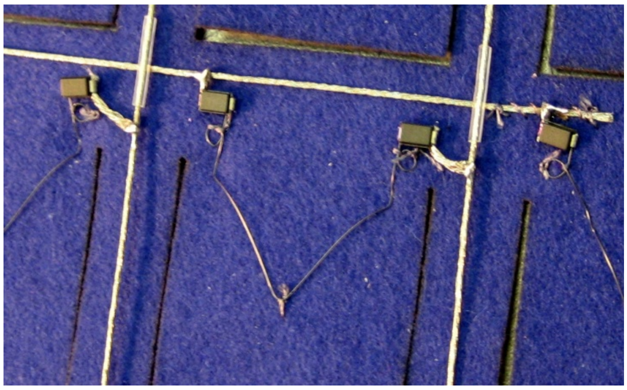

Figure 4. Detail of SMA sewing loops and diode connections.

In the initial prototypes, diodes were crimped to the SMA and to the conductive threads that deliver power to every louver, but in its final iteration, this connection was replaced by a small circuit board to which the diodes and individual louvers are soldered. There were two main motivations for this change: (1) the conductive threads had to be replaced by thin multi-stranded wires to reduce unwanted electrical resistance and *Shutters* power consumption, and (2) to facilitate construction, it was important to design the louvers as individual components which are modular and easy to replace in case of unexpected fatigue or breakage. Finally, the louvers' overall sizes are determined by the practicality of physically assembling and securing the components to the fabric and the SMA's strength to lift them.

Electronic Design and Control

Shutters is designed to behave like a conventional LED display, where every louver can be individually controlled by addressing its respective column and row, and full images are achieved by multiplexing the whole display. However, *Shutters*' 'pixels' are in fact high current resistors and need to be separated from each other with additional diodes with high voltage bias to prevent current distribution over the whole substrate. The resistance of the conductive threads that distribute power in *Shutters* also play an important role. *Shutters'* firmware has to account for the small power variations required by every louver and set its pulse-width modulation to compensate accordingly, delivering a higher pulse rate to louvers with higher resistance.

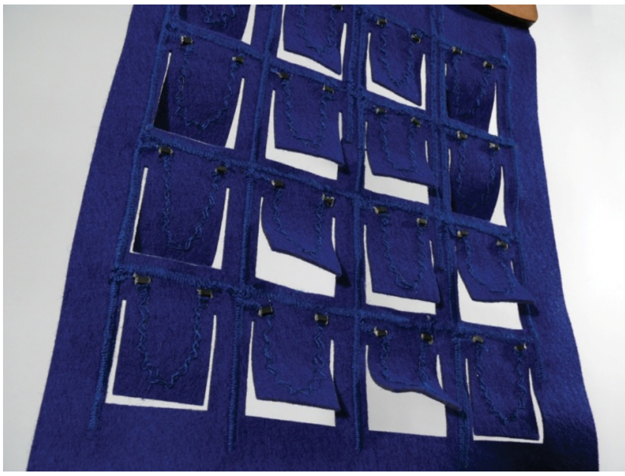

Figure 5. *Shutters'* louvers positioned at different angles.

Shutters has a display property which is unique to shape changing permeable surfaces: its louvers can move inwards and outwards at different angles (see figure 5). This is the kinetic equivalent of bicolor LEDS, but it provides a gradient control of shape and aperture instead of changes in color. Finally, 'pixels' in a kinetic display cannot 'jump' from one state to another; they need to transition from being open to being closed, and vice-versa. This way, gradient scales can be achieved by addressing the louvers at different modulations or counteracting the movement of a louver by powering the SMA on its opposite side.

Shutters controller circuit uses an ATMEGA644P AVR microcontroller, which controls an array of high current 'ground' n-channel MOSFETs (for the rows) and 'power' p-channel MOSFET drivers (for the columns on each side). The combination of different 'ground' and 'power' MOSFETs keeps heat to a minimum by bringing the logic control line close to VDD (12V) and GND (0V), preventing loss and dissipation in the circuit. Frames and animations can be directly sent to *Shutters* via Bluetooth or permanently stored in a local flash memory.

It is important to note that the power requirements of SMAs should not be overlooked. Every strand draws roughly 0.6A at 12V to be fully actuated, but since *Shutters* is designed to maximize daylight incidence and heat gain, it can potentially save on other forms of energy. Additionally, since the louvers can preserve their physical position without any applied power, they only need to be actuated once, when changing states, saving on power consumption over longer periods. On the other hand, since the SMA used in *Shutters* changes shape at 60°C, it could be unintentionally triggered by solar heat if the temperature on the textile reached that level, however this seems highly unlikely. Increasing the SMA's phase change temperature would in exchange require more energy when the ambient temperature is lower. In the future, *Shutters'* surface could be potentially woven out of photovoltaic threads so that the whole extension of the curtain could harvest the energy to completely power itself.

APPLICATION SCENARIOS

The key to *Shutters'* functionality is in its ability to have a three-state control of environmental exchanges. When the louvers move outwards they allow for ventilation to pass through but, because of their angle, they block daylight. However, when they are bent inwards they allow both ventilation and daylight to come in. Finally, the louvers can rest at a midpoint where they completely block any exchanges with the outside.

The design of a louver grid is an attempt to improve on traditional louvers to allow for the 'blades' in the same horizontal row to move inwards and outwards, and individually from each other. This flexibility opens the possibility for three important functionalities: (1) precise two-dimensional control of shading, so that the daylight can illuminate different parts of a space and be blocked from others; (2) control of the ventilation between different parts of a space by opening and closing the specific louvers necessary to create wind tunnels, and finally; (3) use of *Shutters* as a soft kinetic and shadow display.

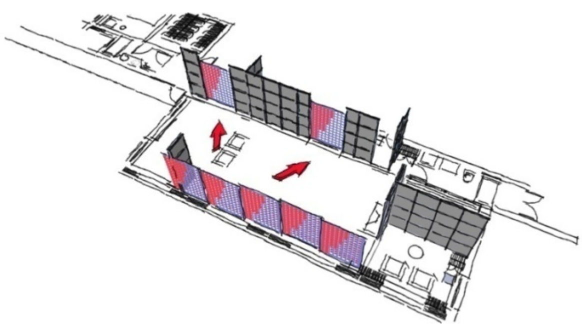

Figure 6. Simulation of *Shutters* controlling airflow. By opening air passages at different parts of the house it is possible to control the path and intensity of ventilation to accommodate the needs of different residents sharing the same space.

In the first scenario, the curtain combines a preprogrammed shading configuration that updates itself over time to maximize heat gain in the winter and minimize it in the summer (according to its geographical location and the position of the sun during the course of the day and the year), while not interfering with the activity of residents. For example, during the winter, the curtain can open itself in the morning to allow the sunlight in, which would heat a room over the course of the day; as the night approaches, it can progressively close itself to prevent thermal losses. A person reading a book, for instance, could also prevent direct sunlight from reaching a table while keeping the rest of the room completely illuminated over the course of a full day. This could be done specifying an area of the curtain that remains closed, while other louvers continue to go through their normal cycle.

In the second scenario, louvers on the north and south façade can be coordinated to create an airflow on the east side of the house, but prevent it from happening on the west side, creating an intelligent environment that accommodates the preferences of various residents sharing the same space (see figure 6).

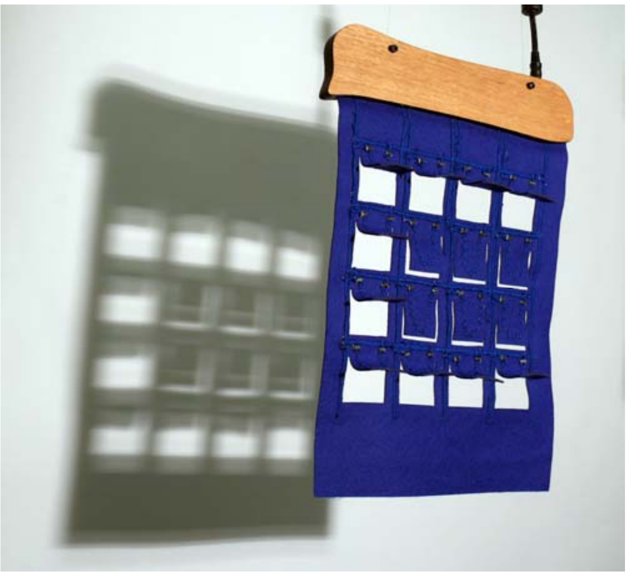

Figure 7. *Shutters* as a kinetic and shadow display

Finally, in the third scenario, since every louver can act as a pixel on an addressable grid, the curtain can be controlled to display images on its surface or project animated shadows on the walls and floor, providing non-obtrusive, ambient information that is relevant to residents (see figure 7). Since the functionality of the curtain is tied to heating and the energy consumption of the house, *Shutters* can function as a kinetic sculpture that provides visual feedback about residents' energy use.

PERMEABILITY IN KINETIC AND SHADOW DISPLAYS

Shutters differs from most displays in two fundamental ways: First, it creates images by regulating the size and angle of perforations distributed over its surface and, second, these perforations can cast controlled shadows over other surfaces. In order to understand how *Shutters* can make effective use of these properties and what its main trade-offs are, we have conducted a comparative visual design study.

Resolution

Similar to other display technologies, the number of pixels per area (pixel density) is one of the most important factors affecting the quality of the images *Shutters* can display. The smaller the space between perforations is (known as 'dot pitch' in conventional displays) the higher the image quality (see figure 8).

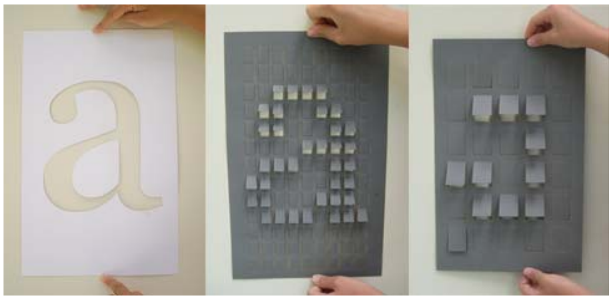

Figure 8. At about half the resolution of the middle image, the letter A on the right is illegible.

Background Contrast and Interference

The contrast between *Shutters* and its background image or pattern is also important. As expected, the greater the contrast between the surface and its background is, the clearer the displayed images becomes (see figure 9). In the case where the background is not a plain surface or is not static, a greater contrast becomes even more desirable.

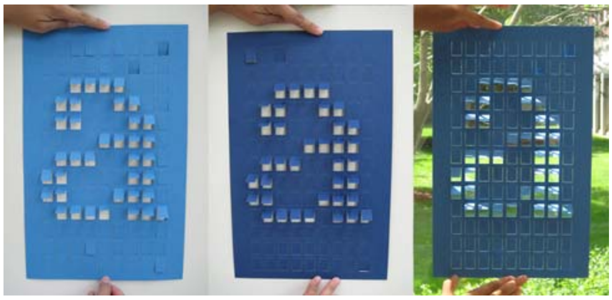

Figure 9. In spite of the busy background, the image on the right is legible due to a high color contrast.

Figure 10. The plain background on the left renders a clearer shadow than the textured grass and brick wall.

Overall, images look clearer against a plain backdrop and this becomes even more evident when dealing with shadows. In figure 10, the grass texture softens the pixel edge and makes the letter **A** harder to see when compared to a shadow cast on plain cement.

Perforation Shape and Distribution

The most unique property of *Shutters* is its perforations and their capacity to influence how images are seen.

When d*irectly viewed*, there are several perforation properties which can affect the quality of an image, such as: the shape of the louvers; the number of louvers per perforation; the overall alignment of all louvers; the capacity of the upper louvers to cast shadows on lower ones; and the backward or forward orientation of the louvers in relation to the viewer. When *indirectly viewed* – viewed through the cast shadow –, the angle of daylight incidence can considerably distort the shape and size of a shadow pixel.

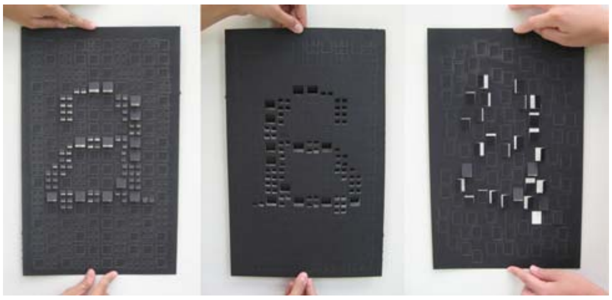

Figure 11. Symmetry in louver size and distribution are not as relevant as the directions in which louvers open and close.

In figure 11, the perforation orientation plays a great role in how the letter **A** is rendered. However, symmetry in louver size and distribution (random or in a grid) do not seem to be as influential as the direction (up/down or left/right) in which the louvers open and close.

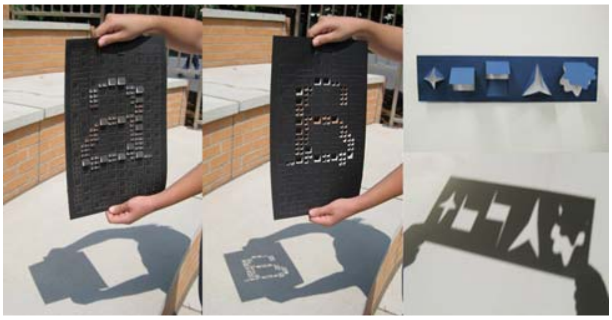

Figure 12. In the left image, louvers are oriented perpendicular to the sunlight, while in the center they are parallel, resulting in completely different shadows. The image on the right shows different perforation designs.

The shape of the perforations, the direction in which they open (backward or forward), and the angle of incident light also affect how images are displayed. The left and center images in figure 12 provide a comparison between louvers which are opened perpendicular or parallel to the sunlight. While both images are clear on the actual display, the shadows they cast are completely different. Finally, the image on the right illustrates how variations in perforation shape also affect the cast shadows.

Future design studies will include a more direct exploration of how louver motion influences the quality of the image displayed; in particular, looking to determine what is the ideal speed for a louver to move. This is important since the pixels are not necessarily blinking pixels on a screen, but objects that need to transitionally pass through different open and closed states to reach a desired position.

CONCLUSION AND FUTURE DIRECTIONS

In this paper, we describe *Shutters*, a curtain composed of actuated louvers that can be individually addressed for precise control of ventilation, daylight incidence and information display. We provide construction details and scenarios of use for controllable permeable surfaces. In the future, we plan to explore the coupling of *Shutters* with different sensing systems that can track people’s position in a house to optimize energy savings, while providing rich feedback about energy use. We also plan to explore more creative applications for permeable surfaces that can be worn on the body.

ACKNOWLEDGMENTS

We would like to thank Joanna Berzowska, Kent Larson and Mette Thomsen for providing the original sources of inspiration for this work, and Steve Helsing for collaborating on the implementation of *Shutters*’ first prototype. We would also like to thank Analisa Russo, Elly Jessop, Josh Kopin, Katie Puckett, Najiyah Edun and the Fluid Interfaces Group at the MIT Media Lab for the innumerous suggestions on how to improve this work.

REFERENCES

1. Berzowska, J. et al. (2005). *Kukkia and Vilkas: Kinetic Electronic Garments*. In Proc. of the International Symposium on Wearable Computers (ISWC'05) IEEE.
2. Coelho, M. and Maes, P. (2008). *Sprout I/O: A Texturally Rich Interface*. In Proceedings of Tangible and Embedded Interaction *(*TEI '08) ACM. pp. 221-222.
3. Coelho, M., Ishii, H., and Maes, P. (2008). *Surflex: A Programmable Surface for the Design of Tangible Interfaces*. In Ext. Abstracts on Human Factors in Computing Systems (CHI '08) ACM. pp. 3429-3434.
4. Garcia, M. (2006). *Architecture+Textiles=Architextiles*. Architectural Design , 76.
5. Jackson, C. et al. (1972). Nitinol - The Alloy with a Memory: Its Physical Metallurgy, Properties, and Applications: A Report. Washington: NASA.
6. Post et al. (2000). *E-broidery: Design and fabrication of textile-based computing*. IBM Systems Journal. 39(3): pp. 840-860.