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A RESPONSIVE MORPHING MEDIA SKIN

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Abstract. Existing media façades do not function as fenestration devices. They have been used mainly for visual communication and aesthetic purposes. This paper introduces a responsive morphing skin that can act as an active fenestration device as well as a media skin. We investigate new possibilities of using form-changing materials in designing responsive morphing skins that respond to environmental conditions and act as a communicative display. The design experiment that embodied this investigation, namely *Blind*, serves as a new layer of analogue media brise-soleil for existing space. It communicates the relationships between interior and exterior spaces visually and projects mutable imageries to the surrounding environment through sunlight. The design process of *Blind* simulates the responsive behaviour of the intended architectural skin by integrating physical computing and parametric design tools. This process includes the integration of soft apertures and architectural morphing skin to introduce a novel design method that enables an architectural skin to be a means of communication and fenestration. It responds to changing stimuli and intends to improve the spatial quality of existing environments through two types of transformations: *morphological* and *patterned*.

Keywords. Media façades; elasticity; responsive architecture; form-changing materials; kinetic skin.

1. Introduction

The rising popularity of designing media façades using LED, fluorescent lighting and projection technology in contemporary architecture is attributed to the increasing accessibility of such technologies. The BIX façade in the Kunsthaus Graz in Austria is the significant precedent of these approaches (Elder and Elder 2003). The GreenPix media screen at Beijing designed by Simone Giostra & Partners with Arup is another salient example that involves the use of conventional LED displays for communication and social interaction purposes (GreenPix 2008). However, there are no existing media façades that have been co-utilised as a fenestration device. Permeability properties of an architectural skin that allows moderation between the interior and exterior conditions can be used as a key consideration for designing a media skin. What if a media skin with permeability features can perform similar visual effect to the conventional media screens?

The recently completed Media-ICT building designed by Cloud 9 Architects in Barcelona demonstrates an energy efficient architectural skin that uses soft materials as part of the visual display. The *soft* façade made of ETFE responds to the user needs. The ETFE skin protects the interior by regulating indoor climate from direct sunlight. When more light is needed, the pneumatic skin deflated to let the daylight in (Ruiz-Geli 2011). This pneumatic kinetic shading device sets an early inspiration to conduct this research work; however, further investigation is needed especially in terms of allowing air ventilation and shadow casting of media skins. Another precedent is the project *'ShapeShift'* which uses an assembly of kinetic membranes using EAPs (electro active polymers) to prototype robotically fabricated room-dividers (Kretzer 2011). However, this prototype needs extremely high energy for transformation and lack of representation of any media contents.

The design exploration presented in this paper investigates the *morphing* aspect of the 'soft' kinetic architectural skin to perform visual communication effect without using LED digital display. In the field of engineering, the word morphing is used when referring to continuous shape change, for instance, no discrete parts are moved relative to each other but one entity deforms upon actuation (Thill et al. 2008). The term *morphing* is used in this research to describe the use of form-changing materials to perform kinetic actuations on responsive skins with little use of mechanical components. In contrast to other kinetic or media façade projects, this research investigates new possibilities of attributing *softness* and *elasticity* in form-changing material system that applies to an architectural skin. It also responds to environmental stimuli and act as a communicative display. The passive and active form-changing materials such as silicone rubber and shape memory alloy (SMA) are used to test these new possibilities. The simple, thin and lightweight design of the *architectural morphing skin* (AMS) provides an economical alternative to the conventional digital media surface by adding inherent potential functions to regulate ventilation and sunlight.

The study of this research intends to expand the repertoire of current responsive digital media skins design by developing an alternative method for architects and designers to integrate form-changing materials with computational processes to design a responsive morphing media skin. It aims to explore the passive and active design strategies integrated parametric design tools and contemporary sensor devices.

2. Soft responsive kinetic system

There are possibilities for implementing the *soft responsive kinetic system* (SRKS) in physically responsive architectural morphing skin (AMS) in this research. This system provides a platform to shift from hard to soft material system approaches for designing architectural media brise-soliel. It also develops an appropriative method for studying soft responsive morphing skin that improves the quality of our design explorations. Instead of inventing systems or synthetic materials, we shift the approach to exploitation of existing form-changing materials that have been applied in other disciplines but are new in the context of this architectural vision. The kinetic actuation of SRKS does not require the use of mechanical components, pistons or motors. Instead the overall system uses form-changing materials for actuation purposes. SRKS served as a proposed system for designing *Blind,* a design exploration for morphing media brise-soleil discussed in Section 3. It is also a novel design method of inquiry which included four elements, *Skin*, *Skeleton*, *Actuator* and *Sensor* for their individual design strategy and implementation (Table 1).

TABLE 1. Elements, design strategies and implementations of Soft Responsive Kinetic System (SRKS).

Elements	Design Strategies	Implementations
Skin	Elasticity	Flexible
Skeleton	Tensegrity	Transformation
Actuator	Form-changing materials	Actuation
Sensor	Adaptability	Sensing

The design strategy of the *Skin* element of the SRKS focuses on elasticity to produce flexible *architectural skin*. Elastic materials deform when force is applied and the deformation is reversed once the force is removed, returning the materials to the original state. The potential energy stored within the material itself can be harnessed to activate the deformation process back to its original state. This offers potential new forms of flexibility, adaptability and deformation using the memory effect in architectural skins. The elastic material used for the design exploration is silicone rubber given its durability, heat resistance and elastic capacity. The heat tolerant material property makes silicone rubber a suitable material to integrate with active form-changing materials (SMAs) to form a morphing skin, addressing elasticity and actuation respectively (Figure 1).

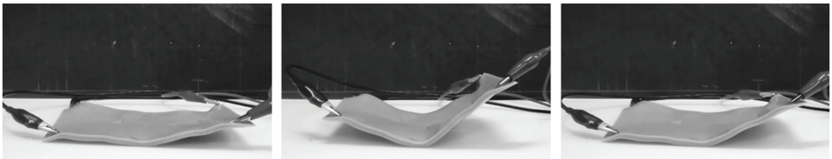

Figure 1. Early experiment for elastic silicone rubber skins set as the elastic component and actuator by electric stimuli.

The *skeleton* element of SRKS focuses on the tensegrity structural approach that reduces the friction between mechanical joints and achieves a lightweight structure. Due to the interdependent nature of all the elements, a slight change in any of their parameters can result in a significant form transformation (Fumar and Zhou 2009). For these reasons the tensegrity *skeleton* was chosen as part of the SRKS and for its flexibility and lightweight components. The lightweight accessible ABS (Acrylonitrile Butadiene Styrene) used as the primary strong explicit materials to fabricate tetrahedral modular components integrated with stainless steel coated wires. Eventually they form the light weight and flexible tensegrity tetrahedral modular skeleton as the exoskeleton structural system of *Blind* (Figure 2).

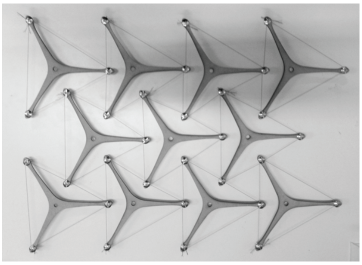

Figure 2. 'Simplified' version of tetrahedral modular skeleton.

The *actuator* element of SRKS addresses the use of active form-changing materials for *actuation* of the SRKS. We proposed the use of shape memory alloys (SMAs) as the active form-changing materials to investigate the alternative of actuation, since the dynamic deformation, expansion and contraction, of SRKS can be achieved and controlled with electrical stimuli. The deformation of SMAs occurs under electrical stimuli using 5 V for a 1.5 amp current to perform potential actuation (Figure 3). The four potential profiles for this 'soft' actuation based on the process of expansion and contraction in specific parts of the SMA wires discussed in authors' previous work (Khoo et al. 2011).

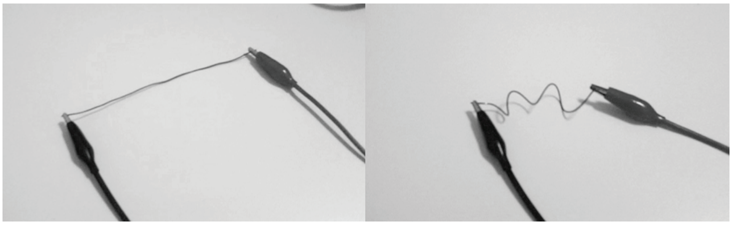

Figure 3. Deformation of SMA wire occurred when heated by electric stimuli.

The *sensor* element explores the adaptability of SRKS in order to achieve morphing skins that display elastic properties, and respond to digital and physical stimuli. This idea is developed using parametric design tools discussed subsequently in Section 3. The application of *Blind* is as a prototypical kinetic shading device and media screen with sensing ability that to regulate shading and visual effect. It aims to improve the comfort level as well as visual communication between the exterior and interior of spaces. This application embodies in an experimental process used design tools such as Grasshopper and Firefly parametric software together with Arduino microcontroller and photo resistor (Figure 4). The integration of these open source software and hardware make initial digital simulation and physical experiments possible.

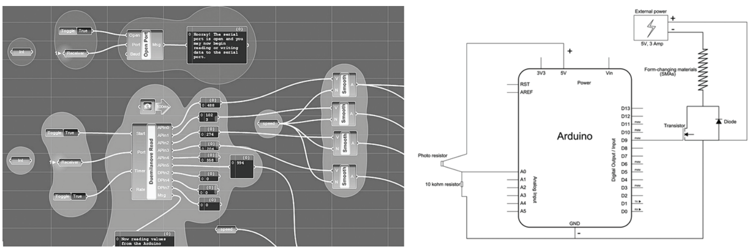

Figure 4. Left: Grasshopper and FireFly parametric schema. Right: diagram of adaptive process of SMA control through Arduino microcontroller with physical computing.

3. Design exploration

The design exploration of the responsive architectural morphing skin through soft kinetic system, called *Blind,* is presented in this section. *Blind* serves as the *analogue media brise-soliel* to display binary images and motion graphics using the perforation process of the soft surface composed by the *'eye-like'* permeable apertures. The '*analogue pixels'* of the surface creates a new layer of visual intervention in the form of responsive semi-ellipsoid canopy to allow communication between the ambient environment and the *Blind*.

Blind is a multilayer architectural morphing skin that composed by two types of triangulated modules (Figure 5). It manipulates sunlight through bending and twisting of its undulating surface. This malleable fenestration through the input of real-time data constantly cast controlled shadows over the surface under its semi-ellipsoid canopy (Figure 6). The shadow casted into the existing surface through this process provides a morphing atmosphere that suggests a continued relationship between exterior and interior space. The conventional digital media screen, in comparison, lacks the consideration of its effect on the interior condition.

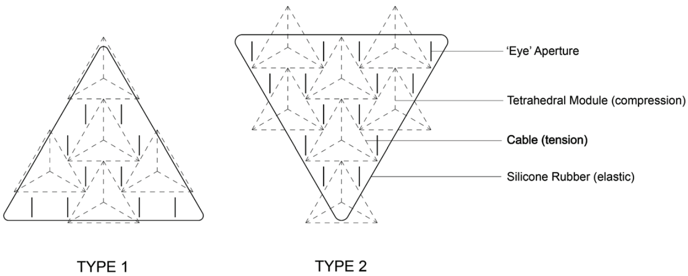

Figure 5. Two typical types of triangulated modular skin embedded with tensegrity tetrahedral components.

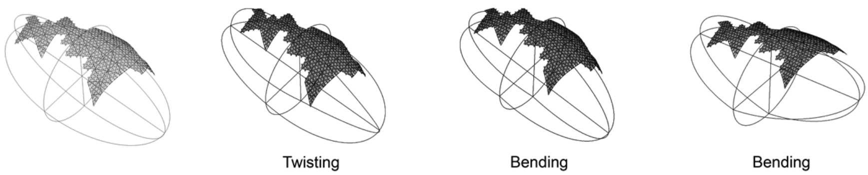

Figure 6. Blind in the form of semi-ellipsoid canopy performed morphological transformation for optimal sunlight manipulation through bending and twisting.

Blind includes two types of transformations that respond enable adaptive visual effects and media communications: *Morphological* and *Patterned* (Figure 7). Morphological transformation is a *global* morphing process of the entire undulating skin structure to control shadows casting and lighting manipulation for various visual effects of space under *Blind*. Patterned transformation involves *local* individual openings that are opened and closed to serve simultaneously as *'analogue pixels'* and as apertures.

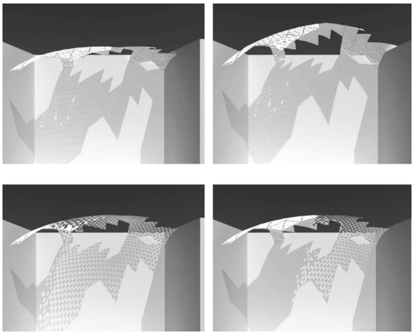

Figure 7. Above: Shadow casting by global morphological transformation. Bottom: Projected domestic morphing shadow and light spot patterns of patterned transformation.

3.1. MORPHOLOGICAL TRANSFORMATION

Morphological transformation explores the global surface curvature of *Blind* to be modifiable while maintains the continuous topology of undulating or flat surface. It responds to various functional drivers to manipulate the lighting effects in global scale. This morphological transformation demonstrates an alternative actuation system using SMA springs integrated with the overall tensegrity structures as discussed in Section 2. The global actuation takes place in between the tetrahedral skeletons and skins and is triggered by the contraction and expansion of the SMA springs through electrical stimuli (Figure 8).

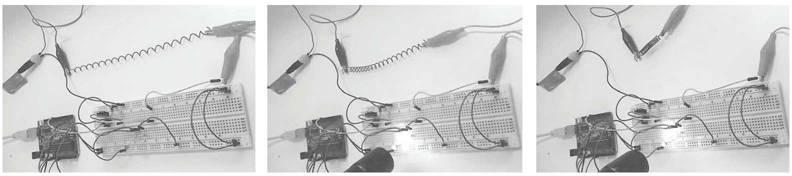

Figure 8. SMA spring responds to direct light through a photo resistor to perform contract and expand actuation.

The adaptability for morphological transformation process of *Blind* is tested by using a photo resistor as light sensor and the torchlight mimicking the path of sunlight to embody the initial global transformation of physical responsive triangulated modular skin (Figure 9). It responds with various morphological states for optimal visual performance as a direct sunlight modulator that creates multiple lighting effects. This global morphing process constantly redefines the face or image of the existing building environment in order to materialise *Blind* as a media brise-soliel as well as responsive intervention.

This process also allows *Blind* to serve as a new transformable visual barrier in between interior and exterior spaces that have been overlooked in conventional digital media façades.

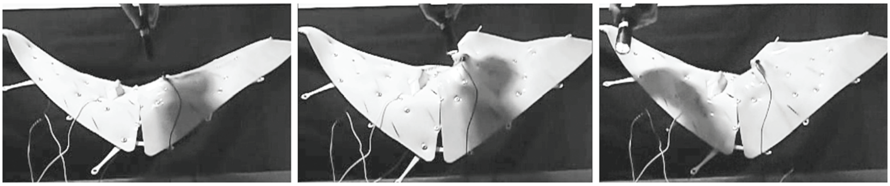

Figure 9. Morphological transformation of two types of physical triangulated modules of Blind responding to direct light for optimal visual performance.

3.2. PATTERNED TRANSFORMATION

The patterned transformation through permeability of *Blind* is generated by the individual domestic ‘soft’ apertures as *analogue pixels* projecting light spots in response to sunlight penetration. This transformation manipulates the spatial conditions of the interior and exterior spaces through the dynamic patterns of the skin surface. The initial geometry of the membrane aperture is inspired by the performance of the eye. The *‘eye-like’* apertures in the geometry are determined by their relative curvature on the responsive undulating silicone rubber surfaces and actuated by SMA wires and springs. This analogy of an *‘eye-like’* permeable aperture functions as a skin muscle mechanism in the eye which allows various changing porous patterns in binary form on the skin (Figure 10). This perforation process created a potential application for the surface of *blind* as the *analogue media brise-soleil*, to display binary images or even motion graphics.

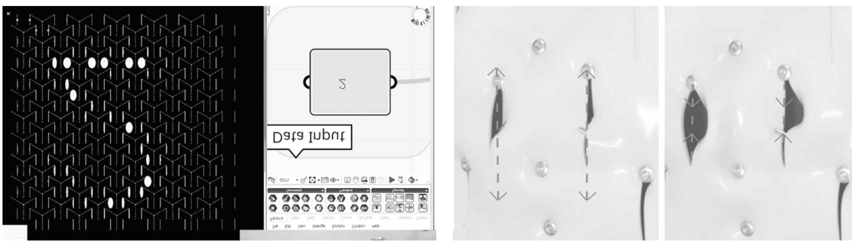

Figure 10. Left: Digital simulation of Light spots fenestration through ‘eye’ apertures formed numeric texts and textual visual patterns. Right: Physical domestic ‘eye-like’ apertures open and close actuated by embedded SMA wires.

The patterned transformation process of *Blind* adds a new layer of aesthetic for visual communication between existing space and external surrounding environment. This visual intervention demonstrated in a digital simulation creates a new media skin for communication between the existing spatial and the surrounding environment through its constant malleable porosity activated by real-time input data (Figure 10). The exterior skin of *Blind* allows light penetrates the 'eye' apertures to form the numeric texts light spots projected on the surface underneath *Blind*. Other textual visual patterns also formed by the light spots penetrating through the 'eye' apertures.

The fenestration of patterned transformation also performs the motion graphic representation in an analogue manner. The actuation of the 'eye' apertures of *Blind* occurs in two states, 'open' and 'close'. This produces an animated *'shadow play'*, which is an illusion of still and animating images caused by the illumination of the *Blind* under the sunlight. This real-time '*shadow play'* creates, potentially, a 3D volumetric analogue cinematic interior environment that responds to changeable events. The patterned transformation allows *Blind* to become a projective device by controlling direct sunlight and artificial lights penetration using real-time input data. This process extends the cinematic ability of conventional shadow play but in an architectural context.

4. Conclusion and future work

Architectural skins have become the interface of buildings in their surrounding urban environments. In general, these architectural devices serve as the building 'billboards' which normally serve as a one-way information communicator. The digital screens of these 'billboards', or more commonly referred to as media façades, often neglect the interaction between the interior and exterior conditions, especially in terms of moderating visual effect and lighting fenestration to the interior space.

We investigate the new potential designing responsive architectural media skins without digital display to achieve visual communication effect using 'soft' active and passive form-changing materials embedded in a tensegrity structure. This approach demonstrates a new method to extend the design of architectural media skins with environmental design considerations, particularly for moderating light in the interior spaces. It is also integrated with physical computing and parametric design tools to form a responsive kinetic system for simulating the comprehensive physical media display prototype.

Future work includes designing and developing a new Architectural Morphing Skin (AMS) that is able to perform sensing, analysis and actuation in one solid-state responsive entity, and installing a full-scale AMS at an urban site for practical architectural applications.

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