RESPONSIVE MATERIALITY FOR MORPHING ARCHITECTURAL SKINS

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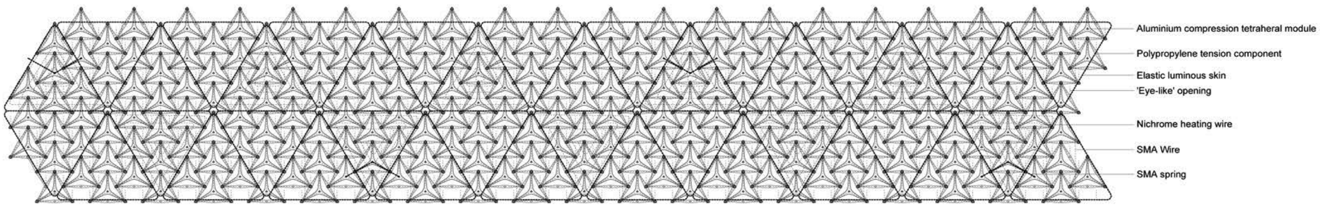
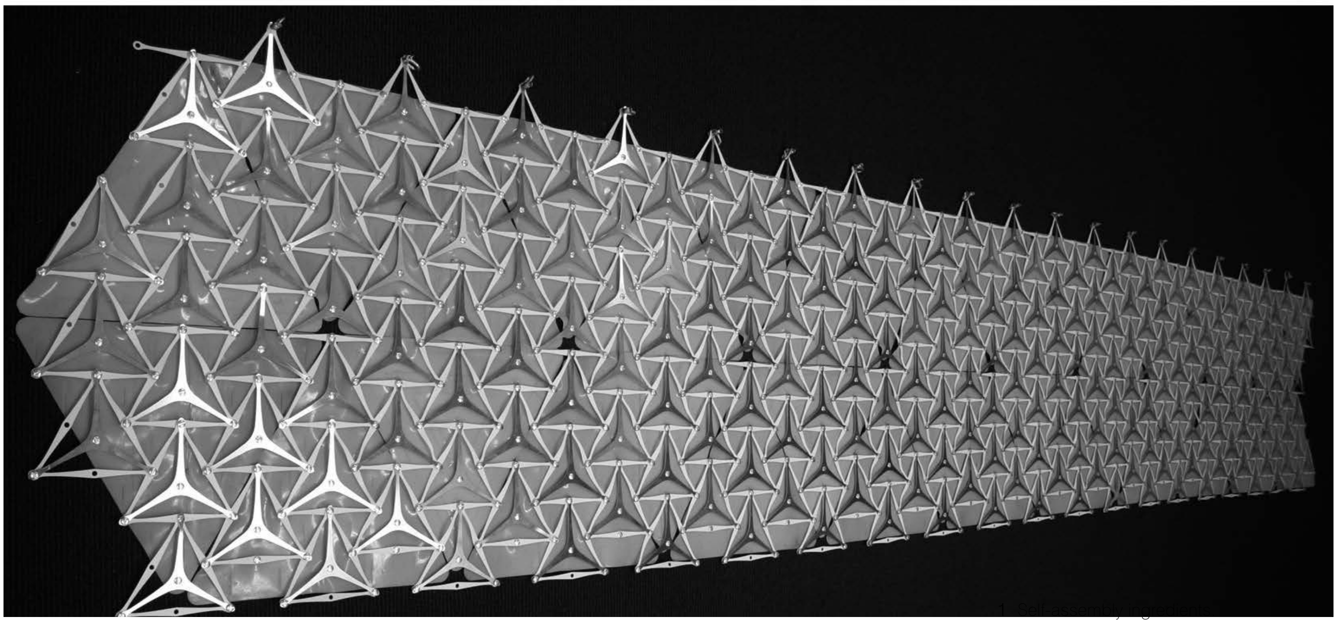




ABSTRACT

This paper presents the design of a novel material system with sensing, form-changing and luminous capacities for responsive and kinetic architecture. This aim is explored and evaluated through an experimental design investigation in the form of an architectural skin. Through experimentation with alternative materials and a rigorous process of designing the responsive material systems, a new architectural skin, namely Blanket, emerged from this research. The newly developed responsive material system is an amalgamation of silicone rubbers and glowing pigments, molded and fabricated in a prescribed way—embedded with shape memory alloys on a tensegrity skeletal structure to achieve the desired morphing properties and absorb solar energy to glow in the dark. Thus, the design investigation explores the potential of the use of form-changing materials with capacitance sensing, energy absorbing and illumination capabilities for a morphing architectural skin that is capable of responding to proximity and lighting stimuli. This lightweight, flexible and elastic architectural morphing skin is designed to minimize the use of discrete mechanical components. It moves towards an integrated "synthetic" morphing architecture that can sense and respond to environmental and occupancy conditions.

1 INTRODUCTION

In responsive kinetic architecture, the idea of responsive building skins is often explored through designing individual sensing components that have discrete mechanisms and movements. This architectural approach is not new and has been explored since the 1960s, for instance, the responsive *brise-soleil* of the Los Angeles County Hall of Records, designed by Richard Neutra in 1962, is one of the first significant examples of responsive architectural skins (Sample 2012, 332). Complex mechanical systems designed for kinetic movements are prone to break and fail and are unreliable in the long run. The Institut du Monde Arabe building in Paris, created by Jean Nouvel in 1987, sets the precedent for this approach (Ritter 2007, 7). These structures and systems engage complicated discrete elements and physical divisions. They use a series of external sensors to achieve the adaptability of the systems. Both the Neutra and the Nouvel building skin systems hindered the mainstream adoption of responsive building skins because of their expensive sensing system and brittle mechanical components.

Seeking alternatives to these led this research to investigate methods to design a responsive architectural skin with fewer mechanical and sensing devices. Technological advancement in material engineering provides the opportunity to use passive and active form-changing materials such as shape memory alloys (SMAs), elastic silicone polymers and phosphorescent glow pigments, to design kinetic and responsive architectural skins. These soft and form-changing materials can be integrated with other sensing materials. The morphing architectural skin presented in this paper provides an alternative approach to address the issue of brittleness in the operation of mechanical and sensing systems. It uses less energy and relies on its inherent multifunctional material properties to change state, morph and achieve a synchronized kinetic movement across the skin. According to Leslie Momoda, the multifunctional material system would require a combination of three or more functions, including logic, sensing, energy storage, structure and actuation. The proposal of this material system would be easily integrated into larger engineered structures because it would be lighter, smaller, less difficult to interface and easier to maintain in order to address the scalability issue (Momoda 2005, 48).

The research presented in this paper aims to explore form-changing materials that can perform illumination, and function as both an actuator and sensor in responsive architectural designs. This research investigates whether this kind of material exists. In addition, if it does, how to apply this in a responsive architectural design context. Is there an opportunity for using a "soft" system approach that exploits the performance of responsive materials and new tools applied to lightweight, flexible and adaptive architectural designs that respond to environmental and lighting stimuli?

These initial inquiries motivate this investigation into unexplored approaches using responsive and "soft" form-changing materials. It extends opportunities for designing responsive morphing architecture with hinge-less actuation and transformation.

By using emerging form-changing materials and alternative tools, a responsive morphing architecture can be achieved with fewer mechanical components and devices. This approach formed an investigation into the potential of existing form-changing materials to design responsive architectural design in the form of morphing skins. Morphing is used within the scope of this paper to describe a seamless and continuous shape-change deformation. This investigation eventually generated the concept of "responsive materiality". Responsive materiality offers an initial concept of movement and change in response to material properties rather than changes in mechanical components, such as actuated motors and gears, in the responsive kinetic architectural context. Current material advancements have allowed this concept to become a reality in which materials with sensing, actuating and feedback loop capacities respond to external stimuli (Kolarevic 2004, 55). Contemporary architects and designers can now reconsider the traditional relationship between architecture and material practice (Kennedy 2011, 118).

2 RESPONSIVE MATERIALITY IN ARCHITECTURAL DESIGNS

There are several precedents related to the concept of responsive materiality in architectural designs. For instance, Achim Menges's recent project, HygroScope–Meteorosensitive Morphology at the Centre Pompidou in Paris, demonstrates a materially actuated responsive skin without any kind of mechanics, electronic control or supply of external energy. It creates a new range of possibilities that propose that materials can actuate as well as sense. This purely passive approach suggests that zero-energy responsive architecture is possible (Menges and Reichert 2012, 53). However, once the material is programmed during the fabrication process, the responsive behavior of the material properties is fixed and unchangeable. Instead of being a negative issue, this passive approach provides an opportunity for this research to further explore a possible hybrid approach that includes passive and active responsive abilities within the materials' properties that can control various states after they are manufactured. Another similar approach is the project Bloom, designed by Doris Kim Sung. This is an architectural installation for sun shading and air ventilation comprised of 14,000 pieces of thermo bimetal (eVolo 2012, 1). This responsive material is fabricated with two thin sheets of metal. Each sheet contracts and expands at a different temperature rate when heated by sunlight. Bloom adopts a purely passive and zero-energy approach through material actuation that focuses on local openings or apertures on its surface. There is an outstanding opportunity to explore this passive approach in the transformation of its overall "global" surface.

1 The morphing luminous skin of Blanket absorbs light energy and provides luminous effects to revitalize the dark condition of the passageway

The Hylozoic Ground project by Philip Beesley sets another precedent in which material actuation is applied in the context of architectural installation. This Hylozoic environment includes several materially actuated elements: the shape memory alloy (SMA)-actuated pores and lashes are driven by Flexinol wires that contract when an electrical current runs through them (Gorbet 2010, 120). This form-changing material is controlled by software that channels electric current to individual SMA wires using a transistor switch. The control system introduces an active material actuation on a small scale by using leverage to amplify the contraction and expansion of the lashes. Although SMAs were invented in the 1960s, this versatile material is still full of potential especially for responsive architectural design. This material provides room to further develop the architectural-scale application for responsive morphing architectural skins. ShapeShift is a project that takes another approach to Beesley's works. A group of students and Manuel Kretzer from ETHZ (the Swiss Federal Institute of Technology, Zurich) used kinetic membranes with EAPs to develop ShapeShift as a prototype of an air control and shading system (Kretzer 2011, 7). It performs actuation by an electro-mechanic process within the materials' properties. Although this early exploration of active kinetic materiality is a novel approach, further development is desirable especially in the context of architectural-scale implications and potential applications. There is also potential for this project to further develop the porosity and permeability of the membrane itself to respond to environmental and communication inputs.

While Menges and Sung focus on the passive approach to designing responsive architectural elements, Beesley's works, Hylozoic Ground project in specific, and ETHZ's ShapeShift move towards an active actuation and sensing approach by using several form-changing materials and an electronic control system.

The current research investigates whether there is a system that exploits both passive and active approaches. There is an opportunity to create a hybrid system that involves passive and active implementation to fully exploit the advantages of both approaches. This hybrid system is expressed and partially explored through the design investigations conducted in this paper. Responsive materiality anticipates a novel form of architectural design, particularly in responsive kinetic architecture. By using materials with responsive capacities, this different approach hints at the great potential in a material system to perform transformation and other adaptive abilities within the material properties. This design revelation establishes an initial step for the design investigation in this paper to further explore the full potential of this different responsive design notion with responsive materiality.

The concept of responsive materiality is tested and explored through a series of material systems. The positive outcomes of these explorations lead to a design of a new morphing architectural skin, namely Blanket. It is a proof of concept embodied in the form of luminous morphing skin that serves as a responsive intervention to revitalize an underused passageway (Figure 1). The subsequent section discusses the early development of Blanket's responsive material systems as well as the design process. These material system explorations are an initial step toward investigating the possibilities of designing an architectural morphing skin that integrates materials and computation.

3 DESIGN INVESTIGATION OF RESPONSIVE MATERIAL SYSTEMS

Recent robotic research has included investigation into active property change in responding materials. However, while there are few precedents for applying these materials in the context of architecture there is a potential to test and implement these materials for full-scale architectural applications especially in responsive building skin design. Based on this potential, this research further explores the concept of responsive materiality in architectural design through the investigations of a series of form-changing, sensing and luminous materials. In this section we explore the potential for materials that combines sensing, passive as well as active lighting and kinetic response for application in responsive architectural skins design.

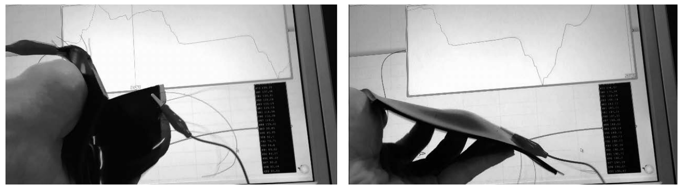
The investigation of the sensing and responsive material system uses the integration of materials with physical computing to create both active and passive sensibility and luminosity. This integration includes materials such as Nichrome wires, SMA wires, phosphorescence glow pigments (strontium oxide aluminate) and translucent silicone rubber (containing polymethylvinyl, polymethylhydrogensiloxanes and polymethvlvinylsiloxane). Table 1 illustrates the aforementioned various responsive materials with passive and active responsive capacity in the focused area of sensitivity to develop a hybrid material system that can sense and respond to changing environmental conditions. This material system focuses on sensing, form-changing and luminous capacities to investigate new design possibilities for a synthetic sensory skin (Table 1). This skin is developed through a synthetic material, Lumina, that is lightweight, and performs simple sensory, kinetic and illumination functions simultaneously. The following three subsections describe the active and passive responsive capacities of Lumina, focusing on the research area of architectural illumination as the sensing and luminous material system applied to fabricate the skin of Blanket.

	Sensing capacity	*Form-changing capacity*	*Luminous capacity*
Active	SMA wires	SMA wires	Nichrome wires
Passive	Glow pigments	Silicone rubbers	Glow pigments

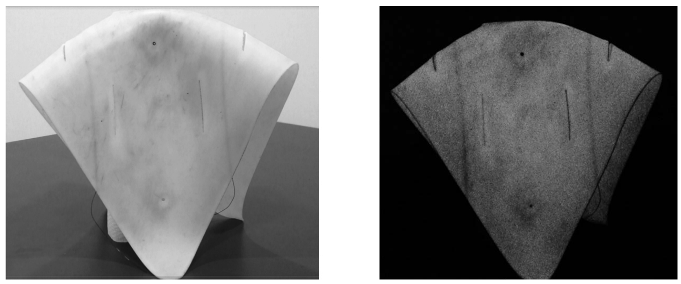
Table 1: Sensing, form-changing and luminous materials with active and passive responsive capacities for the development of Lumina applied to the skin design of Blanket.

3.1 SENSING CAPACITY

An early investigation of Lumina is to test the possibility of integrating various materials and physical computation to develop a novel sensing and responsive skin with fewer discrete components and better energy usage. This initial experiment integrates conductive paints with silicone rubber to test the potential for responsiveness. This process uses conductive paint synthesized with silicone rubber as the initial sensing element that performs capacitive sensing. When voltage is applied to this synthetic soft conductive material, it creates a uniform electric field that causes positive and negative charges to collect on its surface and on the proximity object. While the distance between these two conductive objects is changing, this process creates an alternating current that sends the variable values to the digital platform (computer) through the Arduino microcontroller.



2 Left: early stage physical experiment of Lumina material system integrated with conductive paint and silicone rubber. Right: graph showing variable data received by Lumina skin through its active capacitive sensing the proximity of an object (hand). This is the first exploration to investigate a soft architectural skin sensing external data without a discrete sensor.



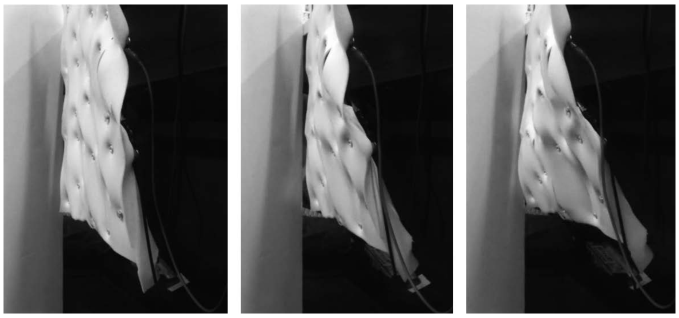
3 Passive sensing capacity of Lumina that senses daylight and absorbs light energy to glow in the dark without external power

This active sensing process is controlled via a digital platform that includes Grasshopper for Rhino™ and FireFly with a physical Arduino microcontroller (Figure 2). The positive outcome of this early sensing material experiment leads to initiating the development of the sensory Lumina skin, which is flexible and elastic and has passive luminous capacity (Figure 3). The development and fabrication process of Lumina, regarding its luminous capacity, is further discussed in the following sections.

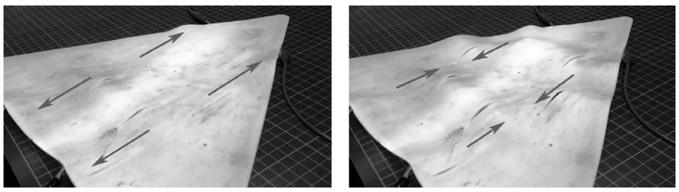
3.2 FORM-CHANGING CAPACITY

The initial testing for the form-changing capacity of the skin is explored through silicone rubber embedded with SMA wires and springs identical to the processes of fabrication in the previous two chapters. Their integration allows the state change of the SMAs to activate the soft silicon rubber as the kinetic element. When equipped with the sensing capacity developed in a previous subsection, this synthetic elastic silicone rubber skin becomes the kinematic performer, as well as the capacitive sensor, in the soft approach without any external discrete mechanical components (Figure 4).

This form-changing skin is eventually fabricated in the form of a triangulated modular system that is used as part of the design process of Blanket and considered for large-scale architectural applications. This system uses a composite approach to integrate the SMA wires and silicone rubbers. The advantage of this composite morphing skin module is not only its lightweight and silent kinetic operation; like its predecessors in the previous investiga-



4 Early experiment of Lumina skin to test the active and passive process for its form-changing capacity. SMA springs integrated within the tensegrity skeleton actively actuate the overall global transformation, while the elasticity of the skin provides passive force to help return to its original state



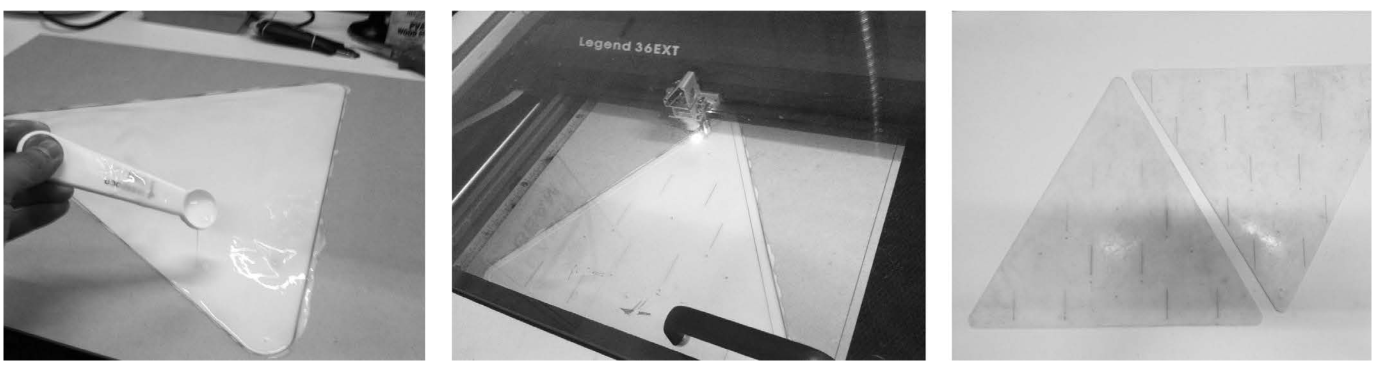
5 Left: eye-like apertures are passively closed by elasticity of the skin. Right: eye-like apertures as porosity are actively opened by SMA wires embedded in the skin

tions, the surface of this form-changing skin also allows individual “eye-like” apertures to open and close for various lighting pattern effects through shadow casting (Figure 5).

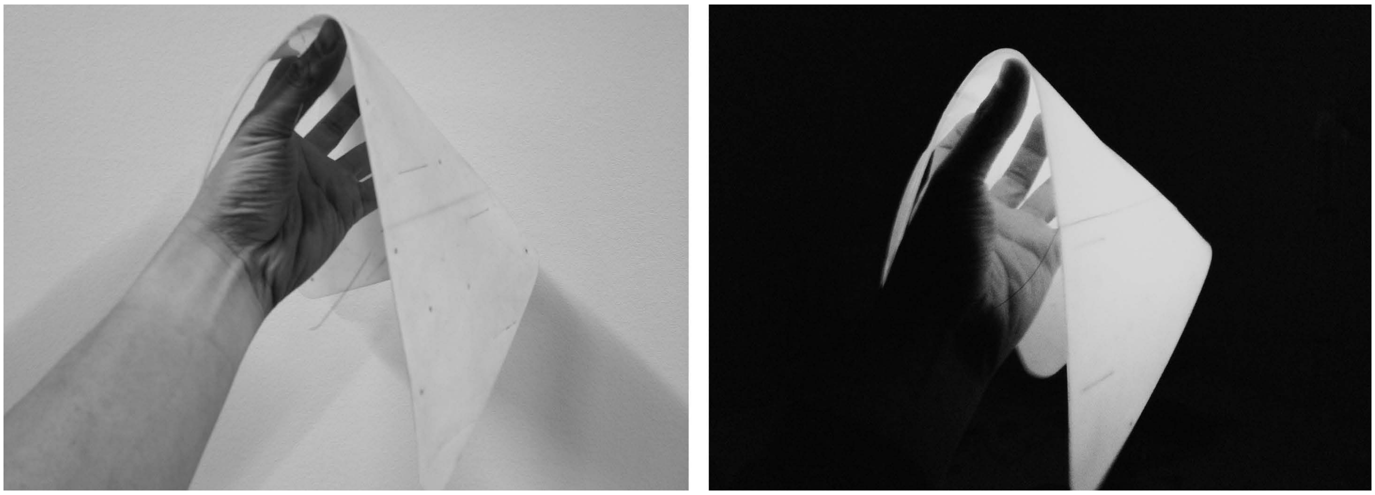
3.3 LUMINOUS CAPACITY

The development of a responsive luminous material, Lumina, is part of an investigation into responsive materials to evoke new possibilities for building skins to sense and respond, particularly for illumination purposes. Lumina material system is composed of translucent silicone rubber and phosphorescent glow pigments with a mixture proportion ratio of 5:1 (Figure 6). Table 2 illustrates a detailed recipe for the three main ingredients with their appropriate proportions in individual volume for molding the synthetic Lumina as a modular triangulated skin (Table 2). The following recipe is a final one after a series of failed experiments with different volumes of materials and mixtures. The goal of the experiments was to come up with a material that is strong and durable while having the desired flexibility, elasticity and glow-in-the-dark properties. It is also embedded with SMA wires for actuation and sensing purposes with conductive paint to form an individual triangulated module with an area of 0.07 square meter with the thickness of 1.5mm as the main component to fabricate the overall luminous skin of Blanket (Figure 7).

6 Left: glowing pigment. Middle: translucent silicone rubber. Right: Lumina in liquid form.



7 Left: molding of triangulated Lumina skin module with an area of 0.07 square meter each with the thickness of 1.5mm embedded with SMA wire. Middle: laser cutting for the triangulated shape skin. Right: Outcome of the skins.



8 Left: Lumina skin absorbing daylight energy. Right: passive illumination of Lumina skin glows in the dark without external power source

Materials	*Volume*
Silicone rubber 1 (polymethylvinyl, polymethylhydrogensiloxanes)	100 mL
Silicone rubber 2 (polymethvlvinylsiloxane)	10 mL
Phosphorescence glow pigment (strontium oxide aluminate)	25 mL

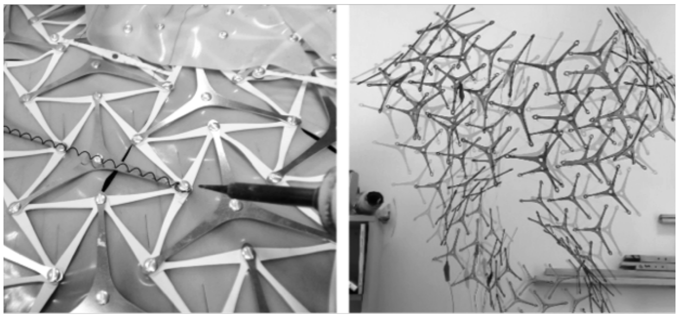
Table 2: The three main ingredients and their appropriate proportions in individual volume to form the triangulated Lumina skin.

The fabrication of Lumina involves integrating silicone rubber and glowing pigment to develop a passive and active luminous material that glows in the dark to be applied in the form of the skin. The passive luminous capacity of Lumina is to absorb light energy during the day and discharge the light energy after dark to produce a glowing effect (Figure 8). When absorbing external heat energy, Lumina can actively produce brightness beyond its passive luminous capacity. An initial test is conducted to observe this active luminous capacity by allowing Lumina skin to absorb heat energy in 100°C boiling water. Through qualitative observation, the Lumina skin obviously glows with extra brightness than its passive illumination (Figure 9).

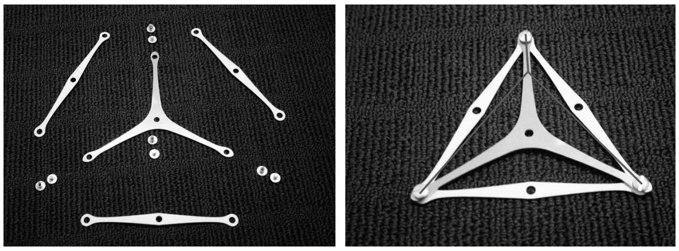
4 PROTOTYPING THE DESIGN INVESTIGATION

Derived from the promising results of the early experimental Lumina material system with its multifunctional and responsive capacities discussed above, this section uses these results to further explore the design investigation. Blanket focuses on a sensing and illuminating morphing cylinder-shape skin as a reciprocal intervention to improve an existing ill-designed and dark condition of the existing building environment. This morphing skin of Blanket is a material system that performs sensing, actuating and illuminating as one integrated entity.

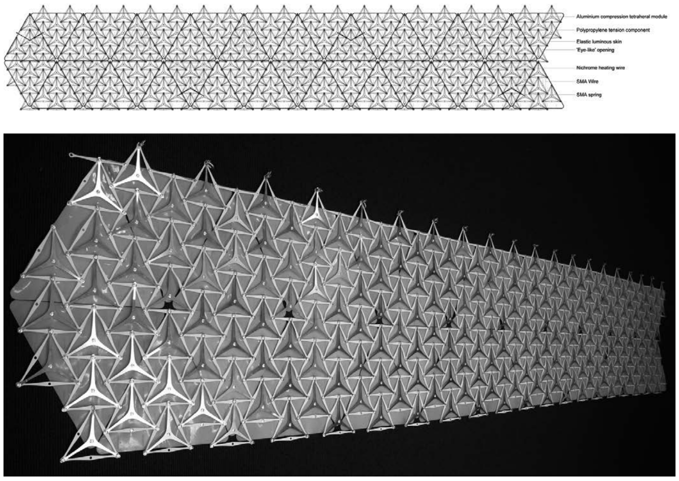
9 Left: Lumina skin absorbing heat energy from boiling water. Right: extra brightness for luminous Lumina skin



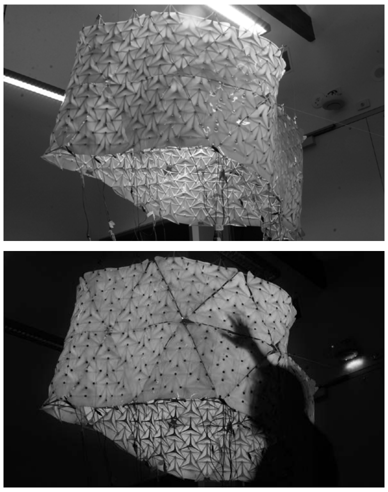
10 Left: SMA spring embedded in the tensegrity skeleton of Blanket. Right: early physical assembly of one row of tensegrity skeleton embedded with two SMA springs to test the overall global transformable capability of Blanket



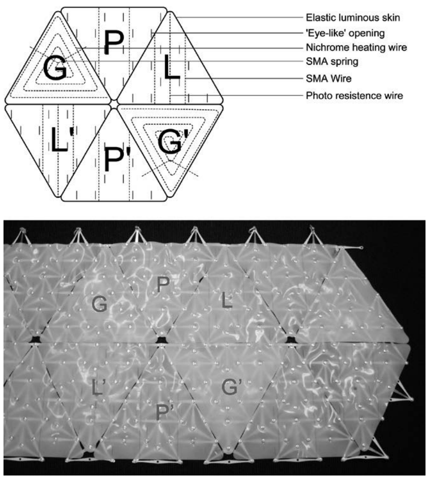
11 Left: the components of tetrahedral module include the compressional aluminium tetrahedron and tensional polypropylene tendon strips. Right: assembly of optimized tetrahedral module



12 Top: two rows of unfolded skeletal strips. Bottom: complete physical fabrication of unfolded tensegrity skeleton of Blanket



13 Top: normal artificial lighting condition for the two-row final physical prototype of Blanket. Bottom: self-passive illumination of Blanket in the dark environment



14 Top: three different types of triangulated responsive Lumina skin panels. Bottom: physical overall responsive skin system of Blanket, composed of three individual types of triangulated Lumina panels

Blanket is conducted through a rigorous method of design investigation that included two fundamental components of the development process: a kinetic tensegrity skeleton and a responsive luminous skin. These components are applied to the design investigation of Blanket as discussed in the following subsections.

4.1 KINETIC TENSEGRITY SKELETON

As an alternative to the traditional self-supporting tensegrity structure, the kinetic skeleton of Blanket serves as the non-classic hanging and inverted tensegrity structure partially supported by the existing 'host' structure. It also serves as part of the actuate system, to perform the kinetic movement for the overall system. This is actuated by the SMA springs that are derived from the previous project work, Blind, to provide a more durable and lightweight flexible structure (Khoo 2012, 207). The nature of this tensegrity structure enables minimum actuation to achieve maximum transformation. This flexible skeleton achieves various transformations without moving hinges and parts. It uses the idea of leverage to maximize transformation in the form of bending and twisting through form-changing SMA springs that can expand and contract to five times their original length. This form-changing process operates through electrical heating of SMA springs controlled by an Arduino microcontroller (Figure 10).

The hanging tensegrity skeleton system of Blanket is composed of six rows of skeletal strips. Each row consists of 72 tetrahedral modules fabricated by compressional aluminium tetrahedrons with a thickness of 1.2mm and 216 tensional polypropylene "tendons" that form the overall cylinder shape of Blanket (Figure 11). This approach and materials selection creates a flexible structure system to achieve a lightweight and strengthened skeletal system for global transformation purposes. The global transformation process of this skeletal system is actuated by four SMA springs per row embedded in the overall skeleton. These respond to the external data from the individual sensing skin of Blanket.

Since there is a repetitive modular structural system for every two rows of skeletal strips, in the final construction of the physical skeletal structure of Blanket, only two rows of skeletal strips are fabricated instead of six as originally proposed to represent the complete version of Blanket (Figure 12). The complete version of this fabrication includes the sensory and luminous skin of Blanket as the envelope which is integrated with this tensegrity skeletal structure. This is revealed and further discussed in subsequent subsections.

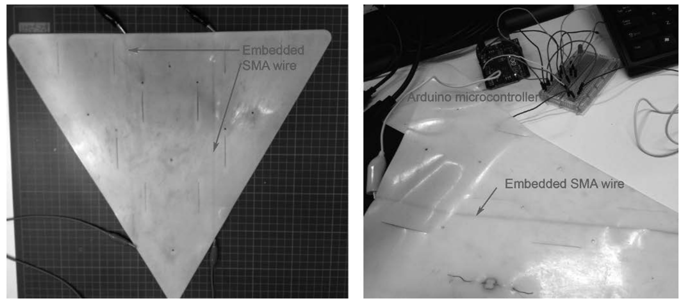
4.2 RESPONSIVE LUMINOUS SKIN

The skins of Blanket are composed by the triangulated modular system that was used in the design process to put the full-scale implementation into consideration. These skins use the composite approach to initiate integration of materials discussed in Section 3 with physical computing to create both active and passive responsiveness and luminosity (Figure 13).

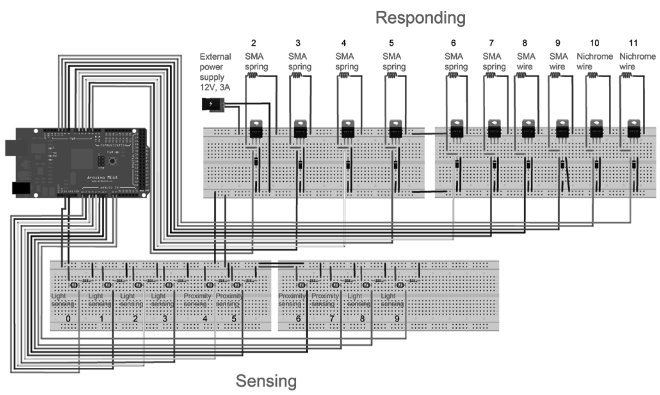
There are three types of triangulated Lumina skin panels with various responsive capacities mentioned above to form the whole cylinder surface of Blanket: Type P, Type L and Type G (Figure 14). The Type P (proximity) panel is a luminous skin that passively absorbs daylight energy and is embedded with SMA wires for sensing and actuation purposes (Figure 15). The Type L (light sensing) panel is embedded with linear photoresist wires that can sense light, as well as with eye-like apertures as individual openings actuated by embedded SMA wires. The Type G (glow) panel is integrated with triangulated spiral Nichrome wires that serve as heating elements to actively heat the luminous skin in order to achieve extra bright illumination. These three skin panels serve their individual functions and respond to each other by being controlled through a simple setting, including a physical computing system and schema that employed Arduino Mega microcontroller with Firefly Firmata protocol uploaded (Figure 16).

Type P is fabricated with silicone rubber, phosphorescent glow pigments and SMA wires to form a modular triangulated skin. It senses the external analog data through capacitive sensing. In addition to the local actuation purposes of controlling the open and closed states of the eye-like apertures, the integrated conductive SMA wires also serve as capacitive sensors to detect the proximity of objects (Figure 17). Based on the positive result generated by the conductive paint used as the proximity sensing element in the early experiment, the two linear embedded SMA wires are the replacement of the conductive paint. This is a more accurate capacitive sensor that focuses on specific areas on the surface of Type P panel. The advantage of this simple sensing technology is that it produces a lightweight and skin-like proximity sensing system within the flexible surface of Blanket. This exploits the potential and possibility for a mono-functional material to play a multifunctional role while exploring novel research approaches and methods.

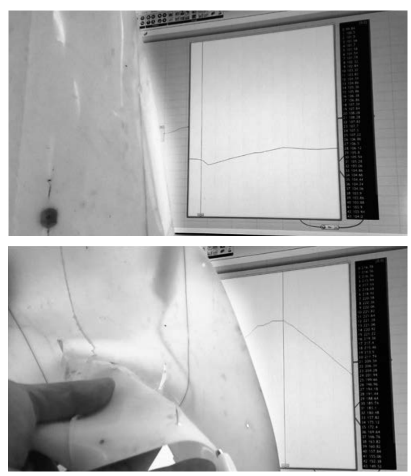
In contrast, the Type L panel has light sensing capacity and is embedded with a linear photoresist sensor in wire form to receive various lighting data and perform passive illumination (Figure 18). When a Type L triangulated skin panel senses that the surrounding lighting level is below ten lux on its surface, the integrated light sensing ability of its Lumina skin triggers the embedded Nichrome wires of Type G to heat the skin for extra glowing effect to the recommended illumination level. In addition to being equipped with the passive luminous capacity of the other types of panel, Type G is a Lumina skin composited with phosphorescent glow pigments and silicone rubbers to perform glowing lighting effects while absorbing heat energy from the spiral Nichrome wires embedded within (Figure 19). This active lighting interaction is complimented by the global morphing of the tensegrity skeleton that is actuated by SMA springs to respond between pedestrians and Blanket. This responsive morphing effect transforms the dark and underused passageway into a vibrant and bright interactive social space during the day and night (Figure 20).



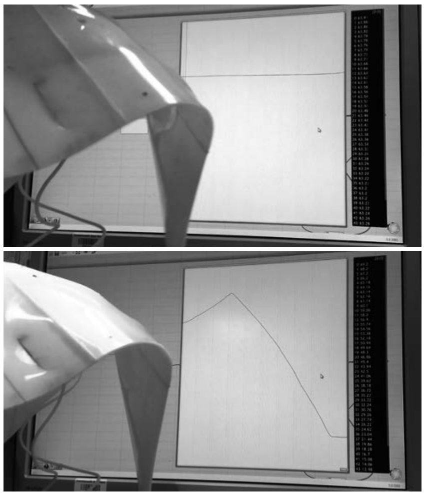
15 Left: Type P is a modular triangulated skin panel embedded with two SMA wires as capacitive sensors within the triangulated Lumina skin. Right: Arduino microcontroller receiving external proximity data through embedded SMA wire



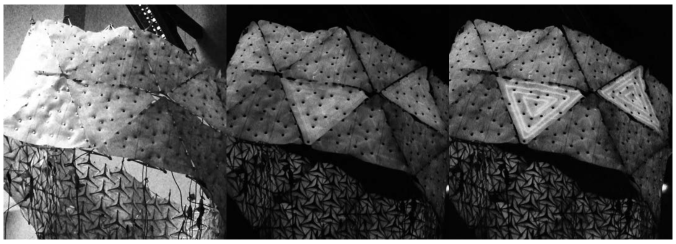
16 Schematic diagram of Blanket. Arduino Mega microcontroller is used in this schematic to allow ten sensing and responding devices, integrated within the skins and skeletal structures, to represent the overall responsive system of Blanket



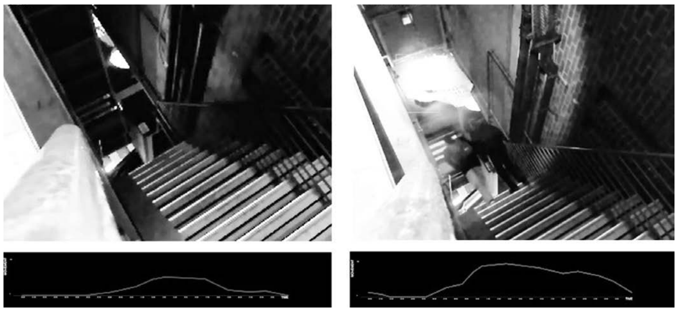
17 Top: Type P with no external data input for the proximity sensing of Lumina skin. Bottom: Type P receiving analog data while sensing object proximity with capacitive sensing process through SMA wires



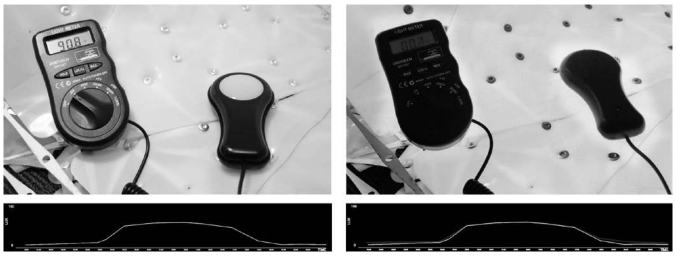
18 Top: Type L under normal lighting conditions.Bottom: Type L receiving external lighting values when sensing extra lighting brightness in the environment



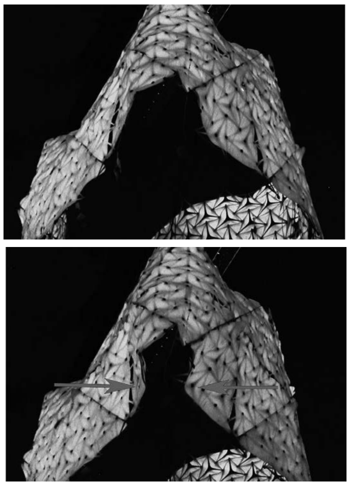
19 Left: Type P with no external data input for the proximity sensing of Lumina skin. Right: Type P receiving analog data while sensing object proximity with capacitive sensing process through spiral SMA wires



21 Left: graph indicates the numbers of pedestrian movement within 24-hour period of the original dark and underused condition of the passageway. Right: graph indicates that numbers of pedestrian movement increased, particularly during the non-peak period of 7:00 to 9:00 pm with Blanket installed



22 Left: the average lighting level of the passageway environment is no more than 50 lux from day to night. Right: lux measurement meter indicating the 0.1 lux for passive illumination and 5.0 lux for active illumination of the Lumina skin



20 Top: Luminous Blanket in static state. Bottom: partial skin of Blanket contracts to respond to the proximity of a moving object, as well as accommodating the object in the darker area by providing extra illumination

5 CONCLUSIONS AND FUTURE WORK

There is a tentative onsite design evaluation for the effects of Blanket as a reciprocal intervention for the chosen passageway. The two shortcomings of the selected site are the lack of social activities and poor lighting conditions. Blanket was installed on the selected site for a 24-hour period to test its effects on these shortcomings and collect useful data for later evaluation. The graphs in Figure 21 reveal the data before and after the installation of Blanket. These data present the numbers of pedestrian movement or motion recorded onsite to represent social interaction and activities (Figure 21). These data were recorded through a motion-detection infrared camera with and without Blanket installed to compare the number of pedestrian movements onsite. The graphs in Figure 21 indicate that after the installation of Blanket, there is an obvious increase in movement in the underused passageway, thereby encouraging increased social interactions and activities.

Although the premise of energy and maintenance of Blanket are beyond the scope of this paper, one of the main concerns of developing the Lumina skin of Blanket is to minimize the use of energy for architectural ambient illumination. Figure 22 shows the passive illumination level of Lumina skin using a lux measurement meter, demonstrating a positive result (Figure 22). The combined passive and active illumination of the Lumina skin, which has 1.5mm thickness, is ±5 lux with less than 3.75 watts of energy consumed. Although the illumination capacity of Lumina skin still does not fully achieve the recommended illumination level of conventional artificial lighting standards, this prototypical luminous material as skin introduces a different paradigm for future responsive architectural ambient illumination and design.

Responsive architectural design is at a crossroads where it can either embrace the silent revolution in current responsive material technological advancements or continue towards exploring existing approaches that rely on discrete mechanical components. Far from suggesting an ultimate solution or replacement to the latter, the former approach, as demonstrated in the evaluated outcomes of the design investigation in this paper, suggests a legitimate alternative to pushing the limit of designing responsive kinetic architecture.

Current technological advancements in material development provide new opportunities for architects and designers to innovate new material systems for responsive architecture. The design investigation in this paper takes an initial small step toward exploiting this opportunity and developing a synthetic material for responsive kinetic architectural design that uses novel methods and tools. Instead of providing an ultimate answer, Blanket and the newly developed material system, Lumina, not only demonstrate a promising design notion of responsive architecture but also offer alternative approaches to address problems and scalability issue of responsive kinetic architectural design and illumination. Their current goal is to revitalize and rejuvenate inferior spatial conditions with a future goal and alternative purpose of finding a range of possible integrations for responsive morphing skins and structures. The result can then be applied to various architectural components, such as façades, walls, ceilings and roofs. In addition, as the outcomes of this research, Blanket and Lumina serve as a trajectory for future research in the field of responsive materials and systems for morphing architectural designs.

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