

Sensory Morphing Skins

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Abstract. *Contemporary responsive architecture often tries to achieve optimised building performance in response to changing environmental conditions. In the precedents a key area of responsiveness is in the building façades or skins. Often however, the skin is made from discrete components and separated equipment. This research explores the potential for designing responsive architectural morphing skins with kinetic materials that have integrated sensing and luminous abilities. Instead of embedded individual discrete components, this approach intends to integrate the sensing devices and building skins as one 'single' entity. This investigation is conducted by project. The project is Blanket, which aims to provide an alternative approach for a lightweight, flexible and economical sensory architectural skin that respond to proximity and lighting stimuli.*

Keywords. *Sensing; responsive; morphing skin; kinetic and phosphorescence materials.*

INTRODUCTION

Human skin is the largest sensor of the body, registering warmth, cold, pain, pressure and other tactile senses (Lupton, 2002). Recent research has also produced skin-like sensors for processing distributed tactile information across textiles (Cannata et al, 2008). This technology is inspired by both biology and material science. Added to architecture it enables new avenues of inquiry into soft mechanisms and flexible sensing found in nature (Vollen and Clifford, 2011). What if this technology was applied to building skins, giving them the ability to perform like our skin? These new possibilities open opportunities for designing the simple responsive architectural skins in constant feedback and interaction with their surrounding environment (Menges and Reichert, 2012). In responsive architectural context, the idea of sensory building skins is often explored through individual sensing devices and mechanical systems considered a 'hard' technology. The label 'hard' literally refers to the context of mechanical systems and their discrete individual sensing com-

ponents. This architectural approach is not new and explored since 1960s. The responsive brise-soleil of LA County Hall of Records designed by Richard Neutra in 1962 is one of the first significant example attempts to address the issue of sensing and responsive architectural skins. The complex systems of these mechanical approaches for kinetic movement with sensing ability tend to lack longevity and reliability. Institut du Monde Arabe building in Paris by Jean Nouvel in 1987 is another precedent for this approach (Ritter, 2007). These structures and systems always serve as complicated discrete elements and divided physically. These approaches also often included a series of external sensors to enhance the adaptability of the systems. Both Neutra and Nouvel systems are unsuitable for mainstream architectural design because of their heavy maintenance and brittle mechanical components. Is there an alternative? Can a responsive architectural skin contain fewer mechanical and sensing devices? Technological advancement in material science provides the

opportunity for using passive and active form-changing materials like elastic silicone polymers and shape memory alloys to design kinetic, responsive architectural skins. This approach considers whether these soft form-changing materials have the potential to integrate with other sensing and responsive materials. It attempts to provide an alternative approach to flexible skins that address the issues of brittleness in the mechanical systems.

There are several recent projects that attempt to integrate sensors and actuators with *soft* responsive architectural skins. One of them is the 'Living Glass' project by David Benjamin and Soo-in Yang. The project integrates silicone polymer actuated by Nitinol wire and carbon dioxide sensing devices to design a responsive kinetic membrane served as an air movement regulator (Benjamin and Yang, 2006). The recently completed Media-ICT building designed by Cloud 9 Architects in Barcelona demonstrates the energy efficiency and implementation of the *soft* approach to kinetic architectural skins. The façade made of ETFE (Ethylene tetrafluoroethylene) uses embedded sensors and multiple Arduino microcontrollers to respond to the user and environmental conditions. The ETFE skin protects the interior from too much direct sunlight and when light is needed, it opens itself and let the daylight in (Ruiz-Geli, 2011). This responsive pneumatic kinetic shading device is an early implementation of the *soft* approach; however, there is still further potential for lighting control and shadow casting. The Hylozoic series by Philip Beesley is another *soft* approach that fitted with arrays of sensors and kinetic devices to explore kinetic architectural membranes through responsive material and mechanical systems (Beesley, 2010). Beesley's work provides insightful knowledge for designing soft architectural membranes that sense and respond to the changing environmental conditions. All the projects mentioned above explore the initial possibilities of material actuation and external sensing ability. They remain an opportunity to investigate form-changing material that respond and sense within an integrated materials system.

This research initially considers how to design a soft responsive architectural skin that integrates a sensory and luminous system within the surface. It explores a method for integrating form-changing, sensory and phosphorescence materials through physical computing process. This approach sets an initial platform for the early design exploration. This research aims to investigate the new possibilities for sensing, illumination and form-changing materials in relation to an architectural skin that can sense and responds to external environment stimuli as single entity. The potential materials used in this investigation are conductive paints, photoresist elements, Nichrome wires, glow pigments, silicone rubbers and shape memory alloys (SMAs). This investigation conducted through a design exploration, called *Blanket*, a prototype sensory morphing skin that serves as a responsive intervention to revitalise an underused passageway at RMIT University, Melbourne. The subsequent sections discuss the development of *Blanket's* responsive materials as well as the design process. These material system explorations are an initial step towards investigating the possibilities of designing an architectural morphing skin that integrates materials and computation.

SENSING AND LUMINOUS MATERIALS

Sensing materials explored in robotic research recently have included abilities for active properties change as well as sensing ability. However, there are few precedents for applying these materials in the context of architecture, especially in responsive building skins. There is a need to test the potential of these materials for full-scale architectural application. The initial sensing materials tested in this research are conductive paints embedded with silicone rubber and SMA. The integration of these materials potentially sets an initial design exploration for architectural application such as responsive architectural skin. While integrated form-changing material such as SMA, the elastic silicone rubber becomes a kinetic architectural system that performs kinematic movement in soft approach without discrete mechanical components.

In addition, current research of newer technologies for lighting in urban environments exploring the materials that provide passive lightings to reduce the demand for delivered electrical energy (Bohnenberger et al, 2011). This approach proposed a ‘solid-state’ lighting system integrated lighting components with material itself. It is an alternative to more typical compartmentalised lighting systems like LEDs and OLEDs (Organic Light Emitting Diodes). Beside the sensing ability of the materials, this research also further explores the potential of passive and active lighting system in the context of responsive architectural skin design.

I argued that the integration of materials with active and passive ‘sensibility’ and ‘luminosity’ such as conductive paints, Nichrome wires, glow pigments and silicone rubber. They provide an alternative for conventional mechanical and LED lighting driven responsive kinetic architectural system. Table 1 illustrates various responsive materials with passive and active sensing ability to develop a hybrid material system that can sense and responds to changing environmental conditions (Table 1). These materials investigate the new possibilities through a responsive morphing system discuss in the subsequent section to design a lightweight and simple sensory luminous architectural skins.

Figure 1
Diagram of responsive morphing system included sensing, analysis and responsive components.

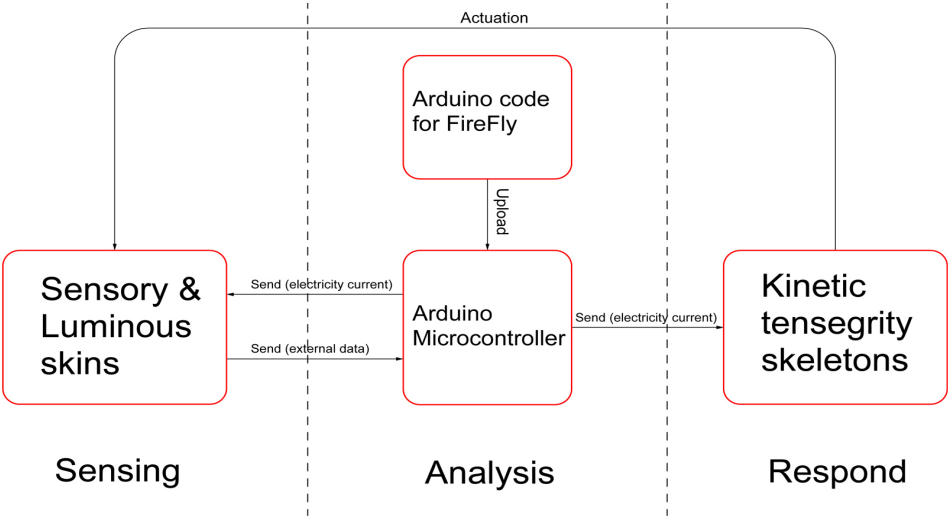


Table 1
Sensing, form-changing and luminous materials with active and passive sensibility.

Sensibility Sensing materials	Form-changing materials	Luminous materials
Active Conductive paints/wires	Shape memory alloys	Nichrome Wires
Passive Glow pigments	Silicone rubbers	Glow pigments

RESPONSIVE MORPHING SYSTEM

The application of the morphing idea to responsive architectural skins is inspired by the 'Hylozoic Ground' project, by Philip Beesley, mentioned in the introduction. This project inspired the idea that sensing, actuation and illumination could be integrated into a single responsive entity. This integrated approach focuses on a responsive morphing system served as a method of inquiry where responsive material properties can be embedded with computation process within architectural morphing skins (Figure 1). The responsive morphing system was designed through the parametric design tools Grasshopper for Rhino™, Firefly and Arduino software. The sensing and actuation of this system was controlled by the Arduino microcontroller, which performed the data analysis and processing.

This system is comprised of three components: sensing, analysis, and responsive parts. They 'communicate' through the Arduino microcontroller, with the Firefly software driving a responsive loop. This system forms a prototype that will be discussed in the next section about responsive architectural morphing skin assembled through two fundamental components: *kinetic tensegrity skeleton* and *sensory luminous skin*.

Kinetic tensegrity skeletons

The kinetic skeleton serves as the tensegrity structure as well as actuator to perform the kinetic movement to the overall system actuated by SMA springs discussed in author's previous work (Khoo et al, 2011). The nature of tensegrity structure allows minimum actuation to achieve maximum transformation. This flexible skeleton achieves various transformations without moving hinges and parts. It is using the idea of leverage to maximise transformation in the form of bending and twisting through form-changing SMA springs that can expand and contract five times of its original length (Figure 2). This form-changing process operated through the electrically heating for SMA springs controlled by Arduino microcontroller.

Sensory luminous skins

The sensory skin senses various external environmental stimuli, causing the kinetic skeleton to respond accordingly. This approach allows the architectural skins that sense and react according to various external stimuli for instance light and proximity. The initial testing of the skins with two aspects: the sensory and luminous ability by com-

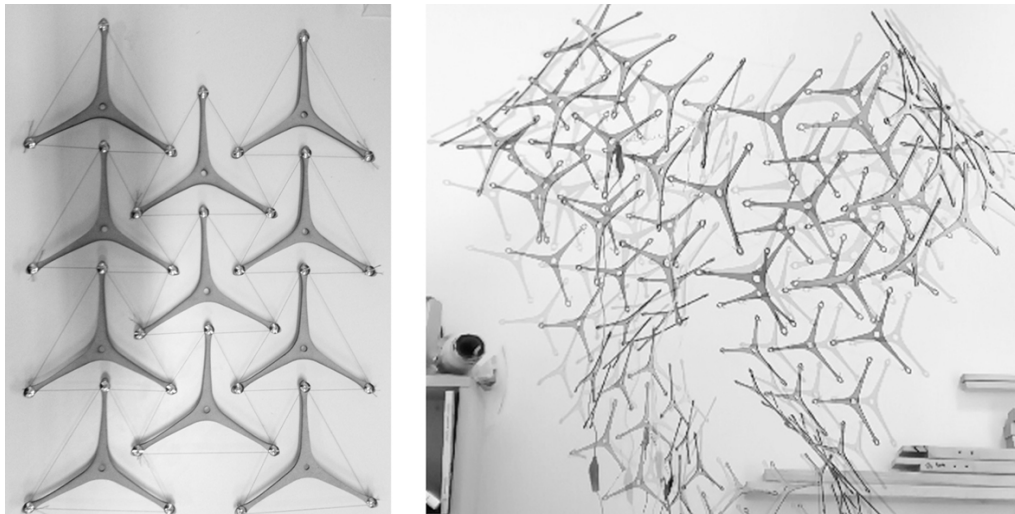


Figure 2
Right: Early experiment for tensegrity tetrahedral modular skeleton. Left: Kinetic skeleton in bending and twisting motion actuated by embedded SMA springs (frames overlaid).

Figure 3

Left: Initial test on composite silicone skin integrated with conductive paint for proximity sensing. Right: First test of luminous skin integrated silicone rubber and glow pigments.

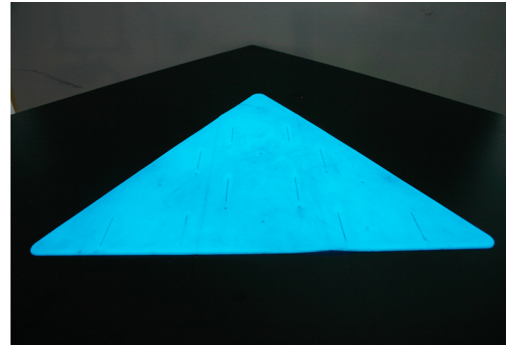
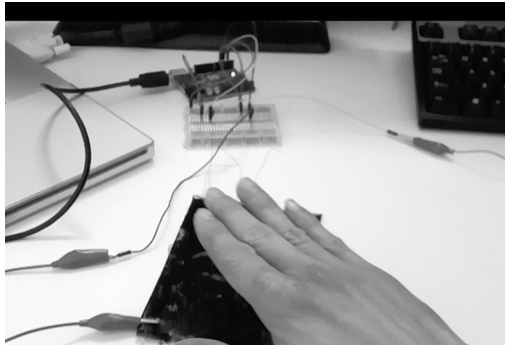
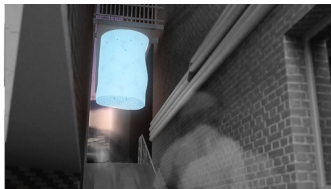


Figure 4

The morphing luminous skin of Blanket absorbs light energy and provides lighting effects to revitalise the dark condition of the passageway.



posited responsive materials (Figure 3). The first aspect investigates the possibility for skin that senses proximity without a discrete sensor, the skin itself integrated with conductive paint forms a conductive surface and creates capacitance to detect moving objects. Subsequence aspects using the method to combine silicone rubber and phosphorescence pigments (strontium oxide aluminate) fabricates a passive and active luminous skin that glows in a dark environment. Both experimental aspects provide the positive feedback allow further development for a complete prototype that using actual site data to test its sensory and luminous abilities.

DESIGNING THE PROTOTYPE

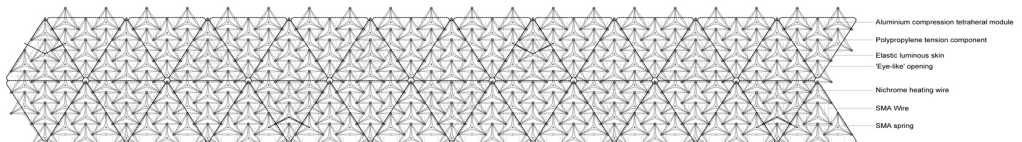
I investigated the sensory and luminous architectural morphing skin through the exploratory design of *Blanket*, a cylinder envelope surface that is soft in

properties and performs responsive kinetic movements based on the responsive morphing system. This design exploration is intended to evoke new possibilities for building skin sensing ability. The site chosen to test this design exploration is a passageway that is currently underused because of its dark and narrow composition. Instead of typical kinetic façade approach, *Blanket* functions as a second architectural skin as 'responsive intervention' to revitalize the existing dark conditions of this passageway through its morphing and luminous effects (Figure 4).

Blanket responds to two stimuli of the site: pedestrian movement and light. By its responsive morphing and illuminating capacities, *Blanket* attracts more pedestrian movements thus rejuvenate the existing dark and quiet site condition. The skin of *Blanket* also absorbs the passive light energy during

Figure 5

Unfolded skeletons and skins of the Blanket.



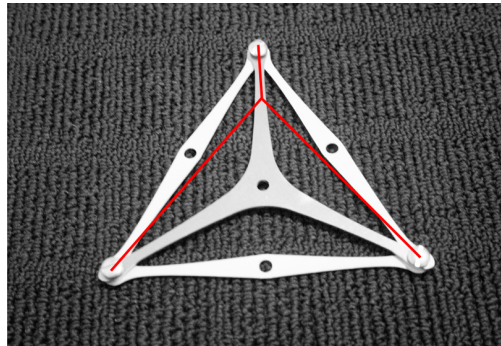
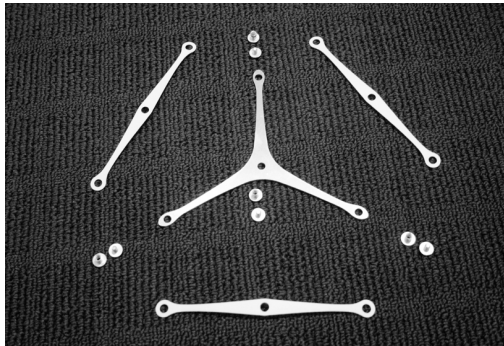


Figure 6
Left: The compressional aluminium tetrahedron and tensional polypropylene components. Right: Assembly of optimised tetrahedral module.

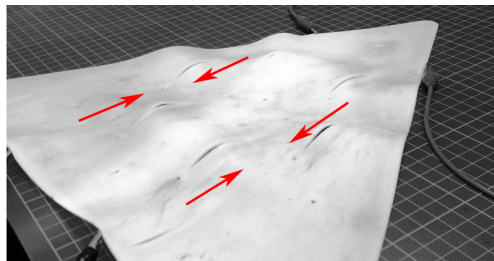
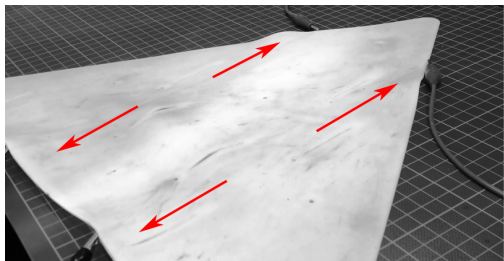


Figure 7
Left: 'Eye-like' apertures passively closed by elasticity of the skin. Right: 'Eye-like' apertures actively opened by SMA wires embedded within the skin.

the day and performs morphing operation for tracking the sunlight through the integrated responsive kinetic skeletons.

The skeleton of *Blanket* is composed by 72 tetrahedral modular components per row (Figure 5) and the overall cylinder shape is composed by 6 rows in total. The optimised aluminium tetrahedral modules and polypropylene tension components formed a tensegrity structure to achieve a lightweight and elastic skeleton for morphing purposes (Figure 6). The morphing process of the skeleton is actuated by 4 SMA springs per row embedded within the overall skeleton and they respond to the external data from the individual sensing skin of *Blanket*.

The skins of *Blanket* are composed by the triangulated modular system that used in the design process to put in the consideration of large-scale architectural application. This system uses the composite approach to integrate SMA wires and silicone rubbers. It forms a composite morphing skin for the lightweight and silent kinetic operation allows indi-

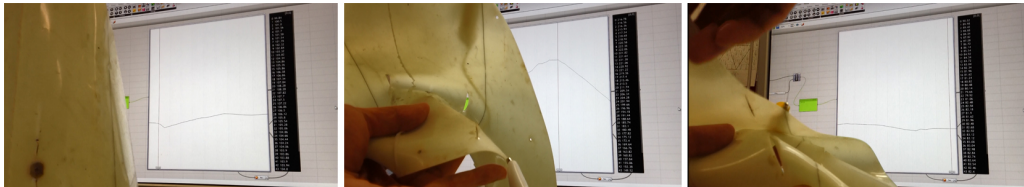
vidual 'eye-like' apertures to open and close for various lighting pattern effects (Figure 7).

Blanket serves two fundamental sensing abilities: proximity and light sensing. It is also included two responsive capacities: movement and illumination. Proximity is sensed through capacitive sensing and responds through kinetic skeleton with material actuation. Luminous sensing is a passive and active ability, sensed through the material of the skin itself, which can store the light energy absorbed during the day and glow when the surrounding environment became dark.

Proximity sensing

The proximity response of the skin of *Blanket* conducted through active capacitive sensing system by integrated conductive paint, SMA wire and silicone rubber as one composite entity. When conduct with electric current, conductive paint blended with the SMA wires and silicone skin serves as a probe surface that uses changes in capacitance to sense changes

Figure 8
Active proximity sensing capacity of the morphing skin through embedded conductive paints and SMA wires.



in distance to the object (Figure 8). It senses proximity object of the surrounding environment and responded through transformation of the skin surface actuated by SMA wire with various configurations. This sensing operation is processed through the Ar-

duino microcontroller and Firefly to allow materials to process external data and respond to them.

Figure 9
Left: Translucent 'Lumina' skins of Blanket on normal daylight. Middle: Illuminated passive sensing skins in the dark environment. Right: Blanket morphed to absorb maximum light energy.

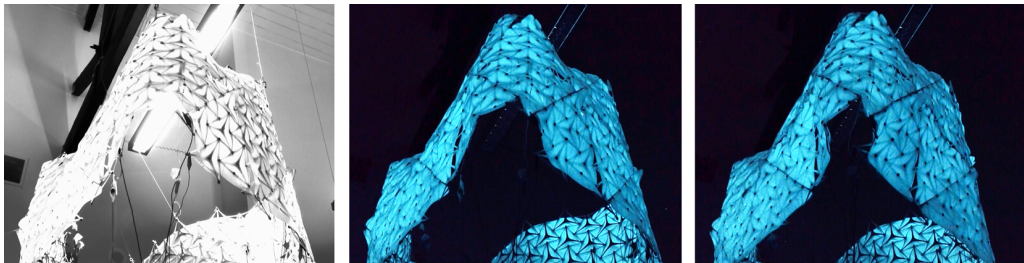
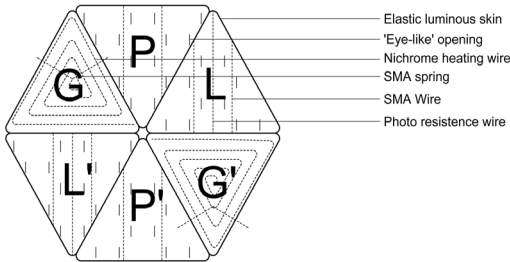


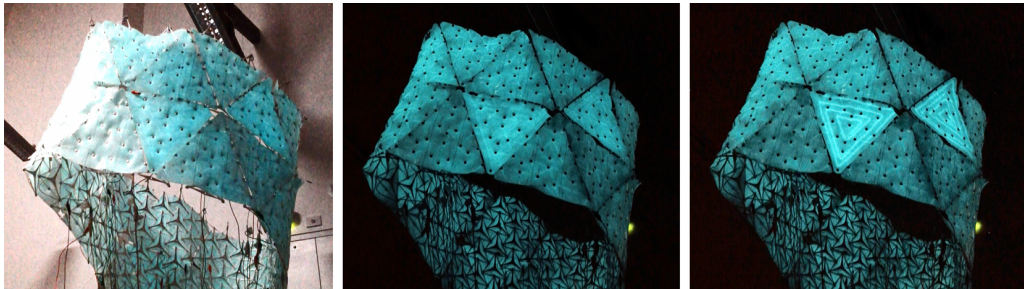
Figure 10
Three different types of re-sponsive 'Lumina' skin panels designed for active sensing and luminous purposes.



Light sensing

Instead of the typical approach as responsive sun shading devices or brise-soleil for building facades, the skins of *Blanket* provide an alternative approach that allows the skin to glow itself providing the illumination for the surrounding environments. I author developed a new composite phosphorescence material called 'Lumina' used as the skin of *Blanket* to absorb light energy during day time and discharge the light energy when dark. While sensing skins of

Figure 11
Left: Lumina skins sensing daylight. Middle: Passive illumination. Right: Type G panel perform active illumination activated by heated Nichrome wires embedded within the skin.



Blanket detect the area with higher Lux level, the kinetic skeleton responds and morphs towards this area to absorb maximum light energy during the day (Figure 9). When light level of the area is lower than 20 Lux, *'Lumina'* illuminate the surrounding area without external power source. The glow effect also revitalises the existing dark condition of the passageway during night time. It creates the reconfigurable lighting effects when human movement is detected through proximity sensing.

There are three types of triangulated *'Lumina'* skin panels formed the whole cylinder surface of *Blanket* (Figure 10): Type P (proximity) panel is a passive luminous skin that absorbs daylight energy and embedded with SMA wires for sensing and actuation purposes; Type L (light sensing) panel embedded with photoresist wire that can sense light as well as with 'eye-like' apertures as individual openings; Type G (glow) panel integrated with the triangulated spiral Nichrome wires that served as the heating elements actively heating the luminous skin in order to achieve brighter illumination. Three of them served their individual functions and respond to each other through a simple setting included physical computing system discussed on previous section.

When atype L skin panel senses the passive glow effect is below 10 Lux on its surface, the integrated light sensing ability of the *'Lumina'* skin triggers the embedded Nichrome wires to heating the skin for extra glowing effect to recommended illumination level. The *'Lumina'* skin composited with the phosphorescence glow pigments and silicone rubbers performs glowing lighting effect while absorbed the heat energy from Nichrome wire embedded within (Figure 11). This active lighting interaction between pedestrians and *Blanket* transforms a dark and underused passageway into a vibrant and bright interactive social space during day and night.

The active luminous lighting effects of *Blanket* created by Type G panels provide the potential visual patterns that alter the atmosphere of its surrounding dark environment. These lighting patterns also perform through the opened and closed states of individual luminous 'eye-like' apertures actuated by

embedded SMA wires. The atmosphere of the chosen site revitalised through the performing lighting effects of *Blanket* to transform the existing environment become a dynamic place for social interaction.

CONCLUSION AND FUTURE WORK

The outcome of this research is a proof of concept. It provides a platform for designers and architects to further study the new possibilities of 'soft' sensory architectural skins with form-changing and sensing materials. Instead of suggesting an ultimate answer for designing responsive architectural skins, this research provides a proposed method that served as a stepping stone for further design discoveries.

For decades architects and researchers have investigated the idea of an architecture that responds to the users and with certain 'intelligence' embedded with it. These investigations led to countless design attempts to produce some very intriguing potential architectural applications. Responsive architectural skin is one of them and perhaps the most common application among the design explorations. The design exploration for this research is the first attempt to develop a method for designing a working prototype with sensory morphing materials system for responsive architectural skin. This attempt to integrate form-changing materials and physical computational process signifies the beginning of a new exploration of responsive skins that go beyond the mechanical approach.

Future work will focus on integrated solid-state sensorial polymers, actuators and piezoelectric sensors to design responsive morphing skins with less discrete parts. Further methods of inquiry will be developed to explore the possible integration of computational process and form-changing materials to fabricate full-scale architectural applications.

REFERENCES

- Beesley, P, Ohrstedt, P and Isaacs, H (ed) 2010, *Hylozoic Ground: Liminal Responsive Architecture*, Riverside Architectural Press, Toronto.
- Benjamin, D and Yang, S I 2006, *Life Size: Volume 2*, Graduate School of Architecture, Planning and Preservation of Columbia University, New York.
- Bohnenberger, S, Zilka, L, Beneyto-Ferre, J and Mainwaring, D E 2011, 'A model for transdisciplinary design in passive illumination', *Proceeding of 27th Conference on Passive and Low Energy Architecture*, p.322.
- Cannata, G, Maggiali, M, Metta, G and Sandini, G 2008, 'An embedded artificial skin for humanoid robots', *Proceeding of IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems*, pp.20-22.
- Iupton, E 2002, *Skin: Surface Substance + Design*, Laurence King Publishing Ltd, London, p.142.
- Khoo, CK, Salim, F and Burry, J 2011, 'Designing architectural morphing skins with elastic modular systems' in C.M. Herr and S. Roudavski (eds), *International Journal of Architectural Computing*, 09(4), pp.413-414.
- Menges, A and Reichert, S 2012, 'Material capacity: embedded responsiveness' in A. Menges (ed), *Material Computation: Higher Integration in Morphogenetic Design*, *Architectural Design*, 82(2), pp.52-59.
- Ritter, A 2007, *Smart Materials in Architecture, Interior Architecture and Design*, Birkhauser, Basel, pp.6-7.
- Ruiz-Geli, E 2011, *Media-ICT*, Barcelona: El Consorci de la Zona Franca de Barcelona.
- Vollen, JO and Clifford, D 2011, 'Porous Boundaries: Material transitions from territories to maps' in G.P. Borden and M. Meredith (eds), *Matter: Material Processes in Architectural Production*, Routledge, New York.

