Living Skins: A New Concept of Self Active Building Envelope Regulating Systems

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ABSTRACT

Building Envelopes plays a key role in improving building energy efficiency and indoor comfort for the occupants. The future lies in the use of innovative strategies based on kinetic, responsive and adaptive solutions for optimizing energy performance while exploiting energy from renewable resources. Today, the construction industry represents the single largest contributor to carbon output, with higher energy demands and costs, along with the lack of design solutions that respond sufficiently to the changes in our environment, adaptive design is required to overcome this daunting perspective to our future and allow us to enter a new era of innovation. Adaptive buildings are becoming more feasible due to advancements in technology along with significant reductions in productions costs. Factors such as improved reliability of automated systems and more efficient versatile micro processing power, allow for greater distribution of embedded network. Adaptive systems use less energy, offer more occupant control in addition to improved overall space efficiency. The aim of this paper is to address the role of interpreting adaptation strategies in building skins systems that would serve to control temperature transmission into the building. The adaptive design approach analyses and evaluates if the application of a design system can result in the improvement of energy efficiency with the implementation of smart responsive materials that can respond efficiently different climatic demands. In other words, the future is moving towards "smart matter", matter that has the ability to adapt, regulate and control.

KEYWORDS: Smart Materials, Sustainability, Adaptive Skins, System integration

1. INTRODUCTION

Architectural praxis is in continuous state of change. The introduction of information technology based design techniques, new building information modelling protocols, new policy demands coupled together with environmental and cultural fluctuations are all open-ended dynamic phenomena which demand the development of adaptive design techniques, processes, for developing performative building solutions. Conventional top down design thinking with its focus on developing and understanding buildings as inert forms, populated with artificial mechanical systems for their sustainment thus needs to be critically analyzed and re-thought in order to attain a state of continual performance via real-time adaptation of the built form and its constituents in a sustainable manner.

A new generation of high-performance envelopes has contributed to the emergence of sophisticated assemblies combining real-time environmental response, advanced materials, dynamic automation with embedded microprocessors, wireless sensors and actuators, and design-for-manufacture techniques. This practice has fundamentally transformed the way in which architects approach building design with a shift in emphasis from form to performance, from structure to envelope (Hensel & Menges, 2002).

In the realm of high-performance buildings, the envelope has become the primary site of innovative research and development. Borrowing a set of terms from the discipline of biology now common place in architectural design, this paper articulates a conceptual paradigm and working vocabulary for the development of high-performance building skins that are smart, intelligent, adaptive, responsive and biologically inspired. Building façades are increasingly developed as complex systems of material assemblies attuned to climate and energy optimization .An expanded understanding of building performance acknowledges that all forces acting on buildings (climate, energies, information, and Human agents) are not static and fixed, but rather mutable and transient. This has serious consequences for the building envelope whose design must transcend its role as mere protective wrapper separating inside from outside.

There has been a surfeit in recent years of research and development of advanced building envelopes, often with adaptive and kinetic features focused on environmental performance. The focus in this paper is turned to how the thickened, adaptive envelope either interior or exterior might begin to condition new experiences of interiority and envelopment that move beyond optimization. Embedded sensing, active control, mechanical actuation and smart responsive materials are mobilized within four case studies discussed throughout the paper to enable architectural interfaces that can become media of communication and mutual relation.

2. THE EVOLUTION OF BUILDING ENVELOPE

The evolution of the building envelope as a focus of design innovation in the twentieth century parallels advancements in envelope engineering and building science, as well as developments in computer engineering, cybernetics and artificial intelligence. Additionally, new technologies, smart materials and distributed systems have spurred the introduction of biological models for understanding the behaviour and design of building systems and their controls. A descriptive lexicon has emerged that employs decidedly biological terminology in conceptualizing architectural design.

Building's envelope can be considered quite literally as a complex membrane capable of energy, material and information exchanges. It can be designed to operate "as part of a holistic building metabolism and morphology, and will often is connected to other parts of the building, including sensors, actuators and command wires from the building management system" (M. Wigginton and J. Harris, 2009). The blurring of boundaries between disciplines has given rise to a near crisis in the definition of their respective roles, responsibilities and professional accountability (M. Addington and D. Schodek, 2005). Even within the discipline of architecture, terms such as "***smart***", "***responsive***" or "***adaptive***" have been used loosely and interchangeably, creating confusion as to their specific meaning and their conceptual relationship to building performance and design.

2.1. Smart

Within the design disciplines, the term "smart" has most frequently been used in reference to materials and surfaces (Addington and Schodek, 2009). Addington and Schodek identify "smart materials" as systems possessing "embedded technological functions" that involve specific environmental responses, operating either through internal physical property changes or through external energy exchanges (Klooster, 2009). They define the characteristics of smart materials as: "immediacy" (real-time response), "transiency" (responsive to more than one environmental state), "self-actuation" (internal intelligence), "selectivity" (a response is discrete and predictable) and "directness" (a response is local to the activating events) (Addington and Schodek, 2009). Smart surfaces and materials can play a significant role in intelligent, adaptive and responsive envelopes because of these intrinsic properties.

One of the most significant characteristics of smart materials is that they have the ability to transform their physical properties and/or shape, or to exchange energy without requiring an external source of power. Hence, they are extremely attractive to building designers who aim to increase functionality and performance while at the same time reducing energy use. Doris Sung, principle of *DO|SU Studio Architecture* and faculty member at the University of Southern California, is experimenting with thermal bimetals for creating self supporting experimenting with the use of thermo bimetal skins that are able to open their pores to self-ventilate as shown below in Figure 1, without the use of external energy sources (D. K. Sung, 2010).

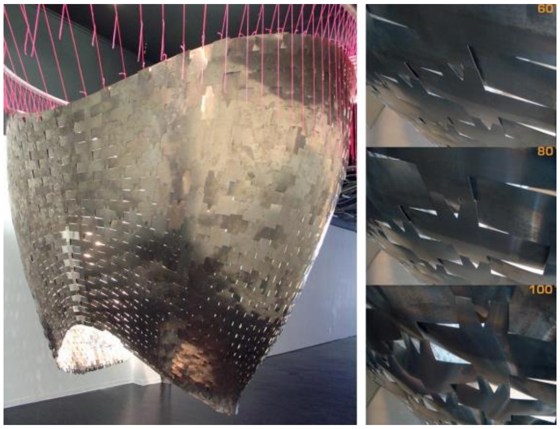

Figure 1: Smart Thermo bimetal Self- Ventilating Skin: installation of prototype and details of skin performance under different temperatures,

2.2 Responsive

The term "*responsive*" is often used interchangeably with "adaptive", but most simply it is used to describe, "How natural and artificial systems can interact and adapt" (Beesley, S. Hirosue, and J. Ruxton, 2006). A responsive building skin includes functionalities and performance characteristics similar to those of a "*smart*" building skin including *real-time sensing*, *kinetic climate-adaptive elements*, *smart materials*, *automation* and the *ability for user override (*L. Schipper et al., 1984). But it also includes interactive characteristics, such as computational algorithms that allow the building system to self-adjust and learn over time, as well as the ability for inhabitants to physically manipulate elements of the building envelope to control environmental conditions (R. Cole and Z. Brown, 2009). A truly responsive building envelope, not only includes mechanisms for inhabitant sensing and feedback, but is also committed to educating both the building and its occupants. In this way, both building and occupant are engaged in a continuous and evolving conversation.

The use of electro active polymers for kinetic skins is also at the forefront of research in the field, given their speed of response, large potential for active deformation and resilience. Manuel Kretzer and students from the ETH in Zurich have developed a prototype dynamic skin called "Shape Shift" (Manuel Kretzer*, 2010)*; a layered, self-supporting unit made of elastomeric films which deforms when electrically charged (Figure 2).

Figure 2: 'Shape Shift' prototype, consisting of 36 individual EAP elements, as exhibited at the Gallery Stark Art in Zurich, (Source: Addington and Schodek, 2010)

While many of these systems are still in the research and development phase, a recent example of a smart skin installed in a completed building is that of the Media-TIC building, constructed in Barcelona in 2011 and designed by Cloud 9 Architects and envelope specialists Vector Foiltec Ltd. The envelope features a pillow cladding system made of the polymer ETFE with encased lamella fins whose pneumatic mechanisms are automatically activated by light sensors that respond to the presence of solar energy (The Living New York, 2010) (Figure 3).

Figure 3: Smart envelope comprised of ETFE encased solar-activated lamella shades developed for the Media-TIC building in Barcelona, Cloud 9 Architects 2011 (Source: Addington and Schodek, 2010)

While smart materials offer many advantages for high-performance building envelopes, their performance is often tightly bracketed within a specific range of climatic conditions and predictable reactions. However, in a high-performance building skin that is required to be intelligent or responsive, it is often necessary to accommodate much broader variation in conditions and performance criteria. The skin may be required to facilitate more complex buildings system communications, to occupant requests, respond to and to adapt and learn over time. As such, smart materials are often incorporated in complex building skins with sophisticated thermal management systems a pairing that would render them "*responsive*" skins.

3.2 Adaptive

The term "*adaptive*" has a dual utilization in this paper: the first use refers to a morphogenetic design evolution which adapts according to environmental design parameters in search for improved resilience in design outcome through a multitude of iterations; the second use refers to the real-time physical adaptation of the design to the surrounding environment based on the previously established parameters in search of an improved symbiosis between the built and natural environment. Ultimately, for this paper, 'adaptive' describes a design approach that seeks to unite multi-scalar factors in order to reach a symbiotic energy efficient design solution.

Adaptive building systems will not only lead to an optimization in terms of functionality, but will also have the potential of contributing to a significant reduction of the energy consumption and material resources. Especially, when the building performance is optimized with respect to climate comfort, advantages on sustainability are found. The Strata System the Helio Trace Facade, with adaptive cladding system, can serve here as an example.

Engineering firm Buro Happold, in collaboration with deployable structures innovator Chuck Hoberman, have established an intelligent surfaces unit called the Adaptive Buildings Initiative (ABI). This design unit has developed a number of kinetic shading and cladding systems, including the Strata™ System, which consists of automated modular kinetic units that can retract into a slender profile (Figure 4). The system is designed to significantly increase daylighting while reducing solar heat gain effects for building occupants up to 81% annually. When analyzed in situ, the system achieved a 42% reduction in total energy consumption for a New York City office tower. (Hoberman and B. Happold, 2010).

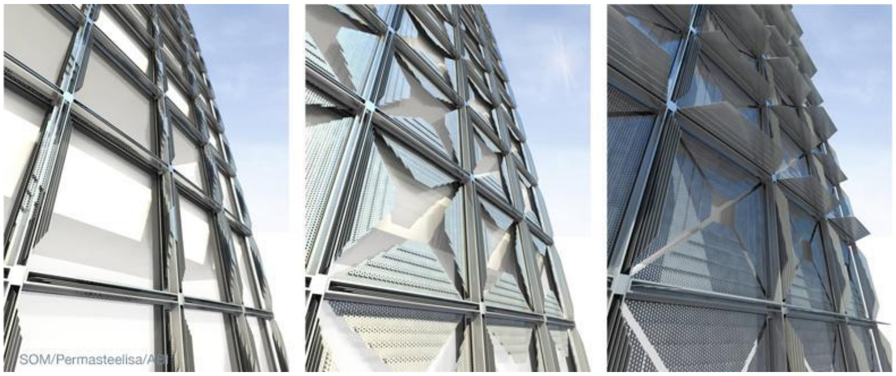

Figure 4: Heliotrace system components: Moveable external sunshades block out the rays as needed, window frames withstand thermal change, and chilled ceiling panels circulate cold water to cool the space without air-conditioning (Source: Hoberman, 2010)

3. BIO-CLIMATIC SELF ACTIVE SKINS

At the beginning of this technological Era, this interaction was not completely respectful with the environment. Most of the energy needed to maintain comfort inside of the building was supplied by polluting and consuming machines. Building required then a more efficient interaction, so designers began looking at Nature. Living creatures, in their perfection, have developed special structures to preserve their inner medium from the external environmental conditions. One of these structures is the skin. Human skin for example, reacts accurately to external stimuli such as temperature, pressure or light radiation, by masterly designed biological sensors. Nowadays, contemporary buildings try to resemble living organisms, and consequently benefit from an adequate skin.

In this paper, this responsive behavior presented as: Self *Active Bioclimatic Strategy (SABS)*. To get this reactive performance in real time the SABS has to be intelligent like human skin is. For example, in summer time with hot weather our inner temperature increases and our skin reacts to reduce it. Opening its pores and sweating the skin refreshes its external layer aiming to maintain constant the temperature of the body. Similarly, an efficient SABS should be smart enough to know what, when, and how to react to changing external inputs to held inside temperature stable.

4. PROTOTYPE OVERVIEW AND DEVELOPMENT

Technology influences, more directly than ever, the external morphology of buildings: directly, since the building's skin is the locus of exchanges of matter and energy between the building and its environment, and indirectly, since modelling tools allow almost surreal explorations of form (Kolter J Z, 2011). More fundamentally, buildings are technical objects extensions of our bodies that allow us to do a number of things that we cannot do naturally.

SABS system will be considered as fully integrated skin system that can adapt to environmental demands and provide opportunities to develop self-sensing capabilities in the proposed facade to achieve energy efficiencies and environmental comfort. This can be achieved by integrating active components (algae bio-reactor panels) in the development of kinetic responsive façade system. Where, sustainability can be achieved by implementing advanced bio responsive façades that use day lighting, sun control, ventilation systems, and dynamic systems. Through cultivating microalgae as energy source from bio reactor façade and make use of waste carbon and generating solar thermal energy in the process.

According to Active and Passive strategies SABS must include:

- Opaque panels (shading devices)
- Transparent panels represented through the bio reactor panels (heat trap system sand natural light)
- Controlled opening systems (ventilation)
- Responsive material combination that will monitor the kinetic feature of the skin.

The ideas of the SABS components come from Modular systems which are not uncommon in architectural design. Their use has largely been concerned with reducing cost and the materials needed to construct full-scale architecture. In contrast to existing kinetic systems, for instance, the Aegis Hyposurface and L'Institut du Monde Arabe project.

4.1 SABS Components

The purpose of the development process is to design self active responsive skins using the soft approach in a simple yet efficient way. The proposed model of SABS skin prototype consists of self-automated façade panels that control airflow due to the temperature, light and humidity changes, though bio-reactor panels controlled by integrated sensors, actuators without any use of mechanical power integration for kinetic features through the use of shape memory alloy "Thermo-Bimetal" (figure 5).

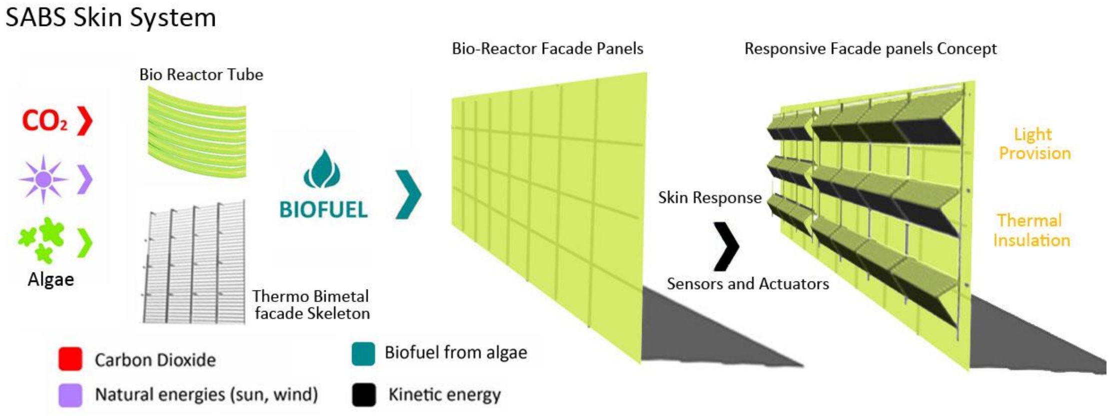

Figure 5: Basic components of SABS skin System

The input material for algae growth is basically carbon dioxide, Nitrogen, Phosphorus and other organic material which are contained in the waste water of the building's output. The carbon dioxide needed for algae growth could be injected through pipes from below the building, as gas is lighter than air and would have a natural tendency to flow upwards. The reason behind using Algae is it's considered the most effective transformer of sunlight converting 3-8 % of the sunlight to energy, while land plants can only convert 0, 5 %. Algae produce around 1, 87 ltr. pr. m2 of oil, where the closed land plant palm produces 0, 6 ltr. pr. m2. (Becker EW, 1982) Also, algae are the most efficient plant in converting solar energy and it can use a lot of nutrients. The fact that micro algae are placed in water provides flexibility in its movement around the building. The algae flow constantly producing oxygen and biomass and with its adaptive movement, the overall bioreactor when exposed to sunlight can be considered a beneficial responsive behaviour in terms of functionality. (Anderson DB, 1985)

4.2 SABS Efficiency Aspects

The adaptations for SABS skin specifically corresponds to three domains of environmental adaptation: thermal performance, shading and lighting control and energy production, resulting in kinetic adaptability, energy generation and conservation as well as transport and usage principles and material property based changes per skin component. The regenerative energy approach, which includes the production of biomass and heat harvested from the photosynthesis process of micro-algae. Solar thermal heat will also be captured and reused to respond to the different lighting and shading requirements. In addition to generating energy, the live micro-algae façade provides both lighting and shading control naturally.

Thermal control aspect will be achieved according to algae growth rate where algae have a thermal insulation property as micro-algae are placed in water, which has a high thermal density. Algae growth rate will be controlled with sensors installed on the bio reactor façade panels, to control the environmental parameters that affect algae growth rate. The sensors will also calculate the sun requirement through the kinetic movement of the bio reactor panels with efficient configurations which are symbiotic with the environment. With the multilayer skin of *SABS*, the responsiveness to light and humidity will be achieved through changing porosity of Shape Memory Alloy wires and thermo-bimetal skeleton (Figure 6).

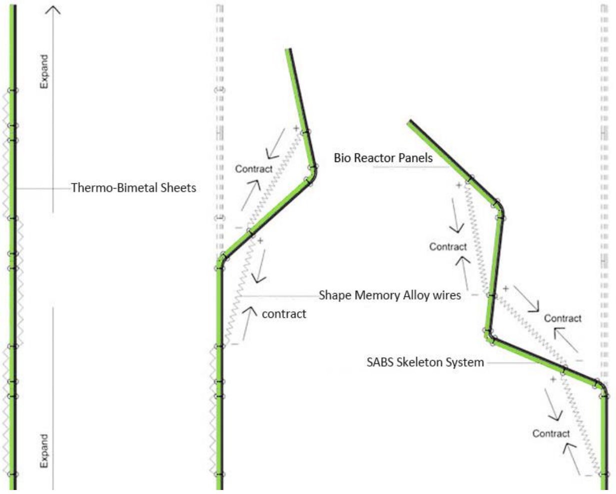

Figure 6: Integrated' approach of SABS layers to *contract* and *expand* to actuate *morphological transformation* through temperature changes.

4.3 SABS Process of Investigation

This on-going study proposes the use of a thermo-bimetal as a smart material in the development of a self active responsive building skin. As the outside (or inside) temperature rises, it is intended that the skin will physically peel open, allowing the building to ventilate automatically. With further development, an active method of CO2 intake and exhaust can be developed. To investigate the capacity of this system in this application, various tile shapes and forms are being considered and modeled digitally.
To conclude, with further development and more physical experimenting SABS could contribute to achieve the following sustainable building aspects:

- The building could adapt in a flexible manner to climatic and functional changes;
- The building skin will morph accordingly, making it more efficient;
- The component in the building is easier to dissemble, making it practical over time;
- By combining biology with mechanics, a more effective solution is allowed, compared to the energy it uses.

5. CONCLUSIONS

Our climate has begun to change dramatically. Global warming will ensure its course. Political, economic and technological developments produce dynamic and globalizing cultures and virtual workplaces among other changes at logarithmic rates. Architecture must respond. In order to keep up with this dynamic world, architects need to reconsider design beyond the digital medium. Hence, the idea of having building envelopes constructed from soft and elastic material does not seem intuitively to be feasible since soft materials do not generally possess robust structural properties. However, advances in soft, and form-changing material technology have revealed their relevance to architecture, especially when integrated with other composite materials such as those used in the aerospace technology, for examples, Aramid and carbon fiber. Current technology on aircraft morphing wing design indicates some of the potential of these materials to be implemented in architectural morphing skins. It is timely to investigate how smart materials can now be applied to designing architectural adaptive skins. This paper investigates new possibilities for applying *'active'* in modular systems for architectural skins that respond to various environmental conditions. It does this through a series of design approaches using kinetic models that combine smart materials and kinetic techniques. One of the related technologies presented in this paper is the kinetic modular system using the passive and active form-changing materials and shape memory alloy. Here they are applied in the novel context of architectural responsive skins. These design approaches tends to introduce alternative design methods. They point to the potential for full-scale architectural applications.

Future work will include a series of experiments that explore the scalability of the modular system and implement it in an actual site context. This approach aims to develop a novel design method and a feasibility study for designing full scale responsive architectural self active responsive skins with current technologies. A further investigation also aims to design *'adaptive'* form changing materials as synthetic composites which have kinetic matter embedded and computational process integrated in the architectural skins. Beyond that, we need to believe that architectural skins can be sensitive, interactive extensions of our own bodies and not just protection from nature.

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