Responsive System: A Prototype for Building Performance

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This paper focuses on developing a prototype of a responsive system with interactive solutions for dynamic environments. The aim of this project is to develop a self-sustained interactive component. First, a conceptual framework of integrating sensors and actuators into a building is set up and tested to achieve an environmentally sensible responsive system. Then an operational scenario has been investigated and a prototype has been tested as well. Lastly, the potential implication of the prototyping is discussed.

1. INTRODUCTION

The interest in responsive systems is growing in architectural design. Developing technology for a sensing mechanism could play a critical role. More interactive and dynamic architecture could alter the physical space in response to the changing environment. There is other research work in academic contexts about a responsive system focusing on the integration and development of embedded sensors and actuators in a building's components to transform the building component's shape and physical properties under the influence of the external environment.[1 2 3] Most efforts have been dedicated to mechanically controlled web-based, networked-sensing systems for a responsive system.[4 5 6] Fewer efforts have been made to find a passive, non-mechanically driven responsive system. (This could also be explained as a responsive system change driven by nature and by the inter-relationship between different parts of the system.) This lack of research presents both a gap and future opportunities.

2. PREVIOUS WORKS

Studying responsive systems in the building context is not a new subject. In fact, quite a large body of research and projects have been conducted and completed. The research and implementation could be divided into two main focus areas: responsive façade components and responsive lighting systems.

In the first focus area, developing a responsive building envelope means that façade components should have the ability to adjust to the exterior surroundings in order to act as an adaptive layer capable of achieving internal thermal comfort and minimized energy consumption.[7] The Arab Institute, designed by Jean Nouvel, is among the first group of buildings to employ a sensor-based automated façade system that responds to environmental conditions. As the first building to meet the Danish 2015 building energy code, the Syddansk University Communications and Design building, designed by Hening Larsen Architects, has a "Climate-responsive kinetic façade that regulates interior temperature."[8] The Randall Museum in San Francisco has an attached component named "Windswept" that is a wind-driven kinetic component revealing the movement of wind as it interacts with the side of the building. During the 2012 Thematic Pavilion Expo hosted in South Korea, a project design by SOMA attracted visitors' attention: this building has a total of 108 kinetic fins on the surface, made of glass-fiber reinforced polymers. "The integration of the moving lamellas within the building's skin was inspired by a research project at the ITKE University Stuttgart that investigates how biological moving mechanisms can be applied in an architectural scale."[9] A shading system was created with movable metal "feathers" to shade the sun in Germany's Q1 headquarters, and operation is based on user input and sensor data.

The second focus area, responsive lighting systems, includes all components, algorithms and systems related to daylight and the control of electrical lights. When it comes to lighting design, light intensity is important as well as glare reduction. Dr. A.J.N. Van Der Brugge and his team have studied how fish have a distinct alignment of their retina cells to perceive polarized light. Light polarization is a technique used by the fish to reduce glare and improve their ability to create an image of prey or predator.[10] Based on this finding, a technique using a polarization film was developed and implemented in lighting design. There are a large number of commercially available responsive lighting systems integrating daylight sensors and shading devices into the building façade; one example is the Lutron system.

3. 0. THE KEY COMPONENTS OF RESPONSIVE SYSTEM

Unlike previous work focusing on mechanical or active control systems, the objective of this project is to develop the conceptual framework of a passive responsive system that is able to provide sustainable solutions for responding to energy conservation, design, and environmental change. This project tries to create a foundation to answer

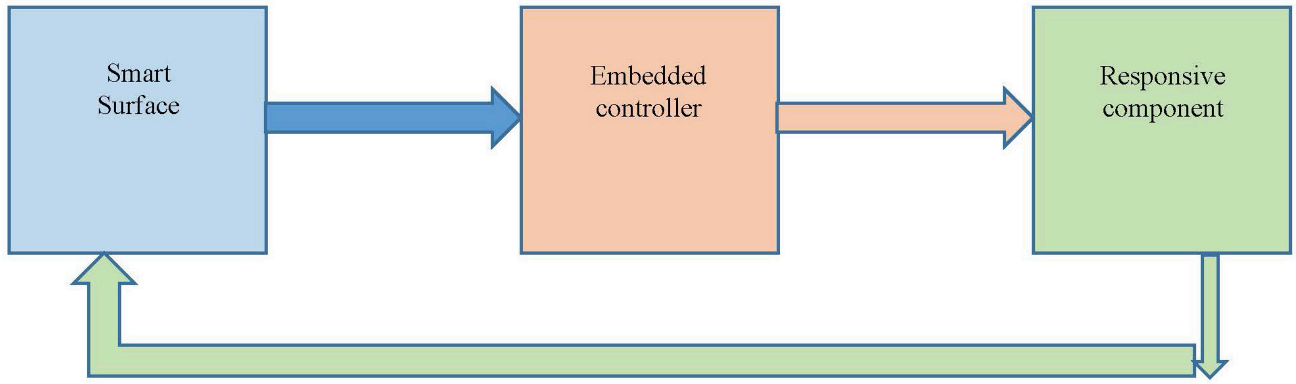

Figure 01: The diagram of the framework of the prototype

the question: How could the responsive system be driven by natural forces? And how could the responsiveness shift from purely mechanical to biological or ecological?

The passive responsive system needs to have three basic ingredients: a responsive mechanism, smart materials, and autonomous control. And nature is a good model to study. Engineers and scientists have long studied biological organisms and systems because of our perpetual fascination with the smart living organism in nature. We have studied how "the intrinsic rules and relationships shape how elementary components can comprise complex organisms and systems.".[11]

3. 1. AUTONOMOUS CONTROL

The idea of combing a mechanical system and a living organism can be traced back to the 1970s. The concept of a soft architecture machine was proposed by the founder of the MIT media lab, Negroponte. He also predicted that the physical environment could produce new forms using computational power and advanced technology.[1] In order to create a passive system, the operation of the responsive component should be embedded with environmental sensors, active actuators, and digital information receivers. These embedded components will draw on natural resources and simulate adaptive characteristics that respond to environmental change.

3. 2. RESPONSIVE MECHANISM

In his book, "An Evolutionary Architecture," John Frazer—a pioneer in the development of interactive and intelligent building—outlined eight aspects of an evolution system, including development through natural forces, self-organization, metabolism, thermodynamics, morphology, symmetry breaking, and the prevalence of instability.[14] This project adapts the idea of evolutionary architecture to develop a responsive mechanism that could maximize the energy-use efficiency based on natural responses. The module could modify the structural behavior and convert the kinetic movement to electric power that could be stored for future use, so the whole system composed of the modules could be self-sufficient.

3. 3. SMART MATERIALS

Lots of attention has been given to innovative materials research and development, with the focus on folding them into the responsive system as a large integral component. The responsive system could be represented in different forms, such as structural, chemical, and materials. Materials are defined by their specific composition and the structure from which their properties arise.[15 12] Some materials are static while others are more responsive to the natural environment. Researchers have done a range of studies on smart materials, such as shape memory metal alloys, biometals, and hydromorphic materials (wood)[16] . The sensors and actuators embedded into the materials can change to adapt to the physical environment through transformable objects. The system then becomes hybrid: a combination of a passive and active system with smart materials that could actively respond to the physical environment.

Smart materials can automatically transform to adapt to the changes in ambient environment depending on factors like temperature, lighting, and humidity. A company called Clothing created the first heart rate-sensing shirt as early as 1998. In 2002 Clothing Plus started mass-producing their heart rate sensor strap in their factory in China. Today, Clothing Plus produces millions of sensor products every year for brands like Suunto, Adidas, Garmin, Philips and Timex. Clothing Plus is focused on both sports and health care.[12] This type of product and research does require a multi-disciplinary approach. The new trend is the paradigm shift from focus on the mechanical to the biological faction.

4.0. DESIGN METHODS

In order to understand the use concept of a proposed responsive system, a scenario is developed to frame the problem in order to test the responsiveness of the system to the environment. The scenario needs to be set up in a way that includes ecological elements so that the responsive system can become an integral part of the ecological system, complying with the natural law of energy conservation.

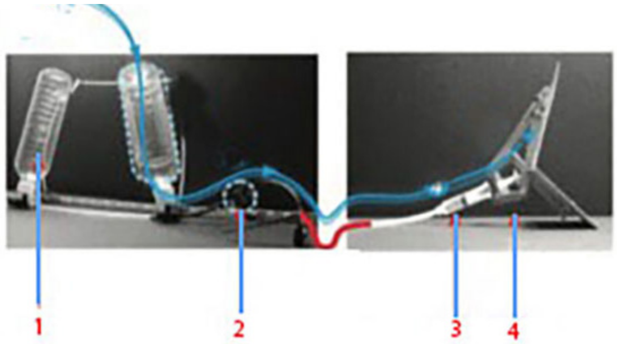

Figure 02: The Hydraulic Sending Mechanism

4.1. A SCENARIO

In this scenario, a set of responsive physical structures needs to be constructed along the East Coast seashore, which constantly faces the threat of hurricanes and coastal flooding. The responsive structure is activated solely by renewable and organic power: hydropower. One other important requirement of this structure is that it needs to conform to the varied sea level. A rainwater storage and water-detecting system was developed. The responsive system has two functions: first, to utilize the water resource in generating the power for the responsive structures and second, to adapt to flooding conditions in the future. The ultimate aim is that the system should be able to be integrated into buildings in the future.

4.2. DESIGN CONCPETS OF THE PROTOTYPE

During the process of designing, constructing and testing the responsive system outlined above, two conflicts arise. First, sufficient renewable energy needed to be supplied in order for the continuous operation of the system and hydropower energy is limited due to the scale. Second, the energy needed for the responsive system to deform to respond to the environmental change is constantly beyond the supply capacity. The mismatch between the high demand for energy and the low energy production seems like an unsolvable dilemma at first. Nature is the resource we turn back to for inspiration. To solve the conflict between energy demand and consumption, we apply the natural law of energy conservation. There are different forms of energy, such as thermal energy, kinetic energy, electrical energy, and potential energy. The base of energy in a natural ecological system is that the energy can neither be created nor destroyed in a closed system, only transformed into different forms. The reason the conflict exists in the prototype design is that it is not a closed loop, because the potential-gravity energy could not be captured and stored. A method needs to be identified so the prototype could gradually store the potential-gravity energy, and release it back to the closed system once the additional amount of kinetic energy is required to keep the responsive system operating. Also, a solution needs to be found by developing an integrated sensing and actuator system that could control the movement of the system with minimal electronic energy consumption. The key components and strategies to establish such a closed-loop system are:

- Physically responsive structure: with emphasis on defining the closed boundary and building a potential-gravity energy storage space.
- Smart surface: using the modules' surface as a detecting mechanism. The accuracy and sensitivity of the detection depends on the material's property and surface geometry. The aim is to blend the material and shape as a hybrid system.
- Mechanical control actuator: implementing the sea level-detecting sensing system as the actuators for variables in the control algorithm.

The purpose of the design strategies listed above is to solve the conflict by learning from natural ecological systems by bringing all the components into one closed system and balancing the mismatch of the energy demand and supply. Other advantages include maximizing the utilization of hydraulic power by taking into consideration not only the water from the ocean but also from the rainwater recycling system. This is also an imitation of a closed natural ecological cycle.

5.0. TESTING THE RESPONSIVE SYSTME

The testing focuses on demonstrating the responsive system's function as a self-sustained interactive component that responds to environmental change. The responsive prototype consists of the three components as outlined in Section 3: a hydraulic responsive mechanism, a sensing surface made of smart materials, and embedded actuators activating the geometric transformation.

5.1. HYDRAULIC RESPONSIVE MECHANISM

In order to store the potential-gravity energy, the hydraulic sensing mechanism is used to accumulate the hydraulic pressure. After the hydraulic pressure reaches a certain level, it will be released and transmitted to kinetic energy. The assembly of the hydraulic sensing mechanism includes: 1) a liquid container, 2) controllable floodgates, 3) a regulator to control the flow rate, and 4) the movable lever. The liquid container is used to collect the rainwater or the seawater. The controllable floodgate decides whether to release the liquid. The flow-rate regulator is used to prevent any over-speed.

5. 2. SMART SURFACE

The smart surface has two main components: smart material and controlled geometry. During the development of the prototype, the future implementation was kept in mind, so the materials chosen needed to be commercially available and easily integrated with future building façade assemblies. A variety of materials was investigated. In the end, stainless steel was selected and the smartness lies in the embedded electrode pads in the stainless steel. When the water rises to certain level it will create a short circuit and send a signal to report the environmental change, specifically the rise of the sea level and/or substantial rainfall.

5. 3. MECHANICAL CONTROL ACTUATOR

For the actuator and control device, an off-the-shelf product is used in this prototype testing. The Adafruit Trinket mini controller is selected

Figure 03: Electrode Pad

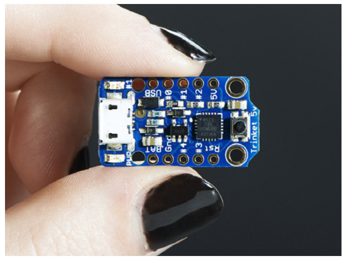

Figure 04: ADAFRUIT TRINKET MINI CONTROLLER

for its low cost. It receives the signals from surface-sensing module and sends signals to activate the motion of the flow regulator and floodgates, and ultimately controls the deformation of the surface geometry.

6. 0. CONCLUSION

As discussed in Section 2, the study of responsive or interactive architecture is not new. The purpose of this experiment is to start to answer the question: How can a responsive system be driven by natural forces? And how could the responsiveness shift from a mechanical paradigm to an ecological and biological paradigm? As Michael Fox and Miles Kemp state, “A biological paradigm of interactive architecture requires not just pragmatic and performance-based technological understandings, but awareness of aesthetic, conceptual, and philosophical issues relating to humans and the global environment.”[13] Responsive systems based on natural principles outline the path of future intelligent performance-based building design, and the integrated sensors and smart materials have become the two foundations of this path. We have seen the growing interest in these two new multi-disciplinary fields. As performance-based and performance-driven design is becoming mainstream, there is high demand for buildings that not only perform well based on current standards, but also perform new types of functions. What if buildings could be used to monitor environmental change? What if buildings could temporary mitigate the negative environmental impacts? The energy conservation, or occupant’s well-being will no longer be the only measurement and indicator of buildings’ performance. We are envisioning buildings that could function as a sensor, controller, and monitor of the environment. This type of prototype testing could pave the path to make this happen. In the process of prototyping, we ought to ask “How can a building do that?”, and “What does this building do?”, instead of “What is that building?” or “How much energy that building conserve compared to the baseline?”

ENDNOTES

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