Programmable Buildings: Architecture as an Interaction Interface Powered with Programmable Matter

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CCS CONCEPTS

• **Applied computing~Computer-aided design**

KEYWORDS

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1 INTRODUCTION

Adaptive designs and intelligent spaces are in the forefront of the current architectural and product design discourse. They engage users in interactive dialogue, allow for public domain authoring, and are critical factors in sustainable designs where buildings monitor their own performance and respond to environmental factors or user needs (figure 1).

The following research discusses current approaches to active and reactive building components and smart building assemblies. One approach uses microcontroller-guided components with distinct elements, each performing a dedicated function such as sensing, actuating, or data processing. The second approach incorporates custom designed smart materials that not only complement or replace the need for electrically operated sensors or actuators, but also eliminate a microcontroller, since in this arrangement the material itself performs computational functions. Presented studies use physical computing and smart-material models as vehicles to discuss pros and cons of each approach to adaptive design in architecture. Building on these observations, the presentation looks into conceptual aspects of integrated hybrid systems that combine both computation approaches as well as unique opportunities inherent to these hybrid designs. The material-based computation--sensing and actuating--are processed locally and on an as-needed basis. It can be achieved on the nanoscale--truly distributed and ubiquitous--with non-explicit appearance. At the same time, the software-hardware integration inherent in smart-material computing sets limitations for dynamic readjustment of behavioral properties and functional configurations. In most instances, smart materials are specifically designed to perform a particular function within well-defined trigger conditions. However, these trigger properties are not easily reconfigurable once integrated into building assemblies.

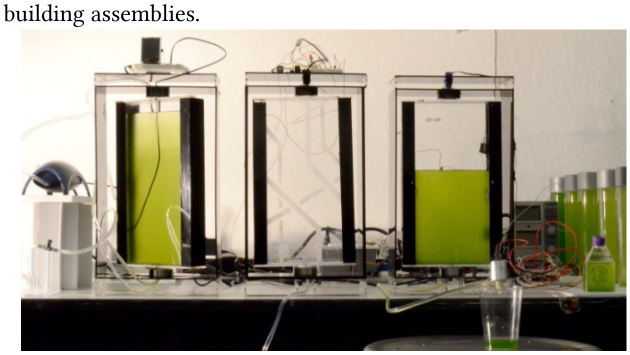

Figure 1: Algae bio-facade panel. Project by Samantha Bard, Mary Lopreiato, and Libertad McLellan supervised by Andrzej Zarzycki, NJIT.

2 CASE STUDY: SMART MATERIAL

Automated shading elements have been designed to effectively control environmental conditions in buildings. Shading systems routinely use sensor and actuator with adaptive-kinetic assemblies to control solar gains and sunlight. These functionalities could also be achieved with engineered materials. Particular classes of shape memory alloys (SMAs) can effectively perform the same task without the needs of temperature sensors, computing devices, or electricity. The Smart Textile project (figure 2) shows a series of SMA strands integrated into a textile ribbon design that perform similarly to mechanically-controlled blinds.

While SMAs can react to particular temperature, it does not respond to the amount of natural light passing through the screen. In order to overwrite the material performance in the assembly an electric current could be run through the SMAs locally to trigger the hot state configuration of the material. This parallel trigger approach demonstrates the opportunity for multilevel integration of smart materials and electronic systems. A microcontroller could work side-by-side to modulate material

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responses and reduce sun exposure. This approach not only would increase overall reliability (redundancy), but also could provide a higher level of movement precision.

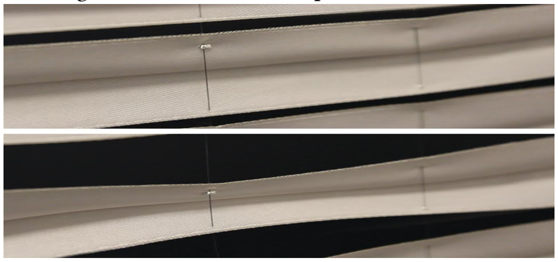

Figure 2: Smart Textile integrating Shape Memory Alloys (SMAs). Credit: Robin Hanrahan | Martina Decker, Material Dynamics Lab

3 DIGITAL-MATERIAL COMPUTING

The hydrogel enabled green wall installation is an example of an active building component that combines microcontroller features with the smart material performance. Green walls improve thermal qualities of buildings and counteract the urban heat island effect. The water management of vertical plant installations is complex and often requires extensive irrigation strategies. Hydrogels are being utilized to control the moisture content in the soil and promote plant health. The polymorphic smart materials can absorb up to 400 times their own weight in water and slowly release the moisture to plants.

Each of these approaches, material- or microcontroller-based, illustrate a promising direction in research and design for adaptive buildings. However, the combination of both approaches into a single integrated platform opens a broader set of possibilities that would allow for more efficient and effective performative designs as compared to a single-focused method. It would also help to scaled-up solutions from individual assemblies to broader networks that not only actively respond to environmental forces, but also behave proactively through electronic networks' ability to share data remotely.

Computing with smart materials removes the duality between hardware and software. Software (behavior) is discretely encoded into hardware (material). This software-hardware integration provides a number of unique opportunities that are not achievable with traditional electronic systems. Material-based computing removes the need for a central processing unit to oversee and control the entire system. Sensing and actuating are processed locally and on an as-needed basis. Since the material-based computation can be achieved on very small scales (nanoscale), it can be truly distributed and ubiquitous, with non-explicit appearance. The material response is direct and can be limited to extremely high-resolution areas. This removes the need for electric circuits that are always on, even in a hibernation mode, and are subject to the temperature, electricity, and magnetic field limitations as any electrical system. These are important characteristics from both energy consumption and heat dissemination perspectives. At the same time, the software-hardware integration inherent in smart-material computing sets limitations for dynamic readjustment of behavioral properties and functional configurations. In most instances, smart materials are specifically designed to perform a particular function within well-defined trigger conditions. However, these trigger properties are not easily reconfigurable once integrated into a building assembly.

Figure 3: Indoor green wall system, Credit: Philip Molino | Martina Decker, Material Dynamics Lab.

Furthermore, current examples emerge that are true hybrid systems combining computing with material strategies and use Dielectric Electro-Active Polymers (DEAPs) as human-computer interfaces. The Interactive, Haptic, Audio, and Visual Interface for multisensorial experiences (figure 4) generates sound through a rapid expansion and contraction of the integrated actuators. The shape change can also enable a visual display and generate a haptic feedback comparable to a braille interface. By measuring the capacitance during mechanical deformation, induced through touch, it can also collect sensorial data. The unique material strategy allows the membrane to act as input and output device at the same time.

The programmable matter allows for an integration of emergent material technologies with digital computing. While this is still largely in early developmental phases, the ability to actively adjust material properties with the use of voltage, light, and magnetic or electric fields opens possibilities for having not only "smart" but also truly adaptive and potentially autonomous buildings.

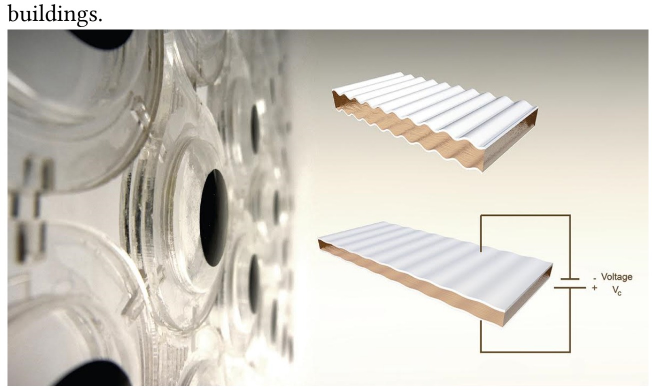

Figure 4: Mockup of Interactive, Haptic, Audio, and Visual Interface for Multi Sensorial Experiences. U.S. provisional patent application No. 62/330,384. Credit: Chris Bartel, Lisa Merz, | Martina Decker, Andrzej Zarzycki, Material Dynamics Lab