Soft Robotics and Emergent Materials in Architecture

Martina Decker
1 New Jersey Institute of Technology, School of Architecture
decker@njit.edu

This paper investigates the potential of soft robotics that are enabled by emergent materials in architecture. Distributed, adaptive soft robotics holds the promise to address many issues in architectural environments such as energy efficiency as well as user comfort and safety. Two examples out of a series of experiments conducted in the Material Dynamics Lab at the New Jersey Institute of Technology are being introduced and serve as a vehicle to explore distributed soft robotics in architectural environments. The design process and project development methods of the soft robotic systems integrated the fabrication of working proof of concept prototypes as well as their testing.

Keywords: Soft robotics, Nanotechnology, Smart materials, Flexible electronics, Adaptive environments

INTRODUCTION - ROBOTICS IN ARCHITECTURE

Robots, that have the ability to perform a multitude of unique tasks, have enjoyed great attention in art and design communities in recent decades (Figure 1). In architecture in particular they have been celebrated for their advanced fabrication capabilities and they are widely regarded as the ultimate flexible manufacturing tool. KUKA (Keller und Knappich Augsburg) robotics were used in car manufacturing when they established Europe's first welding transfer line, built for Daimler-Benz in the early seventies [4]. Now a technology transfer from industries such as the automotive industry is being studied to revolutionize architectural construction processes. Solutions for Building construction and maintenance are being contemplated from the robotics standpoint, especially in architecture schools and innovative offices like Snøhetta (Paoletti al., 2013; Bach et al., 1995; Pigram et al., 2011).

But besides the newly developed architectural processes that include robotics in the design phase as well as the creation of architectural elements, scholars have also been looking at performative, distributed robotics in the constructed environment. Early examples of kinetic, responsive and interactive architectural interventions such as hyposurface [3] have initiated a conversation that is contributing to this important research area. Furthermore the rise of a new prototyping environment that is enabled by Arduino microcontrollers has accelerated the study of robotics in architecture greatly.

The seamless integration of robotic systems into our buildings holds the promise to improve active and reactive environments that will assist with energy efficiency of our buildings and improve user comfort drastically. Distributed adaptive robotic systems in architecture can support an environment that can continually negotiate conditions with the users and their surroundings with a very high spatial resolution. The benefits of such a system lie in the fact that the robotics could perform without the
intervention of a programmer or a specialist to mediate between all the individual constituencies. The robotic system will autonomously adapt without relying on preconceived notions of occupant desires or energy efficiency.

The design for an Adaptive Solar Envelope (ASE) is such an example that was developed at the Department of Architecture at the ETH Zürich and it is looking at buildings as dynamic systems that are able to adapt to changing conditions while taking user satisfaction into account (Rossi et al., 2012). This research integrates aspects from robotics, machine learning, ubiquitous computing, and sustainability in architecture to optimize on site energy production through a careful positioning of photovoltaic elements. Furthermore it explores the potential to assist conventional HVAC (heating ventilation and air conditioning) systems and electric lighting in buildings for energy conservation. The project takes into account the user's desire and comfort at the same time.

**DISTRIBUTED SOFT ROBOTICS AND EMERGENT MATERIALS**

Concerns of safety have always been a priority when it comes to robots operating in the close vicinity of humans. The caged industrial robotic work cells often ensure the wellbeing of workers through spatial separation, while a continued improvement of the interaction protocols paired with ample sensory information is making a close encounter between robots and humans continuously safer (Albu-Schäffer et al., 2008). By integrating a robotic system in the architectural context special attention has to be given to this topic. One of the approaches to a more risk free human robot interaction can be found through the careful selection of materials - in particular materials that reflect the soft nature of our own bodies.

The subfield of soft robotics represents a penchant for a material centric approach in robotics. Common robotic systems comprise of hard, stiff and rigid components that cannot change their shape or physical properties at the material level. Soft robotics on the other hand are making use of progress that has been generated in material sciences and many other disciplines for the creation of a new generation of robotics. Aside from the potential of soft robotics benefitting a secure human robot interaction, soft and compliant material systems can benefit architecture by utilizing their unique properties to control for instance the thermal or acoustic environment.

The application of unconventional material systems lies at the heart of the nascent stages of the very young field (Iida et al., 2011). Nanotechnology, which has accelerated the development of new materials with novel properties, is a key driver in the continuing evolution of soft robotic elements. Sensors as well as actuators have to be non-rigid, soft, flexible, elastic, compliant, deformable, or reconfigurable.

Smart materials (Addington et al., 2005) that have the ability to respond to an external stimulus with a material response are a class of materials that will be instrumental in the creation of soft robotics due to their unique material behaviors. They can be for example polymorphic, luminescent, or chromic in response to electric currents, chemical inputs, pho-
Thermochromic Leuco Dye at 38°C, 32°C, 20°C, 31°C, 30°C, and 35°C | the pigments transition to a clear state at warm temperatures and appear white due to a polymeric encapsulation | Credit: MDL

Thermochromic substances can react to a change in ambient temperature with a color change. Leuco dyes (Figure 2) for instance can be engineered at the materials level to display a color such as red or blue for instance at cold temperature and appear clear in cold conditions. These pigments that are usually encapsulated in a polymeric shell can be easily integrated in a material composite and support the operations of the soft robotic systems. The performative characteristics of smart materials behold a great potential to compliment robotic systems, by infusing the robotic performance with the material's behavior.

The nature of the soft and compliant material properties do not allow us to think of robots as a series of rigid links with rotational or sliding joints anymore that can be easily described in the language of classic mechanics. Hence experimentation and prototyping is and essential tool for the development of soft robotic systems since the elastic materials used, can be highly unintuitive and resist conventional simulation tools (Rossi et al., 2014).

SOFT ROBOTIC DESIGN PROCESS AND TESTING

In a studio conducted at the Material Dynamics Lab at the New Jersey Institute of Technology the potential of soft robotic systems for architectural applications was explored in the spring of 2015. A design process that integrated prototyping and testing supported the development efforts.

One of the resulting designs featured a soft robotic system that strives to manipulate sound propagation in indoor environments (Figure 3).
pneumatic, silicone based soft robotic acoustic tile uses air not only as the actuating mechanism but also as the material that changes the acoustic properties of the system. The prototyping efforts were aided by the soft robotic toolkit [2] that was developed from research conducted at Harvard University and Trinity College Dublin for hands-on design courses (Figure 4).

The pneumatic actuators that the acoustic tiles are comprised of in this project are made of silicone (Ecoflex® 00-50). The actuators are cast in two parts and later adhered to each other. The main part is cast including voids for air chambers that will expand in the assembly once the pneumatic system is activated (Figure 4). The expansion of the individual components can be controlled through variations in the thickness of the silicone components or the use of different types of silicone (Ecoflex® 00-30, Ecoflex® 00-10, Dragon Skin® 30) that have varying degrees of elasticity. This controls the overall deformation of the actuator.

The individual actuators change their shape and volume from entirely flat to slightly convex with a surface morphology that displays a multitude of protruding air pockets. This particular shape change allows the system to influence the absorption, diffusion and reflection of sound. A hand air pump was used for the inflation of the system during the initial actuator testing, while at a later stage the activation of the design was accomplished through several
electric pumps controlled by an Arduino microcontroller setup (Figure 5).

While the small proof of concept prototype and test environment (Figure 6) successfully demonstrated that the sound propagation was manipulated (Figure 7), further research would have to be conducted to fully explore the potential of the soft robotic system to influence its environment in real time.

Another experiment that was conducted at the Material Dynamics Lab resulted in the design for a soft frit that was inspired by Hoberman’s adaptive fritting projects [1]. The pneumatic soft robotic elements (Figure 8) that are envisioned on building facades strive to control solar heat gain through building skins. They expand to block sunlight when the interior environment is getting too warm or contract to allow the sun to penetrate through the glass façade when the interior room temperatures drop (Figure 9). The intervention is configured to assist HVAC systems in buildings to reduce the overall energy consumption that would otherwise be expended to maintain interior conditions with mechanical means.

Furthermore the actuator design featured a material composite that integrates a photoluminescent material (Figure 10) into the silicone mixture. The
robotic system can absorb sunlight during the day and emit photons of light during the nighttime hours. The use of this smart material can compliment electric lighting systems.

In the final design the soft robotic system is envisioned to comprise of a multitude of distributed, individually activated elements that can operate without the reliance of conventional energy production. Each element features a small solar cell that will operate a low power micro blower, which can inflate or deflate the individual element.

A third project developed in the studio is called Soft Barrier (Figure 11). With a series of soft actuators the robotic system can manipulate thermal transfer through a soft and compliant skin. Air pockets in the design can modulate the thermal transfer through the envisioned architectural application. The pneumatic actuators can be controlled individually to inflate or deflate. Furthermore the integration of leuco dyes (such as seen in Figure 2) can change the membranes color to either absorb the energy of the sun or to reflect it back into the environment. This change of the material’s albedo solely depends on ambient temperatures.

CONCLUSION
The projects conducted at the Material Dynamics Lab explored the potential of soft robotics in architecture through the lens of emergent materials. The final distributed robotic designs demonstrated the potential to address many problems such as energy conservation or noise reduction in the constructed envi-
The fabrication of proof of concept prototypes was an essential part in the design process and greatly influenced the final projects. Soft, compliant and stretchable materials are challenging to plan for, since their performance does not always allow for intuitive decision-making and resists conventional simulation software.

Furthermore the studies showed that the soft nature of the various designs allows for installations of distributed robotics in architectural settings in close proximity to occupants. Soft to the touch and malleable, the material enabled designs do not compromise safety (Figure 11).

The durability and robustness of the materials over time yet has to be explored in real world architectural environments. To further the development of soft robotics in architecture truly interdisciplinary partnerships that include architects, designers and representatives from the STEM (Science, Technology, Engineering and Mathematics) fields will be essential. The conducted studio aspired to initiate important discussions on the topic and strived to enable a new generation of architects to be prepared for such collaborations.

ACKNOWLEDGEMENTS
I would like to thank my colleague Andrzej Zarzycki for his support. I would also like to thank the following students for their dedication in the prototyping and testing efforts: Chris Bartel, Dan Beltran Beltran, Ryan Berg, Jorge Cruz, Michelle Ghanime, Paulo Guerreiro, Na'Shawn Jordan, Jay Lin, Salma Mahmood, Lauren McLellan, Lisa Merz, Anthony Morrello, Anthony Samaha, Kwadjo Sasu, and Jesus Vasquez.

REFERENCES
Pigram, D and McGee, W 2011 'Formation embedded design: A methodology for the integration of fabrication constraints into architectural design', *Proceedings of ACADIA 2011*

