Information Materials

Smart material based architectural design

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Abstract. *This paper questions the current use of materials in architecture, which furthers the preference of surface and form over inherent material properties. It then investigates recent advancements towards the notion of a Digital Materiality, comparing various international research activities and approaches. It concludes with the potentials of Smart Materials for the creation of dynamic, adaptive spatial design. With a focus on the work of the Author it represents a number of projects that have been realized in this area within the past years and gives an insight in his recently established Materiability Research Network, a community platform that reveals Smart Materials, their properties and how to self-make them in an applied hands-on manner.*
Keywords. *Smart materials; digital materiality; open source; do-it-yourself; adaptive architecture.*

INTRODUCTION

New visions for architecture and urbanism were often accompanied or driven by radical technological developments, material innovations or dramatic changes in politics, society and economy (Scott, 2007). Based on their structural manifestation and visual character they can be understood as various architectural styles, each more or less representative for a certain period over the course of time (Leach, 2010). Today's society however and especially the self-expression of the individual, be it in fashion, music or art, is extremely diverse, versatile and interminable and therefore hard to be classified as a single and defined representation of our epoch (Palvrey and Gasser, 2008). Similarly the abundant availability of information, the rapid emergence of new technologies, the large variety of available materials and the inconsistency in combining these to create new spaces for a rapidly growing and evolving population renders architecture into an indistinguishable mess of built form, more feeling like constant experimentation than a clear idea on how to give meaning to recent developments (Kolhaas, 2002).

As a consequence and in order to perpetuate norms, quantifiable values and consistency, an innumerous amount of databases, catalogues and libraries are emerging, which sometimes seem to oversimplify their content for the sake of comparability. In the field of architecture and design this becomes especially obvious in the attitude towards materials. Online material explorers like for example www.materialconexion.com or www.materia.nl certainly provide a profound database and offer various ways in order to search and sort materials in relation to specific properties and applications, but through portraying materials as flat entities they also further the preference of the surface (Leatherbarrow and Mostafavi, 2005) which results in a usage that reminds more of applying textures in CAD programs than a thorough understanding of materiality. Furthermore a material's characteristics, no matter how homogeneous or solid they might appear, are under no means finite, since they are always built-up from certain mechanisms occurring at atomic or microscopic scales (Shackelford, 2005), which in turn are dependent on the intrinsic bonds of its particular chemical elements.

DIGITAL MATERIALITY

One large area of research is currently concerned with the idea of encoding information into materials, organic as well as inorganic. This topic spreads the domains of synthetic biology, materials science and chemistry as well as information technology, engineering and robotics but also emerges on different scales in the discourse of contemporary architectural studies. Referred to in a variety of ways and motivated through various, sometimes complementary, hypotheses, the common denominator is the concept of individually "programming" or modifying certain elements within a greater assembly to create an unlimited amount of manifestations of the same initial condition.

In a larger, very applied scale and already transferred into the architectural practice, this happens within the area of digital design and fabrication. While each component in this procedure usually inherits identical properties or consists of the same material, they can be post-processed with numerically controlled machines into mass-customized elements that can then be used to create complex architectural forms. ETH Zürich's Fabio Gramazio and Mathias Kohler refer to this as "digital materiality" and propose to overcome geometry as the core of architectural design towards the design of material processes (Gramazio and Kohler, 2007). Achim Menges at the Institute for Computational Design, Universität Stuttgart, relates to "material computation" and proposes an interrelated understanding of form, material and structure based on computational techniques to analyze material capacities, geometrical restrictions, manufacturing processes and assembly logic (Hensel, Menges, Weinstock, 2010). A similar approach, however on a different scale and less technology-driven but rather biologically-inspired, can be found in the work of Neri Oxman at MIT's Media Lab in what she calls "material based design computation". Her argument is that contemporary architects, engineers and designers are too much focusing on the imposition of form over materiality and she therefore proposes to look at nature where the creation of form happens intrinsically with material defining the structural system, which in turn leads to the formation of shape (Oxman, 2010). Skylar Tibbits, another MIT fellow, investigates the concept of self-assembly, equally influenced by biological phenomena and approaches in computer science. He proposes that in order to keep up with the rapid developments in design and fabrication we need to develop smarter components rather than more complex machines or tools, which would consist of basic assembly procedures, programmable elements and the ability of independent error correction (Tibbits, 2012). This concept very much resembles the idea of Claytronics, a collaborative research project between the Carnegie Mellon University and Intel Labs in Pittsburgh, which is concerned with the development of nanoscale computers that can respond to each other in order to form three-dimensional, tangible objects. While current explorations are still happening in the scale of millimeters rather than nanometers and are facing numerous mechanical and physical challenges (Karagozler, 2009), the idea of single agents, all inheriting the same "intelligence", but with the capability to form larger, more complex assemblies is truly promising. Even more striking however is the notion of a material that can dynamically and reversible reconfigure itself into any imaginable shape – something that Winy Maas would refer to as the "Barbapapa" particle (Czaja, n.d.).

SMART MATERIALS

While the development of such a shape-morphing material is certainly still a dream of the future, there are already a number of composites available that can change their state within a range of varying properties, so called Smart Materials. In some cases even celebrated as the answer for the 21st. century's technological needs (Addington and Schodek, 2005), Smart Materials are generally referred to as materials that are capable of sensing the environment and actively responding to it in a controlled way (Fox and Kemp, 2009), and since they aren't mechanically complex, a separation between structure and driving actuator can be avoided (Lochmatter 2007). Due to these capabilities architects, both in research and practice started to include them in their proposals and are speculating on how they could eventually enhance buildings in order to better deal with ephemeral occupational demands (Kloster, 2007). Motivated through constant advancements in adaptive building technologies Charlotte Lelieveld at TU Delft for example looks at how shape-morphing materials could be used to create dynamic facades that can respond to changing environmental conditions in order to improve building performance (Lignarolo, 2011). Aurélie Mosse, based at CITA in Copenhagen, follows a more artistic approach, trying to reconnect exterior conditions with interior spaces through self-actuated, organically moving ceiling elements based on the minimum energy structures of dielectric elastomers (Mosse, 2011). The growing interest of applying these materials into architecture is also proven by a variety of built projects by renowned architects (Ritter, 2007), the most recent international building exhibition in Hamburg [1] and a large number of art installations (Howes and Laughlin, 2012).

Still, in most cases the dynamic properties of the materials aren't used to their full extent as they are either attached to or combined with traditional, rigid materials, which constrain their abilities (Kretzer, 2011) or simply used to replace existing technologies and devices. Furthermore, following the current attitude towards materials in architecture and in favor of their visual appearance, they are being evaluated, standardized and categorized to fit into existing design palettes and catalogues and by doing so, the active and variable properties of these materials have to be ignored or seriously simplified. And finally the fact that there is only very little information on new material developments communicated to the fields of architecture and design and that it takes decades until prototypical materials are available as applicable products on the market, greatly slows down the creative process and restricts the designer to think within established boundaries.

The idea however, to create spaces that can dynamically change, that can respond and adopt to their environment and that consist of a materiality that blends machine, material, device and application brings up a series of unprecedented possibilities and challenges to the architectural domain.

MATERIABILITY

Throughout my research at the Chair for Computer Aided Architectural Design, ETH Zürich I try to investigate these potentials following two complementary paths.

The first approach is based on my teaching activity in relation to our Master of Advanced Studies course. Herein I lead an annual module that looks at different Smart Materials and their potential for spatial design. In close cooperation with experts from the respective fields the materials are then reproduced in a DIY, hands-on approach. Obviously these cannot reach the durability and efficiency of industrially produced ones, nevertheless it allows understanding their working principle and how they can be modified to meet certain design ideas. This has led to a number of speculative installations:

ShapeShift (2010)

ShapeShift was the final thesis project of Edyta Augustynowicz, Sofia Georgakopoulou, Dino Rossi and Stefanie Sixt (Figure 1). The project investigated the use of dielectric elastomers, a particular kind of electroactive polymers, in order to create dynamic spatial applications. Dielectric elastomers are poly-

Figure 1
ShapeShift as exhibited at Gallery StarkArt, Zürich in September 2010 (Photos: Manuel Kretzer, 2010).

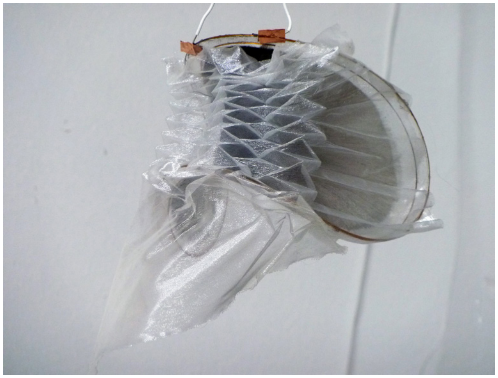
mer-based actuators that change their size, shape or volume in response to a large electrical field. They are thin, transparent, light and stand out from the field of active materials due to their large deformation potential (Bar-Cohen, 2004). While they're usually used to produce artificial muscles, the students focused on highlighting their quality as dynamic surface material. Each element within the structure consisted of a pre-stretched film that was attached to flexible acrylic frames and sandwiched between to compliant electrodes. Once a high DC voltage (3-5 kV) was applied the film was compressed in its thickness direction, which lead to a planar expansion of the membrane. Since the membrane was attached to the flexible acrylic frame, the frame bent when the material was in its relaxed state and flattened out when the tension was removed during actuation. Through empirical design the students then altered the acrylic frames until the movement was maximized and the desired three-dimensional motion achieved. In parallel to the development of single components investigations into structural arrangements were performed. Through connecting a multitude of components together dynamic configurations could be achieved that enhanced the movement even further and resulted in feasible self-supporting structures. Similar to the single shapes the final form of these tessellations resulted from the relationship of the dielectric elastomer to its frame and the connections to neighboring elements.

The main challenge to use dielectric elastomers in real architectural scenarios will be to increase the size, longevity and durability of the components. Automating the manufacturing process could partially solve this, but in order to make the components more stable a different carrier material would have to be used.

Animated Textiles (2012)

The use of Dielectric Elastomers was further investigated during a one-week workshop, held together with Ivana Damjanovic, at the Swedish School of Textiles in Boras, invited by Delia Dumitrescu. During this workshop the participants explored the combination of dielectric elastomers with various lightweight textiles in order to create animated surfaces, structures and assemblies (Figure 2). After a two-day introduction in the art of producing the material the students started experimenting with different shapes and forms, based on previously prepared designs. The results, which exhibited the most promising results, were then fine tuned and combined with a variety of fabrics, knitted structures or textiles. At the end of the workshop each group had built a physical prototype, which was then presented to a larger audience. The participants who were mostly design and textile students were intrigued by the soft and organic movement of the components and speculated how it could be used to make responsive garments. In this scenario the main challenge would be to properly insulate the dielectric elastomer com-

Figure 2
Different strategies that emerged throughout the workshop to enhance the visual appearance and movement of the dielectric elastomers (Left: Joanne Kowalski, Inese Parkova, Nilla Berko; Right: Riikka Saarela, Christina Maschke, Emelie Johansson; Photos: Manuel Kretzer, 2012).

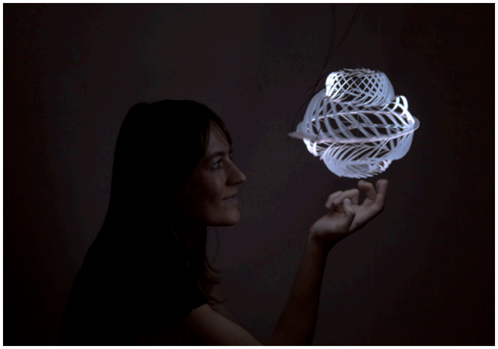


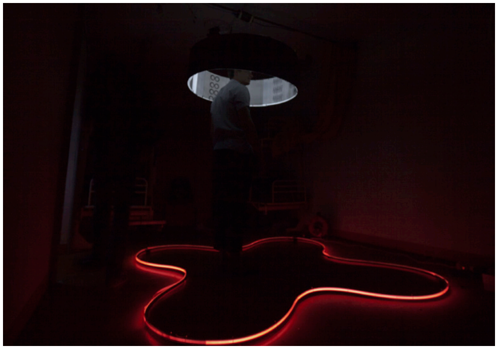
ponents to prevent shocking and potentially harming the wearer.

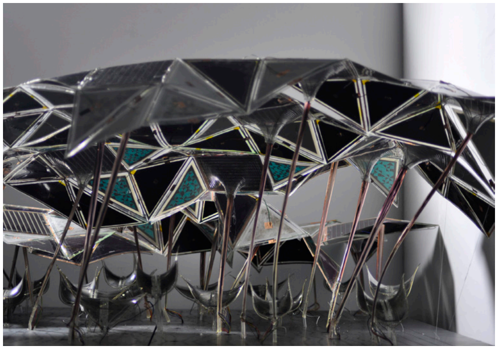
Material Animation (2011)

This was a four weeks MAS module that was supported by Ruairi Glynn from the Bartlett, London. The course focused on the use of electroluminescent foils and resulted in a number of kinetic light installations that each emphasized particular material properties in a different way and context (Figure 3). Electroluminescent foils are extremely thin, flexible and lightweight screens, which emit a homogeneous cold light across their surface without the need for additional infrastructure. The installations were situated in three interconnected rooms in the basement of ETH's Hönggerberg campus, each occupying one of the spaces. Every installation was capable of sensing the amount, location and velocity of visitors. This information was wirelessly transmitted to a server, which compiled the data and sent instructions back to the particular space. Through that every installation knew what the others were doing and consecutively was able to respond in a choreographed and coordinated way, trying to attract more visitors if the space was empty or slowing down if too many people would reside in the same room. In contrast to the previews two projects motion was achieved using standard actuators like Servo or DC motors. Similarly the used smart material was commercially fabricated and off-the-shelf available. While this allowed for more durability and efficiency it also decreased the creative flexibility to design since the material properties could not be changed beyond their set configuration.

Figure 3
Each of the installations was emphasizing the distinctive material properties in a different way. (Left: Vapor by Agata Muszynska; Right: Insomnia by Hideaki Takenaga; Photos: Manuel Kretzer, 2011).







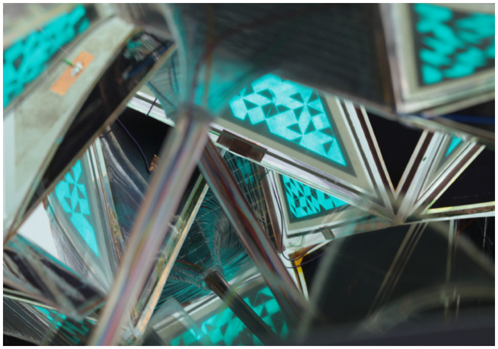


Figure 4
Phototropia in its final assembly showing skin of electroluminescent displays facing down- and dye-solar cells upwards, bioplastic pillars and electroactive polymers populating the ground (Photos: Manuel Kretzer, 2012).

Phototropia (2012)

This project was again realized as MAS module within 5 weeks. It was kindly supported by Luke Franzke, Florian Wille (ZHdK IAD), Paul Liska (EPFL LPI), Andrei Prutaneu, Agostino di Figlia (TU Delft ES group), Jorge Ellert (ULANO Corp.), Beat Karrer (Studio Beat Karrer) and John Meschter (G24 Innovations). Since the creative freedom during "Material Animation" seemed limited the focus within this course was to produce all materials that were used in the installation ourselves. This included the making of electroactive polymers, electroluminescent displays, eco-friendly bioplastics and thin-film dye-sensitized solar cells. All elements were then combined into an autonomous installation that produced all its required energy from sunlight and responded to user presence through moving and illuminating elements (Figure 4). The generated energy was stored in batteries below a base platform and distributed via microcontrollers to the respective elements. Obviously since all elements within this project were self-made their durability and performance did not reach their potential maximum. Consequently a number of industrially produced dye-solar cells had to be integrated in order to achieve the required Voltage. Unfortunately, as the gelatin-based bioplastic remained sensitive to changes in temperature and especially humidity, the installation slowly collapsed after a few weeks of exhibition.

Resinance (2013)

Continuing on the idea of creating self-sufficient, autonomous systems this year's MAS module focused on the assembly of various "smart" components that each have the same abilities but are connected through a distributed network in order to create emergent and evolving behavior. With the rising complexity of the installation also the number of involved people increased. The work was supported by Benjamin Dillenburger and Hironori Yoshida (CAAD), Weixin Huang and Lei Yu (Tsinghua University), Tomasz Jaskiewicz and Mariana Popescu (Hyperbody, TU Delft) and Andrei Pruteanu and Stefan Dulman (Embedded Software Group, TU Delft). The formal design of the project was strongly influenced by the behavior of basic organic life forms and particularly the formation of cellular colonies. It consisted of 40 active elements, produced from a polyester resin enhanced with thermochromic pigments that were all touch sensitive and with the ability to change their surface color correspondingly (Figure 5). The color change was achieved through heating and cooling a liquid inside the hollow elements. The current temperature inside the containers was constantly measured, which allowed it to be mapped precisely onto certain color schemes. Since the color change as such was fairly slow and couldn't be perceived immediately they furthermore incorporated vibration motors that would start shivering once

Figure 5
Resinance during activation. Various colours emerged when the objects were touched. The gradient, organically appearing patterns resulted from the manual process of producing the elements (Photo: Demetris Shammas, 2013).

an interactive input was sensed. Always four elements were connected through a control unit that contained an Arduino Microcontroller with an XBee radio. These units were formally similar to the rest of the objects but without the ability to change their color. They both choreographed the behavior of the individual cluster and sent the current state of each element to its nearest neighbors. Therefore the tactile input not only changed the touched element but was also transmitted throughout the whole assembly, resulting in constantly evolving patterns.

The knowledge and experience that is generated throughout these courses as well as the research I undertake within my PhD studies into understanding different types of smart materials are fed into my second approach, the Materiability Research Network (http://www.materiability.com).

The Materiability Research Network

Funded in a believe in unrestricted access to information and knowledge and a trust in education through creation and physical making, the network first of all provides an online platform that showcases projects emerging from this research, hoping to inspire and encourage its visitors (Figure 6). Secondly it forms a community that brings together architects, artists, designers, students, scientists and researchers who share a common fascination with smart, programmable materials and their potential integration into architecture and design to create softer, more dynamic environments. Members of the network gain access to detailed instructions on how to self-make a variety of smart materials without the necessity of a lab environment. Furthermore they receive well-researched information on the respective materials, where they come from, what they were initially developed for, what the current state of development is and how they could potentially be used in serious architectural applications. The community part of the platform also allows the members to post their own work using a template, which is then published, in the "network" section that is visible to the public. An integrated forum allows them to take part in discussions concerning the topics "real projects", "theoretical discourse", "tutorials and materials" and "comments and general concerns". This enables them to receive further information through the community or exchange their ideas on certain developments in a more theoretical environment. Last but not least an integrated messaging service can be used to get in direct contact with and receive feedback from particular members. The activity (e.g. number of posts, forum entries, friends…) of each member is measured and is reflected both on their user profile as well as the members' list. The database currently provides material information on Thermochromics, Bioluminescence, Aerogels, Soft Robotics, Electroactive Polymers, Dye-Sensitized Solar Cells, Electroluminescent Displays and Bioplastics. Tutorials are published for the making

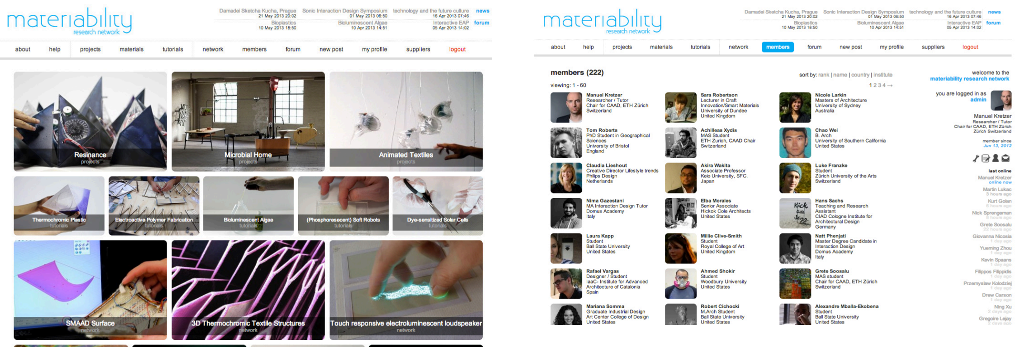


Figure 6
Screenshots of the Materiability Research Network platform (www.materiability.com), displaying the start-page (left) and member's list (right).

of Thermochromic Plastic, Electroactive Polymers, Bioluminescent Algae, (Phosphorescent) Soft Robots, Dye-Sensitized Solar Cells, Electroluminescent Displays and Bioplastics. Membership and access to the network is free of charge, however educational affiliations have to be verified.

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