Towards a Material Agency:

New Behaviors and New Materials for Urban Artifacts

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Abstract

As computationally augmented materials find their applications in architectural practice, we observe a new kind of material culture shaping architectural discourse. This is a kind of material intelligence that is not only introducing a richer vocabulary for designing more expressive, responsive and customizable spaces, but also encouraging us to think of new ways to contextualize the technical imperative within today's and tomorrow's architectural design. It becomes important not only to discuss and extend the technical vocabulary of computational materials in relation to other disciplines that are also concerned with 'designing intelligence,' but also to tie the research's connection to a broader discourse that can respond to it in multiple perspectives. In this paper, I present a position on this emerging field and frame my work in two main threads: 1) the design of new materials that can exercise computationally complex behaviors and 2) the design of new behaviors for these materials to tie them to higher-level goals connected to social, cultural and ecological applications. I discuss these research themes in two design implementations and frame them in an applied context.

1. Introduction

Research in computationally augmented materials is an emerging field that is bringing together different perspectives, techniques and expertises from ubiquitous computing, human-computer interaction, digital fabrication, and material science with the aim of developing a new discourse on 'material intelligence'.

As shape-changing alloys, elastic polymers, electronic textiles, and electro-mechanically programmable surfaces find applications in architecture, we can, on the one hand, observe a rich vocabulary for designing more expressive, responsive and customizable spaces and, on the other hand, find new ways to critically reflect on the behaviors of these materials and discuss the role of material intelligence within architectural design. It is important not only to extend this technical vocabulary in relation to other disciplines that are also concerned with designing intelligent behaviors, but also contextualize the technical imperative within the architecture's broader discourse where these behaviors resonate with everyday uses.

One recent practice in material research focuses on the design of smart composites in which a variety of materials, combined with electro-mechanical components are designed to actualize computational behaviors. We observe a generation of responsive, interactive, task-driven materials that can sense and act on user or environmental inputs. We witness smart columns repartitioning spaces[1], smart skins covering buildings that filter water[2], and observe interventions on facades that can collect, harvest and store energy from a variety of natural resources[3].

In this paper, I present my position on this emerging material culture in two ways: first, within the actual design of the materials by pointing out new directions for material research that will allow it to be able to accomplish more elaborate tasks; and, secondly, in the way the material research can be tied to higher-level goals that have social, cultural, and ecological implications. I discuss these two threads within the context of two design implementations following in the later sections.

2. Designing New Computational Materials

Current trends in ‘material intelligence’ introduce a multitude of approaches and implementations of responsive materials that respond to users and/or the environment with low-level behaviors. Physically or computationally augmented materials introduce new design affordances that utilize a number of basic responses to stimuli[4]. By registering state changes, materials can start building memories (e.g., remembering when they are touched, actuated, or transformed), respond to user input and transform the physical input to another form of energy[5].

One important dimension in this research lies in the design of composites that can combine a set of low-level behaviors and also equip them with a concept of ‘agency,’ an internal monitoring system that can allow them to be ‘aware’ of their own functionalities and eventually manage these low-level behaviors for accomplishing higher-order tasks.

2.1. Material Agency

Computational sciences, ranging from cybernetics, cognitive science, artificial intelligence and robotics research to bio-engineering, already share a rich discourse on the alternative ways to conceive artificial agencies. From chess playing automatas to today’s self-monitoring super computers, the quest for machine agency has traversed many histories, but since the earliest times, architecture’s reaction to machine agencies has almost always informed its technical practice and shaped its design methods[6]. While feedback and process control systems (e.g., thermostats) immediately found their way into everyday usage, self-organizing generative grammars are finding ways to design smart geometries and fabrication techniques for realizing once impossible architectures[7].

Today, a subtle, yet vital paradigm shift in computational agency design marks an era of data-driven, information processing system designs, in which pattern recognition, statistical and probabilistic learning methods combined with signal processing techniques provide new perspectives on the design of artificial agencies. As these numerical methods are prevalently used to construct new kinds of adaptive, self-regulating systems with different levels of agencies, they inspire the design of material systems, which can deliver more complex behaviors that can fulfill elaborate tasks.

Smart composites can now include additional electronic components, memories and computational instructions that allow them to reflect on their own behavior, revise them for changing conditions and make them benefit from a long-term relationship with their user and/or environment, which can provide continuous input to shape the current behavior. While the computational intelligence of the system can also lie in an external infrastructure that would monitor and organize a number of units’ behaviors, it is possible to encapsulate the agency within the composite material itself. Depending on how the composite is used within the architectural design, either as a set of tiles applied onto the surface, or as stand-alone units attached to an existing architecture, the material can not only regulate its own behavior, but also communicate with other units for organizing more collaborative tasks.

2.2. Material Learning

The field of machine learning in computer science, in particular, identifies new strategies to design autonomous systems that can 'learn' from their interaction with users and/or the environment to exercise goal-driven behaviors. Computational systems can be trained for different conditions and have the ability to make informed guesses based on the current state of their knowledge, which has been acquired during the history of their interaction. While these technologies already have everyday uses in optimizing today's communication networks or improving the path-planning algorithms of autonomous house-cleaning robots[8], their implications in architectural design, especially in computationally augmented material research, is still very under-explored.

As a new direction in composite material design, it is now possible to discuss a new generation of self-aware, user-aware, companion-materials that can inform both the design and the production process of building technologies and explore new roles for material-based agencies in today's architectural discourse. As such materials mimic, adapt, and demonstrate an ability to learn in different capacities over time, they can not only extend the existing behaviors of places assigned by their initial architectural program, but also allow their users to have a continuous influence in the look, feel, and behavior of the inhabited spaces.

3. Designing New Material Behaviors

One of the main motivations behind the research on learning systems is to design systems that can show the ability to alter behavior in changing conditions. Their mode of operation includes adaptive processes such as feedback loops, self-calibration, and optimization cycles that allow them to exercise autonomy to adjust their behaviors according to the different interaction patterns they have with the environment. Unlike systems that follow a prescribed plan of actions, learning systems demonstrate a 'bottom-up intelligence' that primarily utilizes the interaction with the world as the basis of their action[9]. While these systems are still pre-programmed for executing certain tasks, their behaviors are left 'underspecified' to allow them to revise their actions for changing stimuli and perform behaviors beyond their prescribed roles[10].

3.1. Task-Driven vs. Goal-Driven Materials

One interesting consequence of the learning material research is the possibility to design goal-driven materials. While today's computationally augmented materials are designed for highly specialized low-level tasks, it is not difficult to imagine the design of an underlying material agency that can combine simple behaviors and choose a relevant strategy, an action plan for the given goal, while continuously revising it based on the current affordances.

For example, a unit of composite material may consist of three layers of behaviors in which it can control the amount of light that it will allow to pass through in a given block (e.g., a shutter or diaphragm), filter the incoming air, and store the incoming light from sunshine on photo-voltaic panels. While the material can execute each task in a timely fashion, if it is equipped with a 'goal' that involves the execution of a particular combination of tasks, an internal monitoring system can evaluate the best time to execute the task instead of doing them simply one after the other. It can compute when it becomes meaningful to let more light in and store it or use that energy to filter the air. If there is a sudden need for clean air, it can even borrow extra energy from another unit on a different façade of the building that has benefited from the afternoon sun.

Here, the underlying goal can be maintaining an optimum condition for the unit, such as maximizing its own lifetime while producing its own power to clean the air. However, the unit can also act with its own agency even within a broader system, a material network, which can perform a larger set of goals by coordinating many kinds of specialized materials that have specific capabilities, logistical advantages and expertise within the system. Eventually, material ecosystems can be designed to be in charge of the heating, cleaning, energy generation and heat management processes of the entire architecture while they are supervised by large scale information and energy networks that form the urban infrastructure.

3.2. Materials with Computational Experience

Wiener suggests that, "a learning machine must be programmed by experience."[11] To be able to avoid a "literal-minded" system, he argues that one needs to program the capability to the system to evaluate its success and failures and even learn from its opponents' performances to revise its set of goals.

It would be an important advantage for a material composite to benefit from a long-term relationship with its users and/or the environment. Similar to the way a traditional material reflects change over time (e.g., wearing out of metal or wood) by physical appearance, composite materials can make use of the history of tasks they execute over time, the information they gather from the environment and apply them over a number of different adaptation strategies that will customize their behavior for a given location. Here, 'material experience' would not only lie in a material's capacity to alter behavior for external conditions, but also based on its internal conditions. As the material starts to age, and is not able to deliver some of its tasks in full-potential, it can slowly re-prioritize the goals before waiting to be replaced by new. For example, when the active components with mechanical actuation are eventually worn out, the material can shifts its focus and begin to use its resources towards utilizing passive parts, such as energy collection, preservation and storage.

4. Design Cases

My current research on 'material agency' involves explorations in the electro-mechanical and optical properties of materials (e.g., fiber optics, LEDs, various sensors and actuators, etc.) and looking at ways to design architectural media that can exercise learning behavior to adjust responses, functionalities, or services for different needs. Here, the work has applications ranging from the design of public interfaces, alternative display technologies to programmable surfaces to writing new behaviors for these systems that enable them to respond to different interaction modalities (e.g., vision, audio, touch, etc.) with users and the environment.

4.1. Self-aware Surface

As a first attempt towards a possible design of material agency, I have built a three-dimensional, foldable, programmable surface, which explores the potential of self-aware structures that can not only physically adapt to surrounding architecture, but also to changing environmental conditions and user needs.

This is a system made of modular composite units, which include two layers of LED arrays for visual output, a mechanical infrastructure for binding units with hinges and sensors, and an electronics layer that controls the sensing, power, data management for the visual output (Figure 1 and 2).

As a public interface integrated into the physical space, the project explores the communicative aspects of architectural elements and their role in an urban semiotic system as discussed by Venturi and others[12]. Unlike traditional static billboards, or Time Sq. style public (broadcast) media façades, the interface intends to create a different kind of relationship with the architectural space by showing a greater adaptability in its form and content, by utilizing the input it receives from the users and environment.

It offers a modular, reconfigurable surface, which explores alternative physical configurations for its users to create new spaces around it. Being able to compute its current geometry with the help of sensors, the interface can switch to different modes (e.g., from public to private, for single user to multi user) and engage with users by self-adjusting the presentation of its content (Figure 3 and 4). Here, users can control the type of information, its flow, direction and rhythm by physically interacting with the programmable surface, such as folding and bending it into different geometries.

As an urban artifact, the display blurs the distinction between a display and an interface, allowing it to exercise an intelligence not only for regulating its own actions (for being an input and output device at the same time), but also for responding to changing environmental lighting conditions for optimizing its current output. Being equipped with light sensors, each composite unit can measure the amount of ambient light reflected on its surface to calibrate its brightness to optimize the contrast level and to save energy by dimming itself when it detects that there is no one around for a certain period of time.

4.2. Interactive Social Catalyst

As a second iteration, I explored the potential of a learning system, during the design of an interactive urban sculpture that exhibits autonomous behaviors with a ‘presumed’ agency. This object is designed as a three-dimensional free-form object covered with fiber-optic cables that allow it to display visual output on the entire surface[13]. Equipped with touch sensors, proximity sensors, speakers and cameras, it can respond to the environment and engages with its audience by playing a number of games with them. Modeled like a character, the object responds to the passer-by. It figures out if someone is close enough to invite for a game. It tries to compute the height of the person from the average height they are touching on the surface and if it can detect that it is engaging with a child, it chooses to play a game accordingly or, if it cannot, it plays a general one.

Here, I specifically look at the means and kinds of behavior the system can learn from its interactions with the environment and form a sense of memory based on the history of these interactions. While the object in this instance is a continuous form and not made of tiles or composite units, I explored a self-organizing agency by segmenting the surface into a grid of sections which are responsible for sensing a particular section of the surface for input and activating the fiber-optic cables distributed in that section for visual output.

I have experimented with how different sections of the object can coordinate with each other and work towards a given goal, such as directing users to a particular area, informing them towards a particular activity, etc. As different sections coordinate with each other to work on common goals, I have studied ways to utilize the sensory input for designing high-level behaviors (e.g., hide and seek game) and use the fiber-surface's agency as a social catalyst to activate the urban space around it[14].

5. Conclusion

Being an extension of the ongoing responsive material research, the design of new 'material agencies' promises new ways to make use of the knowledge and expertise learned from the low-level material behaviors that are beginning to find more applications in architectural design. Materials that have the capacity to learn from their interaction with the environment and those which can demonstrate a 'computational experience' by utilizing this learning over a period of time are suggesting new ways to design high-level behaviors that are increasingly demanded from architectural design.

Especially by tying back low-level responses to the design of energy-saving, environmentally-friendly, sustainable architectural practices, it is possible to identify new relationships between material behaviors, information, inhabitants, and the lived space: as augmented materials are programmed to work on achieving high-level goals (e.g., energy harvesting, pollution monitoring, etc.) they will not only be able to support individual users, but also take responsibilities in improving urban-scale problems (e.g., reducing $C0_2$ emissions) as they coordinate with each other and other information and material networks.

While we are still in the process of designing new material behaviors and questioning their relevance in today's and tomorrow's architectural practices, given the emerging social, cultural, and ecological conditions, I believe that a confluence of computational theories and material practices will not only extend the discussions on an emerging discourse on material intelligence but also inform the design of new spaces and improve the ways we experience them.

Images are embedded only for referencing purposes.
Please use the high-res images attached to the submission
The endnotes follow the image reference page

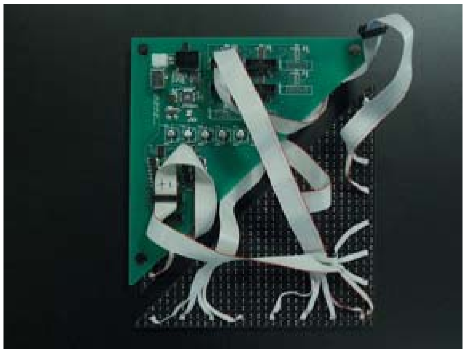

Figure 1. Composite unit detail.

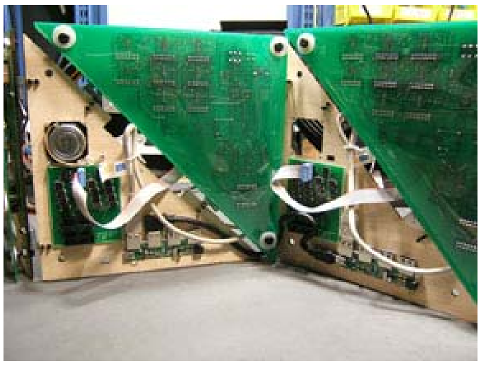

Figure 2. Composites connected with hinges.

Figure 3. Self-aware display in private mode.

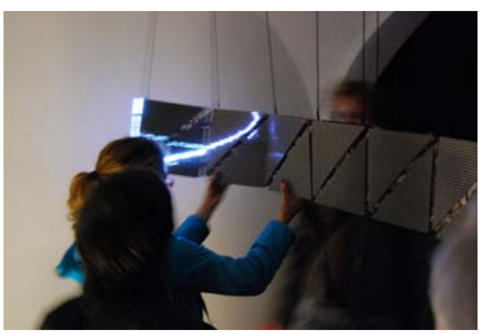

Figure 4. Self-aware display in public mode.

Endnotes

[1] Omar Khan, "Open Columns: Responsive elastomer constructions for patterning the space of inhabitation" (paper presented at the workshop on Transitive Materials: Towards an Integrated Approach to Material Technology, 9th International Conference on Ubiquitous Computing, Innsbruck, Austria, 16-19 September 2007).
[2] Geoff Manaugh, "Jellyfish House," (12 April 2007), http://www.worldchanging.com/archives/006457.html.
[3] In "Grow", Samuel Cabot Cochran, employs "thin film photovoltaics with piezoelectric generators and screen printed conductive ink encapsulated in ETFE fluoropolymer lamination to harvest energy from wind," http://s-m-i-t.com/#grow_target.
[4] Marcelo Coelho, "Programming the Material World: A Proposition for the Application and Design of Transitive Materials" (paper presented at the workshop on Transitive Materials: Towards an Integrated Approach to Material Technology, 9th International Conference on Ubiquitous Computing, Innsbruck, Austria, 16-19 September 2007).
[5] Cochran, "Grow."
[6] Gordon Pask, "Aspect of Machine Intelligence," in *Soft Architecture Machines*, Negroponte, N., (Cambridge: MIT Press, 1976), 6-31.
[7] John Frazer, "New Tools," *An Evolutionary Architecture*, Architectural Association, (1995), 23-64.
[8] Robotics Primer Workbook section on learning. http://roboticsprimer.sourceforge.net/workbook/Learning
[9] Rodney A. Brooks, "Intelligence Without Representation," (preprints of the Workshop in Foundations of Artificial Intelligence, Endicott House, Dedham, MA, June 1987).
[10] Omar Khan, "Underspecified Architecture Performatives" (paper presented at 19th European Meeting on Cybernetics and Systems Research, Vienna, Austria, March 25-28, 2008).
[11] Norbert Wiener. "Cybernetics: or Control and Communication in the Animal and the Machine," 2nd ed., (Cambridge: MIT Press, 1965), 169-180.
[12] Robert Venturi and Denise Scott Brown. "Architecture as Signs and Systems," (Cambridge: Harvard University Press, 2004).
[13] Ongoing research project at MIT Mobile Experience Lab. Design Team: Federico Casalegno, Orkan Telhan, Sergio Araya, Hector Oilet, Guz Gutmann.
[14] William H. Whyte, "City: Rediscovering the Center," (New York: Doubleday, 1988).