PERFORMATIVE MATERIALS IN ARCHITECTURE AND DESIGN

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Contents

Foreword

> *[T]he cosmological point of reference for architecture has shifted from the human to the non-human: from the Vitruvian man, inscribed in a circle and a square as the guarantor of universal validity, to the tangled web of creatures and environments within which humanity lives a promiscuous life.*
>
> Detlef Mertins, 2010[1]

Immanent, dynamic, and *open*: the qualities offered by the voices in this volume are marked by a striking optimism about the expanded powers of performance-based architecture. It could be argued that the 'responsive' functions and design tools of new architecture are fraught with critical problems. New generative and parametric design practices increasingly offer potent methods for manipulating the environment, reminding us of paroxysmic debates over eugenics and behavior programming in past decades. However, if the taboo of acknowledging the myriad mechanical natures of humanity seems to be relaxing, perhaps it is because these increased powers of manipulation also carry increased sensitivity in measuring the impacts of what we do and what we make. The voices in this book speak with confidence. Rather than a commanding center, the sensitive qualities spoken here imply a liminal, involved position within the natural world.

When the ancient Roman philosopher and poet Lucretius watched motes of dust quivering and darting within the sunbeams of his window, he saw atoms at play. Rolling and wavering, the dust spoke of decay and loss, and a vague, shaded shift of life arising—the semiquaver of living seeds. Lucretius followed earlier Greek thinkers in seeing life arising from the chaos-borne quickening of air, water, and stone. Oscillation is implicit in this way of seeing the world, an oscillation that constantly opens boundaries between the part and the whole.

Lucretius implied a kind of *contingent* life energy in his meditation: his motes of dust boil out into higher order forms that register in perception only for an instant before unfurling back out into dissolved surrounding space. Is it possible to inhabit this material state of flux between the figure and the ground? This ancient idea resonates with strands of generative 'bottom-up' thinking that has gained momentum in the early part of our new century. Can this kind of vital milieu be constructed, making a kind of fertile soil for new architecture?

It is tempting to draw parallels with a twentieth-century generation. When Buckminster Fuller proposed his 'operating panel for Spaceship Earth' beside the United Nations, he envisioned networked global markets and enlightened individual human agency as a social and political fundament, while B. F. Skinner's brand of behaviorist psychology[2] attempted to engineer a complete society of happy, productive subjects. Perhaps most poignantly, Teilhard de Chardin[3] projected a 'prodigious affinity' that would take on a global scale. Within the wide range of these sources a collective manifesto was implied, aspiring to the creation of high-performance architectures that emulated complex systems and positioned humankind as the ultimate arbiter of the built and natural environments.

If this preceding generation offers a fundamental conception of the world as a transcending, integrated whole, the voices now gathered seem to lead away from such unified visions. Phil Ayres, Martin Tamke and Mette Ramsgard Thomsen pose practical, concrete questions—"what are the protocols by which these designs can be understood, and into what scales of architectural production can they be turned?" Rashida Ng offers a key by evoking a shared ethical foundation for these projects. In her compelling introduction, she comments that the "evolution of these technologies … foreshadows more deliberate and reciprocal relationships between materials and their proximate contexts … [M]aterials do not simply exist within dynamic environments, but more accurately act as integral contributors to living ecological systems."

The component meshworks of some of these new conceptions seem deliberately weak and fragile, designed to share and shed their forces. Like the fine-grained intermeshed structures of a woven textile, systems gain resilience and strength by densely combining a diversity of elements. Temperature, human occupation, and environmental cycles all work directly on these sensitive components; the materials soak up that influence, distorting and transforming.

Kinds of performance described by these authors seem to move progressively closer to definitions of life. First we may see a receiving function, akin to the way a gauze veil might float around the person wearing it. In the same way that the draping function of a textile can be described as having a particular "hand," structural meshworks may float and move in response to their surroundings, flexing in reaction to physical contact with viewers and local movements of air. Next might be an active, mechanical response where components operate in kinetic patterns, suggesting a combination of electrically driven mechanisms and artificial intelligence. Martina Decker suggests that "smart materials might enable us to create a whole new generation of responsive architectures that were not possible before, an architecture akin to homeostasis in living organisms, wherein a complex system of control mechanisms reacts to local changes in the environment."

Indeed, chemically active building materials are now being conceived, supported by a new generation of material science that permits designers to access molecular structures. Surfaces addressed by electrical charges permit kinetic functions independent from the historical structures of gears and motors; fluid circulation systems operate by depositing delicate layers of material, building up felted skins that seemingly prefer reticulation and turn away from the minimum surface exposures of reductive crystal forms. These "performative" materials maximize interchange with the atmosphere and with their occupants.

They are not, after all, environments that readily increase human power and domain. Instead, one becomes aware of subtle impacts: air, moving around the body, perhaps charges in surrounding magnetic fields that one disturbs as they pass. Perhaps by offering material turbulence as a primary design quality, these works move away from seeking permanence and durability, instead celebrating their ephemerality. These strategies, seemingly rooted in an exquisitely deliberate weakness, increase the potency of this emerging architecture.

Philip Beesley

Notes

1 Mertins, Detlef, Preface to *Hylozoic Ground: Liminal Responsive Architectures*, Cambridge, Riverside Architectural Press, 2010.

2 Skinner, B.F., *Reflections on Behaviorism and Society,* Englewood Cliffs, New Jersey, Prentice-Hall, 1978.

3 deChardin, Teilhard. *Hymn of the Universe*, London, Harper and Row, 1965.

Preface

Performative Materials in Architecture and Design emerged from an event hosted by the Architecture Department of the Tyler School of Art at Temple University in October 2010. This symposium and exhibition, titled INPUT_OUTPUT: Adaptive Materials and Mediated Environments, addressed the convergence of several significant and fundamental advancements in the ways that materials and environments are designed, evaluated, and experienced within architecture and related disciplines. The confluence of innovations in areas of materials science, advanced fabrication, computational techniques, and interactive media was revealed through presentations of nascent research and speculative designs. Collectively, the work considered the interconnected network of inputs that have initiated experimental research in an effort to stimulate the development of materials, assemblies, and systems with adaptive environmental behaviors. The breadth of the work presented provided an expanded lens on how seemingly discrete categories with variable trajectories can create a generative dialogue. This dialogue continued over the next year and a half with some of the initial participants as well as new collaborators providing fresh insight on the context of *performative* materiality.

As an extension of the INPUT_OUTPUT events, this book presents a multiplicity of perspectives from researchers and professionals whose work is conducted beyond the traditional paradigm of architectural practice. Emphasizing the value of research as a mode of design inquiry, the work is experimental and provocative of future innovations not yet applied. Within the book, you will find diverging viewpoints on the relative significance of various design generators to move forward the notion of performative materials. As such, the book should be understood as purposefully heterogeneous, in rejection of a limiting and singular truth.

We are grateful for the level of rigor presented in the work, balancing critical inquiry with acts of making. Similarly, the energy, enthusiasm, and receptiveness of the participants allowed for a stimulating and productive environment in which to consider the themes of the book. We hope that this project will provoke ongoing discussion, engender directed curiosity, and motivate investigative questioning toward the radical reconsideration of architecture's relation to matter and its surrounding atmospheres. *Performative Materials in Architecture and Design* suggests a future in which the reductive dichotomies that commonly define the discipline—such as inside and outside, natural and constructed, technical and poetic, even digital and analog—can be matured, redefined, and less distanced.

Rashida Ng and Sneha Patel, Co-Editors

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We are grateful for the participation and insight of Jason Austin, Phillip Crosby, Ryan Drummond, Jack Fanning, Jeff Goldstein, Joyce Hwang, Thorsten Klooster, Manuel Kretzer, Alicia Imperiale, Eric Oskey, Tim Peters, Vojislav Ristic, Scott Shall, Melissa Shilling, Asbjørn Søndergaard, Robert Trempe, and Jeremy Voorhees. We also would like to recognize the contributions of the following students: Mohammed Alhussaini, Justin Bernard, Claudia Casey, Ashley Drevnak, Crystal Pickard, Tim Nawrocki, Marc Krawitz, Shawn Ryan, Sarah Rushing, and Tim Sheehan.

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Introduction

Hylozoic Ground *(Copyright Philip Beesley Architect Incorporated; Photo: Pierre Charron)*

Experimental Performances: Materials as Actors

Rashida Ng

Performative Materials in Architecture and Design envisions the potential for an expanding role of material inquiry to emerge as a result of the confluence of advancements in both the physical and digital realms. Furthermore, it surveys how the interrelationships between these technological advancements are poised to instigate increased innovation and material invention within the built environment. As architecture and related fields persist in experimental research in areas of materials science, digital fabrication, prototyping, and information technologies, we are simultaneously in the midst of rigorous evaluation of all of our technologies in response to the global directive for more ecologically sustainable paradigms. However, the collective sphere of influence of these developing technologies embodies opportunities for innovation that extend beyond isolated energy efficiencies and reduced material wastes. We propose that the evolution of these nascent technologies foreshadows more deliberate and reciprocal relationships between materials and their proximate contexts. As contemporary discourse surrounding the built realm increasingly acknowledges that materials do not simply exist within dynamic environments, but more accurately act as integral contributors to living ecological systems, the role of such materials can aptly be described as *performative*.

Toward Performative Materials

Coined in 1955 by the British philosopher of language J. L. Austin, the term *performance* is derived from the Anglo-French word *performir*, which means to fulfill or to carry into full effect (Harper 2012). "To perform" is to do, to carry out, or to accomplish, thereby completing a required action or task at hand. When applied to arts and theater contexts, Austin's definition has been slightly adapted to also embrace connotations that extend beyond simple execution of a task to include an original, imaginative, and inspired presentation. As architecture operates within realms of certainty and speculation, the theatrical permutation of the word *perform*, which simultaneously acknowledges its technical and experiential etymological origins, generates a productive definition for this context.

Within the realm of materiality, *performative* can be defined as the physical, sensory, and perceptual interaction of organized compositions of matter with their immediate and expanded environments. These materials can be thought of as enhanced, yet self-aware, at once fulfilling a prescribed set of goals while also allowing for voluntary adaptation. This concept of performative directly acknowledges the dynamic interface between materials and their environs, as if each is an actor with a discrete role within a dramatic improvisational play, obliged to respond to the cue of the other. The script is reflexive, not pre-determined, emerging from conditions of transitory determinacy, changing when influenced by stimuli. Such anthropomorphic characterizations of materials as performative positions the materials as active participants, contributors, and accomplices within a perpetual routine carried out between matter and energy.

Trajectories of Performance

An enduring consideration within architectural discourse, the notion of *performance* is intrinsically embedded within the profession. At a rudimentary level, issues of performance obligate attention to efficacies. Yet over the past several years, architecture has been increasingly attentive to the framework of performance and its potential contributions to contemporary issues within the design of the built environment.[1] Numerous derivatives of the word *perform*—that is, performance, performative, performalism, performalist—have been applied to architectural contexts within several significant publications providing evidence of the mounting interest of researchers, academics, and theorists to this premise. However, today's concept of performative extends the discussion beyond purely technical issues. Within his essay "Architecture as Performative Art," the architect and historian Antoine Picon remarks, "From its Renaissance origins, architecture inherited a concern with effectiveness that other arts did not possess," while also emphasizing that current inquiry into performative criteria within the profession instigates even broader aspirations (Grobman and Neuman 2012: 15). Contemporary research surrounding performance in architecture articulates mediated aspirations that negotiate between quantitative and qualitative measures. This book builds upon the prior work on performance, while focusing on nascent research within converging areas of digital and analog technologies—materials science, robotics, digital fabrication, computations, and interactive media. Our intent is to widen the lens of inquiry and to prompt future research and development of performative materials in architecture and design.

In addition to the technical considerations that will be explored in more detail later, a persistent premise of performative explorations is consideration of the *interactive* capabilities of architecture as stimulated by two principal areas of technological advancement: digital technologies and new materials. Although the architecture community has given more attention to performance from the perspective of digital advancements, both areas of research offer critical viewpoints with fundamental contributions to future design discourse. Furthermore, closer examination of the performance of digital and physical materials begins to blur the boundaries and distinctions between the two, suggesting that these coincident research threads are intimately and inextricably related.

The Digital Revolution has instigated a series of cultural shifts that are comparable to the change produced by the Industrial Revolution.[2] Arguably the most profound innovations suggested by this work have not yet produced widespread implementation within practice, but current experimental investigations in this area suggest a more dynamic paradigm for the production of architecture and space. Picon proposes that the proliferation of digital techniques provokes a corresponding shift toward time-based considerations of architecture as generative of form, in place of the modern functionalist approach. Connecting the rise of digital culture to performance, he writes, "Contemporary performalism is very much about the capacity of architecture to become an event, to participate in a world which is more and more often defined in terms of occurrences rather than as a collection of objects and relations" (Grobman and Neuman 2012: 18). This recognition of architecture as an event suggests an altered dimension of space that can be described in intervals of time, as well as by its physical dimensions. In *Architecture Oriented Otherwise*, David Leatherbarrow (2009: 92) proposes, "Space in architecture is not measured in inches, feet, and yards alone, but also in minutes, days, months, and years." Accordingly, the heightened awareness of temporal aspects of performance also instigates paralleled consideration of the capacity for direct feedback of buildings with their contexts. The proposition of real-time reciprocity suggested by digital performance is comparable to the prospect of responsiveness proposed by smart materials.

Within the realm of physical materiality, the behavior of responsive materials and assemblies challenges the notion of materials as fixed and dimensionally stable as it highlights the acute propensity for interaction of materials with external energy fields, such as temperature, humidity, sound, and light—as well as to human prompts. In opposition to the longstanding paradigm of materials as fixed and dimensionally stable, the emergence of smart materials proposes a destabilizing viewpoint that celebrates materials that interact with the environment in more deliberate and tangible ways. As proposed by Michelle Addington and Daniel Schodek (2005: 1), the most commonly accepted definition of smart materials characterizes them as "highly engineered materials that respond intelligently to their environment." As Addington and Schodek (2005: 4) point out, the introduction of smart materials marks a critical shift of the position of materials in architecture and design, "whereas standard building materials are static in that they are intended to *withstand* building forces, smart materials are dynamic in that they *behave* in response to energy fields." Typically classified as smart materials, shape memory alloys, thermochromic inks, and phase change material exhibit obvious change in direct response to changing external conditions. However, direct acknowledgment of the potential for some materials to exhibit deliberate and purposeful behaviors with their environment embodies broader implications for the use of all materials within design.

The didactic response of smart materials reveals dynamic conditions that may otherwise remain veiled from our conscious awareness. As such, the introduction of smart materials provokes critical consideration of even the most rudimentary materials in recognition that all material systems exist within variable environmental conditions and therefore embody some potential to respond to these active energy fields. Within *Versatility and Vicissitude: Performance in Morpho-Ecological Design*, Michael Hensel and Defne Sunguroğlu postulate, "[T]he definition of smart materials could contribute most significantly to our sensibility and understanding by positing the notion of change of material properties and dimensions fundamentally as a positive project" (Hensel and Menges 2008: 36). Their research into the dynamic behaviors of wood proposes opportunities to manipulate the performative capacity often overlooked within conventional materials. We regard this expanded proposition of performative to elevate the status of materials in architecture, moving beyond materials as artifacts that are selected for their visual and physical properties toward a paradigm of materials as mediators that are celebrated for their vigorous participation with surrounding atmospheres. This conception presupposes conscious awareness that all materials—either intentionally or unintentionally—exist in a state of perpetual change.

A Scientific Prophesy

It is perhaps misleading to suggest that the convergence of material technologies and the digital realm is a recent event as the relationship between the physical nature of matter and the evolution of computing technologies share a mutual history, one that can be traced—at least in part—to scientific innovation. In fact, mounting interest in microscopic material compounds, the prevalence of ontological theories of material behaviors, and the ubiquity of embedded computing technologies were to a certain degree foreseen within a single speech, titled *There's Plenty of Room at the Bottom*, on the transformative potential of nanotechnology by the physicist Richard P. Feynman in December 1959. Put forth as a prompt to the scientific community, this seminal speech provided critical insight into material potentials that to date have not yet been fully realized.

Speaking to a group of his colleagues at a meeting of the American Physical Society, Feynman (1960: 22) asserted, "[T]here is no question that there is enough room on the head of a pin to put all of the Encyclopedia Britannica," as he challenged the scientific world to direct more research into the production, visualization, and use of matter at minimal scales. The esteemed "father of nanotechnology," theorized on the promising potential for the production of minute materials and machines to transform science, medicine, and even more mundane aspects of life. Today, over 50 years later, Feynman's clairvoyant assertions bear striking connections to the innovations associated with present-day materials research. Moreover, his words still read as provocations for future work.

Focusing mostly on the means by which materials could be manufactured and studied at small scales, Feynman's speech also delved into potential connections between nanotechnology with all other areas of material inquiry that are particularly relevant today. Presented as a further goading to his peers, he emphasized the importance of nanotechnology by relating research on the cellular behavior of biological systems to computing technologies. Feynman (1960: 25) cogently described the behavior of molecular matter within biological networks as follows:

"[T]he cells are very tiny, but they are very active; they manufacture various substances; they walk around; they wiggle; and they do all kinds of marvelous things—all on a very small scale." This discussion of the properties of microscopic matter nearly forecasted the proliferation of smart materials as he aptly described the correlation between the diminution of material matter and the subsequent increase of material aptitude or intelligence. In so doing, he intimated that the miniaturization of materials might also embody potential within the digital realm, as the reduction in the size of digital components would make possible the corresponding increase in the complexity of computing systems. Although the correlation between the diminishing scale of material composites, its associated behaviors, and its computing capabilities have just recently received the attention of the architectural explorations, the interrelationships of such digital and analog material interfaces have always existed.

Despite the diminutive size of molecular cells, the physical existence of biological systems does not exist as a static condition, but rather persists in dynamic relation to its circumstance. As illustrated on the cover of this book, the most apparent example of the vigorous conditions of biological storage of information lies in the structure of DNA, a cellular network that essentially serves as a genetic blueprint for the growth of living organisms. The characteristics of today's "smart" materials are indeed analogous to biological systems as the microscopic cells of smart material matter store volumes of information, simultaneously embodying traits, behaviors, and predisposed preferences. Correspondingly, the potential of advancements in nanotechnology for the architecture and design professions resides not only in the ability to make small things, but also more importantly in the potential to embed performative characteristics within the molecular structure of materials. The embedded hierarchy of atomic and cellular molecules reveals the structural logics of mass and void within the space of "solid" materials. Within architecture, the reduction in size of matter as well as computing technologies is leading toward the production of hybridized material composites, with embedded sensors, actuators, and other mechanized parts. In *Materials Matter*, Kenneth Geiser (2001: 252) postulates that such nanotechnologies "present possibilities of materials designed to perform functions and carry out tasks—even to repair and replicate themselves." As one probes deeper into relationships between the molecular structure of matter and its corresponding properties, the distinction between what is a material, a structure, and a machine becomes increasingly obscure.

Beyond Optimization

Returning to the issue of technical performance, I must emphasize the critical importance of *effective* technologies to the future development of the field. In consideration of the ecological challenges posed by our building practices, performative materials must reduce the environmental impact of the built environment while simultaneously providing quantifiable evidence of such. At its core, technical performance seeks to reduce consumptive aspects of architecture and to discern intricate interrelationships between complex variables that affect the collective efficiency of constructed environments. As the advancement of digital computing technologies have enabled greater precision in accessing the effectiveness of building technologies, the ability to simulate, assess, and refine technologies during the design phases offers potentials that obligate continued research and development. However, when considered in isolation, technical research assumes a fundamental risk of delivering oversimplified results that fall short of the more expansive series of performative goals. Leatherbarrow (2009: 44) advises, "Continued dedication to a technical interpretation of performance will only lead to nothing more than an uncritical reaffirmation of old-style functionalist thinking, a kind of thinking that is both reductive and inadequate because it recognizes only what it can predict." Hence, technical goals are best applied within a more comprehensive series of aspirations, rather than as a singular and exclusive ambition.

Accordingly, the goals of performative materiality stop short of absolute optimization. In *Performalism: Form and Performance in Digital Architecture*, Yasha Grobman cautions, "The expanding use of computer codes for optimization and production of architectural forms entails much potential, but also a danger" (Grobman and Neuman 2012: 11). Although the capacity of computing technologies increases, the aptitude of simulation technologies is also rising. However, it would be pointless to even attempt to anticipate all imminent possibilities. While performative technologies accept the inherent limitation of the designer, the goals of optimized systems imply that all present and future conditions have been accounted for within the design. Without relinquishing professional responsibility, the performative paradigm of design advocates a more humble pursuit of cooperative interrelationships between materials and the forces that act upon them, in an attempt to promote rather than to dictate. As exemplified by organic growth processes, the precise configuration of a plant cannot be absolutely controlled or anticipated, as it is dependent upon a multitude of factors that are variable and unpredictable. Rather, the environment in which the plant is placed is designed to be favorable in order to allow the plant to thrive within its setting. Similarly, performative material technologies remain to a certain degree indeterminate.

As opposed to definitive conclusions, the goal of performative materials is symbiotic coexistence that encourages certain material interactions, while discouraging others, always conceding the probability of the unforeseen. In recognition of the mutable and capricious conditions to which materials are subjected, performative materiality accepts a level of unpredictability within design, abandoning the goal of finite control, while simultaneously working toward the synergetic concurrence of built and natural territories.

Realms of Inquiry

This evolving anthropomorphic notion of performative materials and systems persists within a gap between perceived certainty and indeterminate expectation, and interrogates the potential within an enabled architecture to exist reflexively in its environment. The future trajectory of such performative materials suggests alternatives and possibilities that have not yet been fully explored. The chapters, projects, and interviews presented in this book serve to mutually expound on this position. While this book does not undertake to categorically propose all potentials of such an architecture, it does endeavor to incite certain critical trajectories and to participate in the growing discourse surrounding materials within architecture and design. As such, readers should not expect to find a catalog of available products or a series of completed case-study buildings. Rather than presenting applied innovations on the scale of a building, the design work featured within the book foregrounds promising experimental design and research in an attempt to provoke future innovations that might build upon these collective potentials.

The book is organized into four chapters, "Material Ontologies," "Material Elements," "Material Fabrications," and "Material Behaviors," which each include an essay, a series of projects, and one or two interviews with prominent researchers, followed by a concluding essay within the final chapter, "Material Futures." The varied collection of work is intended to present a diversity of perspectives from practitioners, academics, and theorists with unique expertise in emergent areas of research surrounding material culture within architecture. Notwithstanding the organization of the work into discrete categories, readers are encouraged to consider both the expressed and latent capacities for overlap and intersection within the work.

The interviews, conducted by co-editor Sneha Patel, serve to elucidate the underlying motivations that provoke the innovative work of each of these professionals. Descriptive of the design intents and working processes within specific projects and installations, these discussions present diverse approaches and opinions regarding the broader theoretical discourse surrounding performative materials. Collectively, this series of questions and answers comments on the changing role of research, collaboration, representation, and materiality through the interrogation of discrete practices and projects.

Within the chapter "Material Ontologies," Jason Crow probes the historical evolution of our cultural perceptions of materials in order to interrogate the position of matter within the context of digital technologies in his essay "Approaching a Material History of Architecture." Recalling the legendary conversation that Louis Kahn initiated with a brick, this essay envisages the "desire" of digitally conceived matter. As such, it explores the subtle tensions between the ontological status of matter and that of the machine. Following this essay is a selection of projects that explore temporal and phenomenal material potentials. Philip Beesley's *Hylozoic Ground* senses and responds to human occupants through a network of emotive reactions programmed within a geotextile mesh. Manuel Kretzer and Ruairi Glynn's *Material Animation* installation interacts with visitors through variable lighting conditions within a series of interconnected environments. Dustin Tobias' *Breathing Bowels* explores the performative aesthetic of a pneumatic lattice system for heating and ventilation. Also included within this chapter are projects by Sean Lally; Kärt Ojavee and Eszter Ozsvald; Nannette Jackowski and Ricardo de Ostos; Andrew Lewthwaite; and Zbigniew Oksiuta. Finally, Sneha Patel's interview with architect and researcher Steve Pike expands the typical realm of materiality examined within the discipline through his research into microbiological organisms toward the production of partially living installations that highlight perceptual analysis.

Hylozoic Ground uses an interactive geotextile mesh that senses human occupants and responds with caressing and swallowing movement, in peristaltic waves within distributed fields of lightweight pores. (Courtesy ©PBAI; photo: Pierre Charron)

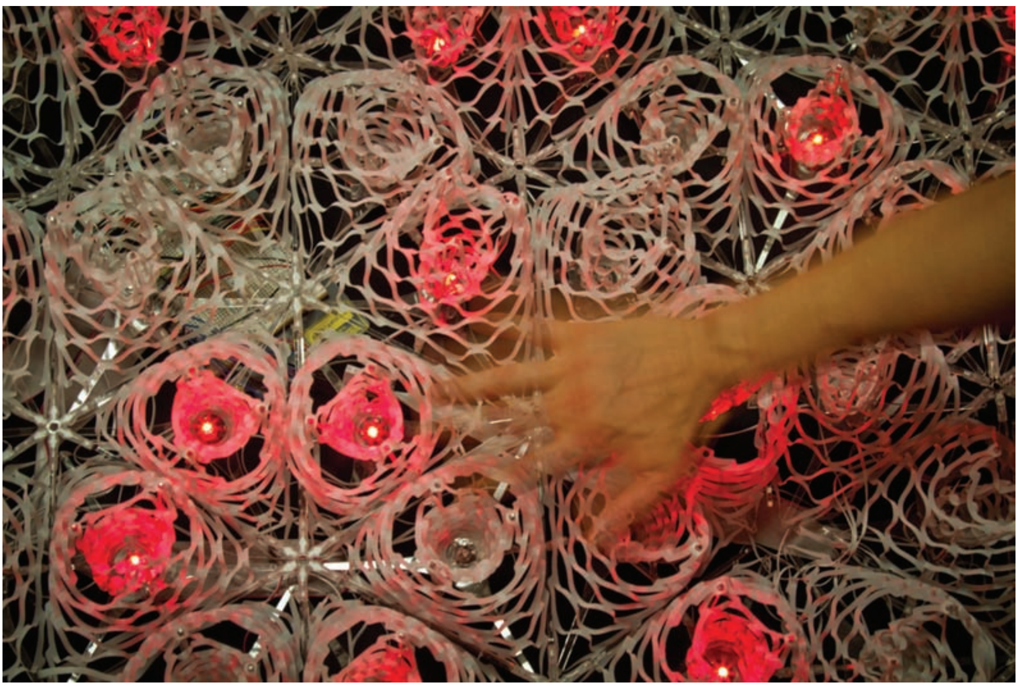
Nonsterile installed at the Architekturgalerie in Munich. The resultant displayed colonizations that reveal specific ambient microbial populations introduced to the gallery, to an extent disclosing the preceding activity and behavior of the visiting public. (Courtesy Steve Pike)

The next chapter, "Material Elements," begins with the essay "New Material Compositions" by Martina Decker, which explores nascent research in the field of nanotechnology. The recent deluge of scientific attention given to matter at this minute scale provokes significant opportunities for the design professions. Moreover, it queries the potential for an expanded role for architects to participate in a broader dialogue surrounding material innovation within the built realm. The projects in this chapter utilize new materials and/or techniques to generate advanced composites. Doris Sung's *Bloom* utilizes a smart thermobimetal to generate a solar indexing device, which is responsive to both time and temperature. Within *Nano-Textiles and Architectural Form*, Klaudia Biala's research investigates the amalgamated potential of nanotechnology and textile manufacturing techniques. Ginger Krieg Dosier's *Biomanufactured Brick* proposes a method of growing architectural materials in a pollution-free environment with a low embodied energy content. This chapter also includes projects by Thorsten Klooster; Manuel Kretzer; Agustin Otegui Saiz; Robert Ley and Joshua G. Stein; and Rashida Ng and Sneha Patel. Liat Margolis and Omar Khan provide their outlooks on the relationships of social and technological aspects of current inquiry into materials. Through a series of questions and responses, Liat Margolis, currently a professor at the University of Toronto, discusses her work with GRITLab, the Green Roof Innovations Testing Laboratory, a research organization that queries the performative aspects of green technologies. Within his interview, Omar Khan describes the broad context of his work with the Center for Architecture and Situated Technologies at the University of Buffalo, a research collective whose work is focused on embedding computational intelligence within the built environment.

A sun-tracking instrument indexing time and temperature, Bloom stitches together material experimentation, structural innovation, and computational form and pattern-making into an environmentally responsive form. (Courtesy Doris Sung)

Reef is a responsive, kinetic installation which investigates the role that emerging material technologies can play in the sensitive reprogramming of architectural and public space. (Courtesy Rob Ley and Joshua Stein; photo: Alan Tansey)

Phil Ayres, Martin Tamke, and Mette Ramsgard Thomsen of the Center for Information Technology and Architecture at the Royal Danish Academy of Fine Arts, School of Architecture, introduce the "Material Fabrications" chapter by interrogating the intricate and complex translation between digital and physical realms. They write of the potential for digital design tools to generate more intimate affiliations between design and fabrication in the essay "Making a Digital-Material Practice." An exploration of the implications of this evolving paradigm, the writing examines the shifting relationships between ideation, representation, and realization of design logics through a discussion of four full-scale prototypes. The subsequent collection of projects addresses the inherent opportunities and limitations evoked by digital means of design and production. *Smocking: Pleated Surfaces*, an exploration by Kentaro Tsubaki, researches the opposition between the imperfection and resistance of physical materials and the implied precision of digital fabrication techniques. Similarly, Phillip Anzalone's *Designed Disorder* researches shot-peening, a metal fabrication process that explores the potential simultaneity of imperfection and accuracy. *The Unikabeton Prototype*, a research project by Per Dombernowsky and Asbjørn Søndergaard, investigates processes of material optimization within common structural elements. In addition, Joseph

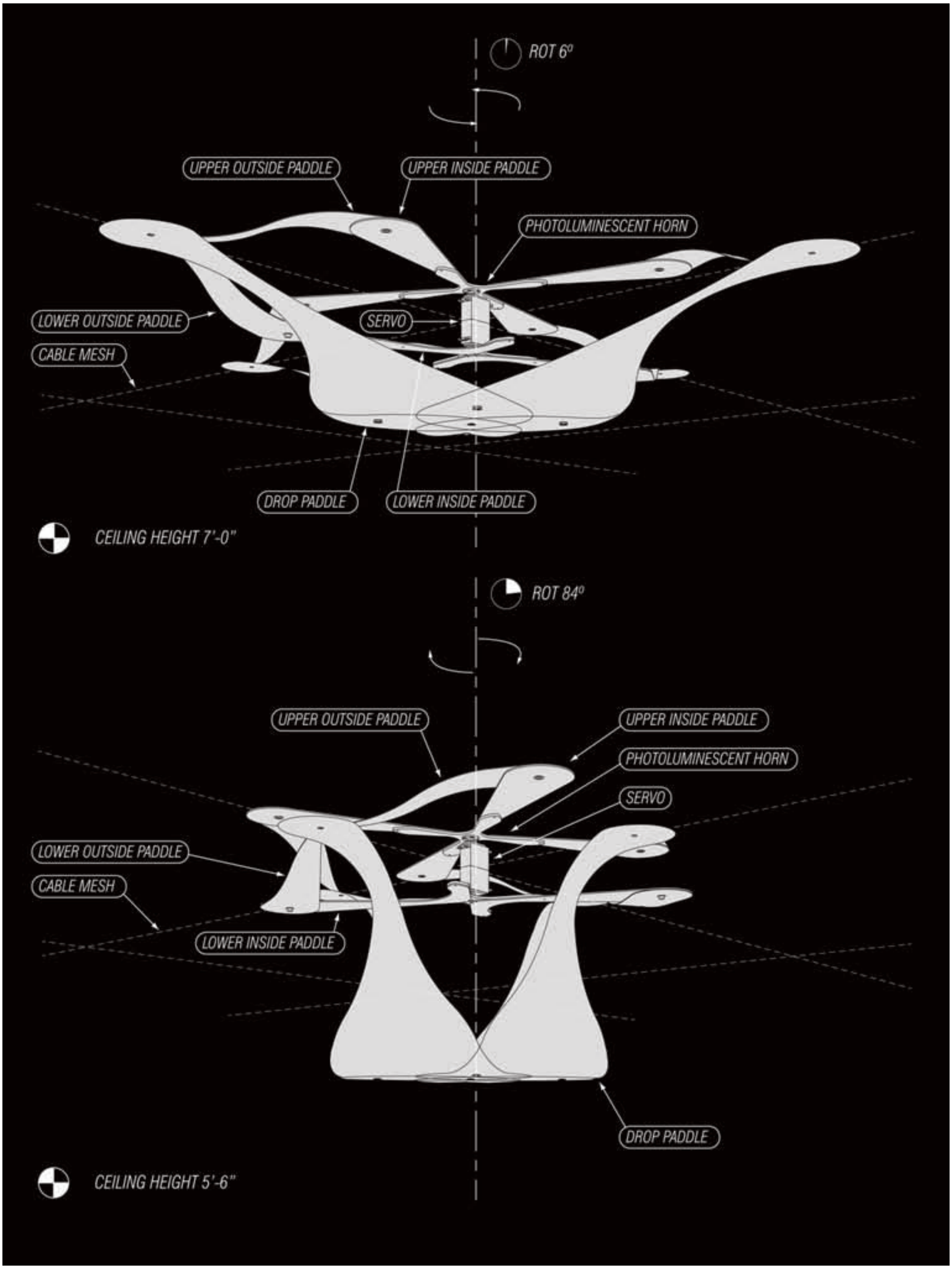


The Oxalis project, a formal exploration of environmentally responsive cladding systems, employs digital fabrication as an iterative investigation tool. (Courtesy Vincent Hui, Mike Lanctot, and Pierre-Alexandre Le Lay; photo: Matthew Gowan, David Marques)

The Unikabeton project set out to explore the architectural and industrial potential in linking topology optimization of concrete structures with large scale CNC-milling of polystyrene formwork. Image illustrates assembling and reinforcing the full scale CNC-milled polystyrene mold. (Courtesy Per Dombernowsky and Asbjørn Søndergaard)

Choma; Ronald Rael and Virgina San Fratello; Vincent Hui; Jeremy Ficca; Joshua G. Stein; and Jacob Riiber contributed projects to this section. The first interview within this chapter highlights the research and practice of Matter Design Studio and Supermanoeuvre, founded by Brandon Clifford, Wes Mcgee, and David Pigram, which queries robotic fabrication and other forms of digital manufacturing. Within the second interview, Patrick Harrop and Peter Hasdell, partners in Pneuma, contribute their insights on immersive systems and interactive environments.

"Live Inputs: Variable Outputs," Nataly Gattegno's essay, interrogates the implications of an architecture that embraces the capricious nature of its localities and the capacity for real-time exchange and feedback afforded by such mutable constructs and introduces the "Material Behaviors" chapter. In exploration of the potential afforded by non-deterministic frameworks over optimized forms, this essay considers the expanding territory of architecture to operate as participatory and dynamic systems that privilege perpetual recalibration within the processes of energy exchange. The projects in this chapter build upon these theories of actuated and participatory environments. Aurélie Mossé's design, *Reef*, transfers the movement of the wind through an electroactive polymer ceiling installation, which investigates smart textiles to encourage interconnectivity between



OpenHouse is a temporary installation consisting of an interactive canopy that utilizes a network of piezoelectric sensors. (Courtesy Francis Bitonti and Brian Osborn)

The Basque Enia project is about constructing architectures in three territories of the Basque country. The architecture is concerned with the unfolding of naturalness, to show this sequencing of nature as seen from the architecture. (Courtesy Shaun Murray)

natural and constructed contexts. *The Stratus Project* by Geoffrey Thün and Kathy Velikov proposes a kinetic architecture informed by the supple forces of our atmospheres, such as light, heat, air, and sound, while promoting a reciprocal dialogue between material and environment. Marilena Skavara's project, *Adaptive Fa[CA]de*, researches the use of neural networks in search of a digital artificial intelligence that is at once evolutionary and adaptive to its context. The work of Francis Bitonti and Brian Osborn; Meejin Yoon and Eric Höweler; Mark Smout and Laura Allen; Karmen Franinovic; and Michael Silver is also presented within this collective. Finally, Shaun Murray's interview challenges traditions of architectural practice through the proposition of a projected and transdisciplinary approach toward the production of design.

Lastly the final chapter, "Material Futures," concludes with Rashida Ng's essay "Speculations on Future Materiality," which considers the shifting territory of material explorations within practice, research, and the academy. Suggesting an expansion of the intellectual and physical space of design, contemporary research in materiality proposes new alliances and close collaboration with disparate disciplines. The evolution of design practice blurs conventional disciplinary boundaries as it embraces transdisciplinary processes of research, prototyping, fabrication, experimentation, testing, and analysis of material systems. The collective influence of multiple areas of design inquiry proposes significant challenges to conventional notions of inquiry, fabrication, and representation within architecture. This essay examines the latent potential of several of these trajectories while also assessing the divergent forces at work to sustain the status quo.

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Notes

1 For example, see Kolarevic and Malkawi 2005, Rahim 2006, Hensel and Menges 2008, and Leatherbarrow 2009.

2 For a discussion of the potential for cultural change as spawned by the Digital Revolution, refer to Rahim 2006.

Chapter 1

Material Ontologies

Algaetecture *(Courtesy Steve Pike)*

on·tol·o·gy

- a branch of metaphysics concerned with the nature and relations of being
- a particular theory about the nature of being or the kind of existents[1]

1 *Merriam Webster's Collegiate Dictionary* (1995) 10th Edition, Springfield: Merriam-Webster.

Approaching a Material History of Architecture

Jason Crow

In spite of our tendency to understand matter as being transhistorical, the materials with which we build as architects today are not the same as they were 20 centuries or even 20 years ago. The concrete of the ancient Roman Pantheon's dome is not the concrete of the Hoover dam. In this essay, I briefly introduce the historical and cultural invention of materiality in order to better understand the influence of matter within the digital project. What is a material? In contemporary architectural discourse, we interpret matter as a fixed set of quantifiable qualities. As material, matter has a strength. It has a resistance. It has a texture. It has a color. We assume that these qualities of the material in question do not change. Qualities are definitively fixed to the material. However, these qualities—the facts of the material—are a result of our own particular interpretation of the ontological status of matter. How might we understand the history of architecture differently if we approach materials as if they have a biography—as if they come into being, live, and eventually die?

Exploring the biographies of materials owes a debt to recent scholarship in the history of science such as that of Lorraine Daston (2000). "Biographies of materials" obviously borrows from her edited collection of essays, *Biographies of Scientific Objects*. However, one must proceed with caution following her example within an architectural context. Paraphrasing the words of Bruno Latour, any object has a series of local, instrumental, and practical networks that surround and determine how it is understood (Latour 2000: 250). In opposition to the progressive nature of scientific inquiry relative to its objects, matter in the hands of the architect always has the capacity to be treated and understood anachronistically. The inherent anachronism of architectural matter develops a tension between the two modes of scientific work on objects that Latour identifies. Discovery is an ahistorical mode of operation in which something has an eternal but unknown existence. In effect, a discovery has always been even prior to its local history. It marks a point in time at which a thing has been found despite the fact that it "had always been there." Invention is a mode of work embedded within the linear progression of a history (Latour 2000: 251–252). It forms a part of a logical progression from one thing to another. An invention will always be superseded by something new. The tension between these two modes is erased within the epistemology of scientific equipment. The biography of scientific equipment uncovers its over-determined state of being. It is an ontological state that allows the objectifying scientist to discover "with" equipment. For the scientist, facts cannot be invented. His or her facts exist outside our temporality. The ontological status of equipment thus prevents a confrontation with historical context.

The intent of suggesting biographies for materials in architecture is to reveal how these networks similarly fix our interpretation not only of equipment but also fix our interpretation of the material we put to use. Matter is mistakenly believed to not change over time. Understanding why and how materials change requires that the stories of matter be recognized and told to reveal their inherent tensions. The biographical approach to materials uncovers the most critical aspect of any given material. Matter is phenomenal. It can slap you in the face. Matter does not play by our rules. While there has been some progress made toward the type of biography mentioned above in the history of science, none of the research has taken into account the uniquely anachronistic relation of an artisan to material. Phenomena of matter receive less attention. Even within the context of Heisenberg's Uncertainty Principle, the scientist desires to elide any ontological instability of his or her devices. It is not good for scientific equipment to resist the work to be done. This attitude is simply not true of the artisan and requires a different epistemological method. Biographies of matter offer a possible approach. How to write such material histories remains, largely, an unexplored question.

Within the context of what is admittedly a prolegomena to approaching material histories in architecture, the goal of the current study is simply to introduce a mode of inquiry. The inquiry is a historical address of the ontology of matter and of the ontology of equipment as its supplement. The desire is to be able to construct a ground upon which notions about the so-called digital matters can be tested. In particular, a major shift occurs with regard to the theorization of materiality in digital projects like Gramazio and Kohler's *Programmed Columns* of 2009 and 2010 (Gramazio and Kohler 2009; 2010). In the spirit of the Speculative Realists, I would argue that the matter of these brick columns, in and of itself, withdraws (Harman 2005: 89–100). Despite the obvious phenomenal presence, the brick in these columns is not allowed to be. In the place of the matter with which the artisan engages, equipment has been substituted.[1] Failing to address the shift from an ontological precedence of matter to the equipment that forms matter falls prey to Graham Harman's criticism[2] of Heidegger's own confrontation with technology (Harman 2010: 5–13). Even Heidegger tends to gloss over the more curious status of equipment.[3] Equipment is not, as in Heidegger's understanding of the tool, an extension of the body. Equipment is ontologically autonomous.

The concern of the gloss introduced here is metaphysical. I will take as an exemplar the ontological status of brick. A special mode of being is implied in Louis Kahn's infamous conversation with brick. When Kahn asks Brick, "What do you want?" he recognizes a desire within the brick. The recognition is an important concession to the brick. The brick is allowed to live and to be by mysteriously being filled with its own self-forming power.[4] Kahn's seemingly mystical approach to the brick appears anachronistic. His understanding of animate matter is deeply embedded in a historical epistemology. Perhaps despite Kahn's own desires, the matter of the brick is literally alive and desires perfection for itself much like more quotidian animate beings. Kahn's anachronism reveals the supplement to the ontological status of material, where matter withdraws and is replaced by equipment.[5] The material aporia covered over by equipment is implicit but not obvious in the work of Gramazio and Kohler. Digital materiality cannot be known without a foundation whether a ground exists or not. The history of brick, which Kahn evokes, provides insight into the grounding necessary to understand digital materiality. In this essay, that history is presented below in an abbreviated form.

Matter: An Abbreviated History of Brick

In order to understand Kahn's material anachronism and Gramazio and Kolher's attempted material elision, the history of the changes to the conceptualization of brick must be traced. Between the thirteenth century and the eighteenth centuries, the story of matter in the Latin West changes focus. The history shifts from a mysterious power that realizes a brick as the vivified creation of God. It moves toward a matter informed with the power of nature by an artisan, and it concludes with dead matter divorced by equating material with the light that animated it. The survey presents the *virtus mineralibus*—literally, the power of stone—of the thirteenth century, the limits of matter-as-form defined in the fifteenth century, the capacity to harness the power of nature to inform matter in the sixteenth century, and the death of matter in the eighteenth century. From the grounding of that historical introduction, the difference between Kahn's brick and Gramazio and Kohler's digital brick can be revealed.

In the thirteenth and fourteenth centuries, a brick was a stone crafted by an alchemist and evocatively filled by a mysterious power from God. In the middle of the thirteenth century, Albert the Great had systematized the epistemology of stone. His systemization integrated stony matters with his understanding of the Aristotelian categories of life. In this work, a treatise called the *de mineralibus—about stones*, he crafted an interpretation of stone that would appear almost nonsensical to our contemporary epistemology of matter. For Albert, not only was stone a living thing, it also contained a mysterious power he named *virtus mineralibus*—hereafter, *power-of-stone*. In the first book of his treatise on stone, Albert explained that the *power-of-stone* was similar to the power of light contained within stones and making them animate. He associated this vivifying power with Aristotle's notion of substantial form, which animates form with life (Albertus Magnus 1967: 24–26). Substantial form for Aristotle is described in his treatise on the soul, *de anima* (Aristotle 2000: Bk II, Ch I). As in the form-matter pair that constitutes all things in the world, substantial form was a power that quickened inanimate form to create the soul. The soul following itself as a model gave life to the body. The doubled pairing of substance-substantial form and form-matter was something that Albert could only imagine as the realm of God's activity. Stone was thus a matter crafted and vivified solely by the hands of the deity. The fabrication of stone existed outside of any potential earthly act.

Albert's student, Thomas Aquinas, would follow with a similar argument questioning the possibility of a human-made gold. In the second half of the thirteenth century, Aquinas

(1997) could imagine a limited human agency in craft. The famous scholastic argued that an alchemist could produce a stone that had the same measurable qualities as real gold. However, Aquinas concluded that the alchemist could not truly transmute metals. He argued that without the addition of the *power-of-stone* by God no human-made material could truly be gold. Aquinas was arguing against the alchemical beliefs of men like Pseudo-Geber, Themeo Judeaus, and the later Petrus Bonus. All would argue for true alchemical creation. Intriguingly, alchemists like Themeo and Petrus believed the creation of brick to be a human fabrication equivalent to God's own creation of stone (Newman 2004: 268–269). A brick did not simply substitute for stone. Nor was a brick an artificial stone. It was, in the alchemical interpretation, a real and true stone made by humans and filled with the power of God at the alchemist's evocation.

By the late fifteenth century, the dominance of Aristotelian explanations of the matter of things in the world was beginning to recede. Form and power took precedence over matter. There was a change in focus from the capacity of the artisan or alchemist to manipulate matters. Interest was beginning to grow in form as a kind of perfect matter, which revealed something similar to the power of God in the power of nature. The drawings of the Platonic and Archimedean solids by Leonardo Da Vinci for Fra Luca Pacioli's (1980) *de divina proportione* are not the pure mathematical abstractions that we would assume when discussing Platonic forms. Albert the Great had proposed a hierarchy of matter in his book on stones where closeness to perfection was made evident in the transparency and regularity of a stone. In the context of Pacioli's transparent bodies, Da Vinci was drawing the matter of the solids approaching form as perfect transparency and shape. With minimal matter left in the thickened lines of the polygonal volumes, the light that could be contained by the form was revealed. Recalling that Albert had associated this light with the vivifying power of God, Pacioli revealed access to the power of God in nature as the light at the limits of the material world.

Contemporary to Pacioli and Da Vinci's solids, an interest was growing in magical mineralizing springs that transformed leaves, twigs, and other matters into stone. These springs contained a natural power equivalent to Albert's *power-of-stone* that could be demonstrably used to transform inert matter into something else by the artisan or alchemist. The fifteenth century brick no longer was made through the alchemist as the instrument of God. The brick was now a certain human perfection of clay shaped by human hand and filled with a godly power discovered in nature. The brick of the fifteenth century was put to use through human intervention.[6]

The capacity to harness the power of nature to create not only brick but also living things that were the equivalent of nature was at the heart of the craft of sixteenth-century alchemists like Bernard Palissy. He developed a sophisticated alchemical theory in which the power of congealative waters could be put to use to create his own animate matters (Palissy 1975: 95–98). Palissy cast living creatures in clay thus capturing their life force and transferring it to his ceramic vessels and grottos filled with fabricated snakes, lizards, snails, and even living stones. This alchemical craft centered on the idea of the mineralizing capacity of waters. These waters in grottos or in rock-forming springs contained a power that was similar to Albert's *power-of-stone*. Palissy's vitrifying power, unlike Albert's, was in the domain of the human and no longer a product of God's intervention. His ceramic creations—including his living stones—were a human-crafted and empowered brick in all ways equivalent to a natural or God-made stone.[7]

The animating power that gave stones and even brick special ontological status would not last. In the late-seventeenth century Hennig Brand would discover, as the philosopher's stone, the element we know as phosphorus. For Brand, the glowing matter that he could extract from nature had the capacity to heal, to transmute metals, and to perform other miraculous feats. It was a kind of pure material light at the disposal of the human being to effect change. For Brand, that power had become a rare thing. To create his phosphorus he collected urine from his assistants over a period of weeks. He then boiled it down to a mass of a black substance, which he subsequently heated to exorbitant temperatures to burn away all impurities. The result, after having started with barrels and barrels of waste material, would be a small lump of glowing matter (Emsley 2000: 19–20). The power in nature that made matter animate was now so minimal that it took a great expenditure to extract a miniscule portion. Though human agency had access to the power that animated the world, it was no longer present in enough quantity to suggest much could be done with it. If the brick was still alive for Brand, it was drawing its last breath.

In 1789, Antoine Lavoisier published his treatise on chemistry and effectively killed matter. The brick was dead. His *Traité élémentaire de Chimie, présenté dans un ordre nouveau et d'apres les découvertes modernes—Elements of Chemistry, in a new systematic order, containing all the modern discoveries* for the English translation of 1790—was part of his successful work to bring chemistry full recognition as a science. Lavoisier's treatise allowed chemistry to finally gain the same disciplinary status of physics and medicine. To accomplish his goals for chemistry, he had to remove any remaining residue of chemistry's alchemical past. He did this by restricting the science to the study of quantity. His reductive activity included an early version the modern periodic table of the elements. Lavoisier placed phosphorus in this table as an element (Lavoisier 1965: 175). More importantly in the history of our story of animated brick, the scientist also inserted light as an element. This categorization of light removed its critical role as the animating power of matter. Reduced to a measurable quantity alongside phosphorous, light became just another inert material. With no special substance to vivify things, the Aristotelian belief in animate matters was gone forever. At this point in the history of material, the matter had been elided by the measures that would come to define and limit it. As did so many other materials in the science of the late-eighteenth century, the brick became representative of a fixed set of qualities like strength, color, and texture. With Lavoisier, the brick finally became something recognizable as a *modern* material.

From the Ontology of Matter to the Ontology of Equipment

Returning to Kahn's infamous conversation, what does the animated brick, the one that points to the history of matter prior to Lavoisier, offer to the contemporary understanding of the brick in Gramazio and Kohler's digital materiality (Gramazio and Kohler 2008)? The introduction to their recent book on digital materiality implies a kind of Aristotelianism for the digital in which the informing of matter by data completes a matter-form pair. However, no life or desire is given over to the stacked bricks of their construction. In fact, in a strange turn, the animate principle of Aristotle's treatise on the soul lands elsewhere onto a personified robot. In Gramazio and Kohler's work, an industrial robot is programmed to assemble bricks in intricate patterns. It picks up individual bricks. It raises them to a gluing station where a measured amount of adhesive is ceremoniously squirted onto the brick. Finally, the brick is placed in a location determined by an algorithm, and the whole process is repeated. In essence, it is the robot and not the artisan doing the fabricating. Variously named Kuka, Rob, and simply "him" in lectures, essays, and interviews; it is Gramazio and Kohler's robot and not the brick that is given some sort of proper being. To understand what a digital materiality is, this shift identified earlier as the supplement of the ontology of matter by the ontology of equipment must be confronted. Digital material is not the matter at hand or the material mounted on a piece of equipment. The digital matter is the equipment itself, and the equipment has quite literally been given its life at the expense of the material it now shapes and forms. Mostly, these now-living things that carve, mold, spray, deposit, grab, pick and place do little more than provide for efficiency and novelty. To understand what emerges from this new means of producing work, the transfer of life from matter to the equipment that shapes material must be contextualized and explained. Kahn looked backwards to understand what his brick might become. Kahn and brick thus worked in concert as a collision of two desires. The result was a fabricated and material metaphor where brick and Kahn lost their identities to the new identity of arch.[8] In the work of Gramazio and Kohler, a privileged ontological status is given to the robot—to the equipment no longer in hand. Engaging in digital fabrication, the robot does not fade away as it stacks. No metaphor is created. Human remains human, and robot remains robot. The brick becomes simply plastic. Brick is only addressed as plastic—something to be shaped—not in and of itself as a potential subject. Plasticity is a buzzword in recent discourses on digital materiality. However, understanding material as plastic divorces the material from the matter. Matter being plastic is material as a free-floating signifier. A plastic brick, in this context, is an aporia.[9] Rather providing an ontological foundation for equipment, the plastic brick founds over an abyss in which material does not matter. Equipment in this state of being has no ground. If I were to ask brick for his thoughts on the tasks ahead, he might simply say, "I don't like glue."

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Notes

1 One might be tempted to question, following Jennifer Bloomer, whether or not the current fascination with varied digital fabrication tools and techniques is simply a nostalgia for a role of the architect as artisan that has never existed. Particularly following the Enlightenment, the architect was divorced from the craft of building. Are notions

of digital materiality simply a delusional response, a home-sickness toward, a relationship to matter the architect never had? (Bloomer 2000: 12–19).

2 I have explored similar concerns with regard to Heidegger's lectures on metaphysics where the philosopher reveals our overwhelming technological condition but relegates it to the future. See Jason Crow, "Time is a Drag," http://www.farmmresearch.com/cmtconference/watch/?p=Jason%20Crow.

3 Harman provides a detailed account of the ontological interrelation between objects in his *Guerrilla Metaphysics*.

4 It should be noted that in Winnicott's definition of the transitional object, the child is allowed to take possession of the object by the mother. Thus, one of the first steps in the formation of the subject is the willingness of another subject to cede power to the object. In the case of the mother, the object is the child. In the case of Kahn, power is ceded to the brick (Winnicott 1971: 2–3).

5 Note that the *supplement* referenced here is the one developed by Derrida in his *OF Grammatology* (Derrida 1997: 208).

6 The fifteenth century is beginning to engage what will become a modern understanding of a resource that can be held in reserve in Heideggerian terms. However, it would be inappropriate to assume that the brick of that time is thoroughly modern. The fifteenth-century brick was not absolute resource. It continued to have a hierarchical position and status within a cosmological picture. The brick still pointed to God even if that pointing occurred more through its form than its matter.

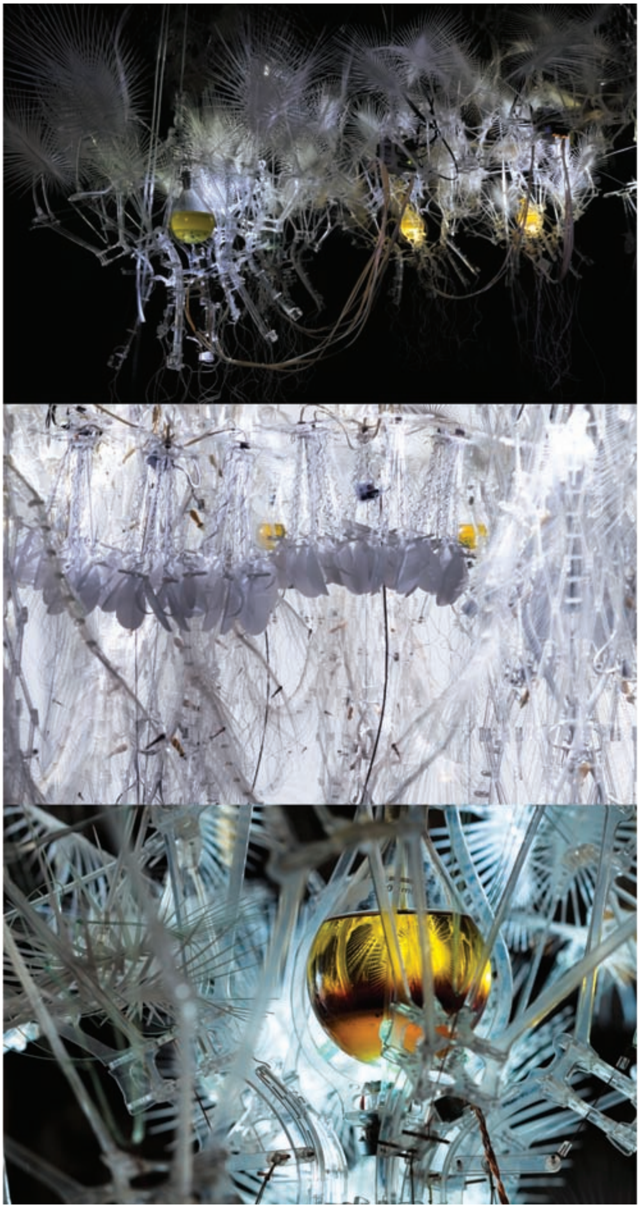
7 Wenzel Janmitzer, a contemporary of Palissy, developed an analogous alchemical craft centered on fire as the vivifying power of matter.

8 Ortega y Gasset defines the creation of metaphor in his *Essay on Aesthetics by Way of a Prologue* through a very similar collision of two matters, which create a new matter. Gasset notes that in this type of fabrication, the originating matters fade into the background in the emergence of the new thing (Ortega 1975: 137, 147).

9 The plastic brick is, perhaps most directly confronted in the more recent work of Greg Lynn. In particular see his *Fountain No. 2* and his *Blobwall Pavilion* (Amelar 2011; Arcspace 2008). His *Fountain No. 2* reveals the aporia at play with his "bricks" not through their materiality. An interest in the quality of color replaces any address toward the matter in play. He intentionally agrees to whitewash the multicolored plastic so that the matter would not be a problem (Amelar 2011).

PROJECTS

Material Ontologies



Hylozoic Ground is an immersive interactive environment exhibited at the Venice Biennale in 2010. Tens of thousands of lightweight digitally fabricated components were fitted with microprocessors and proximity sensors that react to human presence. This responsive environment (interwoven with chemistry) functions like a giant lung that breathes in and out around its occupants. (©PBAI, Photo: Pierre Charron)

Hylozoic Ground 2007–2012

Philip Beesley
Philip Beesley Architect Inc., University of Waterloo

Rob Gorbet
Gorbet Design, University of Waterloo

Rachel Armstrong
AVATAR (Advanced Virtual and Technological Architectural Research), University of Greenwich

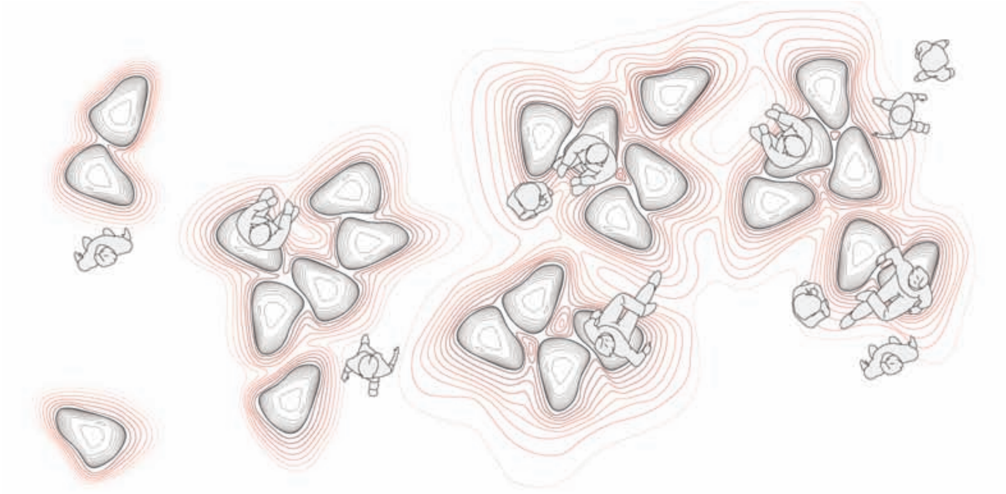
Hylozoic Ground is a collaborative hybrid artwork. The project's title refers to hylozoism, the ancient belief that all matter has life. The work features an interactive geotextile mesh that senses human occupants and responds with caressing and swallowing movement, in peristaltic waves within distributed fields of lightweight pores. The viewer enters beneath an animated canopy interspersed with a dense field of meshwork columns, populated by breathing pore elements and meshed proximity sensors that track occupant movements throughout the space. Filtering layers offer subtle qualities of hovering and gently vibrating fields, capturing the subtle air movements created by occupants.

Hylozoic Ground fuses textile-based sculpture, synthetic biology, and distributed interactive computing and mechanics. Throughout the environment, adjacent elements communicate with one another, spreading occupant signals in waves of emotive kinetic reactions. Processing for this system is based on Arduino—an open source platform that was designed to make tools for software-controlled interactivity accessible to nonspecialists. Several levels of distributed behavior are programmed into the sculpture in order to encourage a coordinated spatial behavior to emerge. Also embedded within the meshwork, engineered protocells are arranged in a series of flasks with a circulation system that helps maintain and regulate the environment. Chemicals within this artificial system are then able to capture carbon and build delicate miniature structural scaffolds.

A chief objective of *Hylozoic Ground* is to explore a new role for architectural environments by transforming portions of static buildings into dynamic responsive generative surfaces and equipping them with near-living "metabolic" (chemically active) functions. These living chemical exchanges are conceived as the first stages of self-renewing functions that might take root within this architecture. A parallel objective is to establish sensitive, renewed relationships for human occupants interconnected with their surrounding environment. A viewer's relationship with *Hylozoic Ground* is gentle. The work is an empathic organism that interacts and suggests the sensation of an architecture that might begin to know and care about its occupants.

www.philipbeesleyarchitect.com

Project Collaborators: Hayley Isaacs, Martin Hanczyc, Pernilla Ohrstedt.



Microclimates can be implemented in a range of scenarios, from the humid summers as a means for pulling humidity from the air to create usable space outside, to colder climates in which the forms can be sealed with heating filaments that warm the trapped air. Each piece alone is capable of only a minimal production of increased temperature, but with the units aggregated together, they have the potential to make sizable changes to the local microclimates. (Courtesy Sean Lally, Weathers LLC)

Wanderings 2008–2010

Sean Lally
Weathers LLC

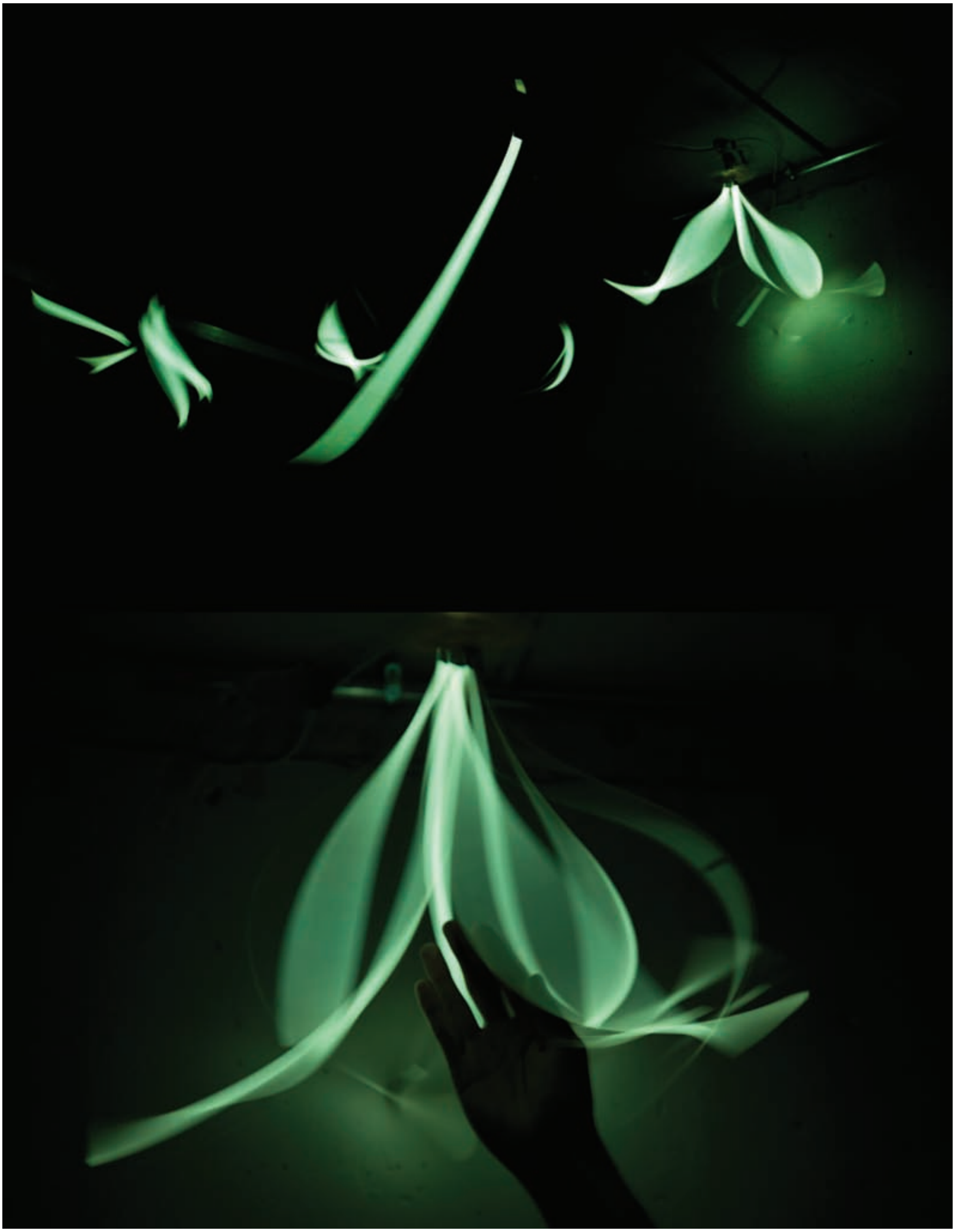
Wanderings is an attempt at a "climatic infrastructure" for commercial and public domains that augments and re-configures existing external microclimates for occupation and programmatic use. The project goes beyond simply "conditioning" exterior spaces, but instead seeks new territories of design, infrastructure, texture, and social interaction. The intention is not to simply move activities "outside" but to tease out the spatial and social implications when "walls" and "geometry" are not the primary means of spatial organization. The intention is to work with energy (electromagnetic, thermodynamics, sound waves, chemical interactions) as a building block material that can be controlled for the construction of architecture.

Acting on the ground plane, *Wanderings* creates multiple zones (microclimates) of distinct and definable edges, boundaries and transitions so as to organize space. The physical properties of these material energies are of gradient properties, intensities, and fallouts. The discreet seating nodes build and aggregate together. Each seating unit may not produce the required thermal or light spectrum necessary to augment the local climatic condition, but clustered together, they do so. *Wanderings* consists of small furniture-sized products that warm the human body through direct physical contact (conduction); in aggregation, this system additionally warms the surrounding air and ground around it. Our energy source uses renewable technology by adapting photovoltaic films and recycling the wasted energy expelled by buildings and existing city infrastructure evident around sidewalk grates. The thermal materials are coupled with spectrums of blue-and red-light that stimulate vegetative growth around the site during the winter months.

Energy plays a pivotal role in the advancement of civilizations especially with regard to a culture's broader knowledge base as energy becomes a launching pad for new explorations rather than only a fuel to run our current ones. Energy within architecture should therefore be seen as a materiality with properties for manipulation and design that become the epicenter of our imagination for seeking design innovation, influencing artistic, technological, and social growth. To do this, energy must become a building material that subsumes both the spatial and organizational responsibilities we currently lay upon the surfaces and geometries that trap or mediate these energy variables while seeking to produce architecture.

www.weathers.cc

Project Collaborators: Benson Gillespie, Ned Dodington, Brian Shepherdson, Curt Gambetta, Viktor Ramos.
This project was financed in part by the Rice School of Architecture.



Open Wires aims to create an environment based on lighted, ephemeral and unpredictable three dimensional shapes. Each element mainly consists of an electroluminescent foil, a square-shaped rotary contact and a DC motor. (Courtesy Manuel Kretzer)

Material Animation — April–May 2011

Manuel Kretzer
Chair for CAAD ETH Zürich, responsive design studio

Ruairi Glynn
The Bartlett Faculty of the Built Environment, University College London

Material Animation is a kinetic light installation, made from laser-cut electroluminescent (EL) foils, which senses location, number and velocity of human occupants and responds through a multitude of wirelessly networked components. The experiment is situated in three interconnected rooms, each reflecting a different theme and approach to physically animate the material in an architectural context. The first room hosts eight floating, jellyfish-like elements that are moving, expanding, and contracting in response to human interaction. The second space is defined by arrays of EL strips, which are suspended from the ceiling and revolve and flicker in high speed. The visual impact is affected by both the revolving speed and the on/off state of the EL strips. The third room is characterized by two optical animations based on moiré patterns that are hanging at the center of the space.

Furthermore each room is equipped with a Microsoft Kinect Camera, which senses the amount of people, their location, movement, and speed, and if more than two people are in a room, also the area they occupy. Every installation is thus linked to a computer, which communicates wirelessly with a remote server that is responsible for data distribution and choreographed performance of the spaces. After the information is compiled on the server individual data packages are sent back for further interpretation on the local PC. This exchange of data packages is used to organize the dynamic variation of elementary responses.

Material Animation tests the potential of EL materials and their beneficial properties such as unlimited viewing angle, longevity, broad range of colors, the possibility to produce them transparently and to thermoform them into 3D shapes.

www.caad.arch.ethz.ch

Project Collaborators: Agata Muszynska, Aleksandar Lalovic, Hideaki Takenaga, Jesper Thøger Christensen, Jorge Orozco, Magda Osinska, Mihye An, Nikola Marincic.
Thanks to Prof. Dr. Ludger Hovestadt (Chair for CAAD, ITA, ETH, Zürich), Emil Enz (Lumitec AG), Romano Kirschbaumer, Jorge Ellert (Ulano Corp.), Florian Wille, Luke Franzke, Karmen Franinovic, Max Rheiner (Zürich University of the Arts), John Sarik, Andreas Schlegel, Klaus Wassermann, Prof. Stephen Gage.

Pneumatic duct modules are assembled to form a continuous inflatable conduit; Duct modules are tiled to create a lattice-like ceiling. (Courtesy Dustin Tobias)

Breathing Bowels — Spring 2010

Dustin Tobias

Breathing Bowels rethinks mechanical building systems and proposes a dynamic heating and ventilation assembly based on the tiling of an inflatable duct module. Unlike conventional forced-air HVAC systems that are designed with performance criteria that foster imperceptibly, *Breathing Bowels* deliberately engages physiological sensation. Arranged on the ceiling as a network of tube-like textile modules, *Breathing Bowels* weaves supplied and extracted air into a single system that is simultaneously decorative and performative. As duct modules continuously inflate and deflate, the system provides a visible and audible record of the exchange of air; stimulating sensations that would otherwise be suppressed by conventional forced-air HVAC systems.

As a response to the 2x2 flat organizational logic of many conventional dropped ceiling systems, *Breathing Bowels* was developed as a 3D textile duct module that can be tiled into a layered, lattice-like ceiling assembly. The duct module, designed to contain chambers for both supplied air and extracted ventilation, was developed through a series of rapid-prototyped models that tested potential duct-weaving patterns. As the ducts are tiled across the ceiling to form a pneumatic lattice, a woven heat exchange system is formed, tempering supplied air by transferring the thermal energy of a room's exhaust. Additionally, as thermal differences between air chambers produce condensation on the surface of the modules, the system attracts particulate content as a wet-filter, purifying supplied air through the accumulation of residues.

Although *Breathing Bowels* attempts to address thermal efficiency and air quality through its woven heat exchange system, its true potential lies in the system's ability to produce both visual and audible feedback. While conventional forced-air systems are optimized to be soundless and are often installed out of sight, *Breathing Bowels* continuously inflates and deflates, creating an animated ceiling of sighs, burps, and hisses. These "other performances" elicit an awareness of a building's systems at work, and form a tangible gauge of energy at use. *Breathing Bowels* has the potential to stimulate a greater consciousness of the energy required to condition our interior environments.

This work was completed in the Advanced Descriptive Geometry Studio led by Professor Michael Young at The Cooper Union School of Architecture.

Symbiosis O/W includes an interactive wall installation incorporating ink that activates in a predefined pattern, while reacting to body heat. (Courtsey Kärt Ojavee and Eszter Ozsvald; Photo: AnuVahtra)

SymbiosisO **January 2009–ongoing**

Kärt Ojavee
Estonian Academy of Arts Media and Design

Eszter Ozsvald
Tisch School of the Arts Interactive Telecommunications Program

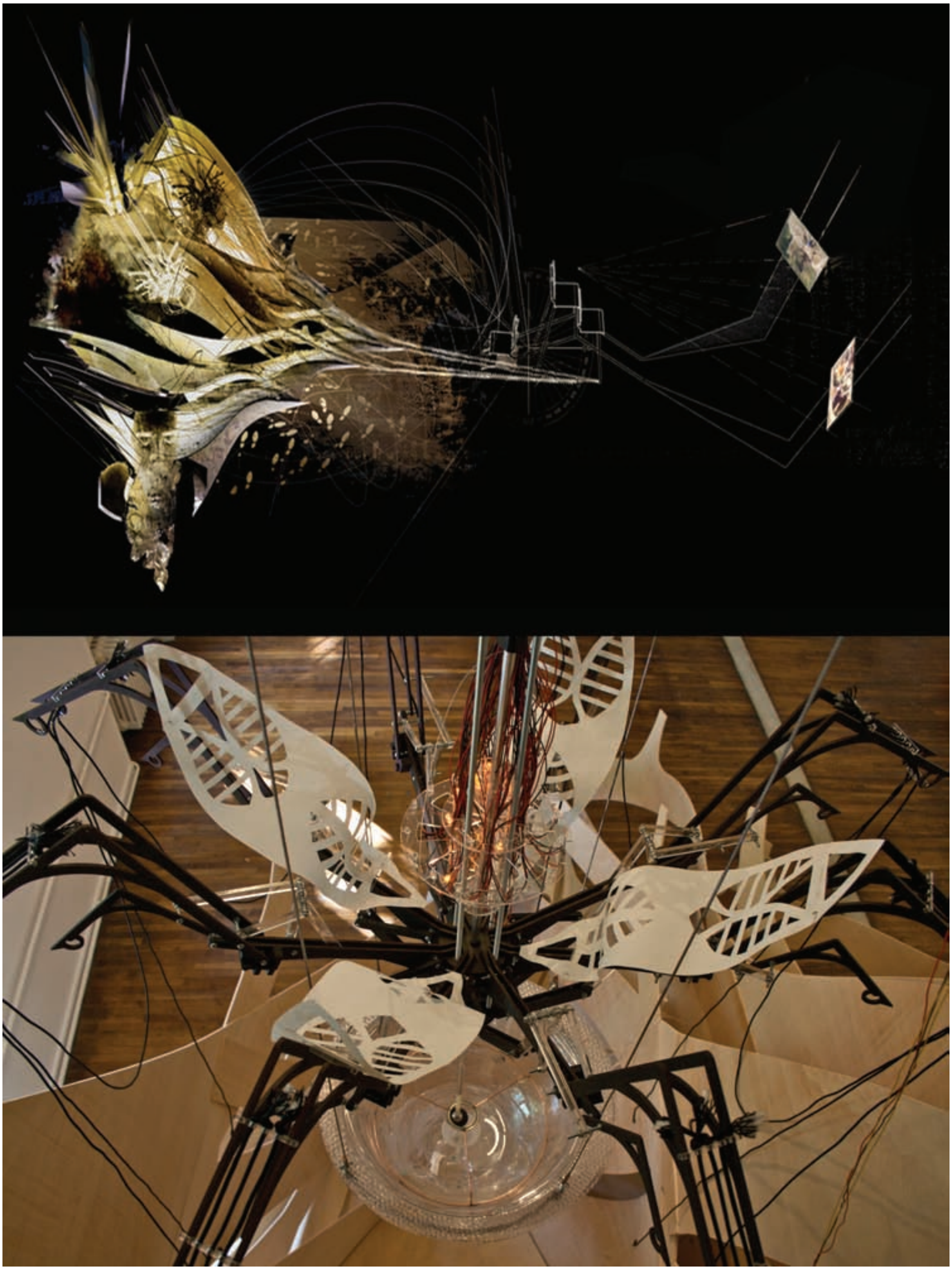
SymbiosisO is a collection of programmable textile interfaces designed to visualize information and express emotions. It is an active, programmable secondary skin; a material to surround everyday objects in the interior, a slow display to present ambient content. *SymbiosisO* is based on a hybrid material composition and suggests novel human-computer interaction through soft materials. The members of the collection behave as organic displays; they react to human and environmental impulses responding with an animated change in color. Since 2009, when the project started, *SymbiosisO* has continuously evolved in concept, form, function, and technology, resulting in the idea of tangible organic displays.

The production of *SymbiosisO* involves both handicraft and digital fabrication. For the construction we combine traditional textiles with soft electronics; we integrate various layers to realize the function within the material. The project is a weave of modern technology and more traditional crafts-based knowledge about textile-making techniques. In this way we give a new function to materials with static patterns or surfaces. It becomes active, as if breathing various pattern combinations in a slow, calming rhythm.

The project's conceptual basis lies in the ultimate power of evolution, where not only does the human civilization impact the environment, but nature itself reacts and adapts to these changes. *SymbiosisO* is unique in the way it combines novel techniques and familiar technologies, introducing intuitive interaction by utilizing well-known materials and objects. *SymbiosisO* is playful, interactive and unexpected but without the demand of one's full attention, therefore providing a new level of engagement. We encourage ambient interfaces and fluid communication aiming to balance the pace of our lives. Our objective is to develop organic, cutting-edge objects that bring the natural rhythms back to the cityscape.

www.symbiosiso.com

Thanks to the Center for Biorobotics, Tallinn, Estonia; Estonian Academy of Arts; Kitchen Budapest; Interactive Telecommunications Program, Tisch School of the Arts.



Ectoplasmatic Library is an attempt to record the ever-changing and increasing information that measures our affiliations to the world. The top image is the organic and digital storage that is triggered by visitors in the space. The bottom image shows the avatar creature converting data into physical actions. (Courtesy NaJa & deOstos)

Ectoplasmatic Library — May 2010

Nannette Jackowski
NaJa & deOstos

Ricardo de Ostos
NaJa & deOstos

The Ectoplasmatic Library is an installation that speculates on how architectural space can mediate the contemporary informational bomb and not only become a perverted mirror of upcoming technological drives. The design is inspired by the concept of ectoplasm—defined as sub-matter; an unstable medium between the realm of the dead and the living—and the concept of a library as providing and browsing information. But instead of finding books, the use of the space itself and the interaction by its users becomes stored data and creates a space in constant change in form and materiality.

The structure is designed to provide fast and slow participation spaces. Any movement within designated zones is tracked and coordinated by two creatures called "medusas" whose behavior is connected to sensors and kinetic platforms. Based on the information captured, the medusas trigger outputs that change the quality of the space in the form of growth, color, texture, and patina layering. While this slow transformation accumulates during the four-week period of the project lifespan, users can also view its recording on screens. Constantly shifting between digital and analogue methods the installation's form was modeled and tested in several scales and a series of prototypes were developed for the spatial arrangement to work with the physical computing elements.

The Ectoplasmatic Library creates a symbiotic loop between the electronic and the organic by manifesting the invisible in an ever-growing visible output. In an age where everything tends to transform into the Internet or digital networks and is produced to exist mainly in digital form (music industry, journalism, etc.) the project discusses how spatial cognition and experience may still be a useful mechanism to inform the threshold between physical and digital environments. *The Ectoplasmatic Library* is part of a series of projects developed by our studio to investigate sentient technologies as social-spatial narratives. Between Zeitgeist and Poltergeist these installations help us to further understand the potentials of interactions between physical computing and users but also of its need for a critical body or in other words, experiential and associative organizations.

www.naja-deostos.com

Project Collaborators: Samantha Lee, Marilena Skavara (Interactive Design consultant).
This project was developed and installed at the Ecole Special d'Architecture in Paris, France.

The Absent Body of Architecture engages two phases of direct material experimentation as a means for investigating the relationship between architecture and time. Wax and plaster models describe the chamber interior and chamber entry during material transformation. (Courtesy Andrew Lewthwaite)

The Absent Body of Architecture 2007–2008

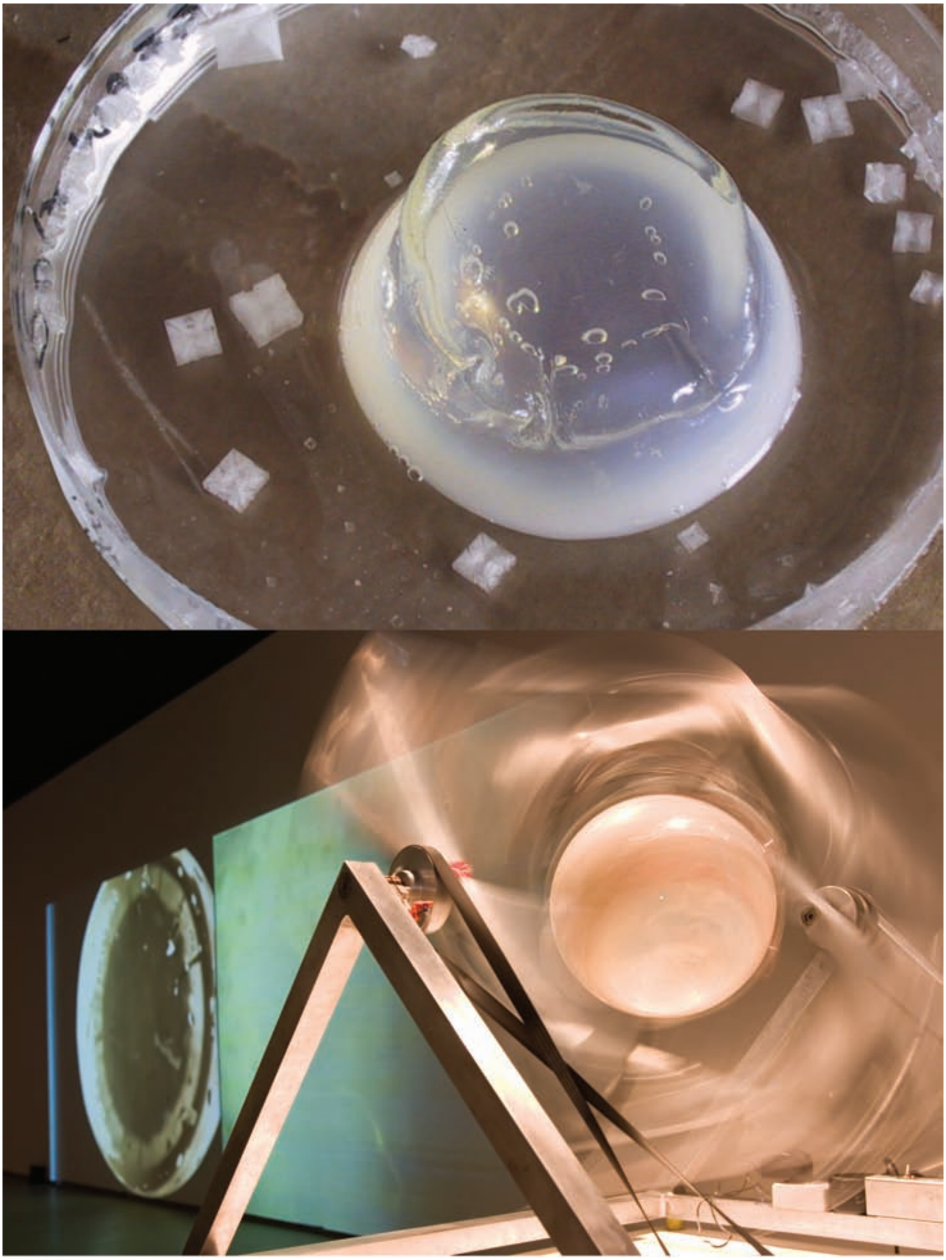
Andrew Lewthwaite
University of Manitoba

The Absent Body of Architecture involves two phases of direct material experimentation that serve as a means for investigating the relationship between architecture and time. The intent of the project is to discover conditions that hover between past and present material states in some way, to treat time as a material in the architectural investigation by capturing the temporality of material transformation in physical form. The use of experimental models, simultaneously scaled to the body and buildings, subjected to simple phase-change transformations allow for a direct and unfolding conversation between the conceptual and material to occur.

Phase one consists of a series of small wax and plaster cast models, altered by anatomical sectioning and lost wax processes with the aim of exploring the qualitative states of presence and absence. The models, post-transformation, reveal the space of the absent body, its impression displaced in a simultaneous act of appearance/disappearance.

In the second phase, the small models become inhabitants of a larger model, the construction of which seeks architectural analogues for the temporal relationships revealed in the early experiments. Set into a 1:1 table, the 1:50 model is constructed with a series of alternating layers of wax formwork and plaster-cast walls surrounding a central chamber. Within this space, a heat-producing plate is cast into the floor with the aim of transforming the wax bodies occupying the interior, and ultimately, the chamber construction itself with the gradual disappearance of the wax formwork. The space below the chamber anticipates the meeting of the phase-change, the inevitable descent of liquid wax providing an opportunity for the architecture to creatively acknowledge the *telos* of its material performance.

In the manner of its conception and making, the project attempts to open architecture up to the unexpected results of material behavior, and the temporal/phenomenal relationships that are revealed in the experimental process. Rather than fixed relationships, the rich, open-ended quality of the process allows the content of the project to emerge in dialogue. The project demonstrates that the use of simple materials and straightforward means of transformation does not necessarily generate simple and straightforward results; rather, time as a material in architecture infuses complexity into its most basic relationships and opens up new avenues for architectural investigation.



(Top) Biological Habitat, model (2003) incorporates ongoing research on future biological dwelling; (Bottom) The Cosmic Garden (2003–2007) is a liquid polymer pneu (a bubble cast) made in space as a container for breeding living organisms. (Courtesy © Zbigniew Oksiuta and VG Bild-Kunst Bonn; Photo top: Wolf-Peter Walter, Meddersheim, Germany; Photo below: Mike Kozak, Toronto; Animation by André Hindenburg, Industriesauger-TV, Cologne)

Biospheres, Not Buildings 2009–ongoing

Zbigniew Oksiuta
Rensselaer Polytechnic Institute

About 40 percent of global energy consumption on our planet is used in the building sector. Despite this, architecture is often still reliant on conventional design, construction processes and energetic norms that were established in the nineteenth century. Stability is often synonymous with architecture. Likewise, separation from the climate, independence from the environment has long been seen as the primary task of architecture. So, while living organisms are dynamic systems that continuously exchange energy, matter, and information with the environment, buildings are not. But can we create living buildings? Can we create objects, which will be born, grow, and die with us to become food for the next form; buildings that are in a continuous process of creation, adaptation, and repair?

It seems that a biological paradigm opens up new possibilities. We now have the methods to study and understand life at the molecular scale. Since the end of the nineteenth century, in laboratories around the world, in petri dishes, in bioreactors and incubators, we have begun to grow a different, third nature. Transgenic organisms, chimeras, and clones are arising out of natural evolution. Biotechnology has developed new life-support techniques, new aseptic habitats, and new microecosystems where soil is a transparent polymer and where life processes occur in specifically controlled conditions outside the natural environment. For architects and designers, collaboration with science offers a way to liberate these new life systems from labs. They can be re-scaled to the human body and tested in situ. Can life processes, that normally take place at the nanoscale, in proteins, acids, and saccharides, happen at a macroscale? This research proposes *Biospheres* rather than buildings—a call to start from scratch rather than attempting futilely to wake up dead objects. It proposes a radical paradigm shift, beyond green houses and vertical gardens that operate only as metaphors to the natural world.

A primary aim of this research is an extended universal biological self-replicating system. This system could have various sizes: a cell, a pill, a fruit, a house, and even a biosphere, and could exist in different surroundings: on earth, under the water, and in space. It calls for a future in which architecture is in dynamic feedback with its environment. A propagule is a tiny package of material that some organisms make so that they can survive periods of dryness and the lack of food. Propagules represent a sort of closed-off "resting" stage in the life cycles of many organisms.[1] I think our buildings are propagules and the time is ripe to awaken them to life.

www.oksiuta.de

Note

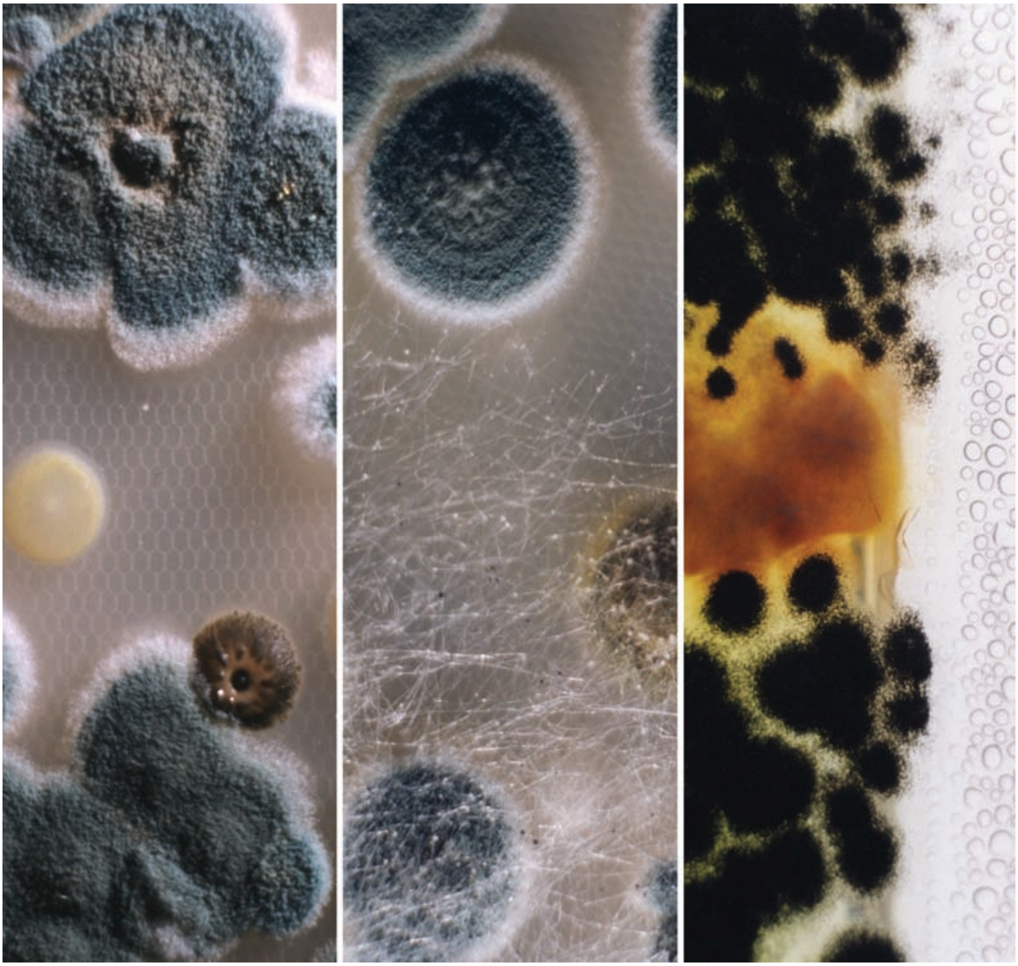
1 As described by the biologist Lynn Margulis and the science writer Dorion Sagan in *What is Life?*, New York, Simon & Schuster, 1995.

Q + A

Steve Pike *with Sneha Patel*

STEVE PIKE is an architect, researcher, and founder of **ar**colony, a forum for experimental architecture. He spent a number of years as a designer before he studied at the Bartlett School of Architecture, University College London, receiving his Masters degree in 2003. His work and on-going research has focused on the examination and exploration of micro-organisms within architectural design, highlighting the parallels between the conditions of form, organization, material, and composition present within their domains and the human-scaled environment. Steve Pike's work has been included in many international exhibitions and publications, including *AD Neoplasmatic Design* (Pike 2008a, 2008b, 2008c), which he co-edited. He is currently practicing with Acanthus LW Architects in London.

The concept of materiality within Steve Pike's work is defined through the innovative use of living matter within design, such that the descriptive terms, *biological* and *adaptive*, are directly examined rather than formally referenced. He discusses how this work engages with an expanding body of design research that employs systems and technologies that are capable of autonomy, radically shifting the architect's role within the construction of the built environment. No longer seen as manifested through a series of fixed and pre-determining criteria, Steve Pike offers an experimental and projective architecture that is fundamentally alive.



Nonsterile *A distinct aesthetic emerges as the micro-organisms Aspergillus Fumigatus, Aspergillus Terreus, Micrococcus, Zygomycetes Rhizopus and Penicillium Digitatum negotiate territory across the growth plane of a Monitor Vessel. Morphological and phenomenological, it challenges prevalent preoccupations with order and hygiene while raising notions of contamination and disgust. (Courtesy Steve Pike)*

Q1. Sneha Patel: Your work has been described as "*microbiological responsive architecture* (Pike 2008a: 16–23)." This approach effectively combines design and research while merging the studio and laboratory, both as a new space of practice and as a distinct set of methodological tools. Can you expand upon the ways in which your work incorporates and places value upon both design thinking and processes and more scientific practices and technologies?

A1. Steve Pike: As is often the case with successful collaborative relationships, the individual parties bring far more to the alliance than was at first anticipated, the combined result being greater than the sum of the individual parts. As my research progressed, I found this to be distinctly the case with the collaboration of scientific practice and the design process. In many respects the two are incredibly similar in their approach. **Both design and science rely upon a body of work that precedes the current moment, yet they are both explorative in their process.** Both share the ability to be truly creative, often contributing something genuinely original and as such are progressive in their approach, shunning conservatism and embracing possibility.

Such common values offer a sound basis for collaboration, though it is their differences that present a combined benefit. Scientific practice demands far greater rigor than that of design; it is far less forgiving. At the risk of over simplifying the process, it generally commences with a notion, a speculation, which is then tested within extremely limited parameters and observed under intense scrutiny, before any conclusion or result is permitted. The equipment and technologies employed are slaves to the process and result; never has the design mantra of "form follows function" ever been more rigorously applied. Design thinking is much looser. **Whilst there are similarities between both processes, design does not demand such a strictly defined result. It embraces associated notions, less tangible considerations, and enjoys the accidental. The catalyst to the design process is usually an idea, the practice is also one of exploration and testing, and the result generally needs to satisfy a given function, but such notions as aesthetics or philosophical meaning, cloud any attempts to suggest a conclusion or a definitive answer. Compared to science this is its weakness and also its strength.**

Within my research themes, I place equal value upon design and scientific thinking and processes; though I am clearly approaching the work from the perspective of a designer. I am not a scientist. Applying a more scientific rigor to my approach is largely necessary due to the nature of the material that I employ, but also a deliberate attempt to inform the working methodology and ultimately the result. **Putting myself in the position of a scientist approaching this work, the application of design thinking liberates the decisions, introducing wider possibilities and permission to consider such matters as aesthetics.** I consider this exchange to be mutually beneficial.

Research within design is absolutely essential. In many respects it provides the driving purpose of the design process, with each progressive step, each designed component, each collective project striving to test or resolve a series of critical research questions.

Q2. Sneha Patel: What unique challenges have you found in extending beyond the architectural or design disciplines? And similarly, what have been the most rewarding aspects of engaging in an interdisciplinary approach to design?

Process *The preparation of Monitor Vessels and growth plates under sterile conditions at the UCL Department of Microbiology laboratory. The specific composition of the growth medium is tailored in order to target particular ambient microbial populations. (Courtesy Steve Pike)*

A2. Steve Pike: The introduction of living material to my research projects and the decision to manipulate their behavior determined an approach outside typical design thinking, requiring an interdisciplinary working methodology. As an architect I am familiar with the limitations of having to achieve a particular technological outcome; however, there is often a broad range of acceptable results with a wide choice of tested approaches. There is far less room for maneuver when an intended objective is identified that incorporates microbiological material whose behavior is partly anticipated by established scientific principles. In short, the flexibility normally offered to design is severely curtailed by the restrictions necessary to facilitate the desired scientific result. Far from presenting an obstruction to the design process, this assisted the work in developing a degree of refinement. **Design generally achieves better results when distinct parameters are introduced, the outcome potentially possessing greater integrity.** In this instance, parameters were introduced that required expertise outside common design practice, demanding significant input from other disciplines.

The interdisciplinary approach necessitated working closely with professionals not normally associated with architectural design. Microbiologists and mycologists based at University College London, in particular Professor Conrad Mullineaux, contributed their expertise as well as the laboratory environment which enabled the work to be carried out. This exchange of ideas and amalgamation of knowledge proved to be incredibly rewarding, introducing new possibilities for the practice of design; the laboratory as design studio (Lim and Lui 2002: 152–157).

Other more familiar collaborations took place in fabricating the numerous physical components generated by the research. **Historically, the architectural designer was directly connected to the process of manufacture.** This connection is of immense value, offering detailed knowledge and experience of production techniques and the behavior of materials that is largely removed by the virtual manner in which we currently practice, communicated by the transfer of information. The relatively recent introduction of CAD-CAM processes presents an opportunity for the designer to re-engage with this knowledge and experience, albeit in a contemporary manner. **To conduct my research in a virtual environment was not a viable option; the vessels and support infrastructure had to be physically made. The procedure of design by making proved considerably rewarding.**

Rather than providing the role of a generator of an aesthetic, or at the very least the obvious treatment of material, digital tools are more being applied as a means to achieve a sense of materiality determined by other considerations. Many designers are exploring concepts of materiality that are deliberately free of any digital approach—perhaps more phenomenological.

Q3. Sneha Patel: In working with living matter at such small scales, it is only through the colonizing progression of microbes that your work becomes truly visible. As such you have deliberately shaped the role of aesthetics within your projects that I see as manifest in two important ways.

Firstly, it finds functional and aesthetic resonance by realizing the necessary apparatus, vessels, and support structures for microbial growth, closely linked to

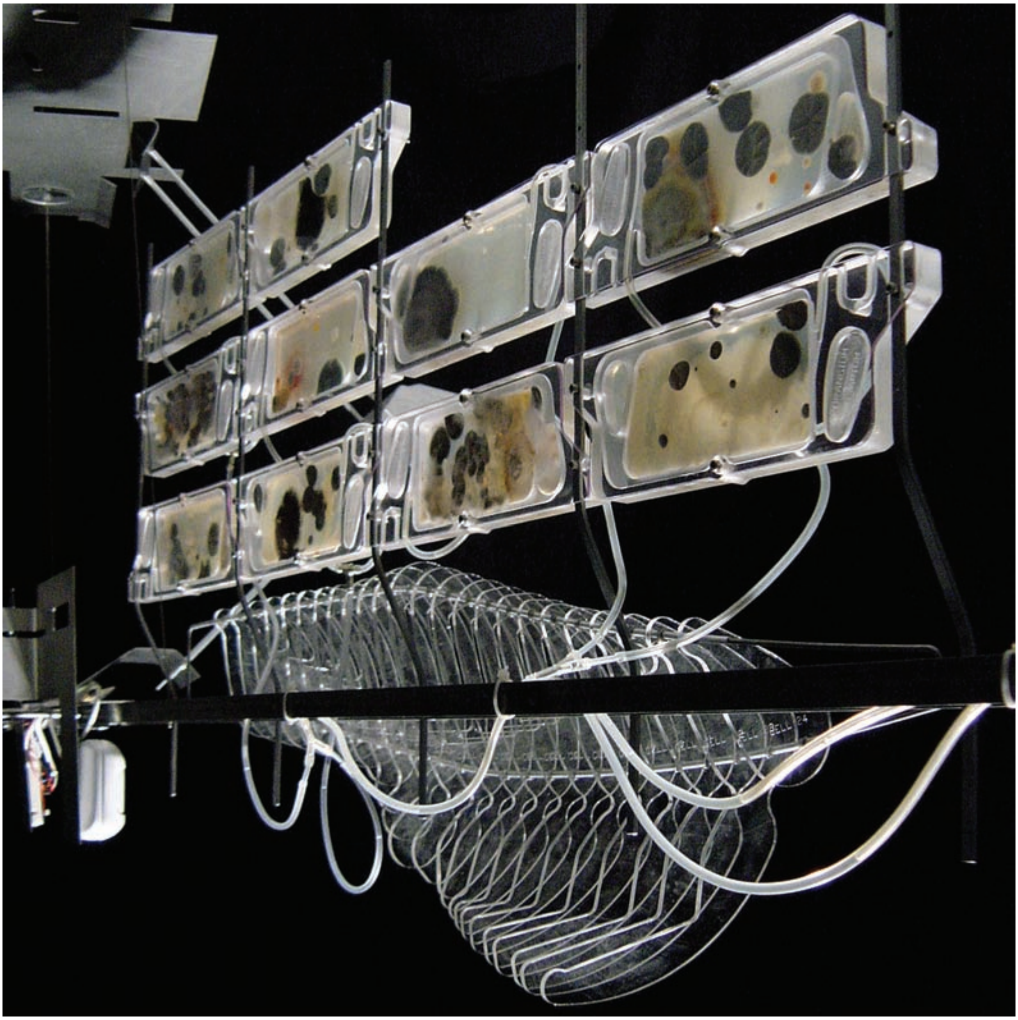
Contaminant_Monitor Cells *As a derivative of laboratory apparatus, the form of the Monitor Cell was developed and fabricated by CAD-CAM processes, allowing accurate manufacturing molds to be established. The composite mold was then employed in order to generate multiple Monitor Cells. Following exposure, the Monitor Cells exhibit distinctly site-specific colonial growth. (Courtesy Steve Pike)* laboratory equipment, but often designed and produced at unique installation-based scales. Secondly, the work becomes a demonstration for the emerging and continuously changing composition of micro-organisms, elucidating an environment that is present but not always visible.

How do you see these two aspects of design working in relationship to each other in your work?

A3. Steve Pike: Your eloquent assessment of these aspects of my constructed projects is indeed accurate. **Initially, as my research progressed, the issue of scale presented a considerable problem. Micro-organic material is largely undetectable at its individual scale, hindering the visual currency that informs the majority of design. However, it soon became clear that in order to effect the immediate environmental modification or monitoring that emerged as a central consideration of the work, a collective presence of microbes would be necessary.** These colonial populations possess an identifiable visual language, displaying a rich and challenging aesthetic, contributing the distinctive appearance of the work. The vessels, facilitators, inhibitors and general support infrastructure required to propagate and maintain the microbial populations are primarily a practical requirement. Without them the micro-organic colonies would not exist. However, this undeniably offers the opportunity to introduce the aesthetic language of the laboratory. **The components designed and created are not solely concerned with their functional requirement, though this clearly demands a functional rigor; decisions are made from the designer's perspective, considering the visual impact and any associated notions that are communicated.** The aesthetic displayed by microbial growth is intrinsically connected to that communicated by the fabricated support structure.

Q4. Sneha Patel: With regard to the previous question, how do you balance and/or value your ability to control or manipulate the installations you design (and the particular facilitation and inhibition of specific microbes) with the inevitable relinquishing of control necessary when working with living organisms?

A4. Steve Pike: The **issue of manipulation and control of micro-organisms is absolutely central to the work.** If the ability to inhibit the growth were not present, the microbes would proliferate unrestrained removing any design intent or facility to utilize a specific embodied mechanism or behavior. **Nevertheless, I consider it important to relinquish a degree of control; permitting the living material to partially determine the result.** Conventional design thinking assumes that the designer retains ultimate control over the outcome. In practice the extent of such complete control is largely debatable as inevitable external influences are present and no design is conducted in absolute isolation. The intent however is to maintain control. **My work engages with an expanding body of various design research that deliberately employs systems or technologies that are capable of autonomy**. The inclusion of living material maximizes this intent. The most



Contaminant *Fabricated components, support infrastructure and proliferating micro-organisms integrate; the resultant installation composing a semi-living hybrid. (Courtesy Steve Pike)*

that the designer can hope to achieve is to manipulate the behavior of the living material. **Balance is an entirely appropriate term to use, as a fine line is pursued between releasing control to the unregulated micro-organic colonies and maintaining determined restrictions.**

In detail, when specific microbes are targeted for use, the designer must employ new approaches, such as within the chemical composition of the media for the growth planes or in the particular application of physical environmental conditions. In these instances, **the**

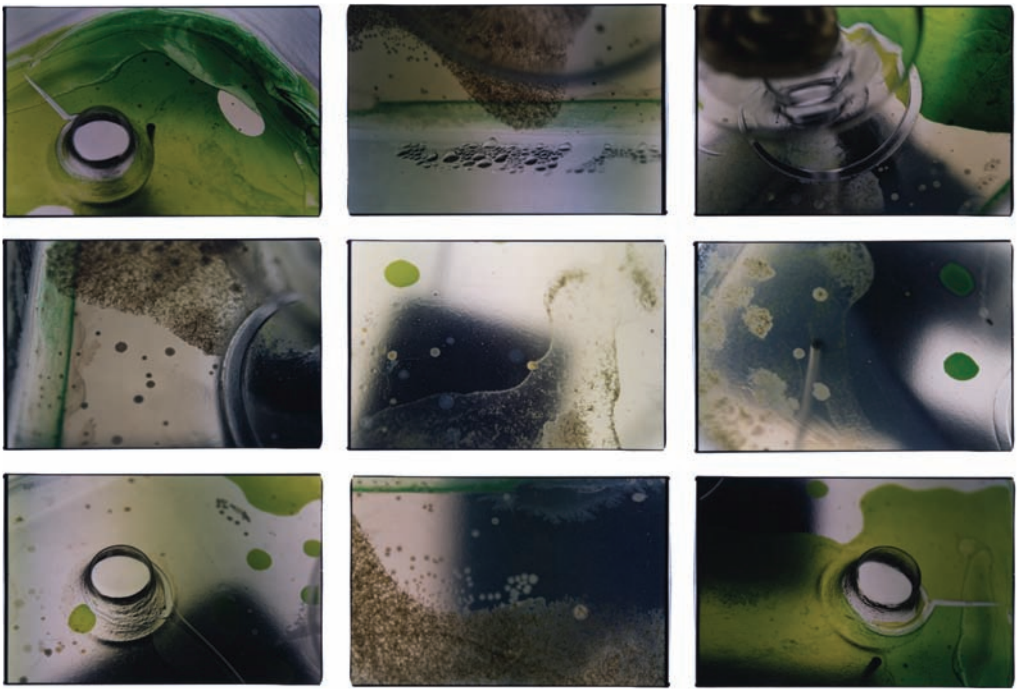
design intent manifests as introducing parameters rather than determining objects. The living material will then react according to its known and established behaviors, but never to such a predictable extent that the outcome can be entirely predetermined. This for me is an important aspect of the work; engaging with the independent process of the living systems and challenging the notion of complete control. Additionally, it opens an often sensitive dialogue concerning such issues as genetic modification and behavior control.

A large proportion of the desired result of my work is dependent upon relinquishing control to the living material, introducing a degree of chance. In many respects this proves contradictory to the notion of optimization.

Q5. Sneha Patel: Your projects (such as *Contaminant* in London (Cruz and Arroyo 2003: 201–207) and Berlin and *Nonsterile* in London, Coimbra, and Munich) have been installed in various locations. In each setting, the work presents a different composition due to the differences and specificity of both the environmental conditions (air, light, humidity, etc. ...) in which the work is situated and the interaction with the visiting public. Visitors, though often unaware, give presence to the work as their own microbial input effects the growth of housed micro-organisms within the installation. In what ways do you feel that this expands upon traditional or static notions of materiality within design, the environment, and human interaction? Do you feel your work aims to expose new cultural definitions of materiality?

A5. Steve Pike: **The work deliberately attempts to broaden the accepted notions of what constitutes material in design, particularly in architectural design.** *Contaminant* (Pike 2008b: 24–29) and *Nonsterile* (Pike 2008c: 72–77) both attempted to identify the ambient microbial populations present in the air that surrounds us and additionally the undeniable connection that we have to such populations. **The environment in which the projects were placed, and the visiting public unwittingly introducing the material itself, were critical components of the installations. This is a deliberate attempt to challenge the traditional assumption that material is a static, largely inert entity that is remote from human interaction apart from its presence and signs of wear or aging. The work explores the consideration that material, environment and human activity are all connected; through the coincidence of these factors the material emerges.**

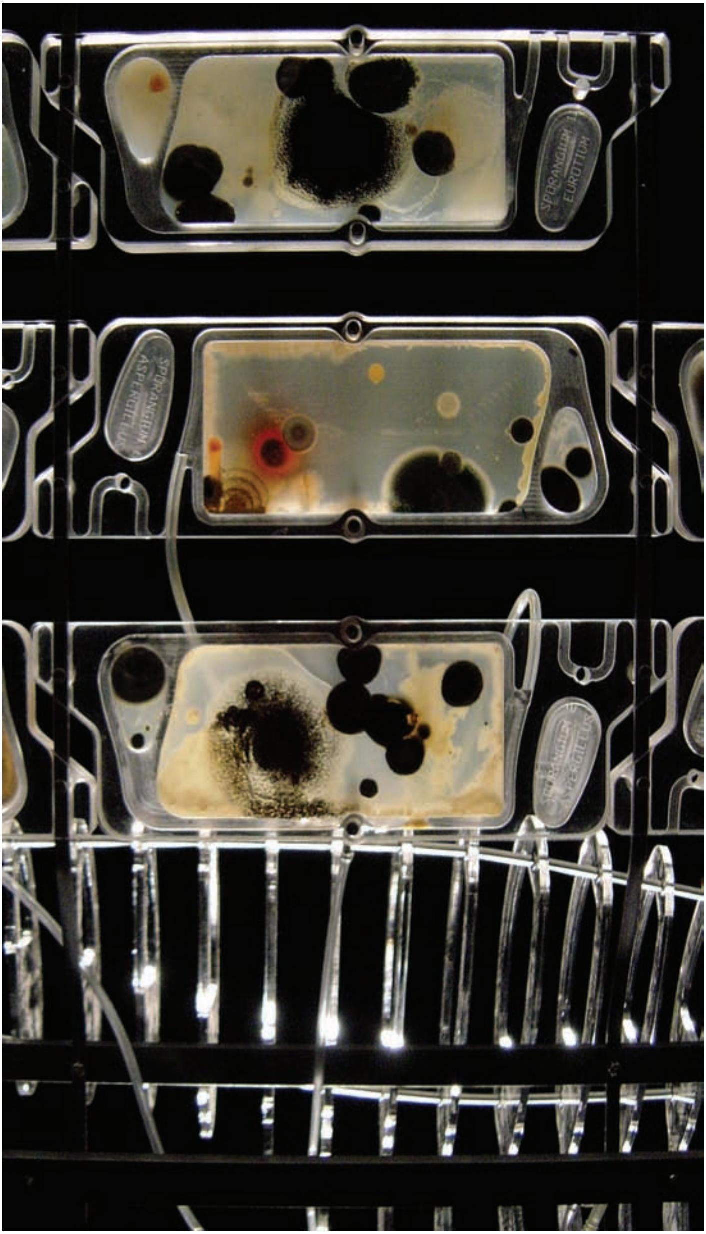
As our knowledge of microbiology expands, its presence has permeated through our cultural and social considerations. Architecture and design is clearly part of this process, the biological influence is apparent and prevalent. Rather than focusing on "bio-form," which is valuable in its own right, this research is concerned with the utilization of actual



Algaetecture *Details of the preliminary Interaction Vessel. Specific micro-organisms selected for their environmental requirements and anticipated behaviors are introduced to fabricated components such as sporangiophores, facilitators, and inhibitor nodes. (Courtesy Steve Pike)*

living material. The interactive nature of the material dictates a morphological consequence, revealing an almost epidemiological trace of human activity. **The resultant display is often uncompromising, challenging perceived notions of hygiene and disgust. This aspect of the work is central to my current investigations into the theme, questioning the notion of beauty, whether there is a developing "bio-baroque" aesthetic and, from an architectural perspective, challenging the modernist notion of order and control that underpins much current design practice.**

My work values: adapting lessons of form generation, organization, composition, symbiotic relations, sustainable systems from the micro-biological domain—challenging aesthetics that embody perceived notions of beauty and hygiene.



Contaminant_Growth Plates *Visitors to the installation introduce particulate matter, catalysts for the transformation of Monitor Vessels. The micro-organisms Aspergillus Fumigatus and Aspergillus Terreus, present in our built environment, and Micrococcus, found on the surface of human skin, compete for colonial territory across the growth. (Courtesy Steve Pike)*

Further Reading

www.arcolony.com

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Chapter 2

Material Elements

Shape_Shift *(Courtesy Manuel Kretzer, Edyta Augustynowicz, Sofia Georgakopoulou, Stefanie Sixt, and Dino Rossi)*

el·e·ment
- a distinct part of a composite device
- the simplest principles of a subject of study
- a constituent part[1]

1 Merriam Webster's Collegiate Dictionary (1995) 10th Edition, Springfield: Merriam-Webster.

New Material Compositions

Martina Decker

Reports of advancements in materials science arrive at our doorstep almost every day, with news of astonishing innovations. These breakthroughs in the design of matter are frequently framed, however modestly, in terms of the role that new material compositions might play in achieving solutions to some of the most daunting problems of our time. By now, we are quite familiar with implied, and explicit, promises of how new materials will help satisfy our growing energy needs, curb our energy consumption, provide us with access to clean, abundant drinking water, and, clean up our toxins that are polluting the environment.

Many of these emergent materials have been propelled by advancements in nanotechnology, which has experienced accelerated growth since the 1990s. During the 18 years that spanned from 1990 to 2008, the number of patent applications related to nanotech grew by 20 percent annually. During the same period, the number of issued patents increased by 23 percent every year (Shapira et al. 2011: 592). Various additional indicators, such as federal funding, dollars spent, and increases in market reports, research papers, and journals, show that nanotechnology has the potential of becoming the next general purpose technology (Youtie et al. 2008: 315) that will influence many industries for years to come, including the construction industry. Recent studies show that, after biomedical and electronics applications, nanomaterials will likely have a greater impact on the construction industry than any other sector of the economy (Lee et al. 2010: 3580).

Although it is frequently described as a field, it is neither possible, nor useful, to describe nanotechnology as a distinct profession. Rather, like the territory of a vast field, it is shaped by the many disciplines that have made it accessible over the past few decades, and continue to expand its frontiers. These include physics, chemistry, biology, medicine, pharmacology, and other health sciences, ecology and environmental sciences, agronomy, and all of the diverse divisions of engineering, just to name a few. One thing that can be said, though, is that all of the disciplines that are involved in nanotechnology have one fundamental thing in common: the observation and manipulation of matter at the scale of individual atoms and molecules—the nanoscale.

To get a better sense of the scale of nanotechnology and the minuscule dimensions of the products that it yields, most commonly in the form of nanomaterials and nanomachines, one can contemplate the growth of our own fingernails. Growing an average of 3mm in length per month, a single fingernail grows about one nanometer every second of the day. Within 100 seconds, it has reached the upper limits of what is considered the nanoscale, and has thus surged beyond the realm of nanotechnology.

With the essential material components of nanotechnology having a size of 100 nanometers or less, in at least one of the three dimensions, the diminutive scale of nanotech might suggest developments of little consequence. However, nanotechnology is uniquely positioned to influence the fundamental properties of matter, imbuing new materials with entirely unusual chemical or physical attributes, precisely because it operates at this scale, where billionths of a meter matter. This is one of the reasons why nanotechnology is claimed by so many disciplines and is touted as a technology that offers such diverse opportunities for an extraordinarily wide range of applications; it is, fundamentally, a "field" that is portrayed and understood dimensionally.

Seeing and Making on the Nanoscale

Perhaps the most influential factor in the emergence of nanotechnology, a development that continues to spur the evolution of high-performance materials with properties that excite the imagination of architects and designers, was the arrival of advanced microscopy technologies and techniques. These tools revealed insights into the composition of substances at a scale never witnessed before, nor understood better. Thanks to the advent of scanning tunneling microscopes and atomic force microscopes, which materialized in the 1980s, we have been able to observe nanoscopic structures, both biological and mineral, and determine their chemical make-up with such precision that we can verify the location of specific atomic elements within a specimen.

As the spatial resolution of our microscopes continues to tunnel toward quantum states, the revelations they have provided have brought us closer to understanding why materials perform the way they do. Currently, the most powerful electron microscope in the world is the Transmission Electron Aberration-corrected Microscope (TEAM) (Girit et al. 2009: 1705) at the Lawrence Berkeley National Laboratory, which has a spatial resolution of about 0.05 nanometers, which is roughly half the diameter of a very small, isolated atom. When the Scanning Transmission Electron Holography Microscope (STEHM) becomes operational at the University of Victoria, Canada, it will be able to zoom down to 40 picometers, which, at 0.04nm, is well below the nanoscale.

Beyond the observation and characterization of substances and specimens, advanced microscopy has also enabled us to act on acquired knowledge in some surprising ways.

An Atomic Force Microscope (AFM), for example, "feels" the three-dimensional surface conditions of a substance by moving a tiny "finger" across its surface. We use the tip of this probe to measure and image the structure of specimens (Gross et al. 2009: 1110), but we can also use it to actively manipulate that which is being observed (Deng et al. 2011: 275308). We can utilize the AFM to push and pull the very nanostructures that a specimen is composed of, and direct it to add and remove nanostructured components that are hundreds of times smaller than the wavelengths of visible light.

Since the introduction of advanced microscopes, such as the AFM in 1986, the tools of observation have slowly evolved into tools of manipulation, and of making, at the nanoscale. This approach to making, which involves the use of a large tool, such as a microscope, to fashion a small product, is known as top-down fabrication. It is a common method for making nanoscopic materials and devices, and it seems slightly familiar to those of us who have used a tool to extract, harvest, and shape raw materials that are macroscopic.

In addition to top-down methods, there is another approach to creating matter, which builds upon foundations laid at the opposite end of the dimensional spectrum. With self-assembly, we can fabricate materials from the bottom-up—atom-by-atom, molecule-by-molecule—and bio-molecular engineering has enabled us to program DNA to assemble molecular components into products. But it is really an amalgamation of the two approaches, both bottom-up self-assembly and top-down techniques, that has produced many of the achievements in novel materials that we have witnessed. Nanolithography (Lenhert et al. 2010: 275), for example, can turn a substance into a sensor by using the tip of a "pen" to deposit molecular "inks" upon the surface of a material.

This new domestication of matter encourages a fresh way of thinking about the future of synthetic materials, for our buildings and products, with categories that are not merely defined by extracting, harvesting, cutting, casting, or assembling material products at the macro level. With this newly gained precision in making, the term "material composition" no longer refers to the simple combination of bulk materials alone, now that we master the molecular structure of substances and create materials with functions and behaviors that we design.

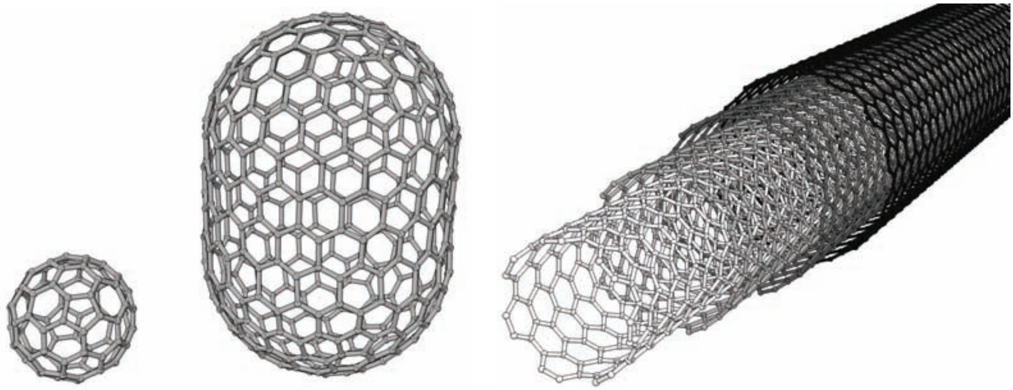
Nanomaterials and Composites

Particular attention has to be given to the element of carbon in this context, and its potential as a tiny building block in the making of functionalized materials with unique properties. We are very familiar with its most common, naturally occurring manifestations: diamond and graphite. While diamonds are amongst the hardest materials and demonstrate a very low electric conductivity, graphite is extremely soft and is an excellent conductor in comparison.

The properties of these two materials, and their extreme difference in appearance, already suggest the versatility of carbon. Carbon atoms bond to themselves, and many other elements, an attribute that has led to an abundance of novel nanomaterials of which this element is a vital constituent. Fullerenes, for example, which are a genus of molecules that consist entirely of carbon, come in a variety of shapes, including hollow ellipsoids and spheres. Cylindrically shaped fullerenes, commonly known as carbon nanotubes, have been heavily studied over the last decade for their diverse properties and have already found their way into a number of products that are available on the market.

Carbon nanotubes are, essentially, multifunctional materials. They are already being used in photovoltaic solar cells (Chen et al. 2011: 1815) and batteries (Lee et al. 2010: 531), due to their electrically conductive and semiconducting properties, and their shape-shifting (Aliev et al. 2009: 1575) and selective filtering (Gavalas 2011: 1) capabilities are being studied for various medical and aerospace applications. And, perhaps closer to architecture and its allied professions, a broad range of industries have been pursuing nanotube-based applications that take advantage of the remarkable strength-to-weight ratio of carbon nanotubes, due to the unrivaled strength of their carbon-carbon bond.

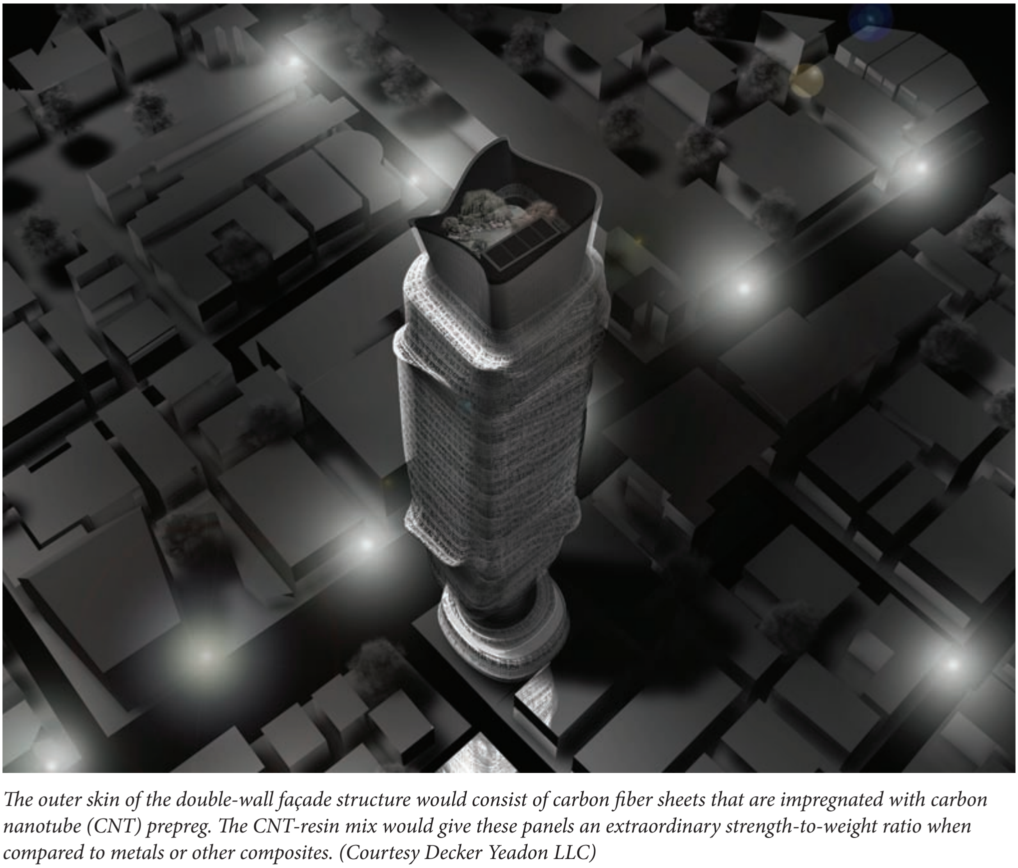
The high strength-to-weight ratio of carbon nanotubes has benefitted numerous manufactured products, but this particular property can be difficult to achieve in material composites, as the individual nanotube components within the bulk matrix of the composite are strongest when they are aligned to resist tensile stress. Still, products ranging from tennis racquets and golf clubs, to bicycle frames and automobile components, have been improved with the strength of nanotubes.



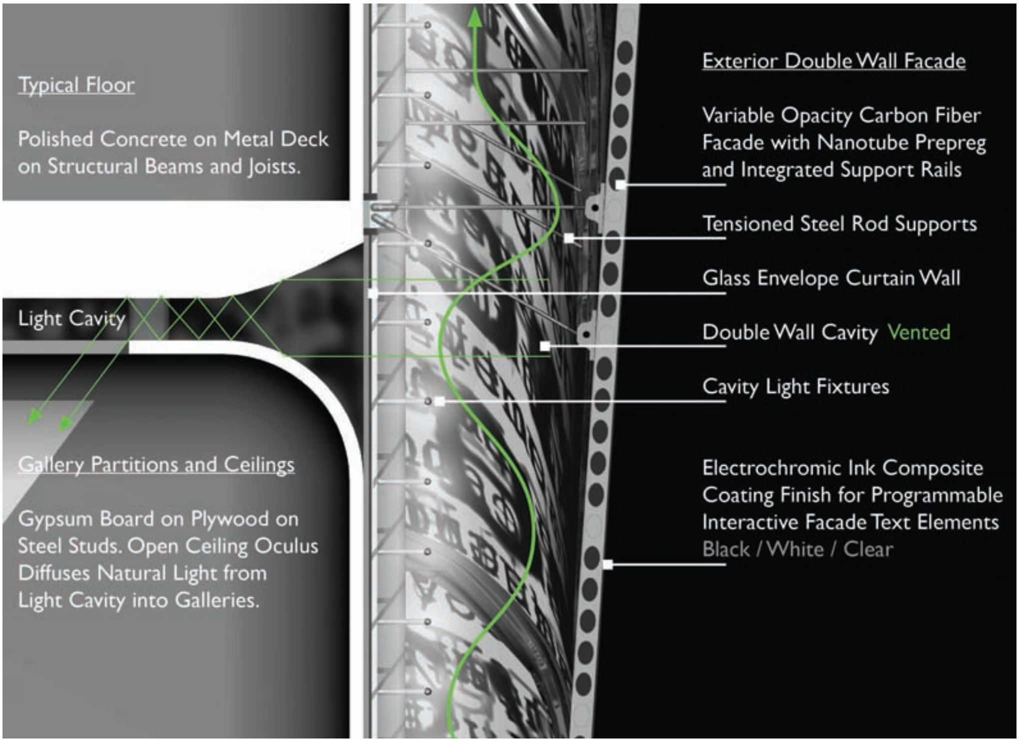
Fullerenes consist entirely of carbon, and take full advantage of this element's extraordinary range of bonds as a universal building block at the nanoscale. Carbon atoms can be assembled into various nanoscale architectures that offer a diverse but distinct set of properties. Pictured on right, carbon nanotubes (CNTs), which belong to the fullerene family, can be synthesized through a number of different methods, including Chemical Vapor Deposition (CVD). During the CVD process, the CNTs grow, atom by atom, out of a catalytic metal substrate when it is exposed to a hydrocarbon vapor. (Courtesy Decker Yeadon LLC)

At a larger scale, Zyvex technologies has built a 54 foot boat, named Piranha, that features a carbon fiber structure with a nanotube-enhanced epoxy resin. The result is a corrosion-resistant boat that is 75 percent lighter than conventional boats of a similar size. Cruising at 25 knots, the Piranha's dramatic reduction in weight enables 76 percent in fuel savings when compared to its aluminum and fiberglass counterparts. The Piranha, and products like Easton's carbon nanotube bike frames for BMC, demonstrates the potential of such nanotube-infused prepreg composites for architectural applications.

The construction industry could benefit greatly from integrating nanocomposites into conventional building systems. Double skin façade technologies, for example, could comprise an outer façade layer of nanotube-impregnated carbon fiber panels that complement a standard inner glass curtain wall. Such a system would not only benefit from the lightness and strength of the composite, it might also be able to take advantage of some of the excellent electrical properties of carbon nanotubes. Printed as a pattern of electrically



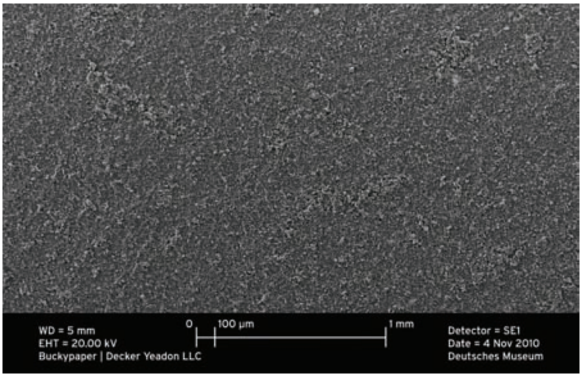
The outer skin of the double-wall façade structure would consist of carbon fiber sheets that are impregnated with carbon nanotube (CNT) prepreg. The CNT-resin mix would give these panels an extraordinary strength-to-weight ratio when compared to metals or other composites. (Courtesy Decker Yeadon LLC)

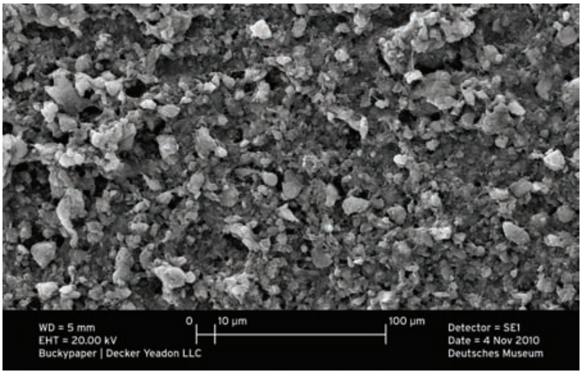


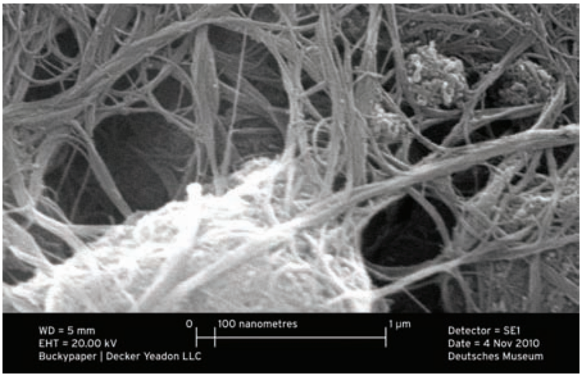
Taking advantage of the electric conductivity of CNTs, the carbon fiber composite would be coated with a patterned electrochromic ink matrix that can be changed, from white to black to transparent. Like a large display screen, the changing colors of the surface would enable time-based media to be broadcast. (Courtesy Decker Yeadon LLC)

conductive ink, a network of nanotubes could serve as sensory nerves that detect any cracks or stresses emerging in a structure, or, could provide a means to turn façade panels into displays, by emitting light, or by delivering an electric charge to electrochromic pixels on the façade's surface.

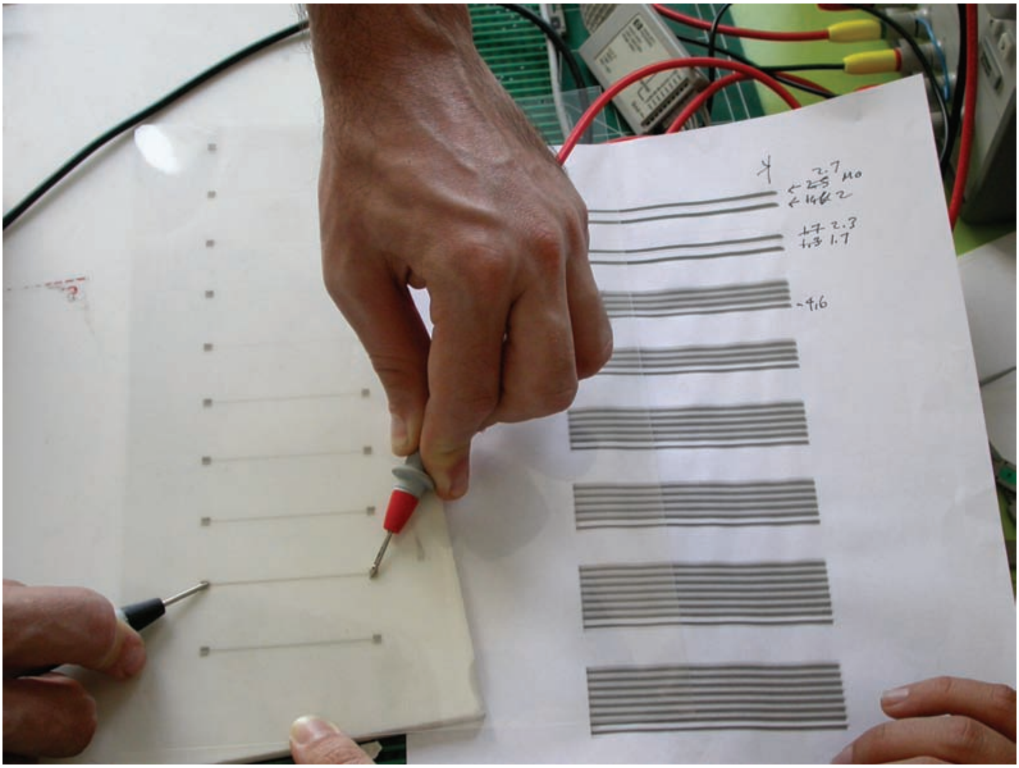
Our firm in New York City, Decker Yeadon LLC, has taken a hands-on approach to examining how carbon nanotubes might be used to create flexible electrodes and circuits for a variety of applications, from flexible displays in the built environment, to electronics in textiles and artificial muscles for architecture. Experimenting directly with single- and multi-walled carbon nanotubes, we created an electrode sheet material that consists entirely of networks of carbon nanotubes; it is called Buckypaper. We also synthesized a carbon nanotube ink solution that conducts electricity. We have applied this ink to nonconductive substrates like cotton or paper, transforming them into conduits that conduct electricity. The nanoink can either be brushed, sprayed, or inkjet printed onto a variety of substrates to create electrically conductive surfaces.







Buckypaper is the product of combining top-down and bottom-up fabrication techniques. The CNTs, as the essential ingredient in the Buckypaper, were synthesized through CVD, wherein the carbon end product is assembled one atom at a time. After disbursing the CNTs in liquid and filtering them, a thin layer of CNTs, called Buckypaper, is left on the surface of the filter. (Courtesy Decker Yeadon LLC)

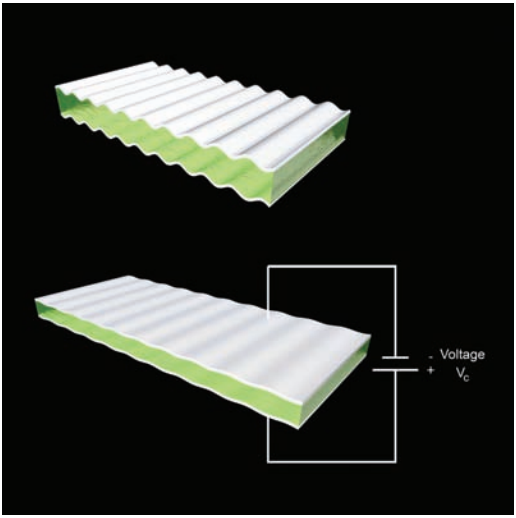


After dispersing CNTs in deionized water and a surfactant solution, the resultant ink was applied to paper, cotton, and film products in order to create electrically conducting patterns on the material's surface. (Courtesy Decker Yeadon LLC)

Smart Materials

When conductive coatings are applied to flexible substrates, to form a composite material, their electrical conductivity is often compromised by cracks that form when the composite is stretched. This phenomenon can be witnessed in a particular class of artificial muscles, known as Dielectric Electroactive Polymers (DEAPs), which change shape in response to an electric charge. These smart materials are composed of a thin silicone or acrylic film that has metallic electrodes coated on both faces. When a positive charge is applied to one electrode and a negative charge is introduced to the other, electrostatic forces attract the electrodes to each other, thus squeezing the polymer core and causing it to elongate.

Often, as DEAP composites elongate, the thin metallic coatings that are used as electrodes can develop cracks and lose their ability to conduct electricity. One way to avoid this has been to lay down the electrodes as a corrugated structure (Benslimand et al. 2011: 1), like a wrinkled skin, which allows them to flex and move with the muscle. However, if they are stretched beyond a certain point, the metallic electrodes will still become damaged and their



The corrugated structure of the silver electrode in this example of a Dielectric Electroactive Polymer (DEAP), allows the electrode to stretch and move with the muscle when electricity is applied to operate the system. (Courtesy Decker Yeadon LLC)

electric conductivity will be compromised. Conductive nanotubes and nanowires might provide another approach to addressing this problem.

Recently, researchers at North Carolina State University were able to entice nanowires to take the shape of an oval coil that is much like a spring (Xu et al. 2011: 677). The nanowires were fabricated on an elastomeric substrate and, due to their coil configuration, could be stretched to 104 percent of their original length without being compromised. Unlike previous corrugated configurations of nanowires, which showed localized stress and failure in the peaks and valleys, the stresses observed in the coiled nanowire springs were distributed across the entire shape of the sample. Although the nanostructures comprised silicon nanowires, the researchers estimate that this technique could be used on nanotubes as well.

This nanotech development might prove advantageous for the advancement of DEAP smart material actuators. Pairing a version of the nanospring electrodes with DEAPs could improve the performance of the material by allowing for a greater movement in the actuator. One could also speculate that this would greatly improve the lifespan of the artificial muscle, making DEAPs a more viable candidate for applications in architecture.

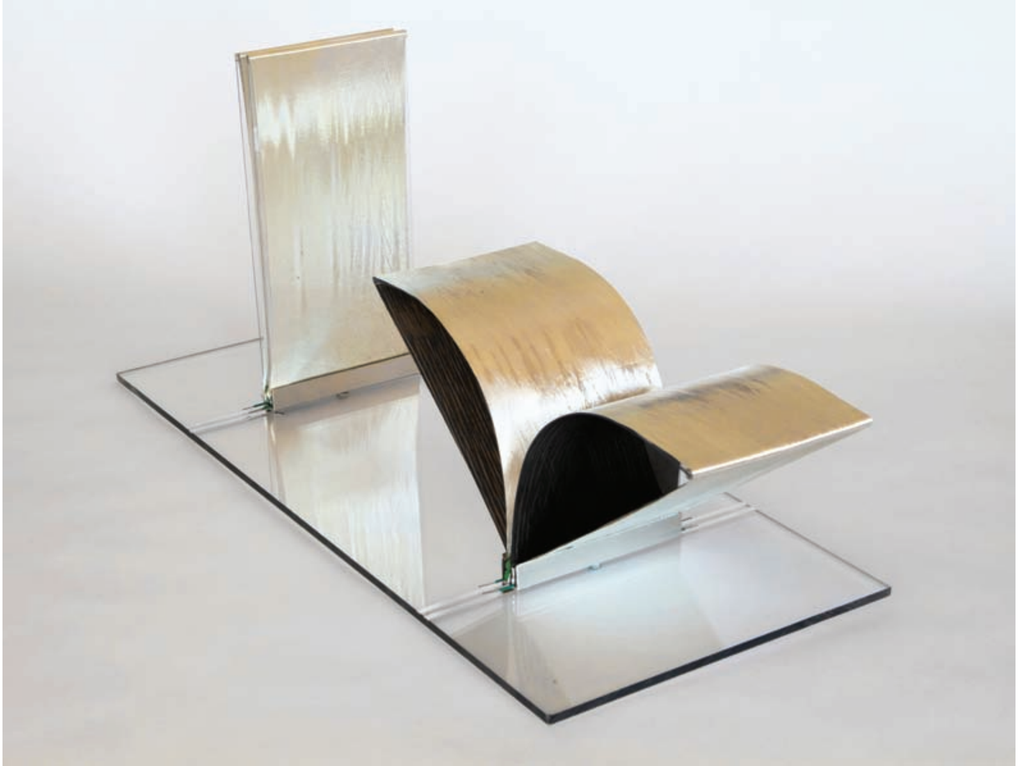
Like all smart materials, DEAP artificial muscles respond to external stimuli; that is to say, smart materials react to changes in their environment. Hence, a smart material can also be considered a device, and so the potential of artificial muscles in architecture and design is rather broad. Artificial muscles enable a whole new approach of thinking about actuators in a manner that surpasses simple robotics. They are strong but lightweight, and their compact geometry can help to perfect existing systems with an elegance not possible

In the Homeostatic Façade System project, ribbons of DEAP muscles would open and close to control solar heat gain through a building's double skin glass façade. Since DEAP embodies the function of the motor and the shading material at the same time, the system benefits from an extraordinary lightness and can simply be adhered to the glass surface. (Courtesy Decker Yeadon LLC)

before. It is no surprise that smart material motors and actuators dominated 56 percent of the smart materials market in 2011 and are expected to account for 63.5 percent of the USD $40.1 billion smart materials market in 2016 (McWilliams 2011, Executive Summary).

In architecture, artificial muscles could be used to complement existing building systems. They could obviously be used as actuators to control the flow of gases and liquids in mechanical systems, for example, but we already have many conventional valve technologies that work rather well and some that would perhaps work better. More importantly, these smart materials might enable us to create a whole new generation of responsive architectures that were not possible before, an architecture akin to homeostasis in living organisms, wherein a complex system of control mechanisms reacts to local changes in the environment in order to maintain stabile internal conditions, such as temperature.

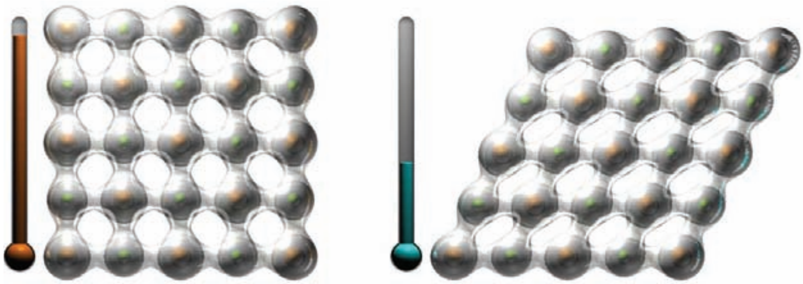
To maintain stable temperatures within buildings, and conserve energy, double skin façades are known to assist in the task of buffering thermal energy transfer from the interior



This sectional detail model for the Homeostatic Façade System shows the DEAP muscle wrapped over a flexible polymer core. The DEAP includes silver coatings that serve as electrodes and assist the system by reflecting and diffusing light. (Courtesy Decker Yeadon LLC)

to the exterior, and vice versa. The airspace in between an outer glass curtain wall and an inner glass pane creates a zone that mediates between conditions outdoors and our built interior spaces. To extend the efficacy of double skin façade technologies, the Homeostatic Façade System takes advantage of artificial muscles while drawing upon a model of homeostasis in biological systems. Instead of using conventional motorized shading devices to further the control of solar heat gain, DEAP artificial muscles are used. The smart material is not only the motor that drives the system, it is, at the same time, the shading device, the means to control airflow within the cavity, and a diffuser of light.

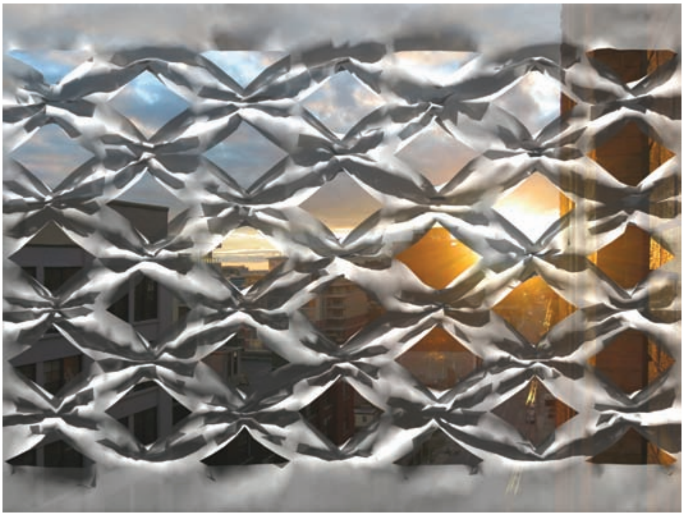
In the Homeostatic Façade System, a DEAP ribbon that can flex and bend is continuously fastened to the glass façade, which is only possible due to the lightweight nature of the smart material actuator. The ribbon can open and close along any segment of its length, independently, which allows for a high degree of control. Although a very high voltage differential needs to be applied to the electrodes in order for the system to operate, the system consumes very little power because no electric current is permitted to flow



A transformation between a high temperature state and a low temperature state in the SMA's crystalline structure guarantees the repeatable memory effect. The material looses its polymorphic capabilities if it is deformed beyond the recoverable level where the crystalline structure of the alloy is compromised. (Courtesy Decker Yeadon LLC)

through the elastomer core of the DEAP ribbon. Thus, the system conserves energy while complementing conventional mechanical heating and cooling systems.

Another example of a shape-shifting smart material that has a great potential in helping control solar heat gain right at the façade of buildings is a shape memory alloy (SMA). Also called memory metals, they count as a class of thermoresponsive smart materials because of their ability to change shape due to changes in temperature. At lower temperatures, the SMAs can be easily deformed. As temperatures rise, however, the material will return to its original shape, which is often referred to as its "remembered" state. The memory effect takes place in a predictable and



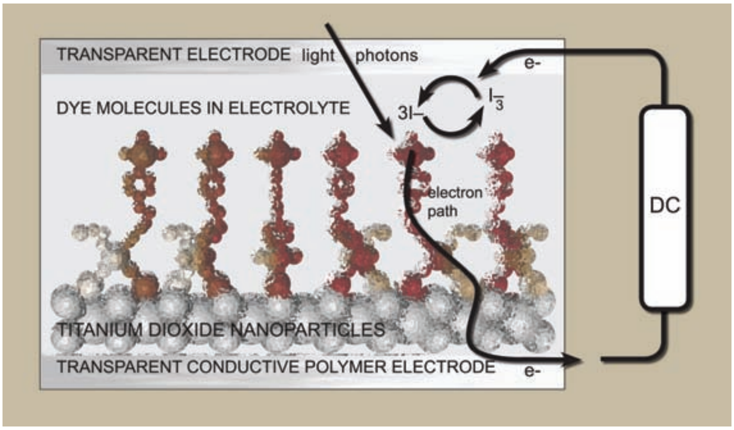
The SmartScreen uses integrated SMAs to open or close perforations in its textile, to regulate heat transfer through windows. The shape change is in response to changes in ambient room temperatures. (Courtesy Decker Yeadon LLC)

Testing of the SmartScreen III prototype over the course of a day, at temperatures ranging from 21 to 26 degrees Celsius. (Courtesy Decker Yeadon LLC)

repeatable manner, but it is essential to control the deformation of the alloy, as straining the material excessively will compromise its crystalline structure at the molecular level.

Many shape memory alloys that are readily available on the market rely on large changes in temperature that are achieved by an electric current that heats up the SMA due to resistance in the metal; the most common of these are nickel-titanium alloys. But by doping shape memory alloys with impurities like copper or cobalt, their response to certain temperatures can be manipulated. R-Phase SMAs are uncommon, but they are particularly well engineered to respond to small changes in temperature. Being able to adjust the smart material to modest changes in ambient room temperature enables us to achieve shading devices that do not rely on sensors, electricity, processors, or even humans to operate solar screening systems.

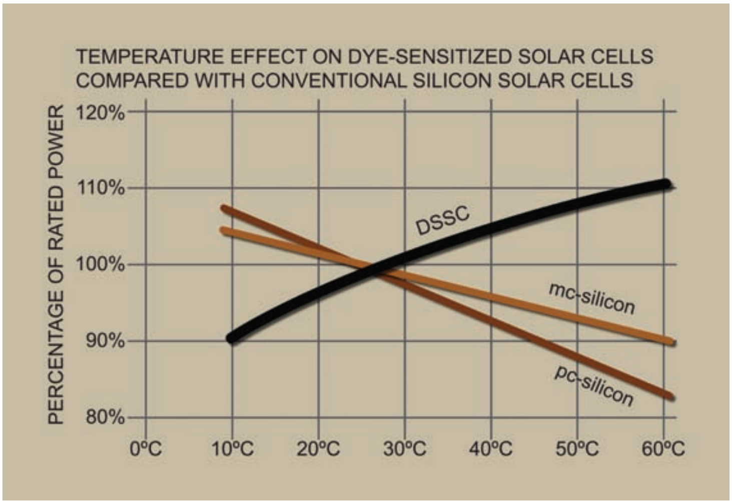
Smart materials, such as these low-power material motors and actuators, not only hold the promise of helping us conserve energy, they can also produce useful forms of energy. Many of these smart materials generate electricity in response to mechanical stress, thermal fluctuations, or solar radiation. Considering that most of our energy is still being produced



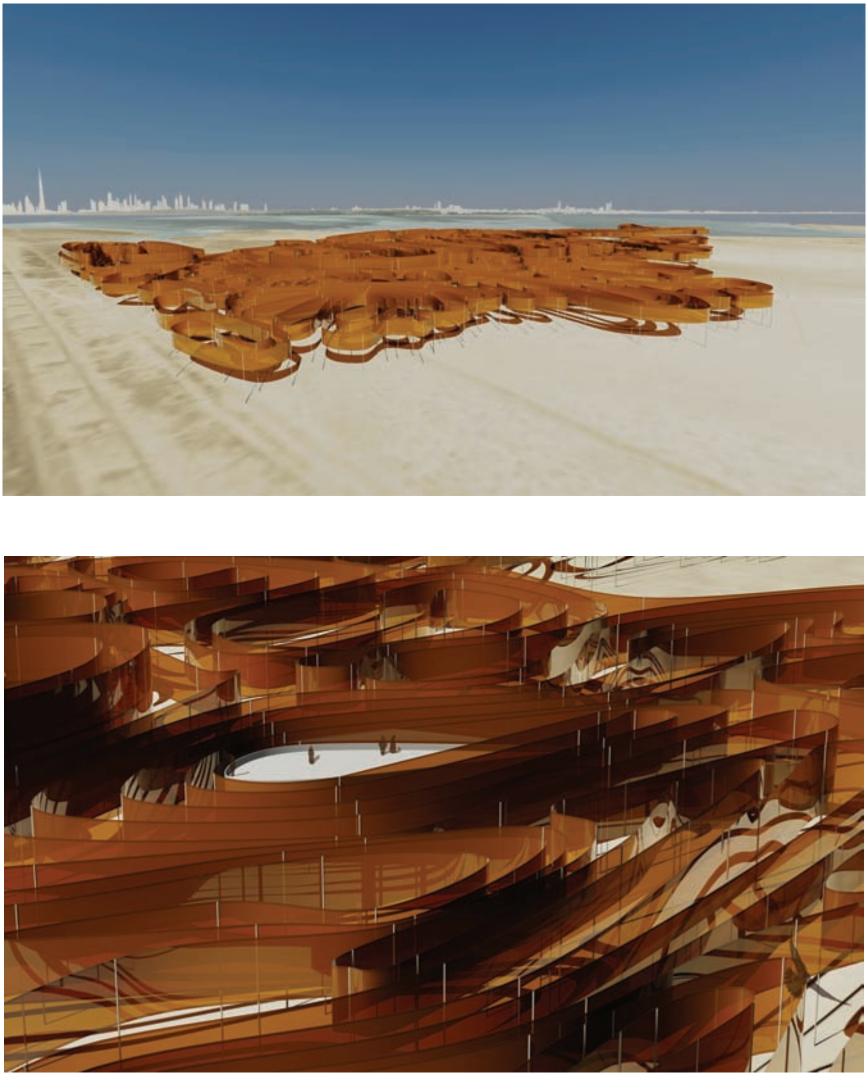
This diagram of a Dye-Sensitized Solar Cell (DSSC) illustrates electron flow within the thin photovoltaic membrane. (Courtesy Decker Yeadon LLC)

by burning fossil fuels, these smart material transducers have drawn a significant amount of attention and funding for some time now. Transducers might be the key to turning waste energy into useful energy, by making unavailable energy accessible in another form.

Of all the smart material transducers, photovoltaic solar cells are the most mature material technology. In the late 1980s Michael Grätzel paved the way for a new generation of photovoltaics, by inventing Dye-Sensitized Solar Cells (DSSCs). He abandoned the use of planar electrodes and moved toward more fractal surface structures (Meyer 2010: 4339). Today's DSSCs exploit



In contrast to conventional silicon-based solar cells, the efficiency of DSSCs increases as their temperature increases. (Courtesy Decker Yeadon LLC) the nanoscale by utilizing titanium dioxide nanoparticles for their extremely high surface area. The organic dyes, which play an integral part in the electron exchange that results in an electric current, are coating the nanoparticles and can be harvested from botanicals like raspberries, cranberries, or pokeberries. This dye-titania mix is saturated in an electrolyte and embedded within thin laminations of transparent electrodes to complete the solar cell.



The Light Sanctuary project features vertically mounted DSSCs in an energy-producing desert installation outside Dubai. Forty kilometers of photovoltaic ribbons meander through the desert, taking advantage of the material's ability to perform in a vertical installation. (Courtesy Decker Yeadon LLC)

Today, we are well into the post-silicon age of third-generation photovoltaics. DSSCs are already found in a variety of consumer products and are slowly making their way into architecture. The particular appeal of DSSCs lies not only in the ratio of production cost to efficiency, when compared to first- or second-generation technologies; the flexible, lightweight, translucent (and in some cases even transparent) nature of the material allows for a whole new approach to designing with thin films that generate power.

Unlike their silicon-based counterparts, some thin film photovoltaics can absorb light across 140°, which makes it possible to install them not only horizontally, but also vertically. They perform well in different climates and, unlike silicon-based photovoltaics, they actually become more efficient when ambient temperatures rise.

Now that DSSCs have emancipated designers from the use of manufactured photovoltaics that are dark, rigid, and limited in terms of their installation, design innovators have returned to thinking about energy production in our built environment. One example is GROW by SMIT LLC, which combines two smart materials to create an energy harvesting installation that found it's way into the collection of the Museum of Modern Art in New York. Inspired by ivy growing on buildings, Samuel Cabot Cochran and Benjamin Wheeler Howes conceived an artificial leaf that uses thin film solar photovoltaics and piezoelectric generators to produce electricity from the Sun and the Wind, respectively. The modular design can be installed on buildings and linked with a network that appears to be growing like vines on façades. A similar product by the same company, called Solar Ivy, is exclusively photovoltaic.

Biomimetic and Bioenabled Materials

Innovative products like GROW and Solar Ivy are often described as being biomimetic, as if they are capable of emulating the essential performance features of organisms that have evolved over billions of years. But plants use photosynthesis to turn the Sun's energy into chemical energy, not electricity. This is not to say that growing plants cannot demonstrate how we might produce useful forms of energy. When it comes to leaves, it might be more instructive to examine the process of photosynthesis itself, rather than focusing on generating analogies through appearances of form. One day, an artificial variety of leaves just might enable us to truly emulate nature, by creating chemical energy in the form of hydrogen fuel.

Moving entirely away from solid-state technologies, a wet, soft, artificial leaf has been created by researchers from North Carolina State University, the US Air Force Research Laboratory and Chung-Ang University in Korea (Koo et al. 2011: 72). Its light-sensitive components are integrated into a water-based gel, and, once the Sun's energy excites the photoactive molecules, they generate electricity in a manner akin to plants forming sugars. Interestingly, in addition to synthetic light-sensitive substances, the gel matrix also works with organic compounds like chlorophyll, making it a device that extends the frontiers of biomimicry toward a true bioenabled technology. As a next step, the scientists intend to create self-regenerating, self-healing, and self-replicating samples; the idea is that the closer we approximate nature, the more sustainable and environmentally friendly our technologies could become.

Materials Praxis

Whether novel materials are nanostructured, smart, biomimetic, or bioenabled—or perhaps even cut across all of these categories, as is the case with the wet, soft artificial leaf—they all have one thing in common: they are clear evidence that, during the past three decades in particular, our relationship to matter has changed and we have dramatically expanded our approach to making material compositions. New insights through advancements in microscopy have enabled an enlightened grasp of the workings of matter, ultimately allowing us to design desirable substances with atomic precision and manufacture them.

These insights and developments are the result of a concurrent increase in interdisciplinary scientific research (Wagner et al. 2011: 14) that has engaged professionals from numerous fields, such as biology, chemistry, physics, and engineering. Designers and architects are used to multidisciplinary collaborations in their daily efforts to create and improve our built environment and they could play a more vital role. But this would require an uncommon approach to thinking about materials, one that moves away from thinking about materials as products that are merely given, selected, specified, and acquired. Recent and rapid achievements in materials design should encourage designers to take the specification of materials further, beyond the building products that they form. We might start by identifying material properties.

A research team at MIT, led by Lifeng Wang, has developed a new method to create material composites that will allow us to do exactly that. The approach permits us to define a set of properties (e.g., stiff, strong, impact resistant, tough, or energy dissipating) and create a composite that meets all of the desirable parameters (Wang et al. 2011: 1524). The process relies on the combination of two basic materials, one glassy and the other rubbery. These binary components are arranged into a variable assortment of lattice structures, forming arrangements that allow both materials to be continuous within the sample. The composites are printed with sub-millimeter resolution, but the team is confident that their approach to the fabrication of co-continuous material composites can be scaled down even further.

Whether synthesis techniques are complex, or offer elegantly simple approaches to creating materials with specific properties, such as the method developed by Lifeng Wang's team, none of these processes suggest specific applications for the materials being developed. They are means without any particular end. In fact, of the thousands of materials research papers that are published every month, very few new discoveries will ever find any application in the future whatsoever. That is not to diminish the importance of these achievements; such discoveries are essential to, and enable, advancements in materials research and disruptive technologies. But identifying and developing relevant applications for materials advancements requires a broader set of knowledge and skills, the kind of expertise that architects can offer in critically assessing opportunities in the built environment.

At the very least, collaborations that include architectural expertise in materials science research can only be beneficial in addressing some of the problems that are unfolding around us. Many global challenges, such as climate change, can be directly linked to our buildings and their operation. Even if such collaborations do not directly result in the production of novel material technologies for our projects today, or tomorrow, we need to lend our vision to the creation of innovative solutions that might be made possible by emergent materials. But we should also keep in mind that achievements in materials research, regardless of whether or not they result in commercialized products, will always serve as enabling technologies. Eventually, they will impress their worth upon the means of architecture, and it will be difficult for architects to avoid the encouragement to remain relevant. If we look at the long trajectory of digital technology in architecture, and its rapidly expanding role in the conception and execution of architecture over the past 30 years, today, it is not uncommon for architects to be engaged in activities that were once called the work of a "programmer." Let that serve as a recent example of how interdisciplinary collaboration shaped architectural practices and continues to contribute to the ongoing evolution of the field.

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Q + A

Liat Margolis *with Sneha Patel*

LIAT MARGOLIS is a landscape architect, researcher and Assistant Professor of Landscape Architecture at the University of Toronto. She is also the principal investigator of GRITlab (Green Roof Innovations Testing Laboratory), where she examines the environmental performance of green roofs, green facades, and solar technologies. Liat Margolis is the co-founder and former director of Harvard Graduate School of Design's Materials Collection, and former director of research at Material ConneXion, Inc., in New York City. She is the co-author of the book *Living Systems: Innovative Materials and Technologies for Landscape Architecture* (Margolis 2007). More broadly, Liat Margolis's research focuses on the knowledge transfer of multi-performance materials and technologies across disciplines, particularly in relation to performative landscapes as urban infrastructure. She received her Bachelor's degree in Industrial Design from the Rhode Island School of Design and a Master's in Landscape Architecture from Harvard's Graduate School of Design.

As the former director of research at Material ConneXion and the Harvard Graduate School of Design's Materials Collection, Liat Margolis has spent a number of years critically assessing the changing conditions of materiality in the design fields. She discusses these conditions in relation to material taxonomies, technological transfer, and material invention. Her work considers the systemic, cyclical, and changing behaviors of the environment to develop innovative proposals for critical concerns such as water scarcity and energy usage. While deeply invested in the technical data and research that can be derived from instrumentation and testing protocols, Liat Margolis also argues for the broader cultural, social, and geopolitical issues inherent in her work more generally.

Green Roof Innovation Testing Laboratory (GRITLab) *Panoramic view of green roof instrumentation at the John H. Daniels Faculty of Architecture, Landscape and Design—University of Toronto. (Courtesy Liat Margolis)*

Q1. Sneha Patel: You have written that design innovation today is reliant on our current condition of material "hyperchoice" (the emergence of more and more material options) and technological knowledge transfer that is predicated on a cross-disciplinary exchange between design and other fields. Can you expand upon what you see as the pros and cons of a continuously expanding material palette in architecture? How do you define the role of cross-disciplinarity in architecture and what do you feel are its biggest advantages and disadvantages for the future of design practice?

A1. Liat Margolis: I would like to preface my response by placing "hyperchoice" in a longer historical context. Invention and innovation are inherent human desires and impulses. Those are evident in any historical time period and borne out of physical necessity, economic, and/or political values and an ongoing existential pursuit of meaning and beauty. The current condition of "hyperchoice" is innate and not any different than the seventeenth-century colonial obsession with collecting rare things from the New World. The difference in the twentieth and twenty-first centuries lies in the globalization of material production, which has led to a change in the scale and pace of transformation, an astronomical production volume, and widespread access. We no longer have to commission explorers to embark on life-threatening journeys to collect exotic goods, we simply type in the URL and credit card number.

In that sense, **one can argue that along with "hyperchoice" comes an increased loss of genius loci and local know-how.** For instance, the transfer of materials and technologies across climates and ecologies may overlook efficiencies that were once well understood. Yet, perhaps the more significant argument against "more" is the increase of waste as a result of the rapid de-vogueing of materials and the disinterest in material durability both on a physical and cultural level. As long as we are not obliged to pay for the embedded energy and life cycle costs, the insatiable desire for "new" and "more" will prevail.

On a positive note, **a culture that is invested in material invention and innovation is also synonymous with a thriving design culture.** One can look to Italy's furniture and product design legacy since the 1950s as an example and find a parallel co-evolution with the most advanced research in plastics. The same material technologies and design ideas then manifested in the 1960s architectural visions of modular cities and inflatable structures. **The exciting aspect of rapid developments in material technologies is the ongoing adaptation from one sector to the other, which changes the theoretical and practical capacities of a discipline.**

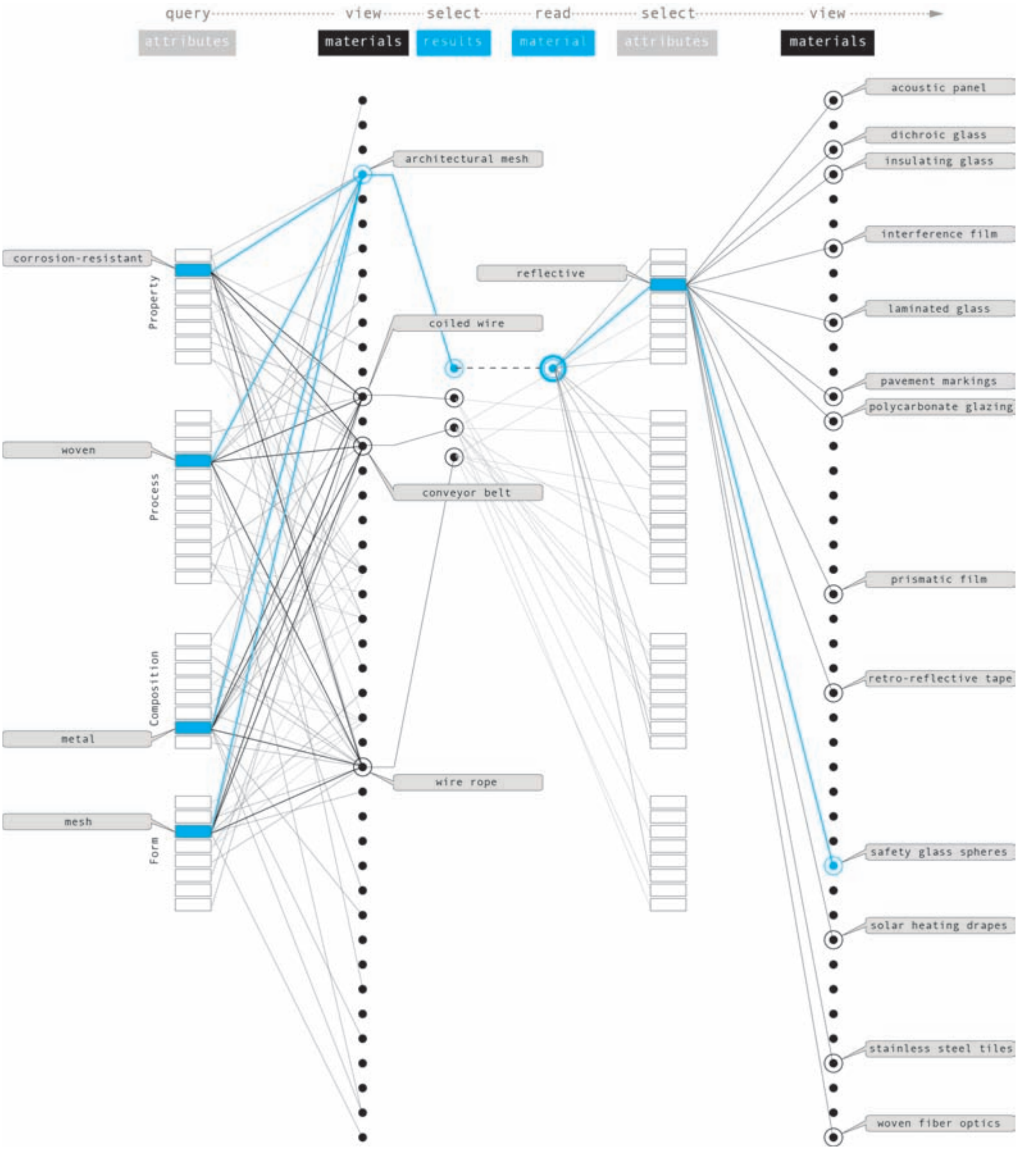
Technological cross-pollination is also part of collaborative practice. Most design projects constitute a multidisciplinary team with an ever-expanding range of expertise from anthropology to geology to finance. The academy has also followed this model by introducing students to a range of peripheral and complimentary subjects from ecology to real estate. However, cross-disciplinarity is much more difficult to achieve in academic practice than in professional practice. This challenge is a product of institutional protocols (such as tenure, peer-review, accreditation, amongst others). **In my experience, the establishment of a research platform through government and academic grants (based on an applied science model) is one successful mechanism that facilitates a diverse group of expertise to plug in, exchange knowledge, draw field-specific findings and disseminate accordingly.**

Materiality is conceived as a process, a life cycle, sets of related and contingent metadata.

> **Q2. Sneha Patel:** In your essay "Encoding: Digital and Analogue Taxonavigation" in *Material Design: Informing Architecture by Materiality* (Margolis 2011: 148–163), you define material as both matter and meaning. This definition allows a far more mutable context for materials in architecture that encompasses a wide-range of behavioral, cultural, physiological, political, and ecological attributes (amongst others) as well as commonly understood physical characteristics. As material meaning can be re-contextualized in these ways, what do you feel are the most relevant thematic streams that are informing how we project meaning upon materials today?

A2. Liat Margolis: **I would classify the interest in materials today into three categories: moral code, sensorium, and technophilia.**

The *moral code* category refers to the widespread discourse on sustainability and social responsibility, which includes a comprehensive evaluation of environmental and cultural impacts. This category also has a technical imperative (energy efficiency, conservation, water management, zero-waste, biodegradability, toxicity, reuse) and emphasizes quantitative analysis. However, the pitfalls of this thematic stream are over-simplification (such as greenwashing or incentive programs), unfounded claims (pseudo-science) and



Material Taxonomy *Diagram of the Material Collection's database at the Harvard Graduate School of Design. (Courtesy Liat Margolis)* a misalignment with aesthetic and formal issues. In the context of social responsibility, material specification is often prescribed as a *vernacular redux* that can offer a solution for job creation and economic empowerment, as well as a means to preserve cultural traditions.

The *sensorium* category includes six subthemes: (1) pattern and ornament, (2) optical effects, (3) ephemeral or atmospheric materiality, (4) responsive materials, (5) green walls, vertical landscape, and "bio-machine," and (6) anti-material.

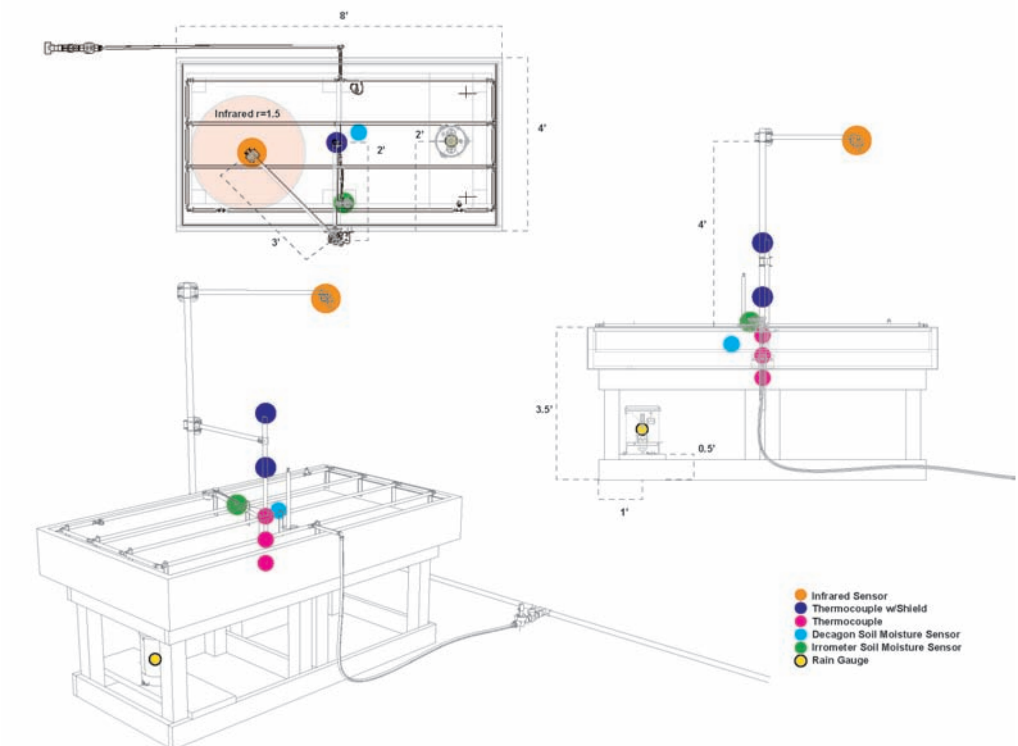
The *technophilic* category is primarily characterized by digital fabrication and material assemblies. While the emphasis is on geometry as spectacle, this interest certainly overlaps with the *sensorium* subthemes in terms of the production of effects. The digital capacity for "infinite customization" has redefined the conventional understanding of material as a commodity form (i.e. standard dimensions). Customization also overlaps with the interest in parametric construction software as well as sensor-embedded responsive and interactive environments.

In this sense, materials are recognized as sets of properties that are interchangeable in the planning phase, or adaptable once applied.

> **Q3. Sneha Patel:** An expanding materialist discourse has been shaped by increasing experimentation with materials as integral to the design process. Rather than specifying material products at the end of a design process, more and more practices are utilizing material investigations, and testing protocols are critical tools within the design process. Can you expand upon the role of an experimental set-up in your work and its utilization as a part of a feedback loop in research and design?

A3. Liat Margolis: My current work at the University of Toronto focuses on the validation of environmental performance. In particular, I investigate green roof, green wall and solar photovoltaic technologies. **The Green Roof Innovation Testing (GRIT) Laboratory was launched in context of the 2009 Toronto Green Roof Bylaw and its construction guideline. The primary question that the lab investigates concerns the efficiency of the guideline relative to stormwater management and evaporative cooling.** While Toronto sets an example by being the first city in North America to legislate the construction of green roofs (on any new construction above 2000 square meters), it never physically tested the green roof construction guideline in context of its regional climate, but instead copy-pasted those from different climate regions and only modeled those theoretically.

GRITLab includes 33 test beds that compare four contested components: growing media types, depths, plant communities, and irrigation regimes. Each bed is equipped with eight sensors (for a total of 264 sensors), which measure soil moisture, runoff, and temperature in real time. These datasets are compared to a weather station climate data (solar, temperature, precipitation, humidity, and wind) that is installed on site.



GRITLab Instrumentation *Diagram of the Green Roof Innovation Testing Laboratory (GRITLab) sensors configuration. (Courtesy Liat Margolis)*

The study has three objectives. Firstly, the data acquisition and statistical analysis is anticipated to inform Toronto's Green Roof Bylaw guidelines as well as the Green Roof Professional (GRP) training through Green Roof for Healthy Cities (an industry association). Secondly, the research lab is conceived as a cross-disciplinary educational model where landscape architecture students gain hands-on experience and training from a range of expertise from biology to soil science, hydrology and thermodynamics, building science and statistical analysis, irrigation, and computation. The third objective is concerned with the development of an evaluation tool (i.e. a downloadable app), which is transferable to any climate context. In other words, **the findings of this study are only applicable to a specific climate context. However, the experimental design and evaluation tool will address a bigger question concerning the validation of claims, codes, and the efficacy of implemented projects over time.** Once a green roof is inspected, the city has no right to enter the approved private property and monitor its green roof's longevity, let alone its performance. Embedded sensors and remote monitoring may prove to be the next trajectory in design to accurately quantify the cumulative effects of green infrastructure.

In the context of my current research work ecology pertains to the study of biological entities and processes, such as plant growth, biodiversity (biomass distribution) and the relation to species habitat, specifically insects, pollinators, and birds.

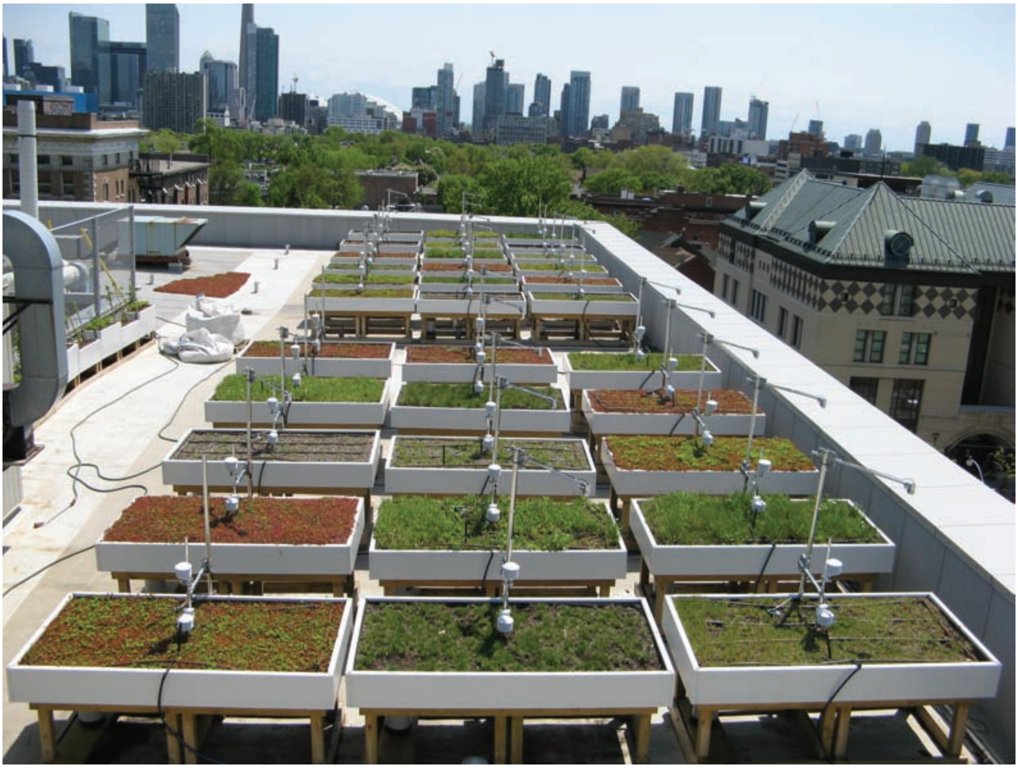
Q4. Sneha Patel: As the former Director of Material Research at Material ConneXion, a materials library and consulting service founded in 1996, you assisted in establishing a new model of classification for material collections. As part of this, you describe the importance of "lexical ambiguity" within material classification today, and providing nonlinear, relational formats of categorization. Furthermore, you have written that "an important objective of the accretion of material taxonomy is the appropriation of terminology to generate metaphors for design operations (Margolis 2011)." What are some useful terms and/or descriptors that have provided operative clues within particular projects you have undertaken?

A4. Liat Margolis: About four years ago, my colleague Aziza Chaouni and I began to research the ways in which design has addressed water scarcity, particularly in the extreme conditions of arid and semi-arid climates (Chaouni and Margolis 2010). As part of our exhibition and symposium titled *Out of Water*, we surveyed case studies from around the globe, ranging in scale, technique and materiality, expertise, budget, energy consumption, management and geopolitical context. **In order to comprehend the complexity of water and its presence in our built environment, we developed a new lexicon for water**.

When water is scarce, wastewater, saline water, and vapor from humidity become resources. Hence, water has a relative meaning; one that is contingent upon availability, technology to collect, treat, and distribute it and the means (economic and political) to do so. The lexicon includes the range of water qualities, physical states, and hydrological context (i.e. river, lake, ground water). It also included its secondary intended uses (such as irrigation) and points to the difficult, and at times contentious questions of water allocation, consumption rates, management, ownership, access, and human rights.

Each case study was classified according to its primary operation relative to water: "collecting" (*water supply and storage*), "converting" (*water quality*), and "distributing" (*water delivery networks*). Under "collecting", projects ranged from topographical landforms for water catchment to architectural facades and vapor collecting devices; under "converting", projects ranged from desalination to subsurface wetlands; and under "distributing", projects included regional, national, and trans-border water distribution.

Another aspect of our research concerned the definition of water infrastructure as the intersection of technology and management at various scales. First, we discovered that water scarcity is a symptom of a variety of factors, which not only include climatological conditions, but also anthropogenic ones, such as water diversion, over-consumption,



GRITLab In-situ *View of green roof instrumentation at the John H. Daniels Faculty of Architecture, Landscape and Design—University of Toronto. (Courtesy Liat Margolis)*

deforestation, unsustainable agriculture, contamination, failing infrastructure or the lack thereof. Current discourse on water management critiques the prevalent separation between water infrastructure and urban environments and argues for a heightened level of resilience and functionality (environmental and social) through adaptive and flexible solutions (Masoud and Margolis 2011).

Q5. Sneha Patel: While the complex issues of sustainability within design practice definitively include environmental issues such as stormwater runoff, flooding, climate control, and energy conservation, a problem-solving approach alone typically does not allow the disciplines of design to speculatively engage these issues toward future innovation. In her article "*Nevermind All That Environmental Rubbish, Get On With Your Architecture*," (2009: 24–29) Penelope Dean describes the danger of a prevalent acceptance of "green architecture" as a "techno-science." Beyond this narrowed focus on quantitative aspects of material performance and product specification alone, how can design redefine sustainability to include issues of poetics, experience, and interactive engagement?

A5. Liat Margolis: I agree with Dean's cautionary statement and aversion to jargon and insincerity; however, **I do think that the expanded field of landscape and architecture includes a diversity of streams and pursuits, some of which are more invested in *techne* and some of which are more invested in *poesis* and even some that explore ways to merge the two.** The design fields have the capacity and obligation to master technical knowledge and continue to question the products and techniques that are championed by industry. Material ConneXion, Inc., for instance was founded specifically to fill the communication gap between design, materials science, and manufacturing. Likewise, the publication *Material Design: Informing Architecture by Materiality* (Margolis 2011) features design-research works by architects such as Toshiko Mori, Nader Tehrani, Sheila Kennedy, and others who demonstrate how the technical investigation of material properties is directly linked with aesthetics, tectonics, and experience (passive or interactive). **I therefore find the suggested schism between the technical and poetic aspects of environmental agenda problematic.**

Two examples of current works relating to this come to mind. The first is the 2012 conference at the University of Southern California titled *r{AIR}efied futures*. Featuring the Canadian artist An Te Liu, the architects Tom Wiscombe and Philippe Rahm, the conference compares the "utopianism of indoor-outdoor living" that emerged in Los Angeles in the twentieth century due to its "presumed proto-medicinal atmosphere and climate" with today's strategies to mitigate inescapable dust and smog. It examines architecture's role and form relative to the treatment or conditioning of atmosphere.

The second is an upcoming book titled *Immanent Natures: The Laboratory as a Metaphor for Architectural Production* (working title) by the University of Michigan Professor Amy Kulper. As described by Kulper, the book explores the "conceptualization of the natural world in the context of a discipline whose divided institutional legacy frames the natural either as an applied science or a fine art. These questions are lodged in an artificial distinction, and emanate from a desire to craft alternative narratives for the influences of science and scientism on architectural discourse." Kulper compares the nineteenth-century invention of the term "taxonomy"—as a "rubric under which the detailed classification of the natural world aligned itself "—with the contemporary appropriation of scientific terminology as a generative design technique. She cites examples from UNStudio's *Design Models* to Herzog and De Meuron's *Natural History* to FOA's *Phylogenesis*.

Both examples I would argue, point to a very significant, yet not new relationship between design and nature, or technology and poetics that is absolutely relevant toward the formation of architectural narratives.

"EMERGENT" TECHNOLOGIES are complex systems that exhibit patterns (e.g. weather phenomena, social media, etc.).

Out of Water *Photograph from the Out of Water Exhibition held at John H. Daniels Faculty of Architecture, Landscape, and Design in April 2011 in conjunction with a conference of the same name. Out of Water is a response to the looming challenge of water scarcity. (Courtesy Aziza Chaouni and Liat Margolis)*

> **Q6. Sneha Patel**: Your co-authored publication, *Living Systems: Innovative Materials and Technologies for Landscape Architecture* (Margolis 2007) recognizes an increased interest in landscape within the field of architecture. In it, you provide a deeper understanding of the operative potential within landscapes as dynamic systems, inherently adaptable to the cyclical processes of natural systems. How do you feel this understanding of landscape can facilitate a new role for materiality within architecture and landscape architecture?

A6. Liat Margolis: In *Living Systems* landscape materiality is described as a dynamic and cyclical process, whose materials, whether natural or constructed manifest a set of attributes that are transformed by environmental (biological, climatological) occurrences. **In other words, landscape materiality can be described as a continuum of environmental cycles.** For instance, the materiality of a standard urban street does not only come to support a circulation network, but also as a hydrological network and a thermodynamic network

Out of Water *Photograph from the Out of Water Exhibition; the exhibition constructively re-imagines urban futures through the use of innovative water technologies for collection, treatment, and distribution of water in arid climates. Out of Water showcases speculative scenarios for a new water culture in arid climates envisioned by a select group of young architects, landscape architects, material technologists and urban planners. (Courtesy Aziza Chaouni and Liat Margolis)* (vegetation cover and associated evaporative cooling impact urban heat island effect and ultimately energy consumption, impervious and pervious surfaces contribute to stormwater runoff management). **The significance of landscape materiality is its multiscalar implications.**

This definition of landscape materiality is meant to expand the professional code of construction and material commodities (i.e. paving, fencing, planting, water features). *Living Systems* suggests the development of a parallel code that would outline material properties relative to the management of environmental systems. Granted these qualifications have become codified through LEED, however, such guidelines and incentives target the material specification phase of design as opposed to the conceptual phase. *Living Systems* opens up a question concerning the formal and aesthetic vocabulary associated with performance and links the ecological scale of the region with the architectural scale of experience. **The interest in environmental systems is most productive in my opinion in the blurring between architecture and landscape, both now describing a broader sense of materiality—a zone of interface with environmental systems.**

The things that matter most in my practice are education, exchange of ideas, creativity, curiosity, fun.

Further Reading

www.oowproject.com

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PROJECTS

Material Elements

Bloom is made primarily out of a smart thermobimetal, a sheet metal that curls when heated; the form's responsive surface shades and ventilates specific areas of the shell as the sun heats up its surface. (Courtesy Doris Sung)

Bloom **November 2011–August 2012**

Doris Sung
DOSU Studio Architecture, University of Southern California in collaboration with Ingalill Wahlroos-Ritter and Matthew Melnyk

A sun-tracking instrument indexing time and temperature, *Bloom*, stitches together material experimentation, structural innovation, and computational form/pattern-making into an environmentally responsive installation. The form's responsive surface is made primarily out of 14,000 smart thermobimetal tiles, where no two pieces are alike. Each individual piece automatically curls a specified amount when the outdoor ambient temperature rises above 70°F or when the sun penetrates the surface. The result is a highly differentiated skin system that can smartly shade or ventilate specific areas under the canopy without additional power. For demonstrative purposes, peak performance of the surface is designed for Spring Equinox 2012.

This proof-of-concept installation demonstrates the efficacy of thermobimetal as an exterior building surface serving one of two functions. The first involves the bimetal's potential as a sun-shading device that dynamically increases the amount of shade as the outdoor temperature rises. The size, shape, and orientation of the tiles are positioned strategically to perform optimally to the relative angle of the sun by use of advanced modeling software. The second function for the bimetal is to ventilate unwanted hot air. By optimizing the contortion of individual bimetal tiles, any captured heat would trigger the surface tiles to curl and passively ventilate the space below.

Bloom proposes a sustainable, passive method of reducing reliance on artificial climate control systems and, ultimately, waste of valuable energy by using available shape-memory alloys.

Bloom was installed at the Materials & Application Gallery in Silver Lake, California.

www.dosu-arch.com

Project Collaborators Design Team: Dylan Wood (Project Coordinator), Kristi Butterworth, Ali Chen, Renata Ganis, Derek Greene, Julia Michalski, Sayo Morinaga, Evan Shieh Construction Team: Dylan Wood, Garrett Helm, Derek Greene, Kelly Wong (Core Contributors), Manual Alcala, Eric Arm, Lily Bakhshi, Amr Basuony, Olivia Burke, Kristi Butterworth, Jesus Cabildo , Shu Cai, Ali Chen, Taylor Cornelson, Erin Cuevas, Matt Evans, Chris Flynn, Renata Ganis, Bryn Garrett, Ana Gharakh, Oliver Hess, David Hoffman, Alice Hovsepian, Casey Hughes, Ross Jeffries, Justin Kang, Syd Kato, Andrew Kim, Glen Kinoshita, Ingrid Lao, Jennifer MacLeod, Max Miller, Mark Montiel, Laura Ng, Robbie Nock, Raynald Pelletier, Elizabeth Perikli, Nelly Paz, Evan Shieh, Hector Solis, Raven Weng, Leon Wood, Tyler Zalmanzig.
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This work is part of ongoing PhD research conducted at the Tokyo University of the Art in the development of architectural forms based on nanotechnology and 3D textiles. Experiments in nano-textiles include studies of moisture content (20 percent shown) and corresponding geometric configurations. (Courtesy Klaudia Biala)

Nano-Textiles and Architectural Form 2009–ongoing

Klaudia Biala
PhD Research, Architecture Department at Tokyo University of the Arts grandma*LAB*

It is fascinating that the ancient technique of interlacing fibers, or weaving, can be easily used to make a textile anywhere in the world, yet our latest technologies and calculation methods are unable to predict and decipher the structural complexity of this same textile. Traditional craft techniques continue to inspire and teach us, and comprise an essential component to meaningful innovation. As we enter the Nano Age, we are faced with questions of how to design at smaller scales in collaboration with science and biology, and using speculative yet fascinating new ways of manufacturing and making. This study investigates nanotechnology combined with traditional weaving techniques, especially multi-layer weaving, to simultaneously create a skin, a structure, and a form.

At the nanoscale, the introduction of tiny atoms and molecules is often too small for most hosts to notice and reject, therefore the properties of the host can be altered. The example shown, explores the introduction of nanoparticles that allow the host, in this case polyester fibers, to act and react to the moisture content of the environment. The host-fibers are then woven using the technique of multi-layer weaving so that they can expand into 3D shapes. Strength and fire resistance are achieved by complexing these fibers with others, such as encased hemp and aramid. As the fibers react to the moisture in the environment they elongate and shrink and interact with the other fibers to form and shape a dynamic structure.

This process allows us to move away from manufacturing methods based on assembled parts and instead move toward printing whole objects seamlessly, atom-by-atom and molecule-by-molecule. This research provokes that the scale of thinking has shifted; in architecture this could eventually mean moving away from the need for divisions between structure, building skin, and materials.

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www. grandma*LAB*.blogspot.com

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This project was financially supported by The Japanese Government Ministry of Education, Culture, Sports, Science and Technology (MEXT) and The Canada Council for the Arts.

BlingCrete. Close-up view of mockup (glass and concrete) in random pattern, green matrix (Photo: Boris Trenkel); Magnetic Positioning of Concrete [computer simulation]. (Courtesy Klussman, H., Klooster, T., and Winkler, C.)

BlingCrete—Light-Reflecting Concrete October 2009–September 2011

Thorsten Klooster
Task Architekten, University of Kassel Visual Arts and Architecture

Heike Klussmann
University of Kassel Visual Arts and Architecture

BlingCrete represents a new genre of materials with its own logic of effect that cannot be described simply in terms of the usual categories of heavy and light or form, construction, and surface. It is a material admitting the creation of subtle surfaces that manage to mediate between material and light and thus indirectly refer to the relationship between mass and surface. These surfaces do not represent a static energy state, but rather permit a flowing transition to formulation and set the architecture in motion. Despite their "flatness", the 2D surfaces made of this material create a 3D illusion. The visitor's vantage point, normally perceived as the "interior facing the exterior" or vice versa, is called into question due to this doubling.

The material, also known as light-reflecting concrete, combines the positive characteristics of concrete (fire safety, solidity, building methods) with those of retro-reflection. Retro-reflecting surfaces send incoming rays of light (sunlight or artificial light) back precisely in the direction of the source of light. This optical phenomenon is produced by embedding glass microspheres in the substrate material. Crucial for the reflective power are the roundness, clarity, and refractive index of the beads, as well as the bond between the glass microspheres and the substrate. The dialog with light, lastingly integrated by the combination of materials, creates the dematerialized aesthetic.

BlingCrete transforms any ordinary space into a highly immersive or interactive environment by low-tech analog modes. It may be regarded as an analog interactive surface.

www.blingcrete.com

Project Collaborators: Hering Bau GmbH & Co. KG; Clemens Winkler, Roman Polster, Negar Jahadi Rafigh, Pat Taylor, Luzia Rux, Jan Juraschek (University of Kassel Visual Arts and Design); Prof. Arno Ehresmann, Dr. Dieter Engel (University of Kassel Institute of Physics, Thin layers/Synchroton Radiation).
Thanks to The German Federation of Industrial Research Associations AIF c.V. (funding agency), the Federal Ministry of Economics and Technology BMWi, and the Ernst Schering Foundation.

Latent Shift is part of ongoing research on the use of phase change material in architectural application. Prototypes developed include continuous core panels that isolate the PCM from its polyester substrate, allowing the material to visually exhibit shifting and variable properties in response to temperature changes. (Courtesy Rashida Ng and Sneha Patel)

Latent Shift **2008–ongoing**

Rashida Ng
Temple University Tyler School of Art, SEAM*Lab*

Sneha Patel
Temple University Tyler School of Art, SEAM*Lab*

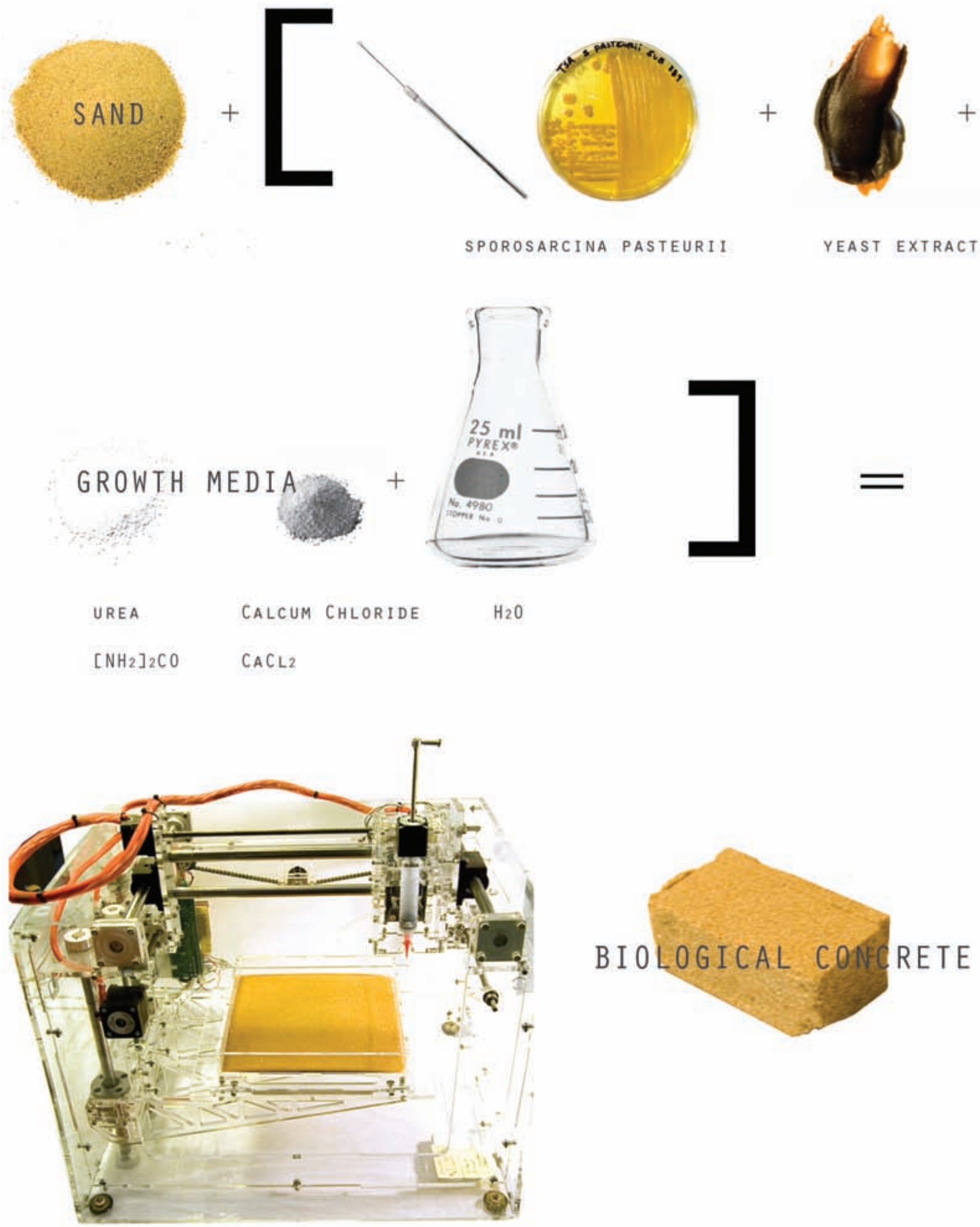
Latent Shift is an ongoing research project that interrogates the potential of phase change material (PCM) to exhibit variable behaviors. It includes a series of prototypes that explore the utilization of PCM within a building façade to produce a passively adaptive system. PCM can significantly improve the thermal performance of buildings due to its ability to store, absorb, and release high quantities of latent heat. Furthermore, the visual properties of PCM shift from clear and transparent to translucent white with each change of state, elucidating the exchange of energy and presenting a tangible model of energy exchange.

Given the amorphous physical nature of PCM, a primary design consideration for the panel prototypes was the challenge of containing the material while allowing for the efficient exchange of thermal energy and light. As such, the fabrication methodologies utilized were devised to both hold the PCM and maximize thermal conductivity, while also retaining daylight transmission values. The continuous core panel (CCP) prototypes allowed for isolation of the PCM from its transparent polyester substrate and utilized surface variations to create channels to house the PCM.

The prototypes explore the passive, yet dynamic, physical characteristics of PCM and provoke consideration that materiality itself can embody a more prominent position within the experiences of spaces. Rather than the minute and imperceptible expansion and contraction of steel, wood, or aluminum, the active change of state within a PCM façade visibly reveals a catalytic exchange of energy with the environment. With this future vision, architectural design and its multiple and complex priorities of spatial organization, occupation, aesthetics, form, and so forth are able to reconnect the building's performance to its experience, closing a gap that has too often relegated building technologies as concealed and estranged design concerns.

architecture.temple.edu
www.seamlab.org

Project Collaborators: Dr. Amy Fleischer, John McCloskey (Villanova University); Dr. Jon Zuo (Advanced Cooling Technologies); Brandon Kruysman, Marco Marraccini, Seth Wiley (Fabrication, PointB Design).
This research was financially supported in part by a grant from the Green Building Alliance in collaboration with the Pennsylvania Green Growth Partnership, an initiative funded in part by the Commonwealth of Pennsylvania, Ben Franklin Technology Development Authority, the Richard King Mellon Foundation, and the Heinz Endowments.



Biomanufactured Brick Material Equation illustration of materials and a modified "Fab at Home" Bench Top 3D Printer with aggregate bed used in the biomanufacturing process. (Courtesy Ginger Krieg Dosier)

Biomanufactured Brick 2005–ongoing

Ginger Krieg Dosier
American University of Sharjah, VergeLabs (Research in Architecture) and BioMASON

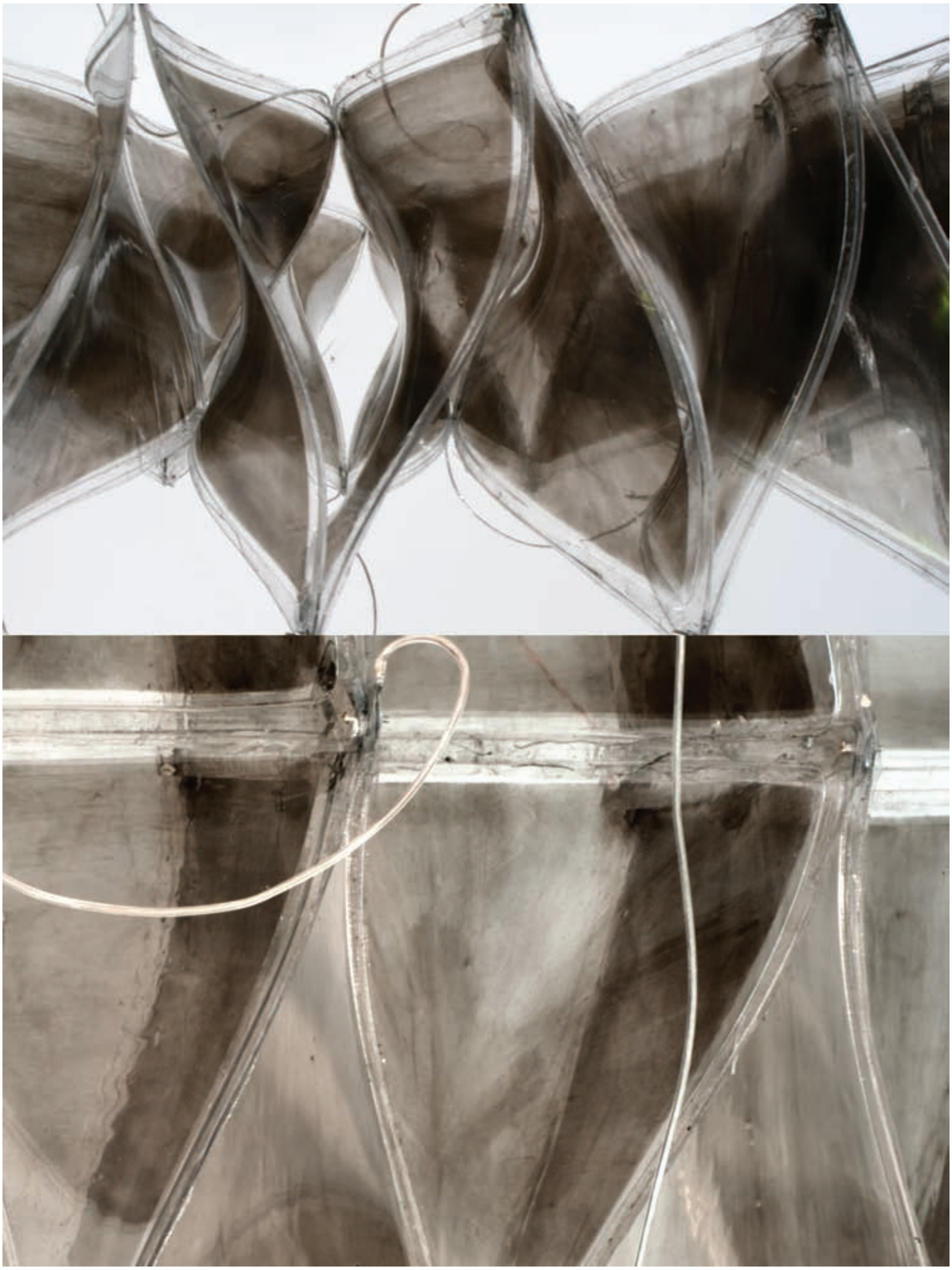
Traditional brick manufacturing requires the use of energy intensive processes for vitrifying clay particles into hardened materials. Its estimated brick production alone emits over 800 million tons of carbon dioxide each year. Simple organisms create hard mineral composites in ambient temperatures, such as coral and calcium carbonate shell structures. *Sporosarcina Pasteurii*, a nonpathogenic common soil bacterium naturally found in wetlands, has the ability to create a biocement material that can fuse loose grains of sand. A hardened material is formed in a naturally occurring process known as microbial-induced calcite precipitation (MICP). The material is made by mixing specific quantities of bacteria, urea, and calcium chloride in a matrix of aggregate, and allowing the biological and chemical reactions to take place. The resulting material exhibits a composition and physical properties similar to natural sandstone and takes a few days to complete. Current structural tests exhibit equal compressive strengths of clay-fired brick.

The proposed bioengineering method for growing architectural materials is pollution free, with a low embodied energy, and can occur in a range of temperatures between 10 and 50 degrees Celsius. As traditional brick construction is heavily dependent on burning natural resources such as coal and wood, this reliance results in increased carbon dioxide emissions and a greater dependency on limited energy sources. The introduction of a bioengineered building unit using aggregate and bacteria offers a natural, renewable, alternative that is locally produced and environmentally friendly.

Biological brick manufacturing can be achieved utilizing traditional casting methods, or articulated by digital tooling to fabricate layered units with a programmed material composition. The use of 3D printing technologies is economically driven as it generates little waste, accommodates a variety of potential materials, provides a high degree of accuracy, and allows for infinite variation. Employing bacteria to naturally induce mineral precipitation, combined with local aggregate and rapid manufacturing methods, this research seeks to define and commercialize a local, ecological, and economic building material for use throughout the global construction industry.

www.biomason.com
www.vergelabs.com

Project Collaborators: Michael Krieg Dosier (American University of Sharjah); Stephen Lokier (Petroleum Institute Abu Dhabi); Jose Bruno Barcena (North Carolina State University).



As the membranes are attached to flexible frames, due to the initial pre-stretching, the frame bends when the material is in its relaxed state. Once a high DC voltage in the range of several kilovolts is applied, electrical charges move from one electrode to the other and the film is squeezed in its thickness direction. (Courtesy Manuel Kretzer)

Shape_Shift **July–September 2010**

Manuel Kretzer
Chair for CAAD ETH Zürich, responsive design studio
Edyta Augustynowicz
MAS Chair for CAAD ETH Zürich
Sofia Georgakopoulou
MAS Chair for CAAD ETH Zürich
Stefanie Sixt
MAS Chair for CAAD ETH Zürich
Dino Rossi
MAS Chair for CAAD ETH Zürich

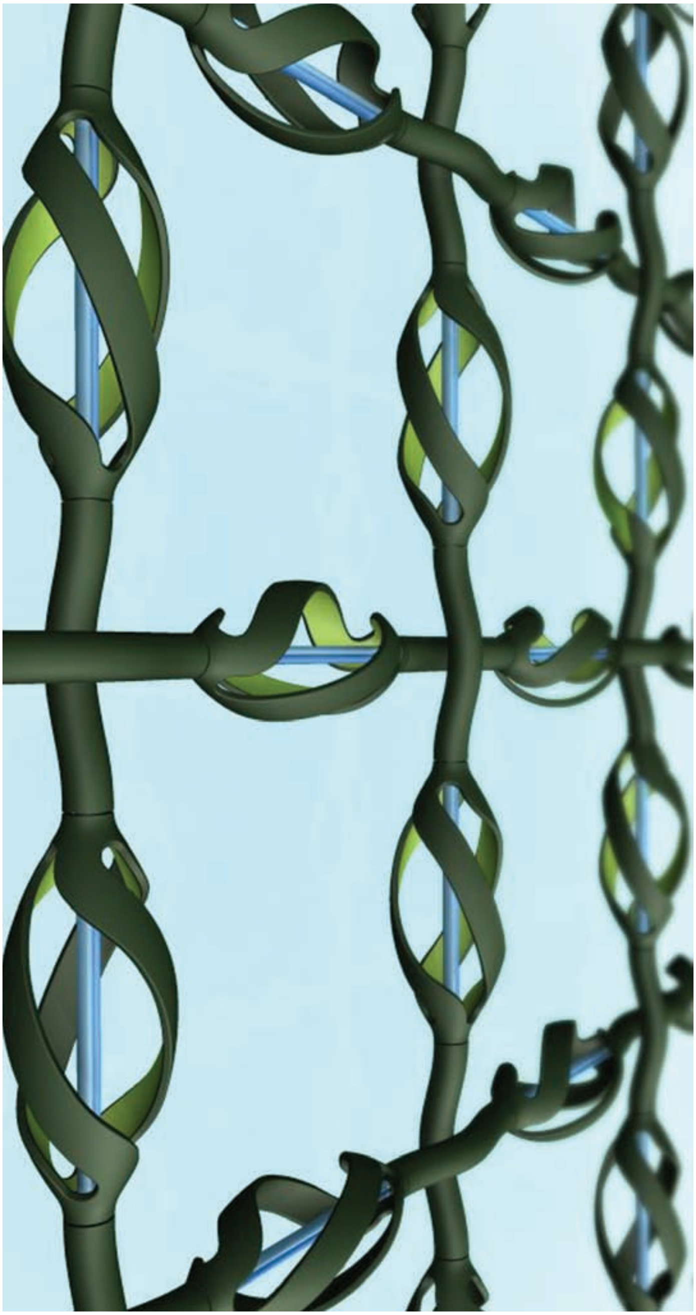
Shape_Shift proposes a new possibility of architectural materialization and "organic" kinetics. It is an experimental installation that explores the unique potential of electroactive polymers (EAPs) in an architectural context. EAPs are polymer-based actuators that convert electrical power into kinetic force and change their shape correspondingly. In *Shape_Shift* the distinctive material properties are used beyond conventional actuator replacement and become orchestrated for their aesthetic qualities. The component-based form results from the material's desire to return into its original shape combined with structural frames that were developed to allow an appropriate degree of flexibility. This minimum energy structure retains a variable stiffness, which allows for a variety of deformations within a given range.

Each element consists of a thin layer of stretched elastomeric film that is attached to an acrylic frame and sandwiched between two compliant electrodes. This is achieved through coating both sides of the film with conductive powder and insulating them with liquid silicon. Once a high DC voltage in the range of several kilovolts is applied, electrical charges move from one electrode to the other and the film is squeezed which leads to a planar expansion. As the membranes are attached to flexible frames, due to the initial pre-stretching, the frame bends when the material is in its relaxed state. After the voltage is applied the material expands and the components flatten out.

Owing to their large deformation potential, high response speed, extreme flexibility, lightness, transparency, and the possibility to tailor them to basically any size or shape, EAPs propose very promising opportunities for the creation of "active" architectural applications.

www.caad-eap.blogspot.com

Thanks to Prof. Dr. Ludger Hovestadt (Chair for CAAD, ITA, ETH, Zürich); Dr. Gabor Kovacs, Christa Jordi, Christian Duerager, Angelo Scioscia, Sebastian Valet (EAP Technology, EMPA Dübendorf); Leonhard Fünfschilling (IKEA Stiftung Schweiz).



Nano Vent-Skin. Micro-turbines generate energy from wind and sunlight creating a photovoltaic skin. (Courtesy Agustin Otegui Saiz)

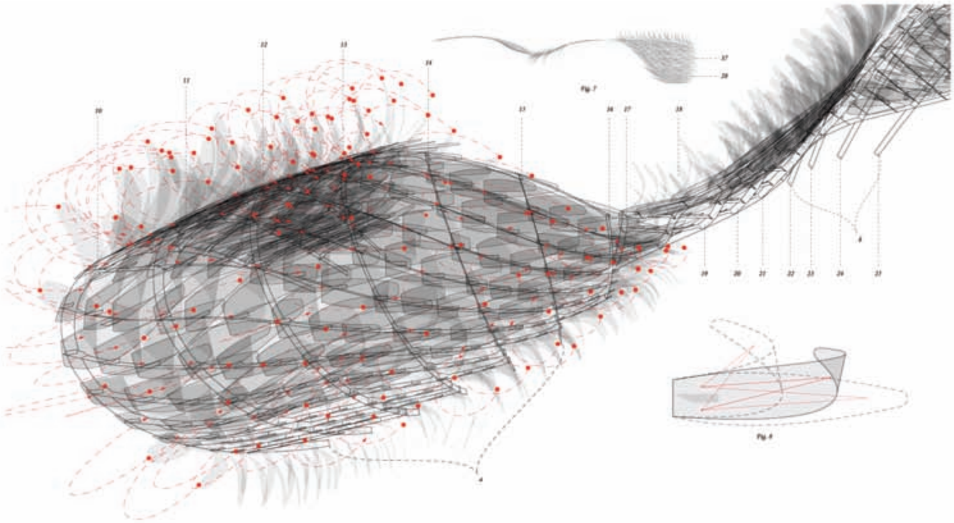
Nano Vent-Skin **February 2008**

Agustin Otegui Saiz
NOS Design Consulting, Universidad Iberoamericana

Nano Vent-Skin is a building skin made out of micro turbines which generate energy from wind and sunlight. For this speculative project, the outer façade of the structure absorbs sunlight through an organic photovoltaic skin and transfers it to the nano-fibers inside nano-wires which is then sent to the storage units on each panel. Each turbine generates energy by chemical reactions on each end where contact is made with the structure. Polarized organisms are responsible for this process on every turbine's turn. The inner skin of each turbine works as a filter absorbing carbon dioxide from the environment as wind passes through it. The turbine blades are symmetrically designed so if the wind direction changes each turbine adapts itself. Nano-bioengineering and nano-manufacturing are used to achieve an efficient zero emission material which uses the right kind and amount of material where needed.

Nano Vent-Skin works analogously to human skin. Every panel has four sensors, each with a reservoir. When a turbine fails or breaks, a signal is sent through the nano-wires to the central system and micro-organisms are sent through a central tube to regenerate this area through a self-assembly process. *Nano Vent-Skin* is not reshaping nature. It is acting as a merger of different means and approaches into energy absorption and transformation, which do not happen in nature. It takes advantage of an expanded knowledge of different species and resources and turns them into a joint, or bioengineered, organism. The result is a skin that absorbs carbon dioxide and transforms two of the most abundant sources of green energy on earth: sunlight and wind. This project aims to stimulate thought regarding the potential of utilizing the micro-scale toward sustainable means and as an application to existing buildings.

www.nos.mx



Reef consists of a series of translucent aggregated fins that filter light in a layered arrangement. A networked control system links the independent fins utilizing shape memory alloys in the form of wires. These nitinol wires provide for 160-degree range of motion for each fin; as the wires contract, the fins are pulled into curled positions. The Reef installation works in tandem with the Storefront for Art and Architecture façade to create interactive layers between private gallery and public sidewalk. (Courtesy Rob Ley and Joshua Stein; Photo: Alan Tansey)

Reef **2009–2010**

Robert Ley
Urbana, Southern California Institute of Architecture

Joshua G. Stein
Radical Craft, Woodbury University

Reef is the culmination of a research endeavor investigating the potential for emerging material technology to shape the public perception of the built environment through the activation of membrane and partition surfaces. Through the implementation of a full-scale construct at Storefront for Art and Architecture in New York, the public engages in the new social nuances revealed in an exhibition program redefined by exploding the perceived "wall" separating private and public space. Using responsive materials, a new definition of "wall" or "partition" generates a diverse range of porous and dynamic enclosures capable of producing sophisticated, flexible responses to the details of an existing program.

Reef investigates the role emerging material technology can play in the sensitive reprogramming of architectural and public space. Shape Memory Alloys (SMAs), a category of metals that change shape according to temperature, offer the possibility of efficient, fluid movement without the mechanized motion of earlier technologies. Operating at a molecular level, this motion parallels that of plants and lower level organisms that are considered responsive but not conscious.

Using an aggregation of 900 responsive shutters that form a singular surface, the installation negotiates the unique site condition of the gallery, imbuing the space with an identifiable personality while simultaneously affecting social and movement patterns both inside and outside the gallery.

Reef was installed at the Storefront for Art and Architecture in 2009 and at the Taubman Museum of Art in 2010.

www.urbanaarch.com
www.radical-craft.com

Project Collaborators: Timothy Francis, Jonathan Wimmel, Elana Pappoff (Design Team); Peter Welch, Daniela Morales, Travis Schlink, Joshua Mun, Darius Woo, Lisa Hollywood, Rafael Rocha, Yohannes Baynes, Phillip Ramirez (Fabrication Assistants); Pylon Technical (Motion control software and Custom Electronics); Active Matter (Interaction Concept and Development).
Thanks to Joseph Grima, Kimberli Meyer, Sara Daleiden, David Brown, César Cotta, Susannah Bohlke, Jim Hudson
Reef was financially supported by grants from the AIA Upjohn Award, the Graham Foundation for Advanced Studies in the Fine Arts, AIA Knowledge Grant, and IDEC Special Projects Grant.
This project was also made possible by the generous support and assistance of Dynalloy.

Q + A

Omar Khan *with Sneha Patel*

OMAR KHAN is an associate professor and Department Chair at the University of Buffalo's School of Architecture and Planning. As an architect and researcher, his practice addresses responsiveness and performativity, spanning the disciplines of architecture, installation/performance art, and digital media. He completed his post-professional studies at the Massachusetts Institute of Technology and his professional studies at Cornell University. In 1995 in collaboration with Laura Garofalo, he established **Liminal Projects**, a practice that has developed performance spaces for artists, interactive and responsive installations, domestic interiors, and award winning competitions. He is a co-founder and co-director of the **Center for Architecture and Situated Technologies** where his research explores transitive materials, responsive architecture, and pervasive computing.

Arguing for an expanded definition of performativity, Omar Khan explains his extensive research and design work in the realm of responsive architecture. Working with soft materials and dynamic structural logics, this work examines how interaction with and within material assemblies can enhance a holistic and enabled experience of space. By critically assessing some of the opportunities and limitations of technologies, the work aims to elucidate the potential of how these technologies can contribute to the reconsideration of social and technical boundaries within architecture.

Gravity Screens *(2010) Full scale gravity screen with different Shore elastomers. (Courtesy Omar Khan)*

Q1. Sneha Patel: In *Material Design: Informing Architecture by Materiality* (Schröpfer 2011), Sheila Kennedy describes your approach to the installation project *Open Columns* as "respite within the discipline of architecture, from the reductive terms of efficiency that have dominated the discourse …. The uncanny material elasticity of *Open Columns* and its rhetorical capacity to elicit conversation and provoke thought is clear …." How important to the project, and your work, generally, are the demonstrative properties of the material and its particular ability to stimulate a social response?

A1. Omar Khan: The choice of rubber in *Open Columns* was really in response to the pervasiveness of hard materials and mechanical movements—pivoting, tracking, scissoring—in architecture. Rubber's variable softness provided an opportunity to reconsider how response to large kinetic objects may be altered through sound or lack thereof, touch that gives rather than resists, and motion that stretches rather than extrudes. Hence the material choice was already framed within a larger set of performances rather than focused on basic material efficiency which probably would have led me to use rubber in a different way. As such, **my interest was not to demonstrate or represent what rubber as a material is, but to use it to do things like create silent motion, perform geometrical gymnastics like stretching and folding, and be reactive to touch and gravity. So I think the rhetorical quality that I am after is not didactic, that is teaching the viewer something about the material or material process, but more performative in that the material enables possibilities in which the viewer becomes complicit and hopefully enabled.**

One of the problems we have faced in pushing for a performative engagement with our work is in considering how to handle the details of assembly. Because we do not have a magic material that can handle all structural and formal contingencies, well considered connections are a necessary part of making robust assemblies especially if they have to move. However, if not handled properly details can draw unnecessary attention to themselves, distracting the audience away from the holistic experience of the space and focusing it on the specific connection. Our approach has been to subsume the detail into a larger pattern that draws the attention outward to the entire structure. For example, *Open Columns*' two colors (yellow and green) are both decorative and materially performative. The decorative aspect is the cohesive pattern that results when all the parts have been assembled, while the performative lies in the fact that the different colors are two rubbers of different hardness fused together. If the project lacked the decorative pattern that drew the perception to the whole, the columns would unnecessarily index their making, calling attention to the parts, and the fabrication of the rubber. I find that uninteresting although it is a strong trope in modern design and continues to be adopted in contemporary performative architecture.

Another aspect that I also try to avoid in the work is to register or index anything through the architecture. The height or movement of the columns do not index the carbon dioxide in the space. Viewing them over a day does not give you a history of carbon dioxide nor

Open Columns *(2007) This installation is a system of non-structural columns that reside collapsed in the ceiling of a space. They are made from composite urethane elastomers and can be deployed in a variety of patterns to reconfigure the space beneath them. (Courtesy Omar Khan)*

does it lend itself to optimizing the space for better management of carbon dioxide. **Like the occupants, the columns are simply acting in the space, changing their proportions through their occupancy and instigating new encounters.** Carbon dioxide, as a material, is not represented by the project but is used to perform in the space. I think many projects working with sensing systems unnecessarily want to open the black boxes and reveal things. I like working with black boxes and keeping them shut.

What materiality has borrowed for the digital is mutability: the characteristic of being more responsive to user and environmental interaction. For the digital we are seeing an expansion from cyberspace—virtual reality, screen space, computer memories—to real space.

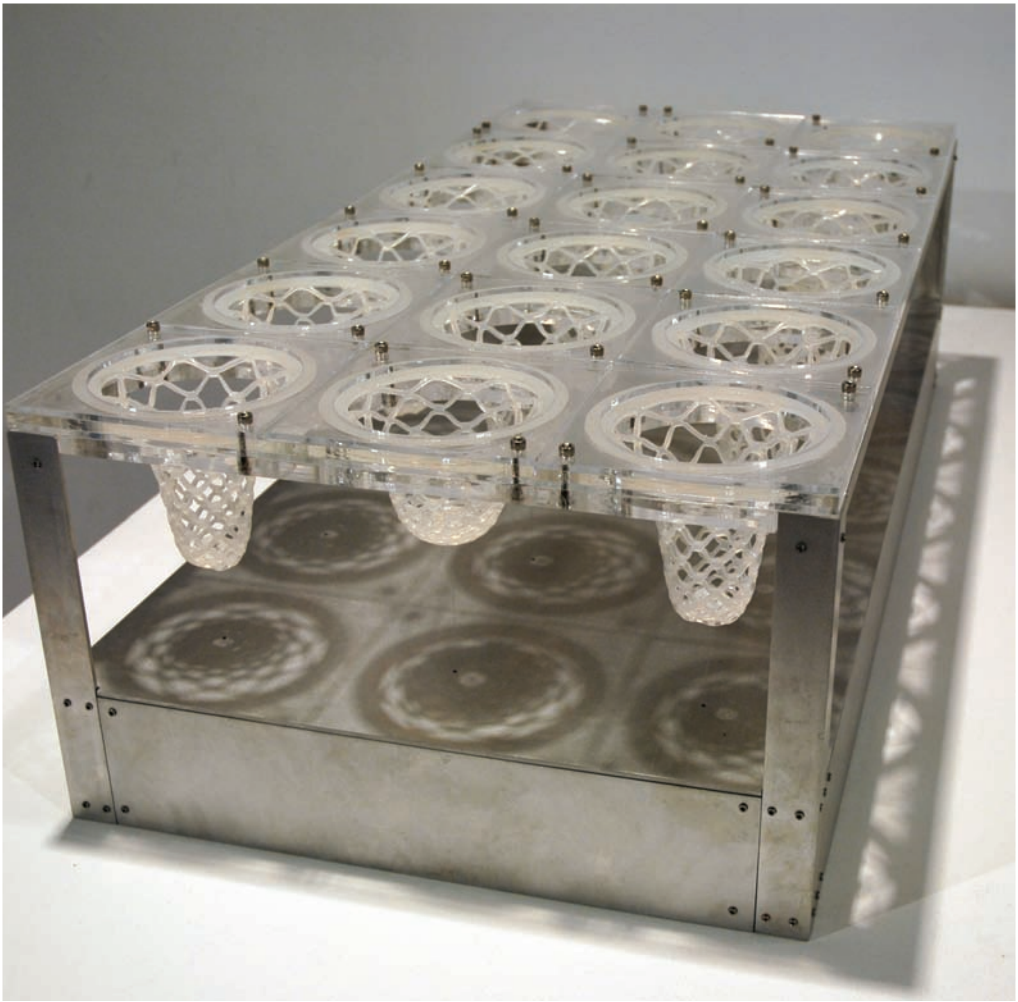
Q2. Sneha Patel: For the *Open Columns* project, you utilize self-similar or “relational” geometries to create rubber parts fabricated from a single reconfigurable mold. This process allows for precise and controlled physical components, yet the very nature or behavior of the rubber forms inherently provide for some variability based on gravity and properties of deformation. The rubber's elasticity makes for a predictable, yet inconstant construct. As you worked on this project, or other similar ones, can you expand upon how control and chance are factored into the process?

A2. Omar Khan: We began experimenting, primarily through trial and error, with elastomers in 2003. These experiments helped us understand the material and develop some best practices regarding measurements, mixing, mold-making, and fusing. By the time we started working on *Open Columns* in 2005 we had enough experience that we could be very deliberate and precise about the material's fabrication. We tried to resolve all potential problems through multiple prototyping. Yet the mutability of the material causes two identical pieces to perform slightly differently, even though their metrics are identical they stretch differently, one being about six inches longer. These subtle differences are perceptible and an inevitable result of working with such a variable material. However, we leave very little to chance because it would make the construction unmanageable.

That said, **chance is a fundamental quality of a successful responsive architecture. But it is meaningless if it is not taken as an opportunity to surprise the user and encourage serendipitous encounters. The problem with chance in interactive or responsive architecture is that it is understood as the unpredictable that happens to the design as opposed to the unprescribed that the design can help to construct.** In our work chance and control are not oppositional but different faces of the same coin. There is tremendous control in the design of *Open Columns*, from the way it is built to the software that runs it. The encounters that it encourages between people and its seemingly unpredictable actions in space are part of its design to foster chance.

A term that I have used frequently when describing such a method of design is "underspecification." You need to underspecify the program of architecture so that it can evolve with each new encounter. But to do this it has to be in control; it has to be able to perform and provoke actions. In other words, you want to underspecify the options of engagement but your architecture must provide adequate variety otherwise people will lose interest. One way to handle this is to make the occupants complicit in developing the variety as *Open Columns* does through its sensing mechanism. Another is to construct the response as a feedback and not rely simply on cause and effect. A third is to provoke complex material's behavior that can mutate the shape and create other spatial and phenomenal possibilities.

"Emergent Technologies" are nonexistent. Technologies do not emerge as if they were submerged in some subconscious. We do not believe in emergence, only in invention and construction which requires the instrument of design.



***Columns Homeostat** (2006) is a performative model to study the spatial performance of multiple columns. Different programs, like a cellular automata or prescribed choreography, can be run on the model. (Courtesy Omar Khan)*

Q3. Sneha Patel: In 2006, along with Mark Shepard and Trebor Scholz, you developed the on-going project titled *Situated Technologies*, focused on ways of embedding computational intelligence into the built environment. The project has resulted in symposia, publications, and exhibitions that bring together researchers and practitioners from art, architecture, technology, and sociology to examine how particular local and context-specific parameters influence the use and experience of developing technologies. Can you expand upon how this project came about? In what ways has the *Situated Technologies* project provided a sort of feedback loop for your own work?

A3. Omar Khan: *Situated Technologies* resulted from a need that Mark Shepard and I perceived was missing in architectural discourse about computing at the time. Ubiquitous computing which had shifted computing from the desktop/laptop to the built environment was just not on many architects' radars. Instead, engagement with computing was predominantly about CAD systems and how the models they produced could be exported into the built world through projections, rapid prototyping and computer fabrication. I suppose we are predominantly still there. But **we felt that pervasive computing—embedded, mobile, and networked—required consideration since it was altering the built environment without the input of architects and urbanists.** With the support of the Architectural League of New York and the inclusion of our colleague Trebor Scholz we initiated the project with a symposium titled *Situated Technologies*: *Responsive Architecture, Locative Media, Social Networking*. The subtitle proposed three investigative trajectories that we could identify at that time which could be influential on architecture and urbanism. They have proven to be prescient although there is productive leaking across those categories as more people begin to work in this area.

Situated Technologies remains the holistic umbrella within which I locate my own work. Through the pamphlets (Khan 2008; Beesley and Khan 2009), teaching in the *Situated Technologies Research Group* at the University at Buffalo and exhibitions, we have been able to explore a whole host of issues that elucidate the intersection of the information environment with architecture and urbanism. Salient issues include urban computing, emerging publics, interactive environments, and networked sociality.

Within the design process, research is a feedback system that requires us to get our hands dirty. We are very much interested in the imaginary of technologies: how they can contribute to rethinking the social and technical boundaries of architecture.

Q4. Sneha Patel: In *An Architectural Chemistry* (Khan 2011: 50–59), you describe an "aesthetic shift" inherent in moving from a mechanical approach to responsive architecture to a chemical one. When dealing with the chemical properties of materials at a molecular level, the aesthetics of mechanization are no longer prioritized. Do you feel this relates to a fundamental move away from overt formal expression? Does a responsive chemical architecture have particular aesthetic properties? If so, how is it described?

Open Columns *(2007) The column's components, laid out prior to installation. (Courtesy Omar Khan)*

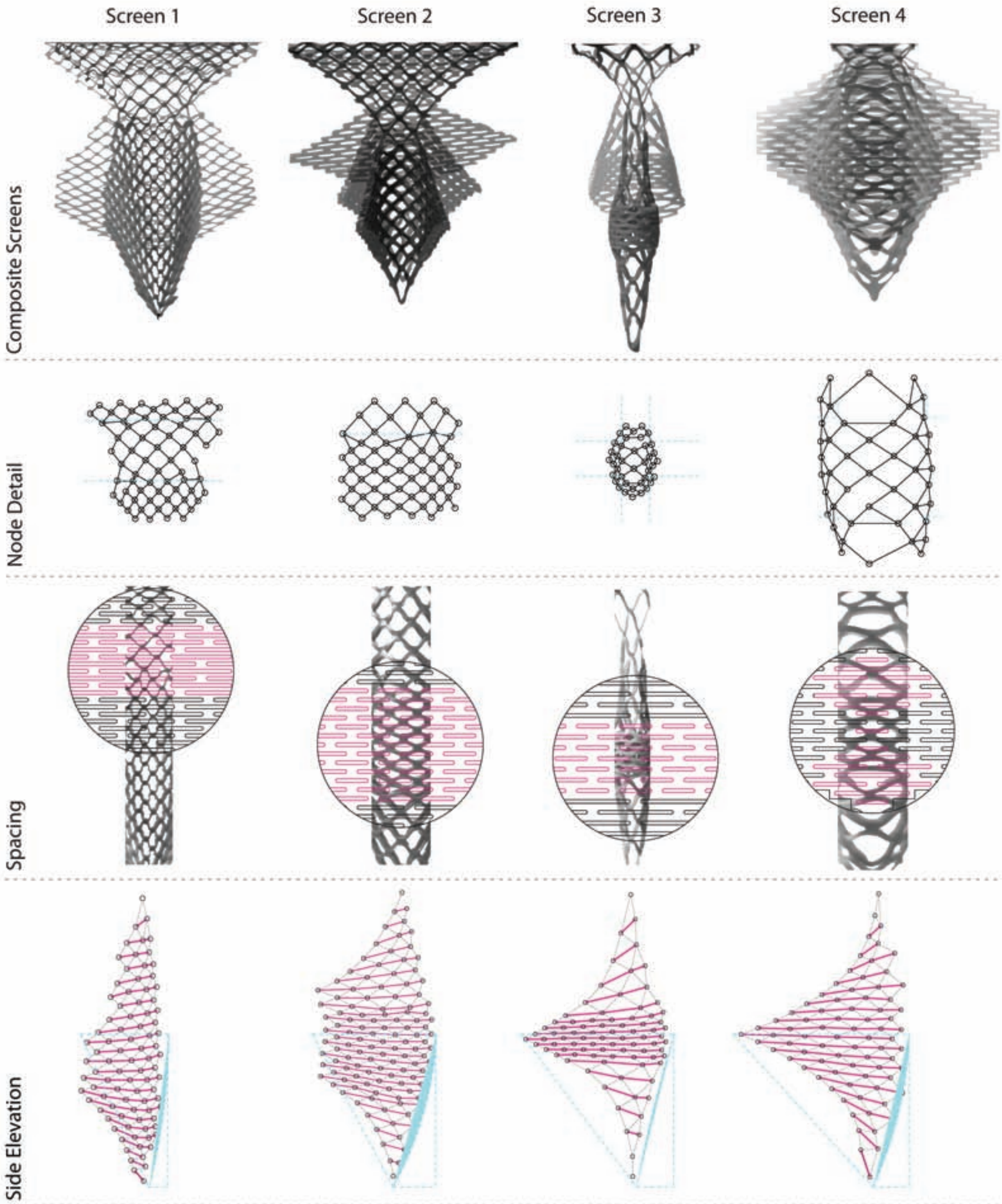
A4. Omar Khan: I do believe there are other aesthetic considerations when one works at the scale of the molecule. For one thing it changes how one defines the architectural detail. **The articulated detail is really a modern invention that purports to express a "truth" to materials. This is an aesthetic truth, which is valuable, but hardly a material truth.** What results from this is the modern aesthetic of self-revealing, celebrated through pronounced connections and formal gymnastics that articulate how things come together. In our case **the real detail is at the chemical fuse; where something goes from hard to soft or translucent to opaque.** The aesthetic ramifications for this are that mechanical connections between parts do not carry aesthetic significance hence it is best to subsume them. What is ultimately suggested by this approach to materiality is one of gradients and not cuts. Hard to soft does not transition through a connection (the modern detail) but through the material patterning. And therefore suggests a different set of criteria for material assembly.

The phenomenal factors that result from a chemical aesthetic are very difficult to represent. As singular materials that exhibit variable qualities, their performance within architecture confounds our ability to read them. They are black boxes and force us to consider what they are doing, or even better, what they could be doing rather than what they are or how they came to be. I think this is liberating.

Q5. Sneha Patel: You have noted the important distinction between the terms "performance" and "performativity"; "Performance involves the total gambit of acting/performing in the world including the social, political, technological, and cultural [and is] relative to a context …. Performativity is focused on measurable actions …. Right now architecture is interested in performativity; bolstered by concerns of energy conservation and sustainable materiality …." In what ways has the term "performativity" positively influenced how you have thought about and developed your work (Hannah and Khan 2008; Hannah and Harslof 2008)?

A5. Omar Khan: The precision in the way we make things is a matter of performativity. It is a technical term that deals with behaviors and plays a fundamental part in the way we think about information, materials and how they come together. Whether we are working with digital information or materials, it is the manipulation of their measures and metrics that helps us build the responsive systems that we are designing. This allows us to make them work in predictable and repetitive ways. However, as satisfying as that can be, the danger lies in letting that be the end. I think many projects suffer from this and we are not immune from trying to make a cool object that demonstrates that it works. But what can result is a very temporal experience and overly determined design that provides little rhetorical value. However, I do believe that if the parameters governing the performativity of a construction can be opened up, through interaction, sensing or some external information then that determinism can be undermined. I suppose what **I am arguing for is a means to tie performativity to the larger concerns of performance.**

I take my cue from cybernetics, an essentially dismissed epistemology within architecture, but needing a revisit if we do not want to reify the environment and separate it from all other aspects of human production. To separate the observer from the observed in this way is not productive.



***Gravity Screens** (2009) Studies of geometric deformation in elastomer screens from pull in a single direction. (Courtesy Omar Khan)*

deadmandancing *(2004) Collapsible towers made of elastomer (25 Shore)—perforated, solid, and embedded with metal—that explored the possibility of using rubber as a construction material. The installation was part of a dance performance, deadmandancing, by choreographer/dancer Koosil-ja Hang. (Courtesy Omar Khan)*

Further Reading

www.situatedtechnologies.net/
www.ap.buffalo.edu/cast
www.liminalprojects.com

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Chapter 3

Material Fabrications

Unikabeton Prototype *(Courtesy Per Dombernowsky and Asbjørn Søndergaard)*

fab·ri·ca·tion

• the act or process of inventing or creating[1]

1 *Merriam Webster's Collegiate Dictionary* (1995) 10^{th} Edition, Springfield: Merriam-Webster.

Making a Digital-Material Practice

Phil Ayres, Martin Tamke, and Mette Ramsgard Thomsen

The projective nature of architectural practice sustains one of the discipline's fundamental relationships—the relation between representation and realization, where it may be argued that this established relation is likely to remain because of the temporal succession that binds the making-of-intent to the making-of-artifact in an architectural context. This does not imply that the values, concerns, roles, and methods employed in the enactment of the relation are given and cannot be placed under continual scrutiny. The particular line of inquiry that CITA (Center for Information Technology and Architecture) follows within this territory concerns digital practice and the relations that can be established between it and the material world. We are concerned with how the digital challenges the way we think, design, and realize architecture through building. Our research is motivated by learning from existing practices of making and combining their underlying logics to the computational logics of a digital design space in order to search for extensions to these practices and the production of novel outcomes. Our research is conducted through a practice-based methodology, which is exercised through the construction of full-scale demonstrators.

This chapter elaborates upon CITA's current research concerns and practice through a re-presentation and reflective discussion of related trajectories of thinking developed and demonstrated in the making of four projects. The four projects were presented together in the exhibition called *digital.material* held at the ROM gallery for Art and Architecture, Oslo, in the spring of 2010. The motive for the exhibition was to explore and demonstrate how digital design practice is enabling a new culture of material thinking in architecture. The four full-scale demonstrators—*Reef Pattern*, *Thaw*, *Lamella*, and *Persistent Model #1*—presented investigations into, and propositions for, ways in which digital tools can be employed not only to reconsider core relationships between representation and realization in architectural practice, but also to examine how digital tools can enable extensions to existing material and craft practices and their associated logics of construction with a particular emphasis on material performance.

A Contemporary Architectural Relation to Material

The architect's modus operandi, certainly over the last 500 years, has privileged the use of representation over direct material contact (Kolarevic 2003: 57–58). As such, the status of representation has become that of essential intermediary for the proposition, testing, specification, and communication of projected spatial intent defined through material fabric and material organization. The architect's chosen methods of representation inscribe limited understandings of the world as abstractions, and therefore constrain (often in useful ways) the way we think about it, what we can think about it and what we propose for it within our design space (Hill 2003: 25). It follows therefore, that as we change our tools and methods of representation we change this design space, and by implication, it is inevitable that certain values and concerns will shift also.

The shift to digitally mediated practice could well be interpreted as a furthering of the protocols of abstraction already inherent within the tools and methods of the architect. In contrast to the continua of the physical world the digital operates to discreet units of time, with information represented by the reductive 1/0, on/off of binary code. It may therefore be considered somewhat paradoxical that digital means of investigation and representation have permitted the architect to gain a closer proximity to materiality, and yet this is precisely what certain branches of digital practice now afford. There are two principle areas in which computation permits this nearness to be established—representation and realization.

In terms of representation, computation permits dynamic attributes of materiality to be explicitly represented over time. This allows the designer to establish a new nearness to material in terms of representing its performance and investigating the roles that processes of realization play in manipulating and steering behavior at the scale of the material itself, the component, larger aggregations, and the interdependencies that exist between these scales (Nicholas 2011: 147–148). In terms of realization, the coupling of digital means of representation to digital means of fabrication presents a different but complementary nearness to material—one in which the drawing becomes the steering of saw, the milling machine, the steel bender or the vast array of other computer-controlled fabrication processes. But access to direct tangible material output provides more than simply a means of realizing determined design intent. Within the design process, digital fabrication offers critical mechanisms of direct feedback that permit the testing and possible modification of the strategies employed for information creation, production, material composition, assembly, etc., through the making of physical prototypes (Ayres 2012: 33–41). The material world can therefore become fundamentally coupled to, and extend the scope of, the digital design space.

The nearness to material proffered by our means of representation and realization presents profound opportunities and challenges to our design culture. If traditionally design has been understood as a process of refinement going from the overview of large scale, undertaken typically by the architect, toward the particulars of the 1:1, undertaken typically by the craftsman, the shift toward an embedded material address necessitates an explicit understanding of material detail and performance to be present at all stages of design. But concurrently and conversely, the challenge of digital design practice also presents a rupture in the meaning of representation. If architectural design traditionally has understood materialization through a language of symbolic signification we need to find new ways to draw for directly addressing material. And if architectural design casts realization as a posterior act to representation—replacing and releasing the representational of its significance and power—then designing through the material creates new opportunities for their correlation.

The inquiries presented in this chapter seek to probe the conceptual as well as the technological thinking of these questions. They discuss four complementary trajectories of investigation related to one of CITA's principle research questions—how might we enlist computational design tools to support the direct consideration of material behavior in design? These trajectories examine the opportunities and challenges of the material nearness that results from the coupling of digital design and digital fabrication. They are defined through specific projects that develop understandings through the design and construction of full-scale demonstrators that have a material basis, an underlying logic of construction, and a representational challenge that presents a necessary role for computation.

The first trajectory (*Reef Pattern*) examines the implications of being able to directly address material through digital fabrication, and the requirement of constructing highly specified representations which embed understandings of the material behaviors that occur during forming and assembly.

The second trajectory (*Thaw*) examines how material performance can be addressed directly within the digital design space to become an instrumental design consideration, and the implications this has on how proposition is defined and specified.

The third trajectory (*Lamella*) examines how computational logics can be employed to extend existing material practices and structural systems into novel territories, and organized to deal with models that are intrinsically data-heavy due to their hyper-specification across scales—from the component to the assembly.

The fourth trajectory (*Persistent Model #1*) examines how digital models can be re-organized such that representations can be re-informed from the realized to support methods of fabrication that are inherently unpredictable, thereby reconsidering the relationship of dependency between representation and realization.

The projects that relate to these trajectories of investigation collectively act as material witnesses to working practices in which fabrication, assembly and construction are considered as instrumental design concerns, rather than simply procedures for the realization of pre-determined design intent. This permits their influence upon the steering of material performance to be extensively explored and exploited within an architectural design context.

Trajectory 1—*Reef Pattern*

Reef Pattern is a shell construction comprising individual steel cells that gain structural stability firstly through the creasing of their sheet material, and then a double twisting in on themselves to create a self-bracing moment. The research question for *Reef Pattern* asked how an engagement with digital fabrication within the design process can promote the design of new structural solutions using traditional building materials. The project commenced with an interest in the practices of textile pattern cutting and the building of hulls for steel ships, and their parallel concern with the production of curved surfaces from flat material. Our interest also extended to methods of describing developable surfaces mathematically.

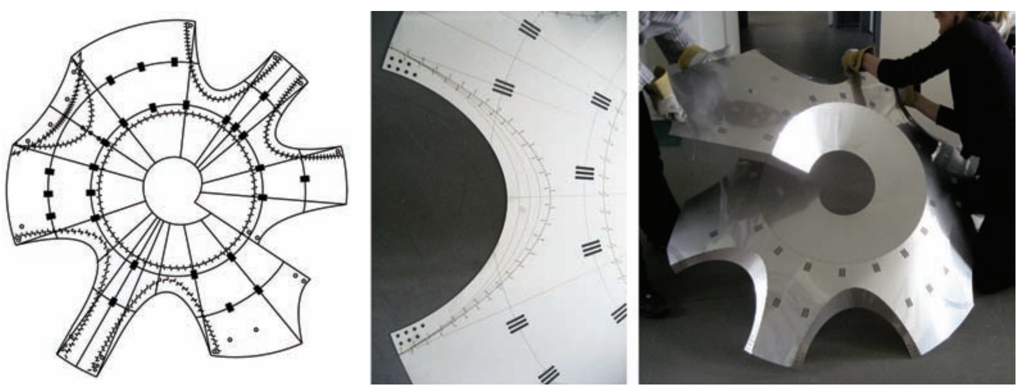
Development began through a series of speculative models and physical probes in which hand-crafted models became the basis of a set of digital prototypes developed through collaboration with both Bentley Systems and CATIA. The use of creasing to construct local strengthening became a central strategy, but this also required the complementary strategy of firstly weakening the material sufficiently along the crease line to enable this procedure to occur. When working directly with material these strategies are simple, almost intuitive to produce, however, describing these procedures digitally proved much more complex than expected. Despite an in-depth modeling and programming knowledge we could not unfold our desired creased surfaces. Where our tools operated at the level of discreet surfaces, the introduction of a crease in a surface established reciprocal relations between two parts.

Reef Pattern, digital.material exhibition, Oslo 2010. (Courtesy CITA)

Physical prototype investigating a self-bracing creased developable surface. (Courtesy CITA)

Changes induced to one side of the surface necessarily influenced the shape of the other. Where material inherently computes this relation our digital models did not. We therefore started collaborating with the mathematician Kristoffer Joseffson from TU Berlin who worked on the making of an algorithm for the unfolding of the surface. Yet the computing of the creasing of a surface proved to be beyond the current state of the art in mathematical description of developable surfaces.[1] The digital descriptions of the curved surfaces were therefore treated as discrete yet linked parts. This allowed the calculation of the shape as a creased surface in a spiral formation. Over the course of further design progression more creases had to be introduced to the cones. The sheet material reacts to forces induced by multiple folds with local buckling and the development of locally flat or doubly curved areas. This physical behavior further confounded the mathematical abstraction of our digital models. Therefore, rather than attempting to describe these complex surfaces in ever more complex and inflexible digital models, we adopted a practice akin to textile designers—operating directly with physical prototypes through an iterative design process of continual adjustment and amending. With the help of parametric models, individual patterns were developed in 2D for each cell. Each pattern was subsequently tested and refined as we learned about the behavioral attributes of the system as a whole through physical prototyping. This technique then informed the packing diagrams to form the structural skin which were also developed as 2D representations and tested in 3D through physical prototyping.

In reflecting upon *Reef Pattern* we identified two principal and interrelated conclusions. The unfolding of complex surfaces into flat patterns are core knowledge sets in the craft-based fields of pattern cutting. However, when attempting to model this mathematically it becomes highly complex. This leads us to an articulation and appreciation of the distinction between the knowledge spaces of doing versus describing, of material practice and the descriptive practices of representation and modeling and the complimentary roles each can play within the design cycle.



Highly specified representations act as direct instructions-to-make using CNC fabrication. The representations embed an empirically derived understanding of the material behavior of bending and twisting involved in the forming of the component allowing for fixing locations and other dependant features to be pre-determined. (Courtesy CITA)

The second conclusion that we determined was that the role of the drawing had changed considerably. Architectural drawings tend toward implying procedures of fabrication and assembly. This is especially the case in the use of the orthogonal construction section, which expresses proposition as a layering of differentiated material fabric. The principal role of such drawings is to instruct others with the requisite expertise in making, and they do so by presenting an abstraction of the artifact assembled. In *Reef Pattern* the implication of operating directly with the means of fabrication required that the drawing become a complete specification of the relevant component. The undeveloped drawing must therefore embed an understanding of the means of fabrication, material behavior in forming, and broader assembly through the precise placement of features derived from a haptic engagement with the material through physical prototyping. A principal implication of this link between intent and the made, by virtue of the drawing, is that the architect who wishes to engage in the direct instruction of fabrication must develop the requisite knowledge of the procedures under consideration, and their material implications. Such an architect must develop the mindset and sensitivity of the maker.

Trajectory 2—*Thaw*

Where *Reef Pattern* succeeded in embedding an implicit understanding of material behavior in the specification of the component, the inability to describe the behavior explicitly meant that it did not become an operable attribute within the space of digital representation. In *Thaw*, the representation of material performance as an instrumental component of the digital design model became a central consideration. The principal representational question of the project was: how can simple parametric tools integrate material performance at the outset of design?

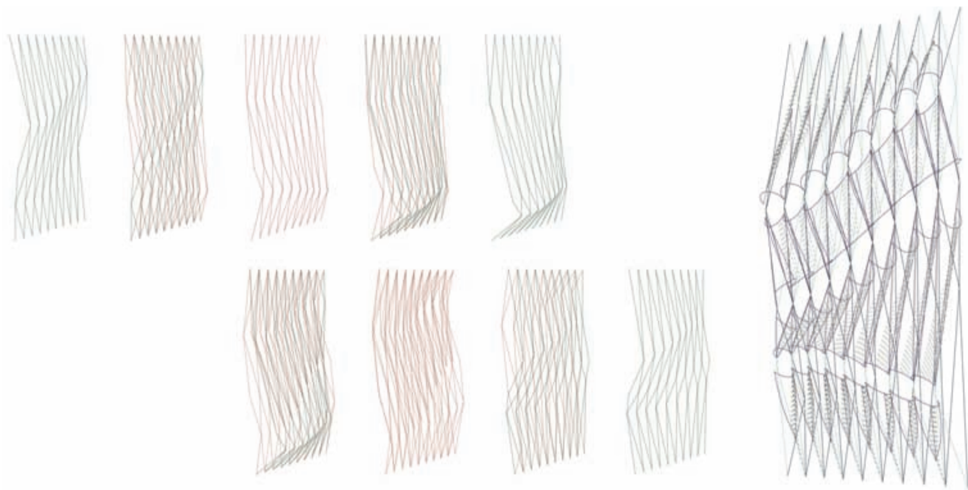
The material performance chosen to be integrated was the bend and flex of wood—specifically that of ash slats. Design intent focused around developing an idea of a soft tectonics that addressed the inherent softness and pliability of the principle material, and the logic of weave was chosen as a complementary underlying organizational principle. Empirical test data of the material's bending performance was used to define and calibrate digital parametric tools which described the bend of the ash slats under progressive loading. The digital model therefore became "soft and pliable" through the ability to represent the behavior of the material, allowing the material system to be designed in relation to its performance against a range of loading scenarios.

Within the project the drawing existed in two different states. At one level it was purely relational—like a weaving pattern it was a material description detailing the lengths of material and their intersections allowing for direct fabrication. On the other hand, it was also a geometric description, which was essential in order to design the cladding skins and develop their cutting patterns. The interesting thing about this parametric sketching is that although the model proved exact enough for the uses we were intending, we could also

Thaw, digital.material exhibition, Oslo 2010. (Courtesy CITA) notice concrete differences between the model and the realized. The parametric sketch could not account for the aggregate effects of material performance, only providing performance feedback at the scale of discrete slats rather than the entire structural system.

In an effort to address this limitation, sketches of the material system were developed as a cloth simulation which provided a more integrated result and allowed the anticipation of the compound effects of material deformation. Although this was not taken further within the

Empirical testing of material performance providing data for the definition and calibration of digital parametric tools. (Courtesy CITA)



The digital model exists both as a relational and geometric description. The ability to integrate material performance into the design tools supports the consideration of a dynamic structure that can subtly reconfigure through the shifting of loads. A partial skin clads the dynamic ash structure, with the geometric information for the location sites being interrogated through the model. (Courtesy CITA)

context of this project, it certainly raised an awareness of the need for future digital models to integrate relations between different scales of material organization—in particular those existing between component and assembly.

The conclusions drawn from *Thaw* are that contemporary architectural digital models tend toward geometric description and as such they rarely incorporate methods for material simulation. As digital fabrication situates us as designers with an opportunity to explicitly consider design intent relative to material understanding, we need tools that allow us to exploit the performative potentials of this linkage. This call for a computational engagement with material performance leads to a new consideration of the calculative capabilities of our digital design tools. Looking toward the tools of structural engineering, computer graphics, and material science, we see a need for our tool sets to incorporate algorithms that enable material description and simulation across a variety of scales—the material, the component, and the assembly. Appropriating tools from these parallel knowledge fields and combining these with spatial design practice would construct a more integrated design space, opening up a richer set of design variables with which to design, prototype, and test.

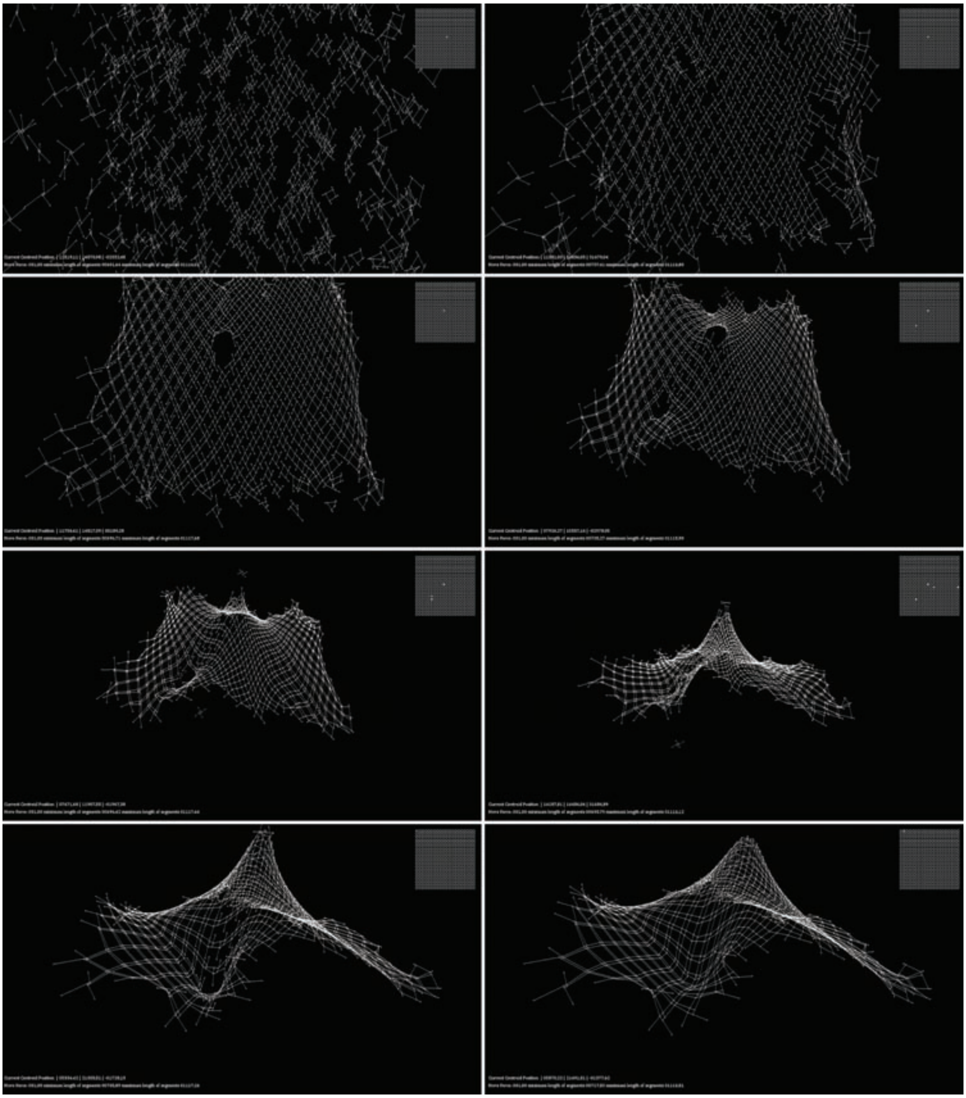
Trajectory 3—*Lamella*

In *Lamella*, the inquiry into the relationship between the digital representation and its materialization was brought up to a building scale. Working with timber profiles, the project asked how computational strategies for mass-customization of individual joints can lead to

Lamella, digital.material exhibition, Oslo 2010. (Courtesy CITA) the variegation of known structural systems. *Lamella* establishes its point of departure in the Zollinger structure, but it employs an agent-based design system to introduce a new formal freedom. Rather than defining the design parameters in respect to material and component dimensions, the digital design model is seen as an environment of mutual negotiation in which individual design criteria are correlated, thereby incorporating an interrelation between scales of material organization.

Originating from the 1920s, the Zollinger structural principal produces large spans by employing short members of low quality timber. The traditional structure is made of parallel arcs of similar length which constrains the outcomes to barrel shapes. The underlying logic of this geometric constraint finds its origin in the industrialized fabrication methods of the 1920s and its protocols of standardization. The barrel is therefore a consequence of standardized junctions—the local connecting detail gives rise to the global effect. Today, the backbone of the wood industry is formed by versatile CNC timber machining centers, allowing for efficient nonstandard fabrication and individualized joinery. The opportunity of this radically different protocol of fabrication with its ability to produce variation and difference was applied to an investigation of the

Physical model exploring a new formal freedom of the Zollinger structure. (Courtesy CITA)



The agent-based model continually negotiates the parameters of the modelling environment. Chosen results are then computed to provide all the necessary fabrication information of the unique joints for direct manufacture by commercial CNC machining centers. (Courtesy CITA)

Zollinger structural system through a series of physical models. The aim was to explore the ability to achieve greater freedom of expression in the resulting geometry of the physical outcomes, and to determine the core logics for controlling global expression through local variation. These were varying the length of the timber elements and varying the orientation tolerances in the joint geometries.

An agent-based model was defined as a method of computing the geometries of the highly interdependent network of beams (Figure 9). The logic of agent-based systems is that they promote local interactions which aggregate to produce an emergent global effect. This is conceptually aligned with the tectonic logic of the Zollinger system as described earlier. This modeling environment also embedded an understanding of the principle constraints arising from material, its production and assembly, locating them as core drivers within the digital model with which to test candidate solutions. Chosen solutions would be computed to directly produce the required local geometric definition of every junction for direct instruction to the CNC machining center, embedding the complexity of the construct into the material rather than relying upon the expertise of the assemblers.

Lamella exemplifies how the values, concerns, and tools of contemporary culture can be employed to extend existing material practices and their underlying logics into new domains of description and expression. This suggests a regaining of the power of architectural intent as a driver for the extension of knowledge with related material practices, rather than adopting existing practices as given. This also holds for the modification, with critical awareness, of architecture's own methods of description and investigation.

Trajectory 4—*Persistent Model #1*

In *Persistent Model #1* the familiar relationship between representation and realization as a sequential process progressing from the intended to the made, was brought into question. By working with steel cushions that are formed through inflation producing results of varying degrees of predictability, it became necessary to consider a circular relationship between representation and the physical material artifact so that "disturbances" introduced by the forming method could re-inform the space of representation in order to permit further design moves. Discreet component inflations of an assembly were conducted after the opening of the *digital.material* exhibition, turning the act of fabrication into a performative event.

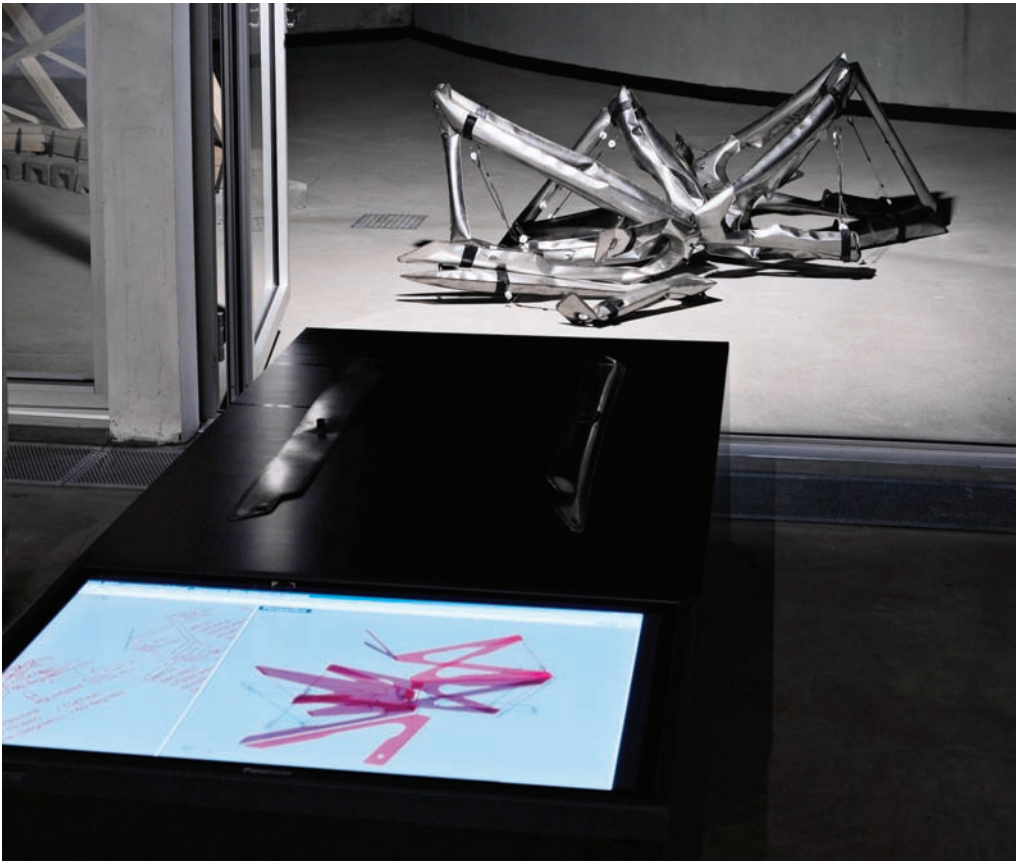
Free-form metal inflation is a fabrication process that establishes a sensitive dependence between the given boundary profile of the component and the material mechanisms at work as the steel cushion moves, under internal loading, from the elastic to the plastic regime in which permanent forming occurs. Being a cushion, the act of inflation increases the cross-sectional area of the component, but because of the low pressures involved there is negligible change in the total surface area. Depending on the boundary profile this leads to self-generating buckling phenomena and a resistance to forming double curvature. Another point of interest is that the inflation process can be arrested and resumed arbitrarily allowing for components to be partially inflated. This leads to the interesting notion of "harvesting" the embedded performance potential of any individual component as required over time, up to certain limits of expansion, through the use of air alone. However, unlike pneumatic structures in which air pressure performs a critical structural role, the free-form metal

Persistent Model #1, digital.material exhibition, Oslo 2010. (Courtesy CITA)

The material forming technique of free-form inflation contributes significantly to the component attributes, causing them to deviate with varying degrees from the initializing representations used to cut the profiles. (Courtesy CITA)

inflations of this project employed air pressure only to form the component, and once formed the internal pressure was returned to atmosphere.

A principle design issue for the project revolved around the fact that the inflation process caused the components to deviate from the initializing drawings used to laser cut the profiles. These initializing representations therefore became redundant for further design speculation as they no longer reflected the geometric characteristics of the physical resources at hand. By employing a forming procedure that contributes significantly to component attributes, and with varying degrees of predictability, the central representational question that arises is—how can these transformations in component attributes be captured in order for them to become instrumental parameters in the design space? In *Persistent Model #1* this question was compounded by virtue of the fact that an assembly was to have its constituent components selectively inflated, driving a continual transformation.



The digital model co-exists with the material artifact continually being re-informed from the material as it is selectively inflated. The digital model therefore reflects and uses the as-existing condition from which to determine further design moves rather than relying upon an idealized condition. (Courtesy CITA)

Such a proposition only served to further defy our ability to predicatively model the result by digital means.

This led to the construction of a representational model that coexisted with the realization, introducing a feedback loop between the space of design and the space of material presence. Changes to the physical construct were mapped back to the representation allowing subsequent design decisions to be made from information reflecting the construct's existing condition rather than an assumed and idealized condition.

This sensitivity and willingness to steer and be steered by material (which is common to the evolving series of trajectories), rather than impose an unyielding will upon it, challenges a predominant aim for architectural representation to provide a complete determination in advance.[2] Rather than complete models, our concerns appear to be served more appropriately by models that aim to be incomplete, open-ended, and inherently more attuned to being continually informed by the complexities of the material world. If we accept Groak's assertion that "the very conventions of representation also can affect the character of the buildings to which they subsequently give rise" (Groák 1992: 150) then it follows that as we alter the nature of our models we also extend the space of expressive potential for the built environment.

Perspectives for a Digital-Material Practice

The concerns, questions, and approaches presented across the four trajectories and their respective projects point toward a rich territory of further investigation for digital representation and material manifestation, furthering our collective practice.

The reconsideration of the relation between representation and realization in *Persistent Model #1* presents an extended role for digital models, aiding in the management of unpredictability across the life cycle of the realized. Further potentials can be seen in the idea of developing logics of transformation that are continually computed in relation to complex goals and dynamic interrelations between critical variables of the design space, as exemplified in *Lamella*, and even into the realized, as seen in delicate material computations and transforms induced by the shedding of load seen in *Thaw*. Such proposition implicates the need to capitalize upon the inherent dynamics of materiality, which in turn is reliant upon our ability to determine appropriate methods of their representation relative to the techniques of fabrication to be employed. The need for curiosity through structured play with material as a means of continually testing the assumptions we build into our digital descriptions of material behavior also points toward a practice that combines equal measures of material investigation with complimentary digital investigation, as seen with *Reef Pattern*.

In researching what a digital-material practice might be and where it might lead, we discover that in attempting to answer the questions we pose ourselves there are always many more that open up. If the projects and practices described within this chapter suggest that there is a new potential between design and material, it also positions design culture in a profound probing of its technologies. Digital design tools are often cast as a means through which to optimize our practice. Through the ideals articulated in projects such as Building Information Modeling (BIM) or Performance-led Design, the digital is cast as a neo-rationalist tool. But this ideal brings forth its own questions and complexities. As the digital provides the ability to work at higher degrees of complexity with more informed and data-heavy models, we need new ways of understanding and organizing the infrastructures of our representations. It is apparent that there is equal demand to consider the meta-design as much as the design itself—the organization of the design framework in order to permit the necessary complex modeling that such practice is beginning to engage in by addressing a broader scope of the material.

In addition, as we gain the ability to directly address material we need to develop the ways in which crafts-based understanding of material and detail relate to architectural design and production. If digital fabrication leads to a bespoke hyper specification in the production of material, what are the protocols by which these designs can be understood, and to what scales of architectural production can they be turned? Might they be employed at the scale of the city as well as the scale of the configuration of material itself? Finally, it is important to maintain the conceptual role of architectural representation. As the organization and fundamental dimensionality of our representations change, how does this affect and change our intellectual heritage, and what values and concerns does it promote for the future?

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Notes

1 Although the computing of the creasing of a surface proved to beyond the current state of the art, the productive outcome of this experience lies in the establishing of cross-disciplinary relations in which questions developed from within one discipline can provide fertile ground for research in others. This serves to promote quicker expansion of knowledge within very specific territories but which have an established applicability to a broader context.

2 In his seminal essay "Translations From Drawing to Building," Robin Evans asserts that a principle role of representation is to provide a "complete determination in advance" (Evans 1997: 156). With increasingly robust and fluid methods of information creation, capture, manipulation, and sharing, the notion of "representational completeness" as a prerequisite for the commencement of realization has been eroded. There is increasing evidence of this erosion being exploited within building construction and practice. See, for example, Mark Burry's account of the design and fabrication of the Rose Window for the Sagrada Família Church (Burry 2003: 111–112) and Jordan Brandt's definition of the *Isomodel* (Brandt 2012).

Q + A

Brandon Clifford, Wes Mcgee and David Pigram *with Sneha Patel*

BRANDON CLIFFORD is an architect and founder of **The Malleablist Movement**. Brandon received his Master of Architecture from Princeton University in 2011 and his Bachelor of Science in Architecture from the Georgia Institute of Technology in 2006. His work focuses on the realization of digital manufacturing through materials, means and methods of production.

WES MCGEE is the Director of the **FABLab** at the University of Michigan Taubman College of Architecture and Urban Planning, where he also teaches courses in robotic fabrication. He received a Bachelor of Science in Mechanical Engineering from the Georgia Institute of Technology in 2001, and a Masters in Industrial Design in 2005.

In 2008, Brandon Clifford and Wes Mcgee founded **Matter Design Studio**, a practice committed to experimentation and research at a variety of scales.

DAVID PIGRAM is an architect, designer, educator and researcher whose work explores complex adaptive systems in design. He earned a Master of Science in Advanced Architectural Design from Columbia University's Graduate School of Architecture, Preservation and Planning and also holds undergraduate degrees in architecture and environmental design. David is the Director of the Master of Advanced Architecture, Design Technologies program at the University of Technology in Sydney and a partner at **Supermanoeuvre**.

Wes Mcgee and David Pigram have collaborated on developing custom software for robotic fabrication.

Brandon Clifford, Wes Mcgee, and David Pigram discuss an expanded realm of architecture in which materiality is no longer seen as limited to a discrete set of parameters but rather is in dialogue with digital models. Through the utilization and invention of advanced fabrication techniques, open-source and custom software, and physics/mechanics-based simulation tools, their work opens up the opportunity to challenge the often presumed digital and analogue divide. By inventing new methods of making through collaborative efforts they have established a paradigm of practice that is founded on research through making, testing and experimentation.

A Change of State *(2006) is an installation developed at the Georgia Institute of Technology. (Courtesy Matter Design and Nader Tehrani; Photo: Phil Jones)*

Q1. Sneha Patel: An exciting and prolific trajectory of your work for some time has focused on the utilization and development of robotic fabrication for design. This work has included fundamental research, prototypes, custom-written software, installations, and development of a consortium of schools/ universities called the Fabrication Robotics Network. Can you elaborate upon how robotic fabrication became an important area of inquiry in your work and the value of creating an open-source platform for shared research? What do you believe to be some of the most valuable opportunities within robotic fabrication for the future of design and what are some recognized current limitations, either within particular prototypes or projects you have worked on or more broadly?

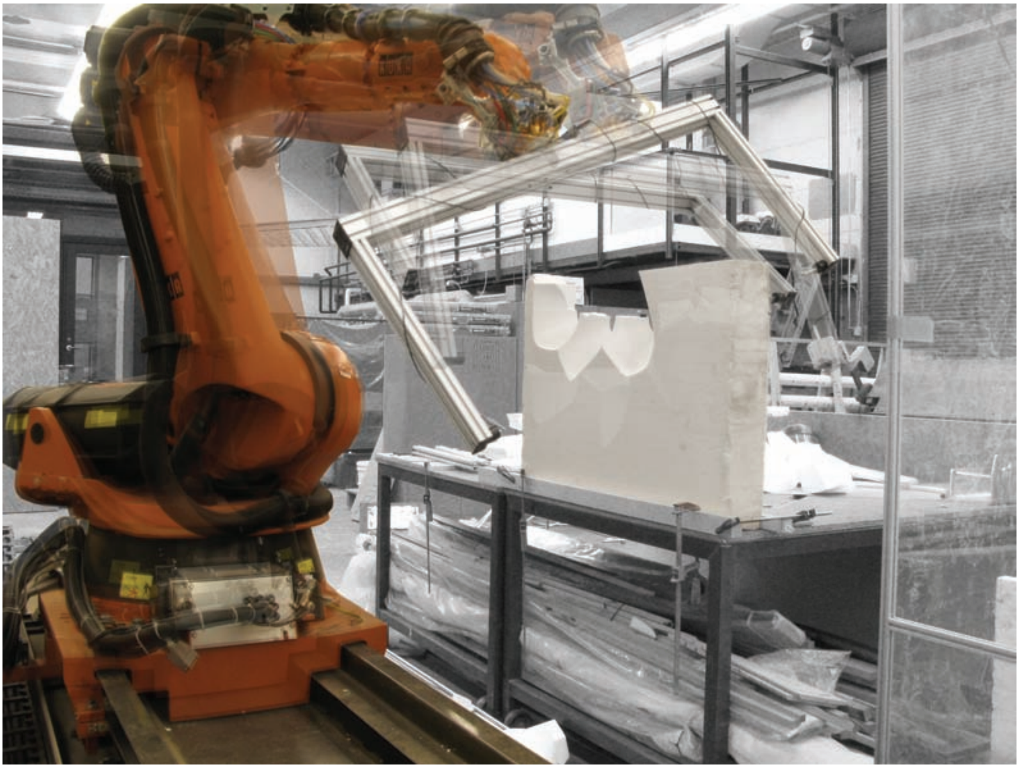
A1. Wes Mcgee: **I think it is becoming clear that robotic equipment is just another tool at the designer's disposal. I think the most interesting research is moving toward sensor-guided work, and near-realtime control.** Also there is an interest in looking at the realities of doing onsite fabrication. One limitation is that of moving up in scale, because at some point you cannot just get a bigger robotic system, you have to deal with either collaborative work between multiple machines, or the complexities of relocating the system on the fly.

I think from the academic perspective the open source idea is very valuable, as in the beginning there were a lot of individuals re-inventing similar software plug-ins, as there really are not well suited tools available commercially. I think there are a lot of schools that are producing high quality work in a short period of time thanks to the sharing of information.

Dave Pigram: Robotic Fabrication opens up the profound possibility of creating strong and meaningful feedback loops between matter and making. **Design conceptualization and design realization can be intertwined rather than sitting on opposite sides of the "drawing divide," a chasm which is too often crossed only once in the design process.**

Brandon Clifford: Robots, like architects, are dilatants. They are not particularly great at anything, but they are capable of so much. In the academic realm of research (in making), a robot (in concert with a partner like Wes) allows for the freedom to create your own tool based on the project, as opposed to creating a project based on the most recent CNC purchase.

I might separate research from the design process. While some would consider research as the first phase of a design process in order to be better informed of the site or the client, we consider it to



***FABLab_University of Michigan Taubman College of Architecture and Urban Planning** (2010)_Custom Seven-Axis Robotic Hot-wire Cutter. (Courtesy FABLab)*

be a parallel action. It is important not to design the research, and not to research the design. These are both very dangerous paths that produce pretty research that solves no problem, or pragmatic solutions to a design problem. A balance and separation need to be struck.

Q2. Sneha Patel: All three of you are active in leading student workshops on fabrication and computational technologies. Recent workshops such as *Hyperbody Workshop* and *Organic Fabrications Workshop* have explored advanced complex modeling and fabrication processes that inherently address issues of material efficiency and geometric constraints. Describe what you feel are some of the most relevant questions students must ask themselves when experimenting with an ever-expanding set of tools, material choices, and techniques, particularly in relationship to "digital design"? How have leading workshops such as these advanced your own work or afforded you to ask different types of questions?

A2. Wes Mcgee: I think the key is to try and balance time between trying to find out what tools are out there (especially new ones), and just looking for a process or technique that may be adaptable to a new toolset. **Of course there is an ever-expanding palette of digital tools, but it is also very obvious when a designer has let a single tool become dominant. I think we generally start with a material, and then see what we can do with it that may not have been done before, or at least make an incremental improvement to a process.**

Brandon Clifford: **I feel strongly an architectural problem must be stated prior to deciding upon a computational model, tool, or material. Nothing is more detrimental to advancing digital design than the advocating of skill building without the fundamental understandings of those intentions.** Some problems cannot be solved through parametrics; they might be better suited for solver-based models. Other problems do not necessitate organic modelling; they might be better addressed through representation. This list continues. I recommend students to ask themselves, "What is the problem I am attempting to solve and what method is required to solve this problem?" The question I recommend not asking is, "What program do I need to learn to get a good job?"

Q3. Sneha Patel: Brandon, you have said, "So much of the discussion surrounding digital design has focused on surface." You have recently been awarded a SOM Fellowship to continue to research the "lost knowledge of stereotomy (the art of cutting solids, most typically stone)" as a counterpoint to this singular attention to surface and as a means to expand contemporary methods of making and construction. How does this research extend from some of your previous work and how do you hope to synthesize historical models with more contemporary techniques?

A3. Brandon Clifford: My work has always involved volume in some way. The *Change of State* installation could be considered the first example of this, but can also be seen easily in *AtmoSPHERE* and the *Drawn Dress*. All these projects were dedicated to creating volumetric occupation from sheet materials—Folding, Bending, Creasing, Stitching, etc. … The projects *Periscope* (Glynn and Sheil 2011; Beorkem 2012) and *Temporal Tenancy* were the first projects to test out this idea with a volumetric material. Foam is clearly a great material to engage this problem of stereometrics. It is light, cheap, and forgiving, but it is also an analog for stone, aerated concrete, plaster, and other more permanent materials.

Periscope: Foam Tower *(2010) 10Up! National Architecture Competition Winning Entry-Site Assembly. (Courtesy Matter Design and Supermanoeuvre)*

In my mind, this is a natural progression through a body of research, but the method has not changed. In all of these previous projects, historical methods have been adapted into contemporary techniques. The *Drawn Dress* project directly adapted sartorial techniques in a digital environment. *Periscope* and *Temporal Tenancy* both translated the developed surface techniques into a spatial and sweeping wire (that carved the blocks). My intention with both the SOM Fellowship and the LeFevre Fellowship is to better understand the intentions of past masons in response to their facilities, culture, knowledge, and tools. In doing so, we will certainly be comparing and advancing these lost methods in the digital environment.

A big shift in our recent work is in the desire and ability to include material behavior in a tight feedback loop with our generative algorithms. Experimentally derived values such as the expansion rate of polyurethane foam, the compressive strength of sandstone or the elasticity/springback of steel rod help to define the digital form-generating behaviors. This work is demonstrating false dichotomy between digital and analog modes of operation.

Q4. Sneha Patel: You have written extensively about the importance of *malleability* within your work and as a current paradigm for architecture, defining it as not simply a material property but the capacity (and acceptance) of responsive change (Clifford 2011: 62–67). In a world in which digital technologies have been predicated on controlled optimization and predetermined outputs, how do you feel the unpredictable, uncertain, or unscripted productively informs your work and design process?

A4. Brandon Clifford: We (and the Malleablists) argue for an architecture capable of responding to unpredictable events. **One approach to design is to consider the designer as the creator of a final form—a pure and resolved physical object. This is an approach that removes the idea of time. Another way is to consider the designer as the facilitator of occupation. This approach is dedicated to systemic thinking, and is therefore malleable to change.**

This is certainly not a new idea to architecture. If we are to be bold, we might say the Malleablists are the reincarnation of Archigram. Both are interested in living, responsive, and adaptable speculations on architecture. The difference between today and when Archigram was speculating is the current focus on the practical, the methods of making, and the inventions behind constructing. If Archigram worked within the constraints of industrialized and standardized materials, the Malleablists revolt against them.

In the end, we use the Malleablist movement to work through ideas and exercises that force us to re-imagine the role of the architect. In turn, these exercises inevitably require inventing new methods of making. For instance, how can we make an architecture capable of adjusting to a variety of programs throughout its life? How can we make an architecture that adapts to the different seasons, as opposed to mediating them?

There are far too many biomimicry (even ones who claim "this is not biomimicry") projects claiming to be inspired by the functional laws of ecology, when in reality they are more formal, and at best structurally inspired. Ecology as it applies to design is taking a total systems approach to the problem.

Q5. Sneha Patel: The Swiss architecture firm, Gramazio and Kohler, have described their projects as combining, "the physics of built architecture with digital logics." Similarly, you aim to ensure equal value to the digital and material in determining how they shape and inform each other. This affords you the ability to utilize material behaviors as an operative tool in adjusting design. How has this type of material-specific data, unique to the digital model, provided feedback to you as designers within your work? When, or how, has the data failed you (if at all)?

Temporal Tenancy *(2011) Princeton University with fabrication by FABLab, Taubman College of Architecture and Urban Planning, University of Michigan. (Courtesy Matter Design)*

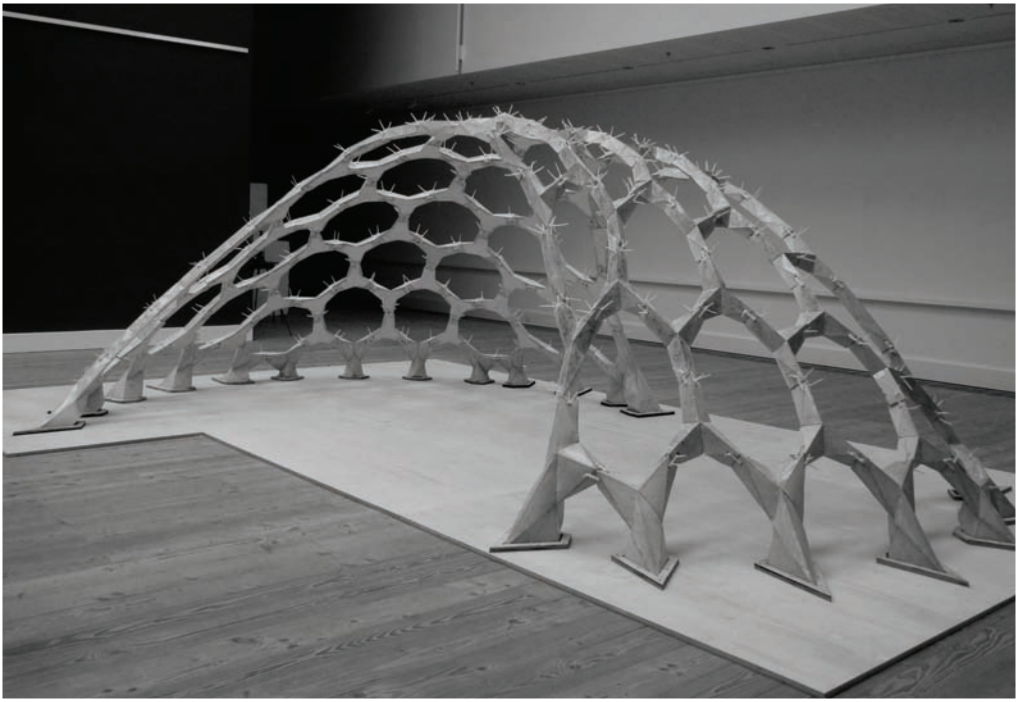
A5. Wes Mcgee: I think the ability to embed physics and material properties into the digital model opens up tremendous opportunities for the process. We are currently working with a project involving heat forming of glass, and it becomes very important to develop an empirical model that lets us predict exactly where the glass will end up. It takes a lot of process research, as it is a material that you cannot directly affect. We are using dynamic relaxation to predict how the glass will behave, and it gives a surprisingly accurate representation.

Materiality is becoming more explicit, in that to understand materials as discrete parameters alone is no longer enough, they must be in dialogue with the (digital) model. It cannot simply be a question of experience or novelty, for example, assigning materials like a flavor. I think the real power lies in developing physics/mechanics-based simulation in the computer. The digital model should provide a feedback to the designer; incorporating material-specific data.

Brandon Clifford: **We always aim to develop reciprocity between drawing and making. Implicit in this are a series of drawing exercises that are conducted simultaneously with a series of material experiments. The hope is that as those two worlds start to weld together, an invented result is accomplished.** Unfortunately, time is the real factor here. In an ideal world, prototypes and in-depth material analysis will verify all assumptions you make. The *Change of State* (Kottas 2010) installation is a great example of this. Over a period of one year, the material was tested over and over to learn its limitations. In projects like *Periscope*, we had less than a month to develop and build the project. Those are the moments when intelligent guesses substitute prototyping. The tower worked, but we were holding our breath (while telling everyone we were positive it would stand).

Dave Pigram: **The digital is the abstract medium of negotiation between intangible impulses and desires that need to be met through material form.**

Collaboration should include our various material systems, which have always had behaviors and desires, but that we are now willing and able to treat as co-conspirators instead of insisting on hegemony.



PreVault *(2011)_Completed with 12 students from the University of Technology, Sydney and the Arhus School of Architecture. (Courtesy Supermanoeuvre, Ole Egholm, and Niels Martin Larsen)*

Further Reading

www.matterdesignstudio.com
www.supermanoeuvre.com

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Glynn, R. and Sheil, B. (eds.), *Fabricate: Making Digital Architecture*, Ontario, Riverside Architectural Press, 2011.

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PROJECTS

Material Fabrications

Optimized rib system, disclosing the trajectories of the forces to the observer. (Courtesy Per Dombernowsky & Asbjørn Søndergaard)

Unikabeton Prototype 2009–2012

Per Dombernowsky
Aarhus School of Architecture

Asbjørn Søndergaard
Aarhus School of Architecture

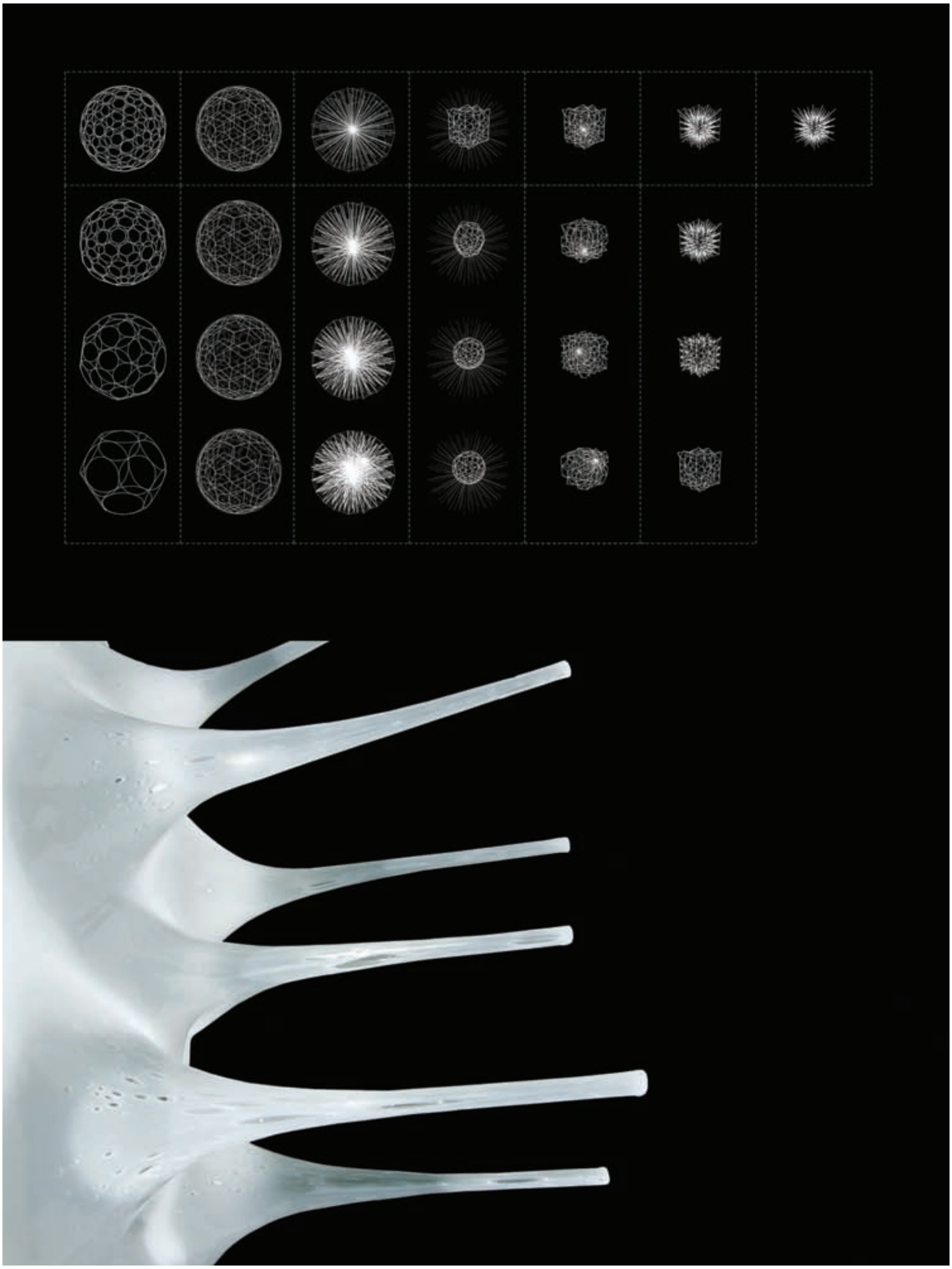
The *Unikabeton Prototype* was developed and realized as a finalization of the three-year, cross-institutional research project, *Unikabeton*. The project set out to explore the architectural and industrial potential in linking topology optimization of concrete structures with large scale CNC-milling of polystyrene formwork. The computational process initiates from a predefined volume, in which simulated material is topologically redistributed toward a structurally efficient layout. The result is the formation of a new geometry, in which maximum structural stiffness is achieved through minimum material consumption.

In initial experiments, Aarhus School of Architecture investigated the optimization of simple, commonly used structural elements. The investigations revealed two main implications: (1) the optimization procedures resolves in highly complex structural morphologies, the geometry of which is fully unpredictable due to the complexity of the calculations; (2) the optimization facilitated reductions in material consumption between 60%–70% in comparison to massive equivalents, while respecting conventionally applied performance demands. Exploring the capacity of the method in tackling complex problems beyond the reach of empirically driven structural design, optimization of a challenging prototype layout was initiated: a minimal surface canopy, asymmetrically supported on three columns. The optimization result was digitally remodeled and milled in polystyrene blocks, creating a mold for concrete casting.

The research findings address fundamental conditions related to the making of architecture: in a pragmatic sense, the material optimization allows for more efficient use of building material resources, adding new tools in the quest for reducing environmental impacts of the construction industry. In a theoretical perspective, the self-organization of material into structurally defined patterns allows for the conceptualization of load-bearing geometries that transcends conventional categorization.

www.fluxstructures.net

Project Collaborators: Aarhus School of Architecture (Design and Optimization Research), Danish Institute of Technology (CNC-Production Research), University of Southern Denmark (Robot Software Development), Spæncom A/S (Production of Concrete Elements); Unicon A/S (Concrete Research and Delivery), MT Højgaard A/S (Contractor), Paschal-Denmark A/S (Scaffolding Systems), and Gibotech A/S (Provider of Robot Technology), Søren Jensen A/S (Engineering Consultants).
Thanks to the Danish National Advanced Technology Foundation of DKK whose contribution (12 million) made the *Unikabeton* research project possible by their generous support.



The boundary of a cube is redefined with a volume packed geodesic order, which is embedded with fan vault modules. The physical prototype close up extends the research that instrumentalizes surface texture as a medium to test digital-hand crafted construction techniques. (Courtesy Joseph Choma)

Contested Boundaries: Digital Fabrication and Hand Craft 2009–ongoing

Joseph Choma
Design Topology Lab, Southern Polytechnic State University

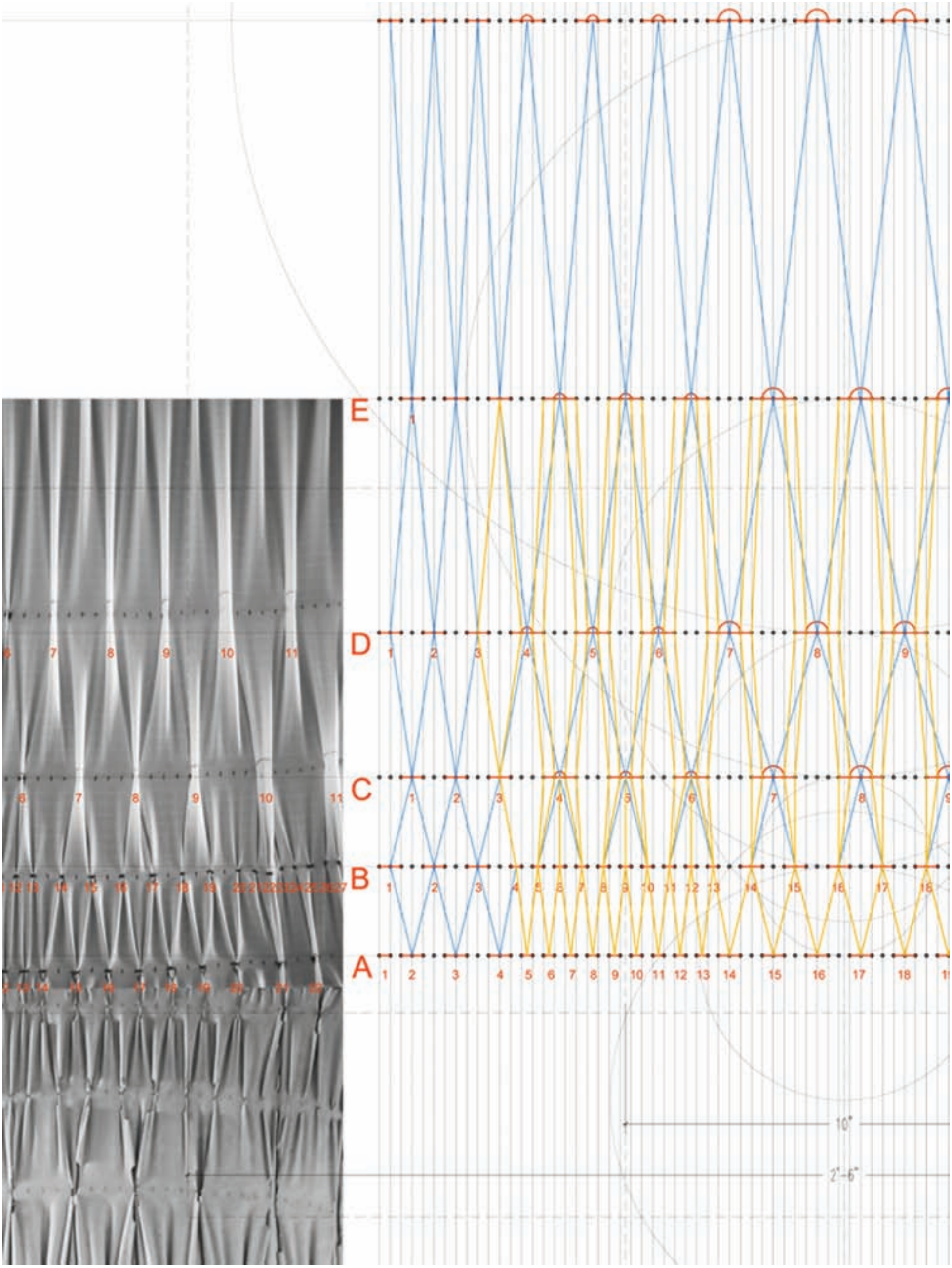
Contested Boundaries investigates the relationship between efficiency, precision, and tactile variation within architectural design and fabrication. In order to design, one must have constraints. Within the design process it is imperative for designers to identify constraints in order to instrumentalize them as a mechanism to generate less predictable new ideas. Often times, designers begin to work within a given medium without explicitly acknowledging how such embedded constraints will influence their design process. The experience and consequences associated with digital instrumentation will yield different results than those emerging out of physical material manipulations. To negotiate this dilemma, a designer must be the conscience of the changing medium's bias and their consequences.

A digitally driven design may be seamlessly precise and consistent but may also feel sterile and distant from the human body. A materially driven design may be intimate and tactile but may lack the accuracy needed to connect elements. Digital fabrication techniques are combined with hand-craft material manipulations in search of a unique hybrid tectonic that merges connection accuracies with subtle but sensual divergences between repeating modules. In this case, the thermoforming properties of plastic were introduced to extend the act of design within the fabrication process. Prototypes have been constructed at the object and inhabitable scales. The challenges associated with translating a consistent material process over each scale have become explicit within this research.

This research does not claim to have developed a "better" fabrication process, but rather asks the question, how do we qualify fabrication processes in our current discourse? With the advancements of rapid prototyping machines and three-dimensional printers, fabrication processes are becoming increasingly automated. Designers are attempting to construct digital descriptions as accurately as possible into physical material, instead of asking the material what it wants to be. A hybrid fabrication process which combines digital fabrication with hand craft techniques suggests an alternative approach to current fabrication trends; automation and optimization. Perhaps, a slightly slower process which yields a sensibility to intimacy is something to be considered.

www.designtopology.com

Physical prototypes were financially supported in part by the Council for the Arts at the Massachusetts Institute of Technology.



Smocking explores the potential of a pleating technique on a fabric formed concrete surface, a manifestation of an equilibrium reached between the surface tension and omni-directional hydrostatic pressure. Formwork analysis and corresponding notational drawing describe Smocking v. 5. (Courtesy Kentaro Tsubaki)

Smocking: Pleated Surfaces of Fabric Formwork — June–August 2008

Kentaro Tsubaki
Tulane School of Architecture

The construction of exceedingly complex buildings is a testament to recent technological advances. The precision and the speed of digital simulation tools "predict and minimize" various risks associated with such endeavors. Simulation is by definition about "predicting the predictable."[1] Yet, the poetics of architecture is a phenomenal performance of physical construct beyond the predictable, evoking an emotional and intellectual response. It is rather shortsighted if the technological objective is simply to minimize risks by subverting material tendencies and limitations. Design decisions based on responses from material processes are integral to the art of craft. How do we embrace the imperfections, the material risks and resistances always present in fabrication and making?

The embodied knowledge of making is gained through the physical interaction with materials, searching for an order rooted in history, perception and materiality.[2] *Smocking* explores the potential of a pleating technique on a fabric-formed concrete surface, a manifestation of an equilibrium reached between the surface tension and omnidirectional hydrostatic pressure. This dynamic process cannot simply be depicted pictorially. A hybrid notational/geometrical drawing system was developed to precisely document the fabrication process and to imply the formal characteristics of the outcome.

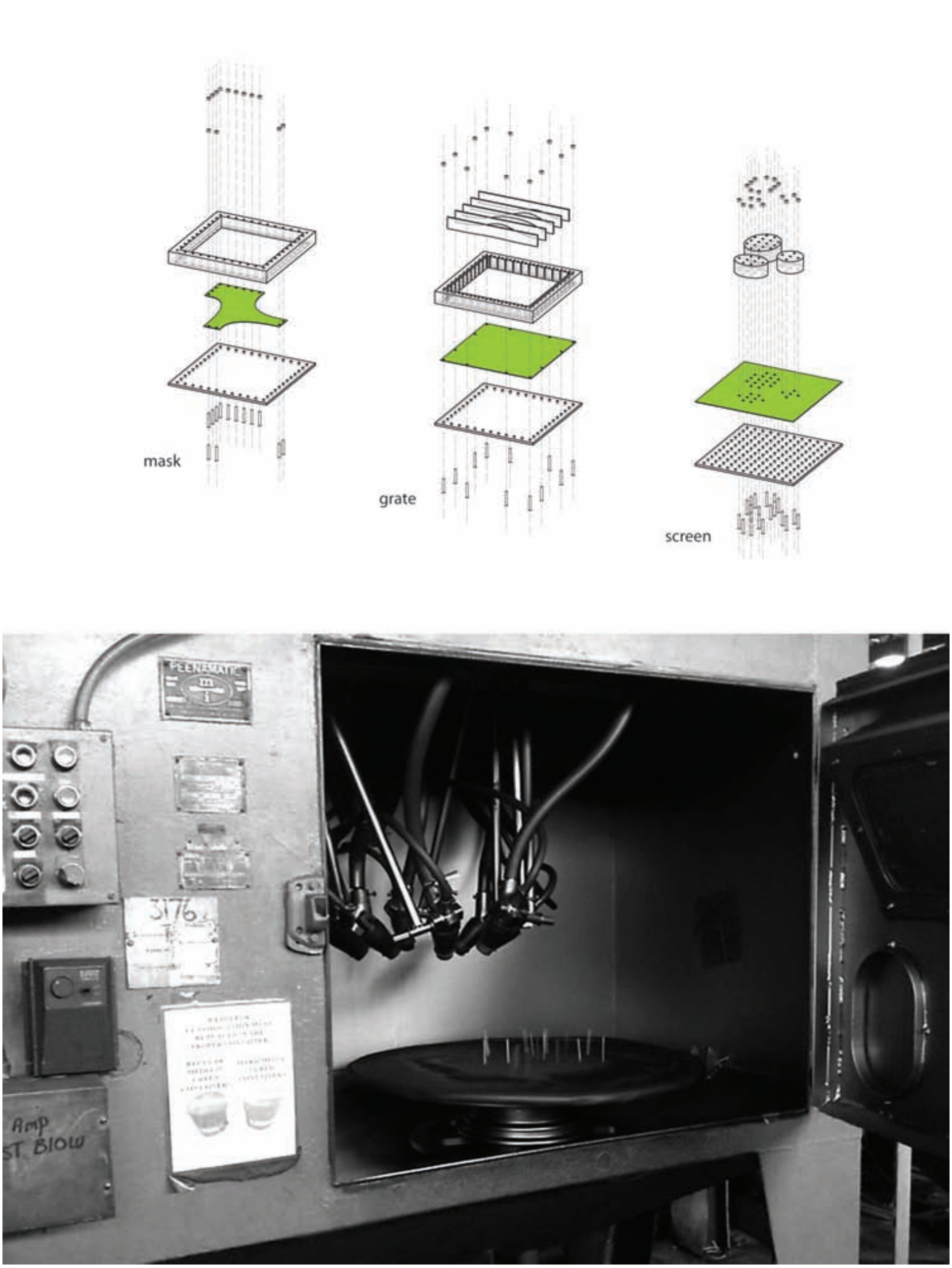
Smocking exposes ways to negotiate the issues of risk and precision contrary to the reality of current building practices; to execute efficiently with minimum risks with computational muscles at its disposal. It represents an attempt to harness the self-organizing tendencies of the physical materials under gravity within the fabrication process. The formal quality is appreciated. However, its performative potential is yet to be explored systemically. Is it possible to calibrate the surface geometry to take advantage of the characteristics of concrete such as high compressive strength and thermal inertia? The project intends to continue provoking the deeply entrenched architectural practice through questioning the obvious and the rational in a fundamental way.

www.ktstudiokt.net

Notes

1 As described by David Leatherbarrow in the chapter "Conceptual Performativity," in B. Kolarevic and A. Malkawi (eds.), *Performative Architecture beyond Instrumentality*, New York and London, Spon Press Taylor & Francis Group, 2004.

2 The "embodied knowledge of making" is discussed by Alberto Pérez-Gómez in the article, "Modern Architecture, Abstraction, and the Poetic Imagination."



Designed Disorder includes ongoing research into CNC shot peen forming. This fabrication process offers the unique opportunity to privilege imperfection or variation when paired with high precision. Images illustrate Peening Jig Prototypes and Numerically Controlled Peening Tools. (Courtesy Phillip Anzalone, Brigette Borders, and Kerri Henderson)

Designed Disorder **Ongoing Research**

Phillip Anzalone
Laboratory for Applied Building Science, Columbia University GSAAP

Brigette Borders
Laboratory for Applied Building Science, Columbia University GSAAP

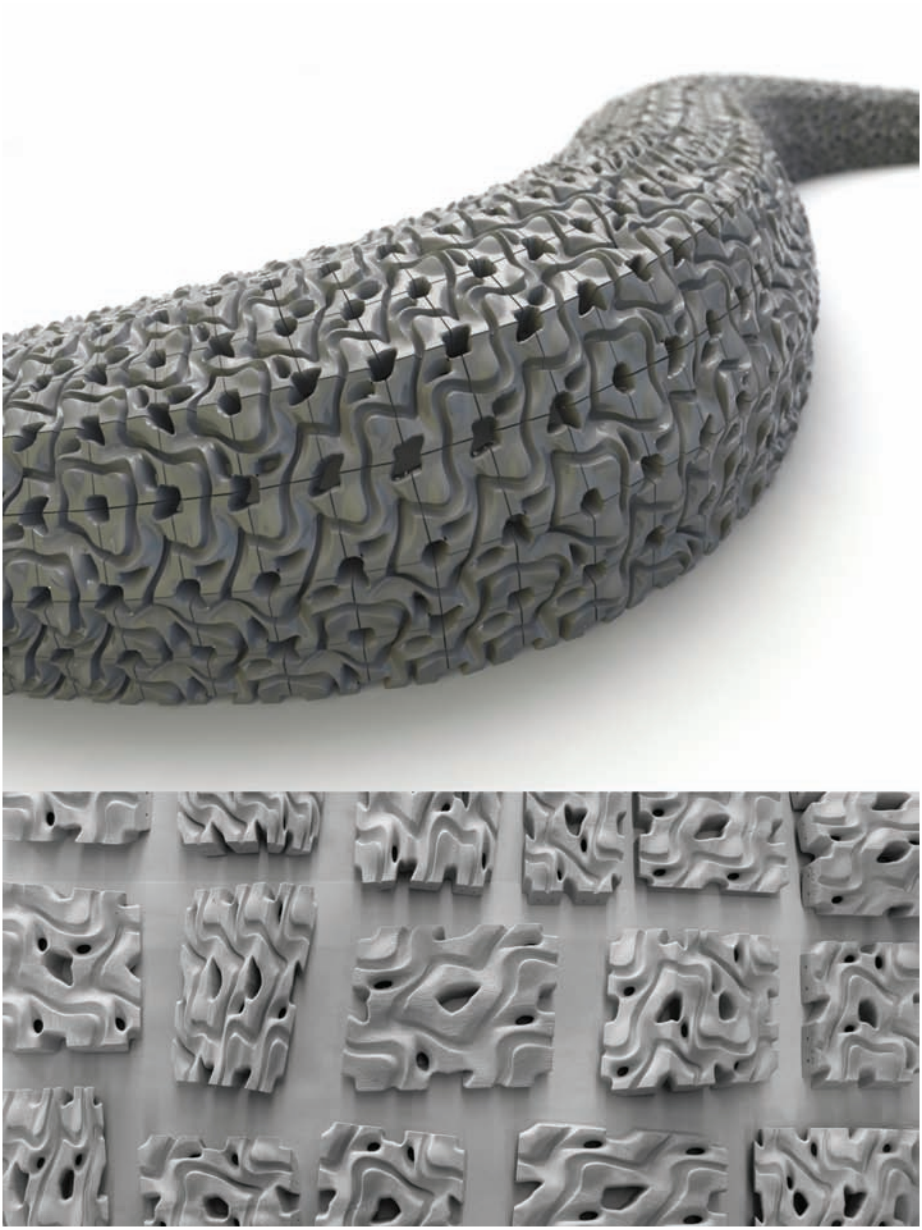
Kerri Henderson
Columbia University GSAAP

The paradox of Computer Numerically Controlled (CNC) precision lies in the ability to design with tolerances previously unimaginable, while the tolerance of one machine may grossly exceed that of another, rendering the precision irrelevant. This discrepancy becomes even more pronounced when CNC fabrication and manual assembly combine. Metal forming, a process well suited for CNC manufacturing, requires immense amounts of energy, chemicals, and heavy equipment, and often leaves large amounts of waste. The material properties and typical products of metal construction require a high level of precision, often necessitating flexible connections to less precise materials to be incorporated into the design process.

Shot peen forming is similar to sandblasting in its process, yet the use of tiny metal pellets, or shot, renders a positive structural result in the material as it is formed. The metal pellets form minute divots in the surface of the peened material, effectively expanding its surface area. When items are peened only a small amount, or if the item being peened is thick, the result is an increase in structural performance through hardening. If sheet metal is peened, however, the surface expansion can actually bend the material away from the peened surface. CNC shot peen forming offers the unique opportunity to privilege imperfection or variation when paired with high precision.

By allowing a standard part to be manipulated with a process whose inputs can be slightly altered to produce dramatically different effects—inputs that control the overall speed and pressure of metal shot but never the exact location of each particle—we can "reproduce" results only as far as we desire. Alternatively, by allowing parameters to remain the same, but the machine to be driven by a human, we can increase the chances of variability, challenging the nature of unpredictability in CNC machining. We can set up a system by which we produce parts nearly identical at the macro scale, yet wildly variable at the micro scale. The entrance of the trace of the hand into CNC precision unites predictability and chance, challenging the notion of CNC, prefabrication, and even perfection, conceding beauty to randomness embedded within exactitude.

www.arch.columbia.edu/labs/fablab



The Seat Slug, a biomorphic interpretation of a bench, is part of ongoing research on developing methods for 3D printing using concrete for the production of long-lasting performance-based components. Because the process requires no formwork, 3D printed concrete components can be mass-customized and contextualized, employing the flexibility of computer-aided manufacturing systems and allowing design parameters to be quickly changed and tested without incurring costs associated with labor and retooling. (Courtesy Ronald Rael and Virginia San Fratello)

The Seat Slug **2011**

Ronald Rael
University of California Berkeley, Rael San Fratello Architects

Virginia San Fratello
San Jose State, Rael San Fratello Architects

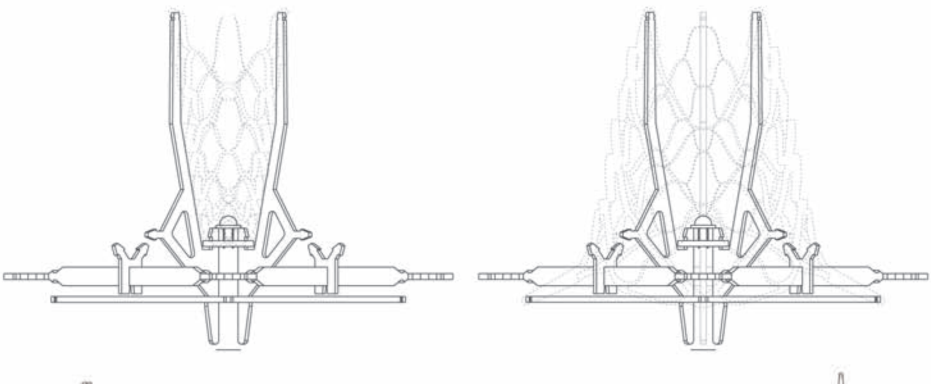
The Seat Slug is a biomorphic interpretation of a bench that showcases how 3D printing can be used to create structural building components directly from 3D models. The design is loosely inspired by *flabellina goddardi*, the newest species of sea slugs discovered in California in 2010, and by the infinite tessellations of Japanese karakusa patterns. It is constructed of 630 unique rapid-manufactured components. The sinuous form, subtle translucency, and wet-look finish engage viewers with a memorable aesthetic experience and a tactile personal encounter with technological innovation.

Conventional 3D printing is an expensive prototyping process, important as a design tool but often falling short within the process of production. As a result, the development of unique, one-of-a-kind building components, generated quickly and economically from advance 3D modeling software was largely untapped. However, through our ongoing research at the University of California Berkeley, we have developed a cement-based polymer and a new process that, for the first time, employs conventional rapid prototyping hardware to produce strong and durable building components that cost far less than conventional rapid prototyping materials. The results include savings up to 90 percent less than comparable powder printing materials, while reaching strengths up to 4700 psi in compression. This advancement in material output from digital modeling software ushers in a new era in building materials, and a new synthesis of design and production.

The Seat Slug has also instigated the development of *emerging objects*, a pioneering design, and research company that specializes in designing and 3D printing objects for the built environment. Design research serves as the foundation for this consulting practice with the aim to work with a range of industrial partners, companies, nonprofit foundations, and creative practices.

www.rael-sanfratello.com
www.emergingobjects.com

Project Collaborators: Emily Licht, Nick Buccelli, Kent Wilson.
Thanks to Dr. Mark Ganter (Solheim Additive Manufacturing Laboratory in the Mechanical Engineering Department at the University of Washington), Artist Ehren Tool, Professor Richard Shaw, Professor Claudia Ostertag (University of California Berkeley), The Department of Art Practice at The University of California Berkeley, The Hellman Family Fund; Luxology.



Oxalis: Redefining Inputs and Fabricating Outputs is a formal exploration of environmentally responsive cladding systems, employing digital fabrication as an iterative investigation tool. (Courtesy Vincent Hui, Michael Lanctot, and Pierre-Alexandre Le Lay; Photo: Matthew Gowan and Davis Marques)

Oxalis: Refining Inputs and Fabricating Outputs — August 2010

Vincent Hui
Ryerson University

Michael Lanctot
Ryerson University

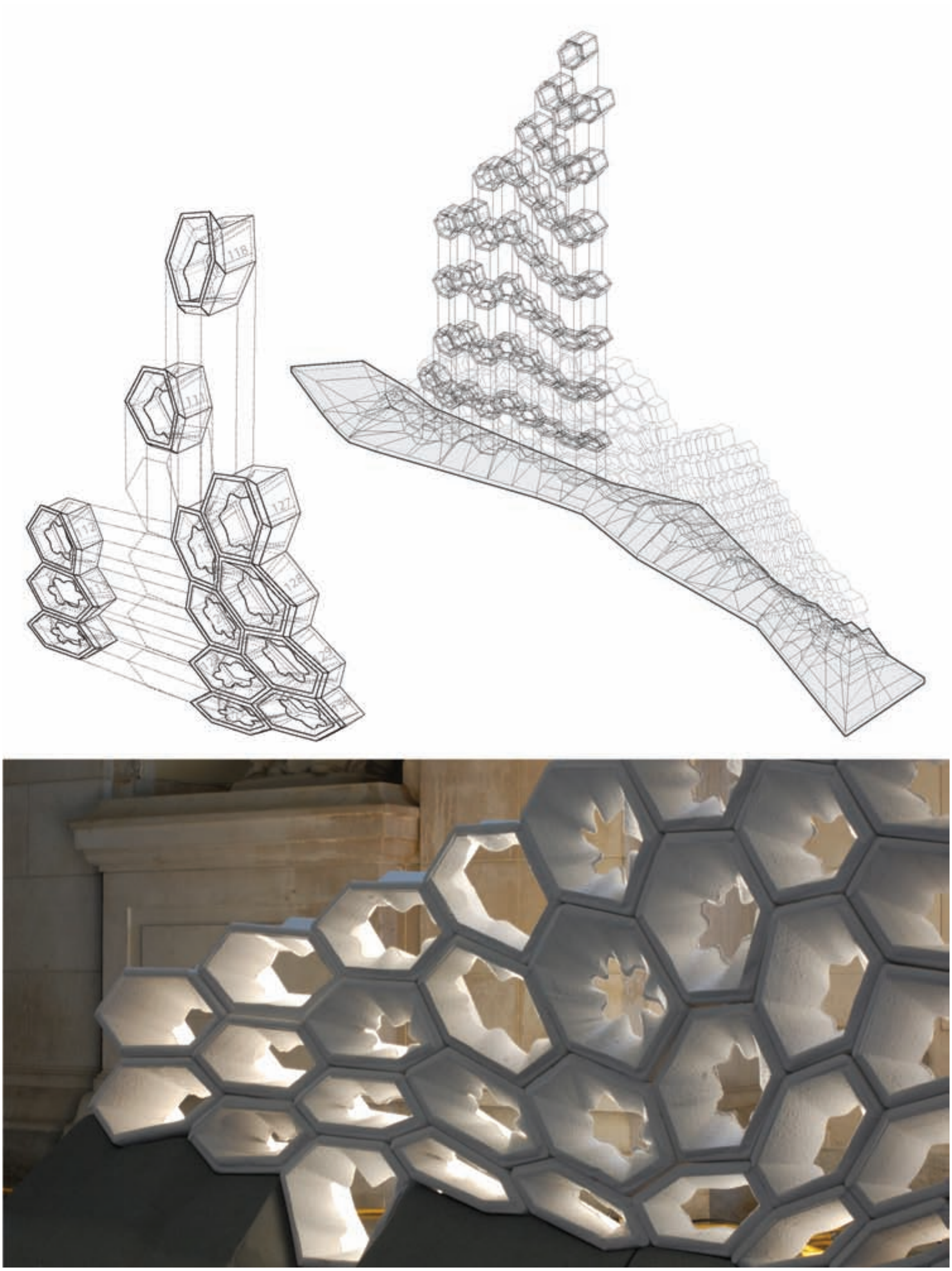
Pierre-Alexandre Le Lay
Ryerson University

The means of architectural design development and conveyance have undergone a recent paradigm shift with the advent of digital fabrication and prototyping technologies. Rather than relying on virtualized representations of architecture, a movement in contemporary architecture has sought to empower architects with the ubiquitous tools of computing extending beyond digital representation and shift toward digital fabrication. The *Oxalis* project, a formal exploration of environmentally responsive cladding systems, employs digital fabrication as an iterative investigation tool. By examining material properties and interactions of the assembly in conjunction with the design execution of conceptually representative geometries, a platform is created to understand digital fabrication and its material output in concurrence with the boundaries of material behaviors.

The development of the *Oxalis* project is a culmination of investigations into material properties, physical computing, rapid prototyping, and assembly efficiencies. The use of 3D printing, laser cutting, and CNC routing of a range of materials allowed the designers to experiment with microlevels of conductivity, moisture control, static charge, and structural optimization. Working in tandem with team members from computer science, mechatronics, and building science backgrounds allowed the design to develop a prototype of a multifunctional cladding system that responded to ambient sound (frequency and volume), movement, and light intensity.

The end result showcases a full scale demonstration of an array of the prototype system and also exemplifies the investigation into the spatial, structural, and tectonic qualities of materials selected. By bridging the gap between the illimitable explorations of generative applications and actual design execution, the project reinforces a new epitome in architectural design where digital fabrication transcends the sphere of simple representation and performs as an investigative research tool.

Project Collaborators: Jamil Jivraj (Technical Assistance), Matthew Gowan and Davis Marques (Photography).
This project was financially supported by the Ryerson Creative Fund.



Pinch Wall is comprised of 145 plaster components, each unique and variable in size, in response to degree and angle of porosity. The components are organized as strata and rest upon a buttressing base; they utilize a "valley" method of stacking in which adjacent casts lock into position. (Courtesy Jeremy Ficca)

Pinch Wall 2009

Jeremy Ficca
Carnegie Mellon University

P. Zach Ali
Carnegie Mellon University

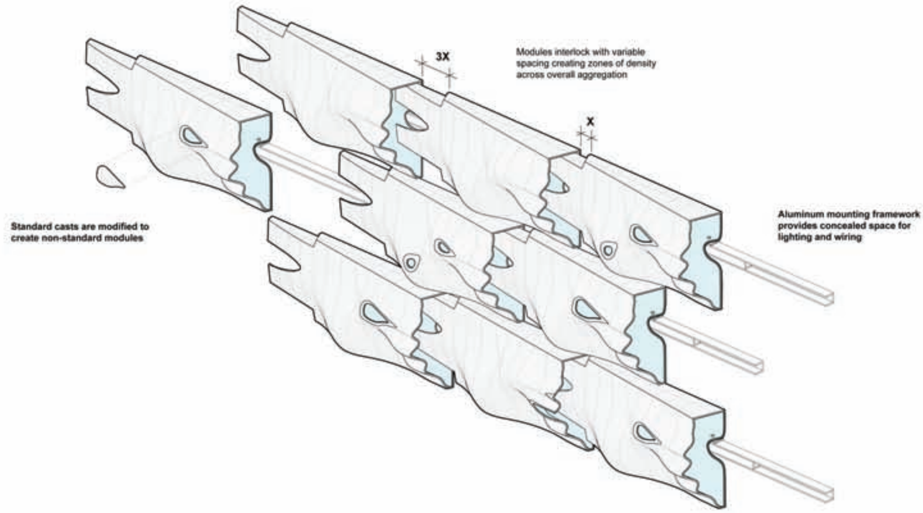
Pinch Wall is the culmination of a design research seminar taught in the School of Architecture at Carnegie Mellon University in the fall of 2009. The architectural screen served as the spatial device through which students explored the convergence of stereotomic construction logic with the porous, mediating qualities often found within the screen. The self-supporting and effect producing potential of the system informed the development of a variable unit that maximizes geometric transformation across the thickness of the unit as a means to achieve interlocking, variably porous units. Production relied upon the fabrication of two-part molds with the use of multi-axis robotic milling. Subsequent high strength plaster casting resulted in the production of a family of unit casts.

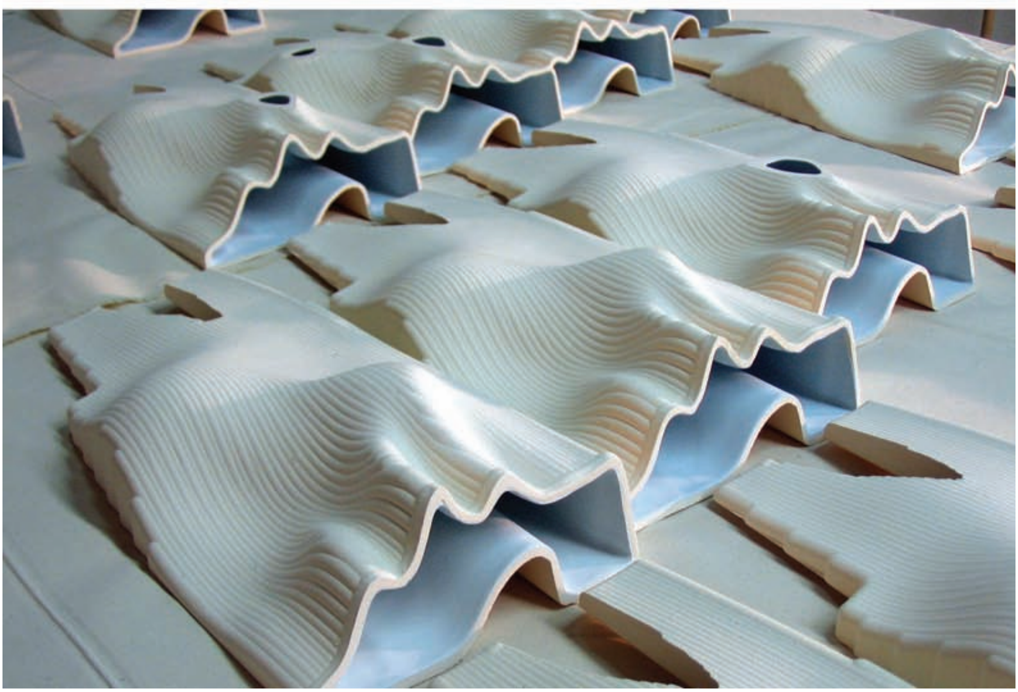
Digital fabrication processes have been heralded as a workflow that extends the digital design process into the physical realization of built form and by extension, implicitly focuses on material reality. The promise of such processes in the academic realm is a material awakening or material consciousness within the student. The shared hope is that this sensibility prompts a reassessment of virtual design data that is often materially and tectonically ambiguous or inert and leads to a more sophisticated, materially informed design process. Ironically, the academic context, in which many of these processes are explored, places significant demands of time and cost upon the work. As a result, this often biases the use of material proxies or simulations, undermining initial ambitions and disassociating form and process from material reality.

As a pedagogical exercise, *Pinch Wall* sought to operate within this reality while maintaining a material rigor. By limiting the processes to two distinct phases of mold making and casting and developing a system of variable units, students devoted attention to the development of the unit with the understanding that geometric transformations abided by the same underlying material and formal logics. Resistance of materials and processes became limits that informed the design process rather than last minute hurdles to be overcome. It is in this space between intent and actualization that the student discovers they must reconcile their will with what they can physically achieve.

www.cmu-dfab.com

Project Collaborators: Arthur Azoulai, Nelly Dacic, Jared Friedman, Christopher Gallot, Spencer Gregson, Matthew Huber, Jaclyn Paceley, Puja Patel, Craig Rosman, Giacomo Tinari, Eddie Wong.





Tectonic Horizons comprise an aggregation of ceramic modules with smooth interior glazing in contrast to a variegated exterior texture. The wall assembly axonometric illustrates the wall-mounted units attached to aluminum channels with internal wiring. (Courtesy Radical Craft)

Tectonic Horizons 2008

Joshua G. Stein
Radical Craft, Woodbury University

Tectonic Horizons is a modular component system that exploits the hybridization between digital fabrication techniques and traditional ceramic processes—specifically slip casting. Ceramic slip casting creates hollow vessels with precise details and is used in the production of everything from porcelain figurines and tableware to larger objects such as toilets and sinks. *Tectonic Horizons* exploits the material specifics of clay and plaster as resistance to abstract digital form-making. This interlocking system of ceramic modules takes advantage of the scalloped texture that occurs naturally within the machining process to channel vision from the striated exterior surfaces toward intricate interior spaces inherent within slip casting.

Rather than using the traditional physical model or positive pattern to cast negative molds, these forms initially exist only as virtual geometry. The negative mold form is then directly milled into plaster blanks eliminating the analog process of mold-making. After surfaces of interface between the two mold halves are milled to the highest possible resolution (to assure a proper fit), any other surfaces are liberated from these expectations of fidelity to an original "model" of geometric perfection. Instead, process (CNC routing) claims a stronger role in determining the form and performance of the final object. While each cast from the mold is identical, a series of post-process cutting operations embeds a new layer of differentiation into each piece.

Tectonic Horizons offers an example of the potential feedback between the abstract space of digital modeling and the physical realities of a material allowed to move and behave according to its own tendencies rather than the desires of pure geometry. This investigation into the opportunities of hybridizing the processes of ceramic slip-casting and CAD/CAM manufacturing also questions the traditional mold-making process by integrating contemporary notions of the non-standard with the economies of scale inherent in mold/cast systems. Pursuing neither the ideal of the uniquely hand-crafted object nor the infinite variability of mass customization, this process capitalizes on the potential of one mother-mold to create a family of casts that are then differentiated through a set of subtractive modifications.

www.radical-craft.com

Project Collaborators: Andrew Heumann (Parametric Modelling), Frank Parish (Digital Mold Fabrication), Winston Nanlohy (Ceramic Casting).
This project was produced in residence at the European Ceramic Workcentre (EKWC).

Porous Ascend utilizes a spatial structure based on geometry derived from patterns of aperiodic tiling and recursion. (Courtesy Jacob Riiber)

Porous Ascend — May 2011

Jacob Riiber
Royal Academy of Fine Arts School of Architecture, Copenhagen

The *Porous Ascend* project investigates how algorithmic and generative approaches allows for the utilization of complex, and by other means unmanageable, ways of devising the schema by which we arrange the parts of an architectural object. The key interest is a possibility to abandon the need to simplify complexity by means of hierarchal ordering, coordinization and division into subsystems. Instead algorithmic and generative approaches allow us to externalize the overview of a collection of parts from the designer and potentially address complexity more directly. As a case study into these possibilities the project pursued to physically realize a structure departing from the concept of applying recursion to the geometry of a non-periodic tiling.

The realization of this pattern—as a spatial and material structure—followed the concept of extruding it into three dimensions as folded components. A bespoke digital design tool was developed for this endeavour. Following extensive prototyping, mapping material tolerances, elements were unfolded and fabricated in cardboard through CNC knife cutting. Due to the nature of the underlying pattern, each of these elements required an additional indication of their relative position to neighboring elements by means of indexes engraved to the corresponding sides. Building proceeded by manually re-folding elements and pairing them one by one with correct neighbors. In the context of non-standard practice, building the structure required the development of new strategies for organizing an assembly process.

The project points towards a novel approach to working with, and reproducing, complexity within collections of architectural components. With no predefined coordinization mapping the ever changing fractal pattern, building proceeds by a locally defined identification and pairing of elements. In this way the project demonstrates that we can build without reference to a global position, by solely referencing the relationships between neighboring parts. Assembly itself becomes algorithmic. This suggests a more locally adaptive and reactive organization of elements and points towards future research that extends the digital domain further into the assembly process.

http://cita.karch.dk/

Project Collaborators: Mette Ramsgard Thomsen, Martin Tamke, Annica Ekdahl (Design Team), Quantum Sails, http://www.sejl.dk (CNC cutting), Tutein & Koch, http://www.tuteinogkoch.dk (Material Supplies).

Q + A

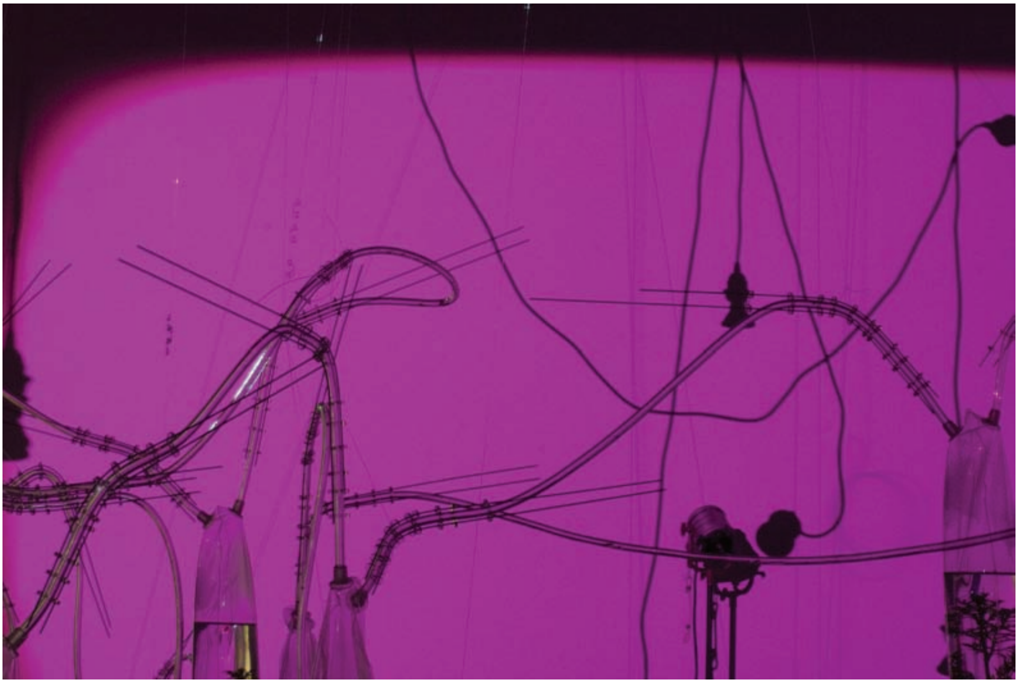
Patrick Harrop and Peter Hasdell *with Sneha Patel*

PATRICK HARROP is an architect and Associate Professor of Architecture at the University of Manitoba. He currently holds the CMRI Chair in Masonry Studies and is an active researcher with CAST (Centre for Architectural Structures and Technology). His research focuses on emerging technology and design with a particular emphasis in electromechanical hacking, digital fabrication and contemporary theory. Patrick Harrop received his undergraduate architecture degree from Carleton University and his post-professional Master of Architecture degree from the History and Theory program at McGill University in Montreal. He is currently a PhD candidate in the Humanities Interdisciplinary program at Concordia University. His current work involves developing new approaches to embedded and interactive technology, where immediacy and responsiveness is delayed and translated into autonomous, complex behaviors and environments.

PETER HASDELL, an architect and academic, studied film theory and computer engineering before graduating in architecture from the University of Sydney and from the Architectural Association in London. He has taught architecture, design and technology in Europe, North America and Asia, including the Bartlett School of Architecture, the Berlage Institute, the University of Manitoba and the University of Hong Kong. He is currently a visiting Assistant Professor at The Hong Kong Polytechnic University's School of Design. Peter Hasdell's research and teaching investigates metabolic systems and interactive technologies with a focus on "artificial ecologies" and issues of sustainability. He is currently a PhD candidate at the Royal Institute of Technology in Stockholm.

Patrick Harrop and Peter Hasdell are founding members of **Pneuma**, a research-based collaborative practice in interactive art and architectural installation. Its focus is in developing complex and behavioral models of architectural membranes using research on composite and new materials, digital fabrication, and performative interaction.

Proposing that design is not distinct from process, Patrick Harrop and Peter Hasdell discuss how their work develops out of a series of specific protocols, material methods and discreet interactions yet without a predetermined form or plan. To this end, the role of *play* is integral to their work; they explain how this word, through its multiple translations, can be useful in provoking a design process that accepts the challenges of heterogeneous, nonlinear and complex conditions inherent within immersive environments and interactive constructs.



***Remedios Terrarium** (2008) is an interactive pneumatic installation exhibited at the FOFA Gallery, Concordia University in Montreal, QC; Detail of liquid cell with weed growth. (Courtesy Patrick Harrop, Peter Hasdell, ShaXin Wie, and the Topographical Media Lab)*

Q1. Sneha Patel: You have described *Pneuma* as an "open source research and project platform" that allows you to initiate research, conduct projects, establish collaboration and disseminate project outcomes. *Pneuma* research and projects investigate issues of indeterminacy in cellular, generative and interactive assemblies. Can you elaborate on what initiated your early interest in these areas of exploration?

A1. Patrick Harrop and **Peter Hasdell**: Indeterminacy is quite a large field of inquiry from an architectural standpoint. But for the most part it is overused as a generalization that tends to weaken its potential by avoiding its specific modes of engagement. **As architects we are all fascinated by complexity, life and even the chaotic order of a vibrant city.**

We have been particularly fascinated by ornamental systems in the baroque. For the most part, the more extreme and elaborate the better. The *Asamkirche* in Munich and

Sans-Souci in Potsdam are two examples that come to mind. This particularly exaggerated ornamental environment seems to be the expression of a radicalized moment when the geometry of procedural craft and proportion seem to reach an almost desperate desire to touch the infinity of recursion by the human hand through self-generating ornament. **Such a complex, mathematical reach for geometric elaboration, although grounded in the procedural logic of Euclidean geometry, is entirely contextual in its execution and its eventual form. It stands to reason then, that particular craftsmen would execute remarkably diverse variations of their work entirely dependent on the spatial, geometric and even material conditions.** Despite a consistent hand and a consistent set of geometric vectors, the end result of these baroque spaces is remarkably indeterminate. We see this early on in the masonry tradition of the gothic cathedral: The controversy over the Milan cathedral was not its proposed span; rather it was the appropriateness of the generative algorithm of the mason that would arrive at a span. One could somewhat imagine these as extracted technical objects with poly-scalar and polymorphic potential.

Research is everything. Pneuma does not view the design as a final outcome but as a process, outputs are a momentary freezing of an on-going and continually evolving process. Research is not distinct from the outcome in the same way that we see that prototype is not distinct from design.

Q2. Sneha Patel: Your work has also focused on understanding the role of unscripted behaviors and component failures within digital processes and interfaces. In a world in which digital technologies have been predicated on controlled optimization and predetermined outputs, how do you feel the unpredictable or uncertain productively informs your work and design process?

A2. Patrick Harrop and **Peter Hasdell**: There seems to be an emerging trend in electronic art towards the objective of building these “uncontrollable” and “unpredictable” systems such as state engines. These are rather complex and highly evolved sensor networks (usually involving vast armies of art programmers) whose intent is to generate an indeterminate condition for aesthetic responsive action. As ambitious as these works are, it seems a little absurd for architects to build these “unpredictable” systems.

Architecture is already complex and interactive as it stands. It has the complexity of heterogeneous behaviors already embedded into its material systems. **We try to think of material behaviors as an added level of programmatic complexity, drawing on the idea that materials within architecture have always been modulators of two or more environmental conditions in their milieu; temperature, moisture, resonance, sound, and in effect are acting as rudimentary modulating systems.**

Artifact 2007: pneunaturae *(2007) An exterior installation as part of a group art festival, Parc Jean Drapeau, Montreal, QC. (Courtesy Patrick Harrop and Peter Hasdell)*

Through the complex layering of various systems in our work we can say our aims are definitely not controlled optimization, but neither are they unpredictability; uncertainty could be an outcome of multiple pathways but it is not a direct aim.

In our work, the ability to play without expectation of outcome, function or truth is critical. *Play* we refer to in multiple senses of the word, also referring to play in a system, an excessive tolerance is one factor that highly optimized systems cannot tolerate. **We value developing performative installation processes that force an interaction with materials and technology and a discovery. We rarely ever plan a global or formal design of an installation piece.** Rather the piece is developed as a series of protocols, material methods, discreet interactions and vague occupations of an installation site. The work unfolds without a real sense of where it is going, but a very strong intuitive sense of what has to be done as a *process*. This is not unlike the medieval masons whose concerted geometric movements would grow a complex building from the human scale into the civic by way of small material gestures. **Our play emerges from the gradual emergence of an architectural order beyond the immediate prototype into the complexity of the larger system.**

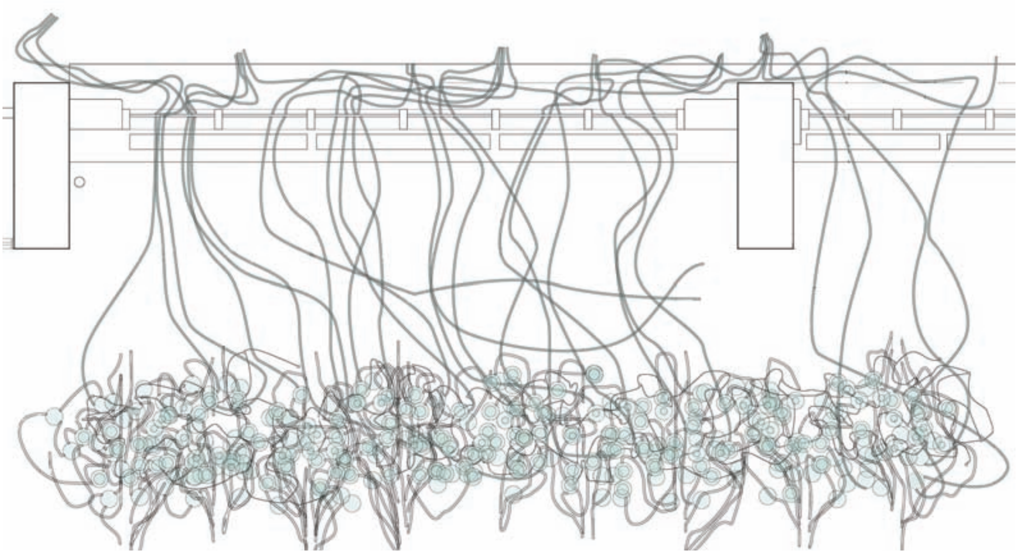
Architects may not be the most "in depth" transdisiplinary practitioners. Yet we are makers and our thirst and ability to brazenly synthesize ideas seems to create the right environment for other disciplines to engage our work.

Q3. Sneha Patel: Prototyping, rapid prototyping, full-size testing, and other tangible forms of making are understood as a critical and valued part of your research and work. Yet unlike many practices utilizing these modes of working the goals of this approach for you seem decidedly less linear and more open-ended. In other words, the prototype is not necessarily seen as simply a scalable, reproducible component leading towards building application, evolving in a deterministic way. How would you describe the value of making within your process? When are certain techniques most effective? Is there an important point of scalar translation within your work?

A3. Patrick Harrop and **Peter Hasdell**: **For us, conventional prototyping in some ways is problematic. It remains a linear process in which earlier prototypes are but poor "shadows" of final iterations.** In *Pneuma*, our intentions with prototyping and in particular with rapid prototyping are actually quite modest, perhaps less strategic and more tactical. We do not see this as a goal oriented approach, but as an open addition process whereby one prototype does not necessarily replace another, but instead exists at the same time in proximity to another. For us this means that **where possible, we try to incorporate all prototypes, even unsuccessful or failing ones within the successive developments or iterations of a project. This perhaps suggests that the project contains a more complete map of its evolution within its matrix, dead ends, failures, weak spots, competent entities and so on.** Of course scalar translations, multiplication and addition of numerous elements are important in such an approach.

Q4. Sneha Patel: *Pneuma Device* is an installation comprised of a series of inflatable cells and BEAM robotics employing electronic sensors, pneumatics, and mechanical systems that responds to the movement of viewers/participants. As part of its design, the installation comes with an instruction manual, allowing the device to be re-deployed or re-situated. Another project, entitled *Pneuma Dispositif*, is described as "a systemic device exploring the complexities of bipolar interactive systems" in which the user "perturbs the system rather than providing an explicit instruction" to the device. In each case, the user or participant is a critical component of the system; in what ways do you feel the legibility of the system is critical to a user? Does the device aim to explicitly communicate the participant's role in the feedback loop or does this vary from project to project? When is the human's role an observer, a participant, an instigator, and so forth?

A4. Patrick Harrop and **Peter Hasdell**: One of our intentions is to construct kinds of milieu's; immersive systems that may co-opt the user or participant which may even require the user's input but not necessarily in a one to one concordance. This means for us that the user's actions, presence, reaction or even expectation is preferably non-linear, in



*"pneus" **FORÊT/FOREST** (2008) Plan of installation and responsive inflatable device for the 8th manifestation international of champ libre, Montreal, QC; Drawing: Evan Marnoch. (Courtesy Patrick Harrop, Peter Hasdell, and ShaXin Wei)*

other words, feedback systems which could be as simple as a delay or retard ideally try to provide multiple pathways weaving together mechanical and electronic systems as constituent parts of the milieu. As such, **the user is important but direct legibility of the system is not.**

Performance we understand as the continual adjustment, perturbation and feedback a piece might have with its changing milieu. In this capacity it is closer to the concept of a "design that operates in exchange with its location." However this is not to say that we actively seek some kind of equilibrium, optimization or homeostatic condition but are rather more preoccupied with the continual oscillations or disturbances and perturbations within a system.

In Pneuma, *whilst aspects of our work are performative, we do not necessarily work with representation and simulation in a conventional sense. We use the term performativity in terms of human/non human relations (as in Butler/Latour/Pickering, Simondon). We understand architecture to be more akin to a living construct and therefore present and evolving rather than represented and simulated.*

Q5. Sneha Patel: Digital technologies in architecture have been most ubiquitously utilized as methodologies in architectural representation that rely on the sophistication and seduction of manifesting the real, recreating the material as an image of itself. Instead, your work aims to discover ways in which these technologies can play an active role in its physical making. What tools and techniques do you feel most effectively align with this approach? What have been some of the most limiting aspects of how digital technologies have been utilized in the field of architecture, particularly in relationship to materiality?

A5. Patrick Harrop and **Peter Hasdell**: **We have had deep discomfort with the notion of representation and the virtualized environment. However the tool seems the most interesting when seen as an opportunity to develop an approach to making.** Again it is a material priority for us. The laser cutter is the best example. Part of our research has been in how to hack a laser cutter to permit precise welding of materials. However at the same time, **computer numerical control, whilst opening a lot of possibilities of customization, optimization and prototype fabrication has also been reductive in many other capacities, particularly in the realms of craftsmanship and specificities of material substrates**. Most materials must at present be relatively isotropic for their utilization within digital fabrication. In *Pneuma*, we view materiality as a series of interconnected substrates or mediums that are active and dynamic, and able, through various conduits and pathways and feedback, to affect other systems in the same construct in a localized way (Harrop 2005). These mediums act or respond at very different rates and in different and sometimes unpredictable ways. The convergence of digital and materiality allows us to do this but our work is not wholly dependent on this.

Although we have quite often dealt with digital tools, particularly in fabrication techniques and programming languages, our work tends towards the analogue. We are more interested in the systemic repercussions of the swarm model of BEAM robotics rather than the "big brain" scenarios that are found in centrally controlled microprocessor environments. This is especially the case when we work with material behaviors and the environmental conditions that perturb our constructions. Matter is vibrant. There is no such thing as a passive material; materials have specific, yet diverse, dynamic qualities that are far more complex than the programmed behaviors one can hope to provoke through physical computing (Harrop 2007: 69–72). What is utterly fascinating about buildings is that they are comprised of complex dynamic equilibriums modulated by a heterogeneous stew of modulus of elasticities, resistances, thermal conductivity and permeabilities. Most interactive artists strive to create a state engine of life like complexity; we hope that our work somehow synthetically reveals what is already there. Truth is stranger than fiction.

Pneuma Dispositif *(2007) An interactive installation at La Galerie Joyce Yahouda, Montreal, QC. (Courtesy Patrick Harrop and Peter Hasdell)*

Q6. Sneha Patel: Peter, in the article "Artificial Ecologies: Second Nature Emergent Phenomena in Constructed Digital-Natural Assemblages" (Hasdell 2006) you write, "…the ubiquity of the digital realm has altered our relationship with the natural world in profound ways, becoming our prosthetic extension to the world. As these two trajectories — one natural, one digital — develop, new possibilities open up for situating a condition both natural and digital at the same time: a hybrid condition full of entities that belong not to one single environment but able to exist in either — in other words, a second nature." Current architectural inquiry probes aspects of performativity and adaptation based on current concerns of energy conservation and sustainable materiality, amongst other issues. How do you feel the concept of *second nature* as explored in your work responds in a unique way to these current concerns?

A6. Patrick Harrop and **Peter Hasdell**: It is difficult to point to any salient lessons, parallels or responses of *Pneuma*'s work to contemporary architectural approaches on sustainability. **It is clear that the more interesting approaches in architecture are beginning to find ways to affect our built environment that do not establish the dichotomies of nature and artifice but instead regard these as part of the same continuum.**

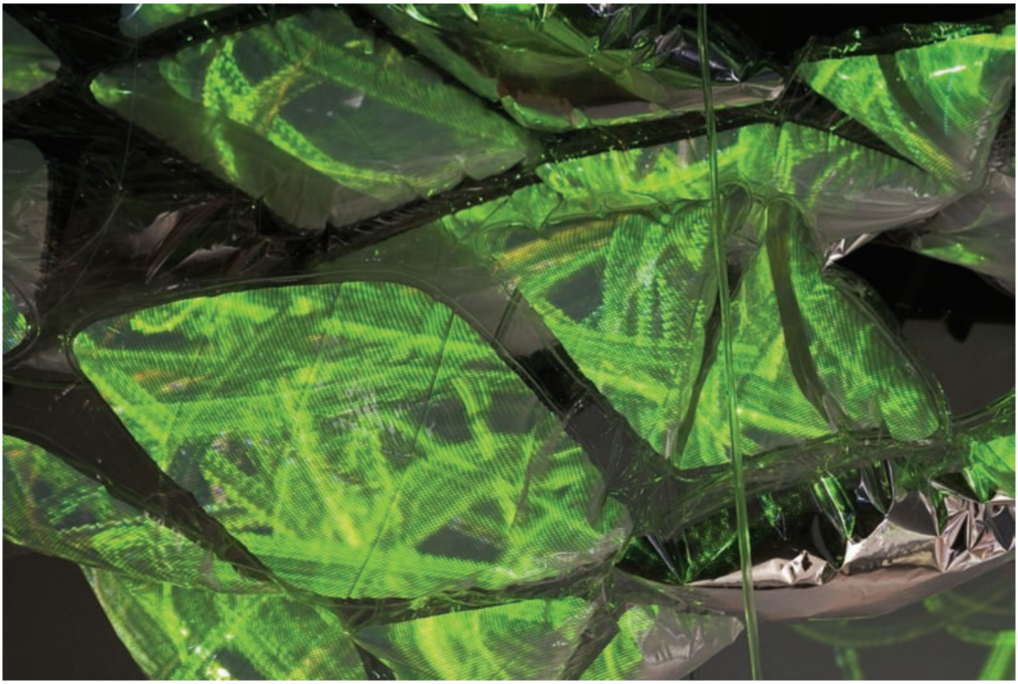
However *second nature* understood as milieu in our work is perhaps trying to define, primarily for ourselves a field of thought, in which we can, at a minimum, break or test our own preconceptions and on a slightly wider level, try to construct installations that attempt to embody these aspects as experience for the participant.

Broadly, we would tend to see ecology as a synthetic condition comprised of natural and constructed aspects. More specifically, there are several aspects of "ecologies" that our work addresses. We would say that they are not "ecological" intentions in the conventional sense of sustainable practices (Hasdell 2010: 92–113). These practices we consider as just being a responsible approach to design: we look for material and behavioral efficiencies in our work as well as engaging in the most efficient electrical systems as possible, including more recently, passive behaviors.

By far the most "sustainable" practice is in our working structure. We take Open Source seriously both in the authorship of our work and where we draw our research. Quite often we will transmit our findings and our methods to anyone who wants to use them. We are quite strict about using non-proprietary techniques and open source platforms to do our work. Architecture has been dominated for the longest time by a closed system of knowledge, yet its practice has been a long-standing cultural project. We did work with interactive specialists at one point, and that wasn't the most rewarding or expansive experience.

There is a strong undercurrent of *ecosophical* critique to our work itself. For most of our projects we work with discreet single purpose systems, not unlike the principles of BEAM (Biology, Electronics, Aesthetics and Mechanics) robotics. As individuals they may be robust, but materially they tend to break down. However, **it is the ensemble of the multitudes of these systems that creates an ecology. This ecology thrives on excess of ornamentation: there is an efficiency in the individual member, however the final piece is almost one of baroque excess. Parts tend to break down, things tend to have unexpected and surprising behaviors. To us, this is part of any ecological system. It is not uncommon for our work to deteriorate over time. This is fine with us.**

Emergent, from our point of view is an over-used term; a pencil was also an emergent technology at one time as was descriptive geometry. Architecture has been responsive for thousands of years without the need for micro-processing or electronics. From this point of view, we see emergence as a questioning of discourse concerning technology.



Remedios Terrarium *(2008) is an interactive pneumatic installation exhibited at the FOFA Gallery, Concordia University in Montreal, QC; Detail of liquid cell with weed growth. (Courtesy Patrick Harrop, Peter Hasdell, ShaXin Wei, and the Topographical Media Lab)*

Further Reading

www.pneumata.net
www.ocular-witness.com

Harrop, P., "Open Sourcery: When Hacking Culture Invades the Design Studio," *Journal of Architectural Education,* 61: 1 (2007), pp. 69–72.

Harrop, P., "Corrupting the Substrate: Risk and Resistance in Mediating the New Materiality," *AI: Architecture and Ideas, Digital,* 5: 1 (2005), pp. 47–57.

Hasdell, P., "Pneuma: An Indeterminate Architecture, or, Toward a Soft and Weedy Architecture," in L.Tilder and B. Blostein (eds.), *Design Ecologies: Essays on the Nature of Design*, New York: Princeton Architectural Press, 2010, pp. 92–113.

Hasdell, P., "Artificial Ecologies: Second Nature Emergent Phenomena in Constructed Digital-Natural Assemblages," *Leonardo Electronic Almanac*, 14: 8 (2006). Available at <http://leoalmanac.org/journal/vol_14/lea_v14_no07-08/phasdell.asp>

Chapter 4

Material Behaviors

Aurora Project *(Courtesy Jason Kelly Johnson and Nataly Gattegno)*

be·hav·ior

• anything that an organism does involving action or response to stimulation
• the response of an individual, group, or species to its environment[1]

1 *Merriam Webster's Collegiate Dictionary* (1995) 10th Edition, Springfield: Merriam-Webster.

Live Inputs: Variable Outputs

Nataly Gattegno

Contemporary design practice demands the reinterpretation and recasting of the territory of architecture. This territory is expansive and routinely employs a promiscuous mixture of design tactics from the fields of fluid dynamic modeling, robotics, advanced fabrication, biology, and material sciences. In doing so it actively generates and designs its own unique formal and environmental conditions. This territorial practice takes in information from its surrounding environment (such as weather, climate, usage, circulation, temperature, pollution) and through a reformulation of these *live inputs* yields formal logics and *variable outputs* that are simultaneously representational frameworks and spatial armatures for architecture and design. There is a fundamental shift taking place in how we expect these frameworks to perform as analytical machines, and how in turn these machines become dynamic, and perhaps intelligent, performative frameworks for architecture and design. This chapter will explore the opportunities of an architecture that relies on changing, mutable, and dynamic inputs and interrogate the variable and evolving outputs that such a design framework may yield.

Input/Output (I/O) in Computing

In computing, input/output[1] (I/O), refers to the communication between an information processing system (such as a computer), and the outside world. I/O describes a system of operation whereby certain trigger inputs are processed and reinterpreted as outputs; inputs are the signals or data received by the system, and outputs are the signals or data sent from it. In computer architecture, where the combination of the CPU and main memory is considered the "brain" of the computer, this processing organization describes a direct relationship between inputs and outputs. Any transfer of information from or to that architectural—computer—framework, is considered an I/O operation.

In its most simplified form an I/O system describes the connection of various inputs and their corresponding outputs through the processor; in other words the relationship between a processing framework and its environment. The relationship described by simple

I/O systems is predominantly linear; as such it is a useful tool to understanding more complex interactions between design frameworks and their surrounding influences.[2]

Key to an I/O system is the interface, which is required to enter the information fed into the processor and interpret the information generated. This interface must have the capacity and logic to interpret the information supplied and the logic to transform it into a desired output. Representationally therefore the interface becomes the repository of the data stream—the stream of information from the input device to the output device—and the mechanism for interaction between inputs and outputs.

I/O in the Design Process

Though this is an overly simplified description of I/O systems, these frameworks of operation and procedural logistics can be useful in understanding and determining potential inputs into the design process, successive outputs as well as design and representational interfaces of "architectural" I/O systems. Inputs are frequently used to describe design prompts in architectural design methodology. Inputs could be tangible parameters such as site, program, and client needs or more elusive influences such as light, energy, or wind direction. A relational framework sets up the discrete relationship between inputs and possible outputs giving rise to an architectural framework of operation that parses through a given set of inputs to yield a relational set of outputs.

This linear translation of input and output is the most simplified transliteration of computing's input-output model to an architectural design framework. It assumes stability, predictability, and control of inputs and as a result can solely rely on static, isolated, and deterministic outcomes. Clearly defined, previously articulated, analyzed, and comprehended, these static inputs become the triggers of the design process and parameters to design for. Stability and isolation are frequently considered as necessary for analysis of complex systems as a way of minimizing variables to be considered. In traditional scientific method sensitivity to the surroundings is considered a disruptive input that interferes with traditional working methods (Beesley, Hirosue and Ruxton 2006). The outputs though potentially multiple exist as solutions to specific inputs. As such the formal outputs can be deterministic, pre-formulated, and controlled. The architectural system developed through this methodology exists in isolation of other surrounding stimuli and any external trigger may be detrimental to the system's viability.

As a result, concepts of feedback, synchronicity, real time, and nonlinearity are rarely considered in an attempt to simplify the inputs and fully control the outputs. Contrary to designing for a predicted average or maximum condition, what are the opportunities in considering unpredictable, nonforecasted "inputs" into architectural design processes? Instead of redundancy and predictability, what could the implications be for nonlinear relationships between inputs and outputs and the feedback loops of operation between them? What complex frameworks for architecture and design are generated when the inputs are constantly changing and (dare we say) alive?

Live Inputs + Variable Outputs

An architectural framework does not exist in isolation of its immediate environment so an a priori determination of the input sources would substantially limit the architectural opportunities and response mechanisms. Contrary to a linear and predictive I/O organization, opportunities potentially lie in a more dynamic and changeable reading of inputs into the design process, which would enable a more variable and mutable set of outputs. These inputs exist in constant fluctuation and may be considered as fields of stimuli or energies rather than finite objects to be responded to.

Typical conditions of program and site are not to be neglected, but re-evaluated as parameters with the possibility of change (programmatic change over time, seasonality of site etc.). As such they can be rethought as energies or parameters that are in constant flux. Furthermore new fields of energies emerge that tap into previously underutilized datasets of influence. Weather, environment, temperature, activation, all become viable triggers for a design framework, but also describe a framework—an output—in constant fluctuation and variability.

This relationship between input and output could be termed as one between energy and form in architectural terms. It could also be conceived of as immediate and synchronous—possibly even real-time—and evolving. This I/O system describes a framework of operation that is mutable and transformable, not simply a linear action and reaction, but an architectural substrate in constant flux and recalibration to the energies of its surroundings.

Epigenetic Landscape

Such an architectural framework could be considered an evolving landscape—a version of the epigenetic landscape as coined by the geneticist Conrad Waddington (1957, cited in Kwinter 1992: 63). The epigenetic landscape is an undulating topographical surface that corresponds to the possible trajectories of growth for any organism, evolving on it. Epigenetics describes the series of influences applied to genes by their environment ("epi": above the genes in Greek) and as such postulates that genetic evolution is not only a long-term process, but can take place within the genetic lifetime of a human being. As a descriptive device (Kwinter 1992), the epigenetic landscape abstracts the movement of a ball on the undulating landscape as the potential evolutionary trajectory of an organism over time. This trajectory is far from static and may recalibrate as a result of a topographic transformation of the epigenetic landscape due to an exogenous factor. When considering the substrate of an epigenetic landscape as described by Waddington, one observes the control mechanism of the topography. A number of triggers tethered to the surface and tethered to each other control the morphology. A single adjustment to one tether triggers a widespread transformation of the landscape and as such recalibrates the potential trajectory of the ball/organism. In epigenetic terms these triggers are environmental such as nutrition and environmental qualities and can reconstitute the formal terms of the evolutionary landscape.

The inputs in other words are external and constantly changing, yielding changing outputs; the energy and form of the system are in constant negotiation and the outcome is unpredictable.

The descriptive model of the epigenetic landscape is a helpful tool in describing the potential framework for a live input and variable output model for architecture. Once set in place, the constant recalibration of the model to its surroundings determines the formal outcome of the framework of operation. This recalibration can be synchronous, asynchronous, or buffered, but the triggers are real and live and thus the relationship between energy and form direct. The inputs are live; the outputs are live as well, generating live frameworks—or *Live Models*.

Live Models + Energy Loops

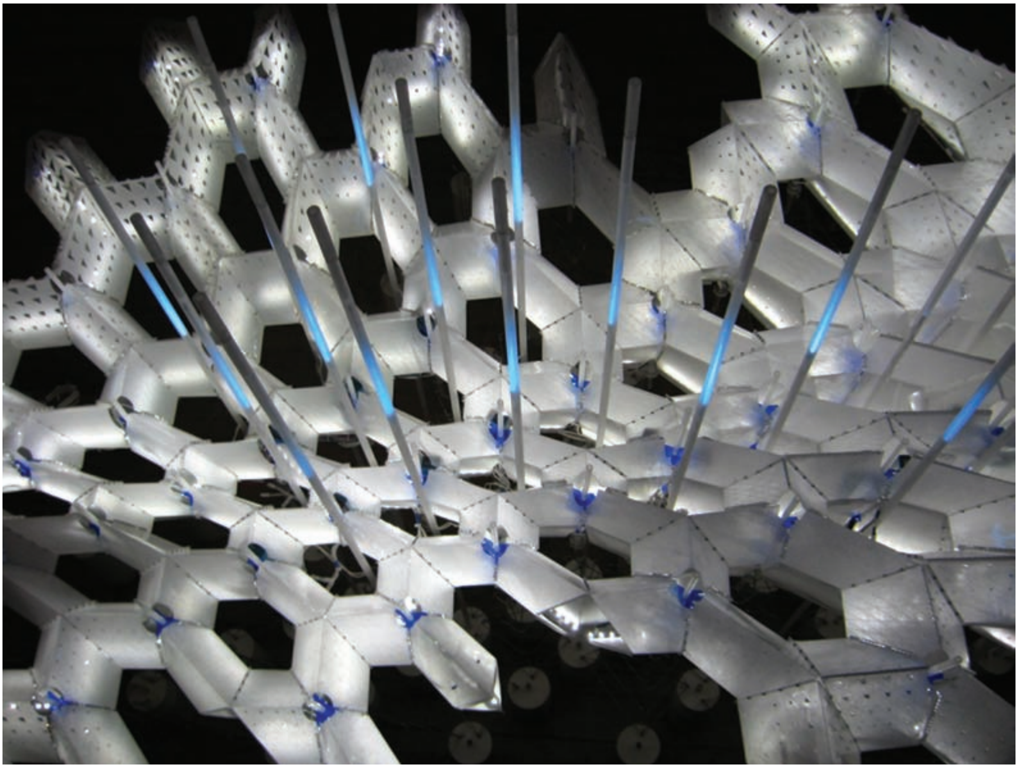
Live Models (Gattegno and Johnson 2012) are dynamic formations that register and continuously adapt to shifting atmospheric and microclimatic energy fields. The most compelling of these models do not merely depict the appearance of things, but seek to reveal

The Glaciarium is an interactive instrument that engages a smaller group of users' senses through the sight and sound of a melting ice core. (Courtesy Future Cities Lab)

The influence of the individual viewer is linked directly to the materiality and sensation of the Glaciarium. Increased observation amplifies the internal lighting effects and, depending on the duration of interaction, dramatically accelerates the melting of the ice core, rendering the environmental degradation visceral and real. (Courtesy Future Cities Lab)

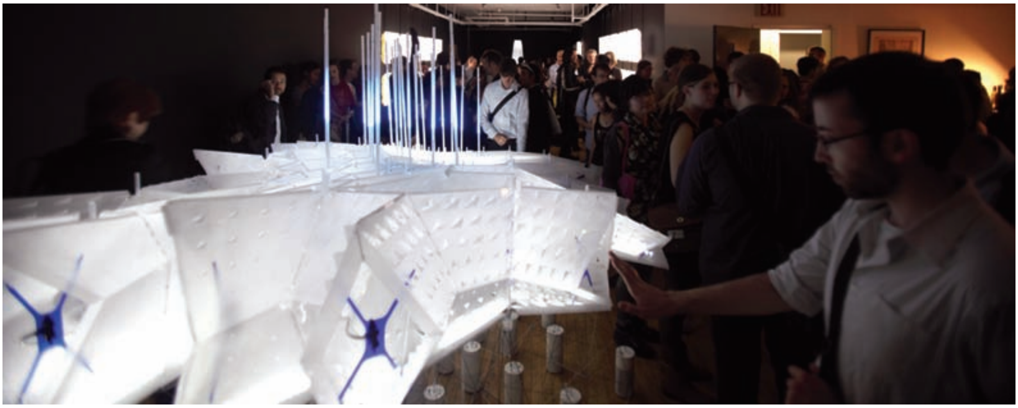
the irreducible nature and behavior of processes in transition. The *Glaciarium* was an interactive device that engaged a smaller group of users' senses through the sight and sound of a melting ice core. The influence of the individual viewer was linked directly to the materiality and sensation of the project. Increased observation amplified the internal lighting effects and, depending on the duration of interaction, dramatically accelerated the melting of the ice core, rendering the environmental degradation visceral and real. The *Glaciarium* was not only capable of calculating the underlying logic of material processes (melting ice), but also revealed emerging organizations of energy, form, and flow in visually and acoustically discernible patterns.

Live Models can be used as analytical engines to understand the patterns around us, and in some cases, as conceptual frameworks for architecture and design. As such Live Models are continually tethered to their environments and in constant negotiation with the energy loops that surround them. The *Aurora* model was an index of shifting territorial resources in the Arctic and a speculative vision for a massive new energy infrastructure and settlement pattern. *Aurora* suggested an alternative approach to the exploration, exploitation, and inevitable colonization of the region. It was simultaneously a projection of an imminent environmental condition, and the materialization of how contemporary political, social, and ecological trends could be channeled toward a more productive future. *Aurora* superimposed the ephemeral qualities of these representations on the dynamic behavior of multiple users, translating the shifting dimensions of the ice into a responsive light field. This reciprocal relationship present in live models describes the larger ecosystem of a project and extrapolates to include the larger ecosystemic influences and energy loops that act upon it. Weather, environment, and circulation become variable inputs that trigger unpredictable outputs.



Aurora is an index of shifting territorial resources in the Arctic and a speculative vision for a massive new energy infrastructure and settlement pattern. Aurora suggests an alternative approach to the exploration, exploitation, and inevitable colonization of the region. It is simultaneously a projection of an imminent environmental condition, and the materialization of how contemporary political, social, and ecological trends may be channeled toward a more productive future. (Courtesy Future Cities Lab)

An ecosystemic design process is primarily concerned with the management of external environmental influences and internal programmatic energies rather than the object of architectural form. Energy management (Banham 1984) comes to the forefront as the regulator and designer of these relationships between energy and form. The design firm AMID (Cero 9) terms the materialization of these energies "energy forms" (Diaz Moreno and Garcia Grinda 2009: 83). Energy forms are distinctly different from postwar explorations primarily concerned with material optimization and efficiency. Buckminster Fuller and Frei Otto's visionary explorations of the relationship between energy and form were guided by an interest in material minimization and efficiency rather than material exchange and fluctuation. Exchange and feedback however, describe architectural systems that are in reciprocal relationship with their environments. They privilege exchange over optimization in the determination of the relationship between energy and



Aurora superimposed the ephemeral qualities of these representations on the dynamic behavior of multiple users, translating the shifting dimensions of the ice into a responsive light field. (Courtesy Future Cities Lab)

form. The results are dynamic design systems of energy management and exchange that disperse, consume, and harvest energy. *Xeromax Envelope* was a quarter-scale experiment for a responsive building envelope calibrated and tuned to its environment. Part robotic structure, part experimental interface, and part microclimatic machine, it registered energy cycles and interactions over time while harvesting solar energy and protecting the building from the local climate. *Xeromax Envelope* was proposed as a second skin for an existing building and activated by and registering present and forecasted conditions. The model wove ultra-thin custom actuators, arrays of light, and proximity sensors through the extent of the surface which transformed as it registered the changing conditions around it.

Live models such as *Xeromax* regulate materials systems with formal and technical characteristics that are in constant fluctuation and energy exchange with their surrounding environment. Buildings are no longer conceived as fixed entities determined by a singular energy type or influence. They are highly complex ecosystems of multiple energies and influences in constant feedback with the environment in which they are situated. These energies have a distinctly nonvisual presence, although their influences impact form. The invisibility of these energies adds to the elusiveness of this design methodology, which is at once precise and measured, yet ephemeral and invisible. The architect Philippe Rahm writes about the "slippage of the real from the visible towards the invisible . . . a shift of architecture towards the microscopic and atmospheric, the biological and the meteorological" (Rahm 2009: 32). Architecture shifts toward invisible influences, stretching between the infinitely small and the infinitely large, the scale of the body and the scale of weather systems. In response to the dissolution of built form, new representational systems need to be developed to measure and quantify both the invisible forces applied to the architectural form and the visible outcome of that interaction. These representational systems need to further span

Xeromax Envelope is a quarter-scale experiment for a responsive building envelope calibrated and tuned to its environment. Part robotic structure, part experimental interface, and part microclimatic machine, it registers energy cycles and interactions over time while harvesting solar energy and protecting the building from the local climate. (Courtesy Future Cities Lab)

Xeromax Envelope is proposed as a second skin for an existing building and becomes a register of present and forecasted conditions. The model weaves ultra-thin custom actuators, arrays of light, and proximity sensors through the extent of the surface which transforms as it registers the changing conditions around it. (Courtesy Future Cities Lab)

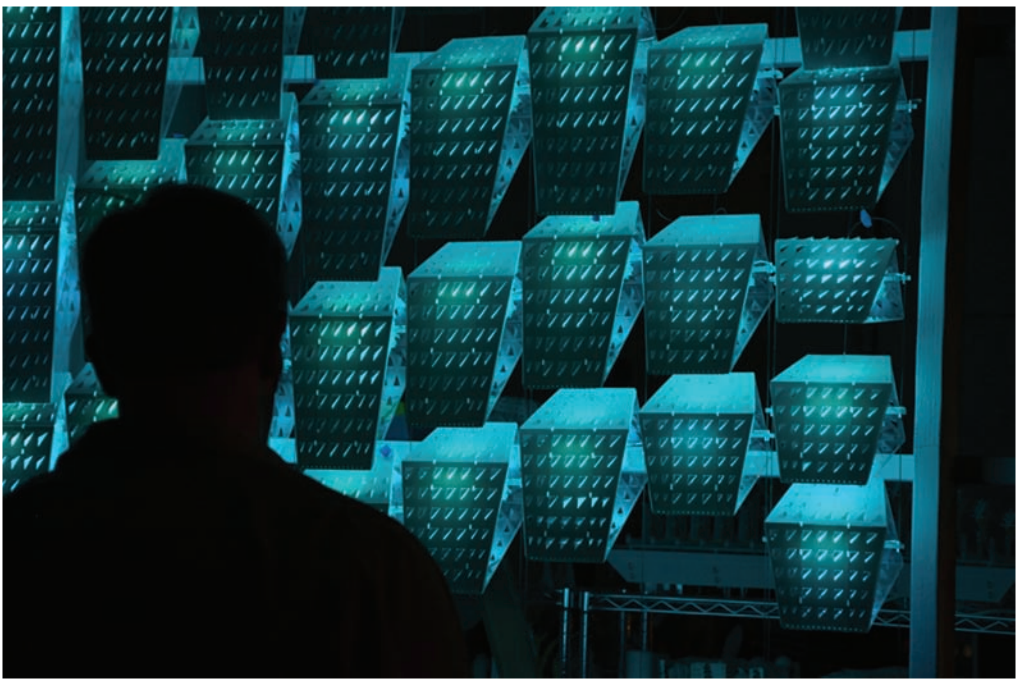
multiple scales of influence, from weather patterns to temperature gradients and urban circulation paths.

Scale, under these terms, is subservient to the interactions between all the parts. Live models describe systems that span scales and are able to address hyper local and global realms through their behavioral logics. They are constantly confronted with a range of environmental fluctuations that vary constantly in magnitude and force. The scale of ecological dynamics can therefore operate as a closed system with respect to local site variables, while at the same time remain open with regard to broader systemic influences that change over time.

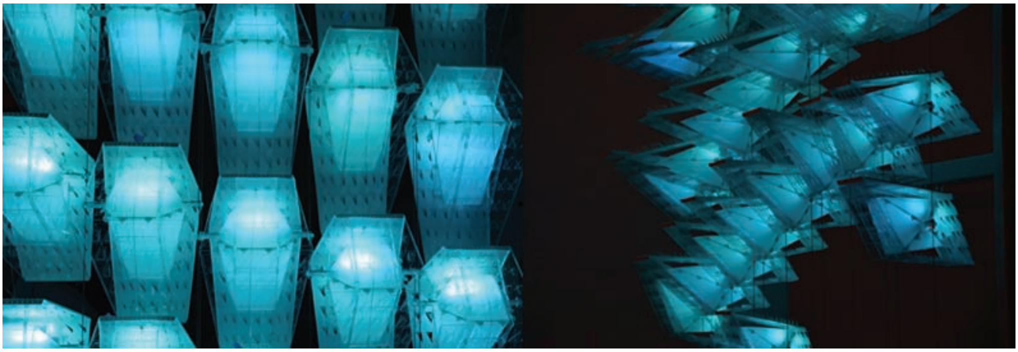
Feedback + Control

Feedback loops between inputs and outputs are incredibly important in establishing a constant flow of information from the environment, to the architectural framework of the live model, and back again. An I/O model would only exist in a linear and hierarchical platform if the loops of information flow did not feed back into the system: a specific input would trigger a specific output. Fluctuation and duration of input would have little or no impact on output. Synchronous, asynchronous, or buffered information flows however, become extremely useful tools in determining the flow of design information to the live model. These terms describe the flow of information back into the system and its recalibration at multiple time frames. The results are much more complex realms of interaction where the complexity of the data flow is calibrated and targeted to have an impact on form and performance.

Control however is a primary question in these systems. Going back to the descriptive model of Waddington's epigenetic landscape, the question still lies as to who controls the epigenetic substrate? What determines it? What sets the rules of engagement and interaction? It is assumed that the system evolves, but by whose rules are those?



Cirriform is a site specific installation exploring the intersection of public space, physical computing, and interactive architecture. The installation situates itself at the threshold between inside and outside, the digital and the physical, the artificial, and the natural. (Courtesy Future Cities Lab)



Cirriform activates the building façade and creates a playful, interactive and intellectually engaging experience that draws people to the building. It performs as an attractor capturing and translating the latent energies of its context into visually discernable formations of geometry and ambient light. (Courtesy Future Cities Lab)

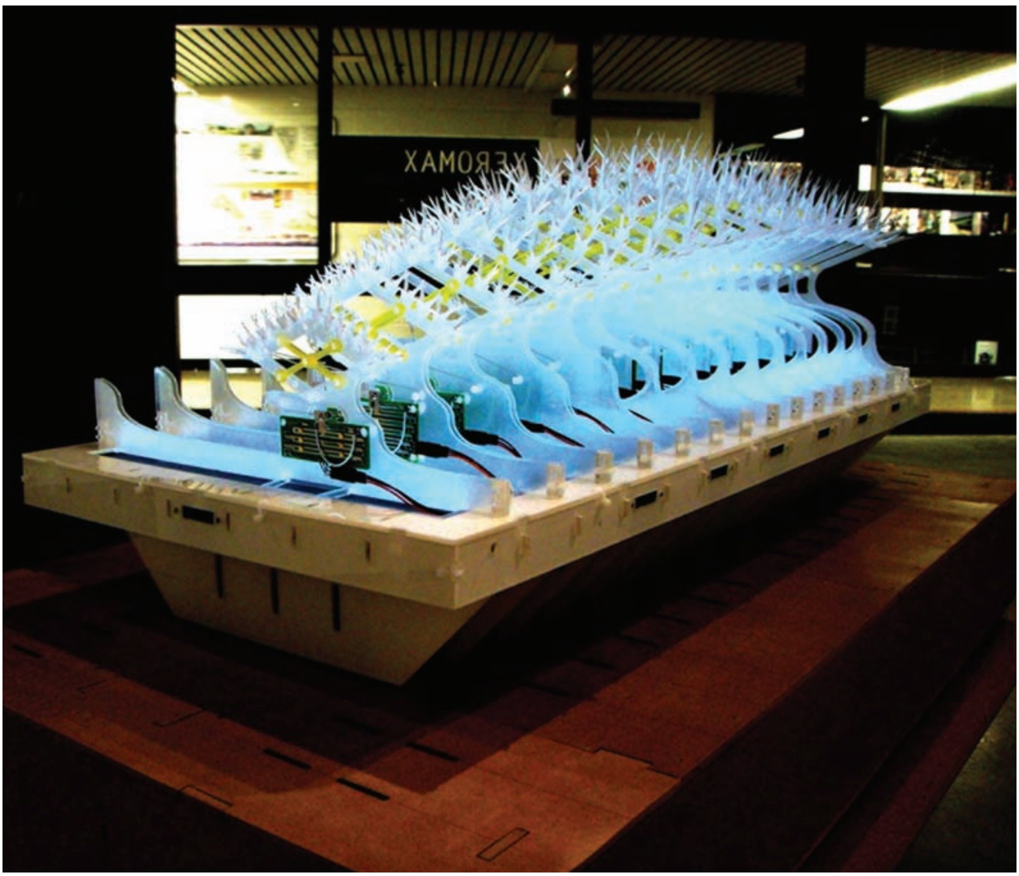
Manuel De Landa discusses this dilemma as one between hierarchy and meshworks—or Symbolic Al and Behavioral Al (De Landa 1998). Symbolic Al would set the rules of the game and play accordingly by controlling the entire system. Behavioral Al would control only a small portion of the system by determining the component behavior and let the game play out. For De Landa the dichotomy is not clear cut, and he describes instead interdependency and coexistence of both models of hierarchy and meshwork, as opposed to the outright victory of meshworks and agent-based models.

Control never exists in its pure state but rather emerges from both the hierarchical definition of the logics of interaction by the designer and the fluid behavioral interactions of the user. The interface of these control mechanisms is the live model, constantly oscillating and reverberating between these two states of control. Rather than operating under a linear and hierarchical system of control or a purely behavioral model, live models thrive in the interface between the two, generating unpredictable and constantly fluctuating control protocols. The resultant outputs are unpredictable, varied and constantly fluctuating. *Cirriform* was a site-specific installation that explored the intersection of public space, physical computing, and interactive architecture. The installation situated itself at the threshold between inside and outside, public and private. *Cirriform* activated an existing building façade and created a playful, interactive, and engaging experience that drew people to the building. It performed as an attractor capturing and translating the latent energies of its context into visually discernible formations of geometry and ambient light.

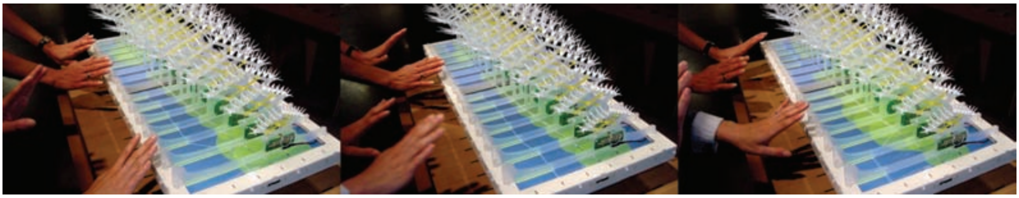
New Tools

The shift from linear to nonlinear and real-time I/O design processes necessitates the development of alternative analytical methods, representational tools, fabrication, and modeling techniques. These are necessary to develop representational and analytical structures that harness fluctuating information sets, negotiate between multiple control mechanisms, and develop data feedback loops. These techniques rely on the development of synthesized tools between disciplines that have previously been considered separate: architecture, design, material sciences, robotics, advanced fabrication, biology, and computer sciences all seem probable cross-collaborations in our field. As such, new collaborative tools emerge that are capable of analyzing, processing, and visualizing these variable fields and gradients of information which in turn become discernible inputs for live models.

Open-source and user-generated data are now readily available through the web (such as Google Earth, Pachube etc.) and allow architectural frameworks to tap into real-time data inputs and respond with variable outputs. Temperature gradients, microclimatic weather



Xerohouse is a prototype for desert living; calibrated, tuned and responsive to its desert habitat. It is an adaptable, mutable and variable desert ecology. Contrary to current trends in desert suburban development, Xerohouse is a porous, permeable and evolving habitat in synchronicity with its surroundings—hyper situated, indigenous and local. (Courtesy Future Cities Lab)



Xerohouse responds to the DNA of the desert: wind direction, solar orientation, temperature, sand. The Xerohouse model graphs interactions on two LCD displays while simultaneously recalibrating the truss geometry relative to external stimuli. (Courtesy Future Cities Lab)

patterns and energy potentials are now possible inputs plugged into a live model. Through sensor meshes and sensor feeds, program plug-ins like Firefly (Johnson and Payne 2011) are capable of translating shifting microclimatic environments and triggers directly into both the digital and physical world. Firefly allows near real-time data flow between the digital and physical worlds, by reading and writing data from Internet data fields and remote or local sensors. These generate the immersive environments of live models that rely on the nonlinear, recalibrating relationship between inputs (for example an Internet data feed) and outputs (for example a servo motor rotation).

Visualization of these new datasets should also evolve to represent shifting and changing datasets. The inputs are no longer static and therefore alternative methods of representation need to be developed to represent these fluctuating energy fields and modes of complex interaction. These techniques may evolve through traditional notation systems of architecture or by co-opting alternative media such as animation, interactive media, and interface design, or statistical and scientific modeling and graphing.

Xerohouse was a live model that experimented with ways of representing variable fields of information that change over time and evolve at multiple scales. It was a prototype for desert living; calibrated, tuned, and responsive to its desert habitat. It was proposed as an adaptable, mutable and variable desert ecology. Contrary to trends in desert suburban development, *Xerohouse* was a porous, permeable, and evolving habitat in synchronicity with its surroundings—hyper-situated, indigenous, and local. *Xerohouse* responded to the DNA of the desert: wind direction, solar orientation, temperature, sand. The *Xerohouse* model graphed interactions on two LCD displays while simultaneously recalibrating the truss geometry relative to external stimuli.

Alternative methodologies and fabrication techniques are required to explore the three-dimensional implications of live inputs in the determination of variable outputs are also being developed and co-opted from such fields of robotics, mechatronics, and engineering. Live models are inherently mutable and dynamic. Fabrication techniques that account for physical transformation and physical variability are integral to their reconfiguration whether materially or mechanically triggered. Complex, highly customizable modeling systems are therefore developed to iterate and test the variability of constantly recalibrated, variable outputs.

Conclusion

Live inputs and variable outputs describe a potential framework for design and architecture that relies on a design process that is messy, polluted, corrupted, and promiscuous in the way it operates between competing inputs, rivaling controls mechanisms, multiple disciplines, and media. It is not a pure and contained design process, but one that is willing to continually re-evaluate its parameters and reconsider its inputs—and as a result its outputs. Far from being a predictive framework, live models strive to project and make viable multiple possible alternatives. They rely on automation and technology yet thrive in the unexpected results of dynamic, evolving processes, and synthetic re-combinations.

Live models describe synthetic ecosystems of occupation that are fluctuating and unpredictable. They describe a landscape that requires profound and visceral participation and questions the conventional notions of static and dynamic space. No longer are we designing architectural frameworks that are to be merely experienced, but ones which enlist our intense participation in the world that surrounds us. These spaces and landscapes require visceral and active participation and rely on interaction to gain meaning. By designing frameworks for live inputs, variable outputs emerge that generate alternative territories of occupation, profoundly different and constantly evolving.

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Notes

1 input/output;—n; 1. I/O the data or information that is passed into or out of a computer; 2. (modifier) concerned with or relating to such passage of data or information (Collins 2010).

2 In economics, an input-output model is a quantitative economic technique that represents the interdependencies between different branches of national economy or between branches of different, even competing economies. Wassily Leontief (1905–1999) developed this type of analysis and won the Nobel Memorial Prize in Economic Sciences for its development.

PROJECTS

Material Behaviors

Reef is a self-actuated ceiling presented at the '1:1 research by design exhibition' at the Royal Danish Academy of Fine Arts, School of Architecture in 2011. Image illustrates a detail of the installation, highlighting a play of light and shadow. (Courtesy Aurélie Mossé, Guggi Kofod, and David Gauthier; Photo: Mathilde Fuzeau)

Reef 2011

Aurélie Mossé
Royal Academy of Fine Arts School of Architecture, Copenhagen,
Central Saint Martins, University of the Arts, London

Guggi Kofod
University of Potsdam, Institute of Physics and Astronomy

David Gauthier
Copenhagen Institute of Interaction Design

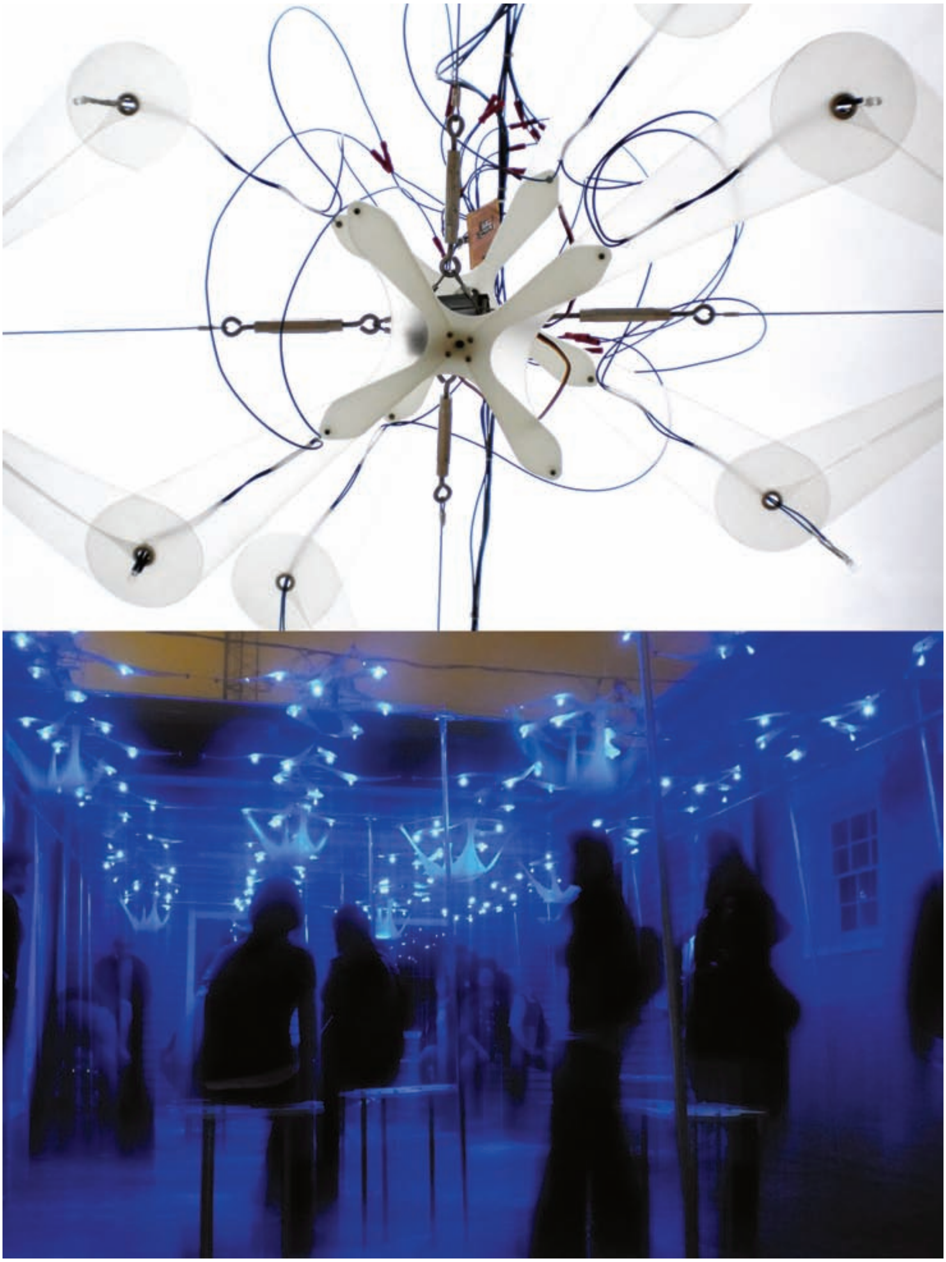
Reef is a "material tale," an embodied narrative exploring, through the design of a self-actuated ceiling, how electroactive polymers can be appropriated so as to contribute to the shaping of a culture of interconnectivity between nature, the home, and its inhabitants. *Reef* emerges from the ceiling as an archipelago of adaptive minimum energy structures. These structures move according to the principle of dielectric elastomer actuation: a family of plastic materials which can deform and change their shape by converting electricity into movement. Connected to a wind sensor, they are programmed to breathe at the pace of the exterior. As they sense wind, they open and close gradually following its fluctuations.

Evoking a canopy of organic creatures, *Reef* is a full scale installation resulting from a cross-disciplinary design process shaped by different modes of representation, where speculative scenarios dialogued with physical models, digital simulations, and material probes to give life to this dynamic formation. From the design of electron exchange to that of an adaptive environment, this digitally crafted surface results from a 2D manufacturing process where self-organization and energy-minimization principles play a central role in the shaping and actuation of its components. As a pre-stretched elastomer sandwiched together with a flexible frame is released, the formation of a 3D complex structure occurs. When a voltage is applied, the elastomer expands, allowing the structure to seek a new minimum energy conformation, therefore resulting in actuation.

Letting nature's rather unpredictable temporality worm its way inside the home, *Reef* transforms the interior into a timescape, questioning our understanding of space and the relationship we cultivate with technology.

http://www.aureliemosse.com

Project Collaborators: Anca Gabriela Bejenariu, Anne Ladegaard Skov.
Reef was generously supported by the Royal Danish Academy of Fine Arts, School of Architecture via a PhD position undertaken at CITA, Centre for IT & Architecture, Copenhagen, in collaboration with TFRC, Textile Futures Research Centre, Central Saint Martins, University of the Arts, London under the supervision of Carole Collet and Mette Ramsgard Thomsen. With the sponsorship of MetOne, the project also benefited of funding from the WING NanoFutur initiative of BMBF (NMP/03X5511).
Photography: Mathilde Fuzeau.



OpenHouse is a temporary installation, designed and constructed for DesCours, an exhibition of art and architecture sponsored by the American Institute of Architects. The installation was a canopy made up of "programmable building blocks" that adjusted in response to human occupation and social interactions within the space. (Courtesy Francis Bitonti and Brian Osborn)

OpenHouse — December 2009

Francis Bitonti
Francis Bitonti Studio, Rensselaer Polytechnic Institute

Brian Osborn
B O T H Landscape and Architecture, Rutgers The State University of New Jersey

OpenHouse is a temporary installation, designed and constructed for DesCours, an exhibition of art and architecture sponsored by the American Institute of Architects. Each year, during the DesCours event, 15 private, and otherwise hidden, spaces within New Orleans are transformed into public spaces that test the boundaries of architecture. *OpenHouse* intervened in 2009 by re-articulating the canopy of a 500-square feet courtyard located within the French Quarter. As visitors fill the courtyard the canopy adjusts in response to their social interactions.

Below the canopy, a number of seating elements are distributed throughout the courtyard. Each seat is equipped with a piezoelectric sensor that is networked to the canopy through a micro-controller. The micro-controller analyzes the patterns of use within the courtyard by counting the occupancy of seats, and returns a programmed reaction through the canopy. The canopy is a field of kinetic PETG plastic components; a servomotor controls each one. If no seats are taken within a given section of the courtyard the canopy reorganizes providing an open, inviting, condition at that location. If a small number of occupants inhabit a portion of the courtyard the canopy assumes intimacy and lowers itself to protect the promiscuous whispers between two lovers. If many users gather in one area the canopy becomes erratic; lifting and lowering to stimulate the excitement of the group below.

Through the integration of information into the palette of common construction materials, the architecture facilitates the behavior of its users spatially, while also making those phenomena legible; allowing for a navigation of the space via social conditions. Through this two-way, read-and-response communication, the architecture and the user form a landscape; where organisms relate to one another in a working ecology. *OpenHouse* questions the finite state of common material assemblages by proposing a universal building block capable of iterative adaptation based on changes in social behavior. Adjustment of the architectural form is enabled through the addition of code to the material of building. This new construction methodology hybridizes software and hardware toward the creation of a new tectonic.

www.francisbitonti.com
www.bo-th.com

Windscreen generated and consumed energy harvested from the wind, translating wind speed into a visual register and indexing the abundance of a critical renewable energy source. This project involved a multi-disciplinary team of students and heightened awareness around issues of renewable energy and public environments. (Courtesy MyStudio, HYA)

Wind Screen: Wind-Powered Lighting Installation — April – June 2011

Meejin Yoon
MY Studio, Höweler + Yoon Architecture

Eric Höweler
MY Studio, Höweler + Yoon Architecture

Wind Screen is an interactive public space installation that transforms the movement of wind directly into light. Responsive in real-time to environmental conditions, *Wind Screen*'s illumination corresponds directly to the wind velocity at each individual wind turbine. Arrayed into an architectural-scaled lattice of multiple small vertical axis turbines, *Wind Screen* generates and consumes energy harvested from the wind, translating wind speed into a visual register of this sustainable energy source. The air currents sweeping across the custom designed and fabricated turbines create a kinetic pattern of form and light. *Wind Screen*'s integrated functional and aesthetic properties seek to transform public opinion about wind energy, turning an invisible phenomenon into a visible renewable resource.

Mechanical energy produced by the wind illuminates a series of light emitting diodes (LEDs) integrated into the vertical axis of each turbine. The turbines use analog electronics to illuminate in correspondence with wind speeds—the faster the wind speed the brighter the illumination. The turbines are designed to fold into a 3D form from a flat sheet of cut and scored polypropylene. The form of the turbine was generated through an iterative study of both Darrieus and Savonius turbine forms to find the highest performance forms that could be made from a single flat sheet. A small voltage booster is integrated into electronics and no batteries are used to store the energy, instead, the light is the direct output of the mechanical energy input of the wind. This "direct-drive" application need not transfer or store energy: energy is consumed as it is produced, creating a real-time visualization of speed into light.

The current debates about sustainability and ecological design place an emphasis on technologies and verifiable performance data. *Wind Screen* participates in the debate about energy and sustainability through an alternative approach. Rather than make buildings more energy efficient, or their building envelopes more airtight, *Wind Screen* works on making wind energy visible, and hence affecting larger attitudes about energy use. *Wind Screen* seeks to develop an "eco-literacy," making the general public aware of energy issues, the ubiquity of natural resources, and the agency of human behavior in the larger context of energy use patterns.

www.mystudio.us
www.hyarchitecture.com

Project Collaborators: Cyrus Dochow, Yushiro Okamoto, Chris Carper, Lauren McClellan, Man Yan Lam, Jeremy Jih, Amanda Levesque, Jack Murphy (Design Team), Mark Feldmeier (Electronics Engineer), Simpson Gumpertz Heger, Paul Kassabian, Matthew Johnson, Monica Simmons (Structural Engineers).
This project was financially supported by MIT and private donations through the United States Artists program.

The "Envirogrammic" Response consists of three separate structures that use and adapt emerging and dormant environmental technologies and vernacular processes to re-establish the environment surrounding the ash pits and lava fields of Lanzarote as the architecture's energy source. The image above highlights one of these structures, River Reversed. (Courtesy Smout Allen)

The "Envirogrammic" Response — March 2010

Mark Smout
Smout Allen, Bartlett School of Architecture

Laura Allen
Smout Allen, Bartlett School of Architecture

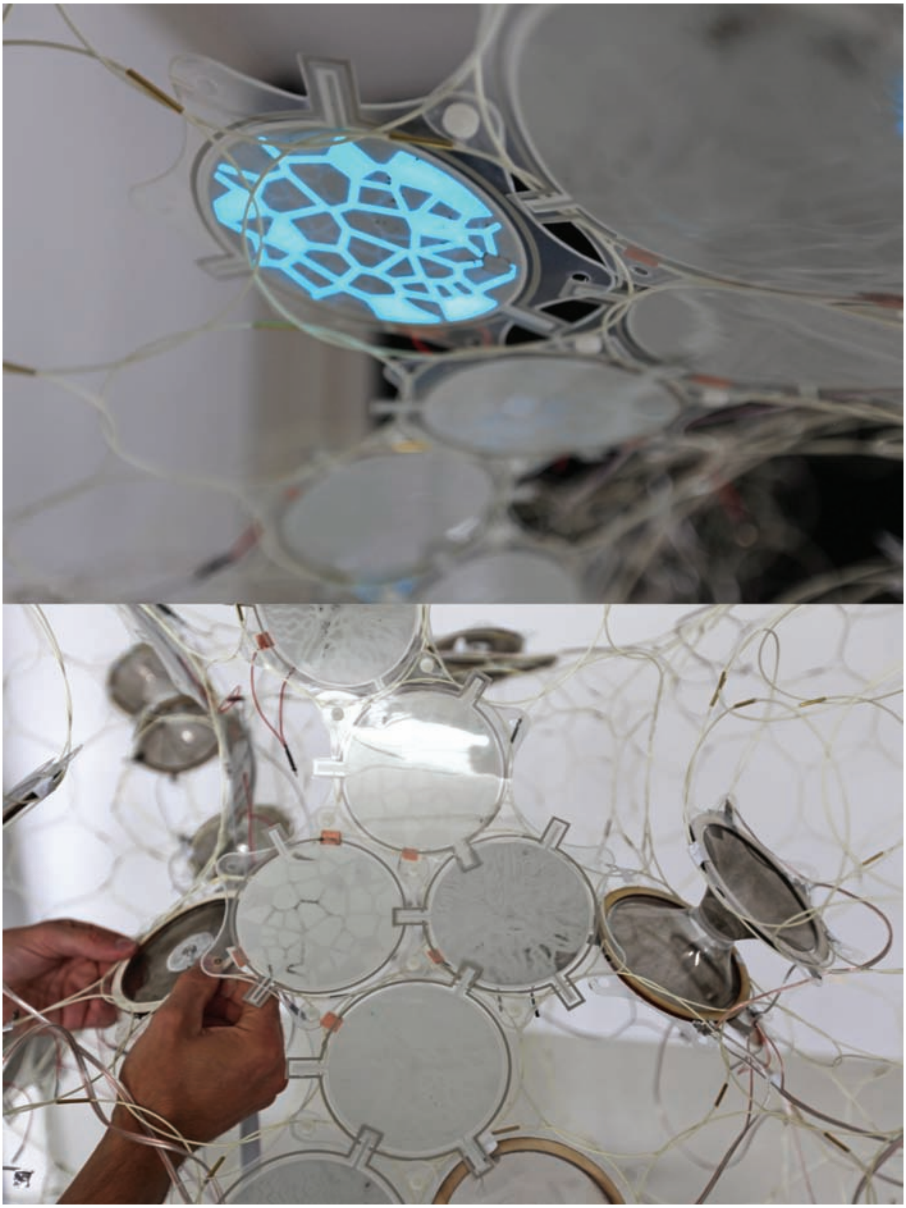
Envirogrammic Response is a design proposal for the Lanzarote lava fields and ash pits and is conceived as a heuristic context to imagine architecture as an ecological system that can function through apposite principles of sustainability for the future of urban and rural landscapes. Lanzarote is one of the few whole islands to be designated a UNESCO Biosphere Reserve that demonstrates approaches to conservation and sustainable development. Through the island's careful governance it has acted as a model for managing development in a sustainable manner and shown how landscape can be critical in providing a summarized vision of nature's complexity and beauty.

In this design project, three separate structures, the *Current Accumulator*, the *River Reversed* and the *Ground Cloud* use and adapt emerging and dormant environmental technologies and vernacular processes to re-establish the surrounding environment as the architecture's energy source. They also demonstrate the hydrologic cycle—the model of the movement of water above, on, and below the surface of the earth. Within the *Current Accumulator*, a landscape of solar ponds, mass walls, walkways, and connecting structures, power is gradually built up as a store of potential energy in large tensioned armatures and a network of cables that suspend the ponds from the surrounding rock landscape.

River Reversed responds to the island's precarious reliance on industrialized processes and its own hostile, dry environment. The scheme exploits the technology of solar chimneys where an updraft tower, more commonly used to provide ventilation, condenses water extracted by evaporation from a glass-covered saline pond. The tower has a reflective internal surface to multiply available light while absorbing radiation on its external surface to minimize heat loss through its mass. The chimney therefore superheats the moisture-laden air to vastly increase the volume of air passing through the system and therefore the quantity of condensation collected.

Ground Cloud is an array of framed fog nets constructed from a laminate of two materials with different rates of thermal expansion, which are held in a curved position while they accumulate moisture. At sunrise, when there is a significant change in air temperature, the differing thermal properties within the frames cause them to tension and in doing so apply pressure to a spring release mechanism. When the pressure becomes too great the spring release gives way, reconfiguring the frames, while also creating microclimates where the droplets fall. At night, as air temperatures decrease, the frames relax back and reset for the following day. Each of these three designs attempts to explore the tangibility of technology and physical laws and phenomena that are inherent in the local and global environment.

www.smoutallen.com



Actuated Matter is the result of a collaborative workshop that explored the application of smart materials in architecture with respect to their ability to envision architecture as spaces that relate to inhabitants in emotive and responsive ways. The final installation consisted of a lightweight assembly of interlocked loops, populated with electroluminescent screens, flexible audio panels, and electro-active membranes. The EL elements consisted of thin layers of phosphor, di-electric and conductive silver which were screen-printed on top of each other. (Courtesy Manuel Kretzer)

Actated Matter — July 2011

Karmen Franinovic
Interaction Design Group, Zürich University of the Arts, Zero-Th studio

Manuel Kretzer
Chair for CAAD ETH Zürich, responsive design studio

Daniel Bisig
Institute for Computer Music and Sound Technology, Zürich University of the Arts

Florian Wille
Interaction Design Group, Zürich University of the Arts

Mathias Gmachl
loop.pH design studio

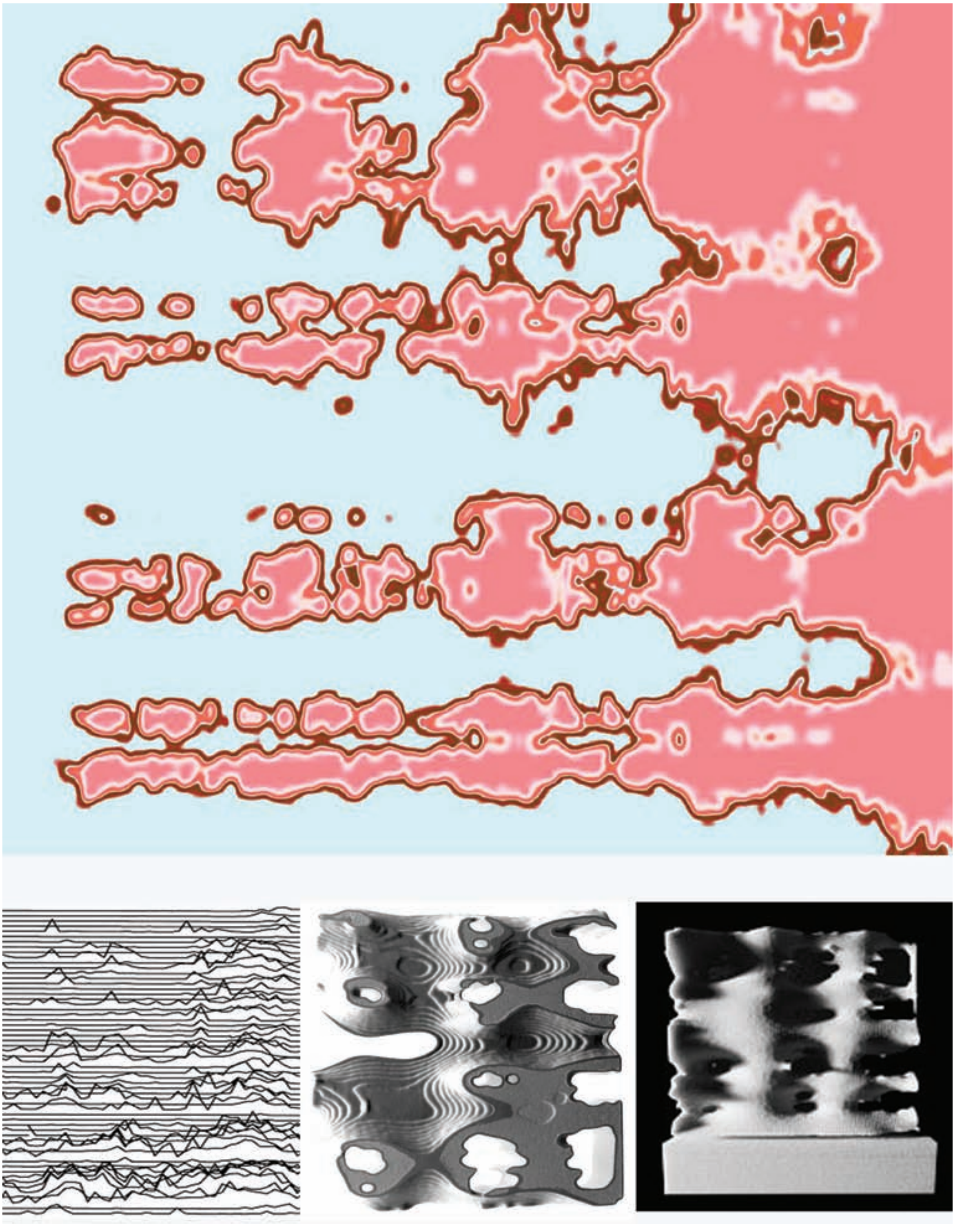
Rachel Wingfield
loop.pH design studio

The *Actuated Matter* Workshop forms part of a research initiative between the Zürich University of the Arts and the ETH Zürich's Chair for Computer-Aided Architectural Design that explores the application of smart materials in architecture with respect to their ability to transform an environment and to relate to its inhabitants in an emotive and responsive way. The focus is placed on the intrinsic properties of materials with kinetic, visual and acoustic feedback, namely electroluminescent screens, electroactive polymers and flexible audio panels, with the goal to explore how such materials can endow artificial spaces with some of the qualities of natural environments.

During the one-week workshop a prototype for membrane structures was produced that exhibited properties of sensitivity, resilience, and decay. The workshop followed an experimental do-it-yourself approach at the threshold between the electronic and mechanic, the analog and the digital. Participants developed sonic, luminous, and moving modules that populated and activated the environment. The workshop's participatory and hands-on methodology showed that highly sophisticated materials could emerge from collaborative creation processes, thus reflecting the goal of developing an alternative, less rigid architecture of the future as a more connected, interlaced, entangled, responsive, and responsible world.

www.blogs.iad.zhdk.ch/emotiveenvironments

Project Collaborators: Katrin Bächli, Urban Bieri, Szilveszter Buzasi, Allison Dryer, Luke Franzke, Laura Kaehr, Moritz Kemper, Roman Kirschner, Jorge Orozco, Barbara Peikert, Margrit Rieben, Maria Smigielska, Andrés Villa Torres, Silvan Zurbruegg.
Thanks to Romano Kirschbaumer, Jorge Ellert (Ulano Corp.), Christa Jordi (EAP Technology, EMPA Dübendorf).



The Pin Scanner Experiment used a haptic probe to map small dust particles. From a flat, compacted sample emerged an unexpected landscape of undulating forms. (Courtesy Michael Silver)

Beyond the New Materialism—The Pin Scanner Experiment 2011

Michael Silver
Michael Silver Architects, Ball State University

Eugene Wigner's still unproven interpretation of Quantum Mechanics states that only a measuring device operated by a conscious observer is capable of effecting matter's condensation from wave to particle. In other words, objects in the physical world are inseparably bound to the mind of a living subject. But even if Wigner is wrong, and consciousness does not "collapse the wave function" the Kantian "thing-in-itself" will remain forever unknowable outside the act of perception.

In *The Pin Scanner Experiment* a small 3D digitizer was used to record the flat surface contained in a one-inch square box of dust. With each touch of the machine's automated probe, small particles in the sample were gently displaced. The resulting scan produced a series of "pits and trails" that were re-materialized as physical objects using different 3D printing techniques. In effect, the mapping machine reads what it writes. While *The Pin Scanner Experiment* is not a scientifically rigorous demonstration of "observer-created reality" conducted on a quantum scale, it does illustrate the co-creative relationship between the act of observation and the thing observed. The way we take our measurements determines the form of the world. Both an old materialism, based on static essences,[1] and a new materialism, centered on incessant transformation, are likely to ignore this calculus preferring instead a design discourse that marginalizes subjectivity by imagining a world made of intrinsically real stuff existing outside the measurement situation. By relying exclusively on third-person reports of experimentally accessible mechanisms in the brain, neuroscientists run the risk of reducing mental activity to physical processes while avoiding the deeper issues that make such a move problematic. As Thomas Nagel has pointed out, "*If the subjective character of experience is fully comprehensible only from one point of view, then the shift to greater objectivity … does not take us nearer to the real nature of the phenomenon: it takes us farther away.*"[2]

If buildings rest too heavily on the expression of their material properties, functions, and methods of assembly, digital or otherwise, they run the risk of becoming narrow artifacts incapable of even approaching life's most interesting questions. Future encounters with these issues will be complicated by the fact that walls, columns, and floors seem so convincingly solid, so "out there" as absolute forms of exteriority. On the other hand, we have the ineffable fact of consciousness itself, a truly astonishing phenomenon that evades description, but one that must be explored through design as an antidote to the now ascendant views of naïve realism in contemporary culture. To realize this goal it is enough for architecture to expose the limits of neo-materialist dogma and the monopolies it holds over our imagination.

Notes

1 The infinite divisibility of sub-atomic particles cannot be experimentally refuted. A proof to the contrary would require an endless series of experiments and endless amounts of energy.

2 As written by Thomas Nagel in "What Is It Like to Be a Bat?" from *Mortal Questions*, New York, Cambridge University Press, 1979.

Adaptive Fa[CA]de was presented at Digital Hinterlands, an exhibition at Arup Phase 2 Gallery in London as part of Design Week in 2009. The kinetic prototype consisted of a grid of twenty-five individually controlled panels. A side view of the prototype shows the 3D-printed components that hold the panels, allowing them to tilt along their x-axis. (Courtesy Marilena Skavara)

Adaptive Fa[CA]de 2009

Marilena Skavara

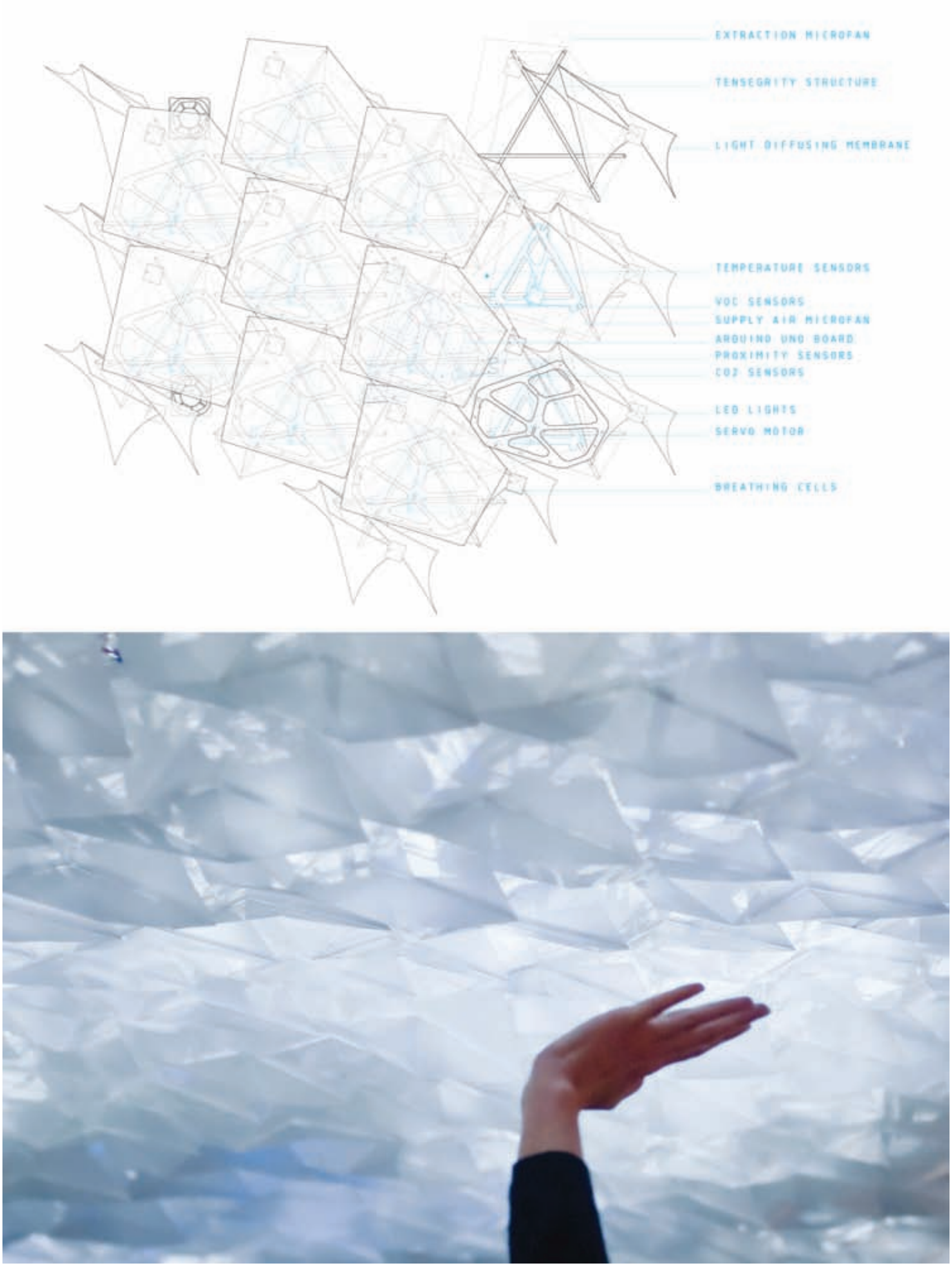
Driven by the need to effectively mediate the light levels of buildings and following the paradigm of natural systems, *Adaptive Fa[CA]de* explores the possibilities of learning the emergent complexity of Cellular Automata (CA) with artificial Neural Networks (NN) to control an adaptive skin. While it is often assumed that adaptation to a complex set of phenomena requires equally—or even more—complex control mechanisms, *Adaptive Fa[CA]de* suggests a simpler control system in terms of independent units, yet more contextual to its environment. *Adaptive Fa[CA]de* utilizes the inherent complexity found in several CA to effectively minimize the input from the environment and achieve maximum adaptability, significantly reducing energy and cost and leveraging the building's performance.

A finite grid of panels, each capable of tilting to various angles but obeying a CA rule, allows different amounts of light to penetrate the building. Using CA patterns as an interface between external conditions and desired overall and local optima throughout a building, the signal is efficiently communicated down the façade. The kinetic prototype shown here was manufactured with laser-cut acrylic panels connected to a system of 3D-printed joints. Each panel was operated by a simple servo motor and the whole grid was controlled by a centralized script running real-time in processing language. The script included a fixed virtual model, a given 7-state CA rule, and an artificial NN employed to train the system.

This project suggests that complex adaptations can be achieved and that complexity itself can be the tool for a deeper understanding of our natural and constructed world. The fact that the system is able to accommodate complexity both in the environmental data and in the CA structure itself suggests that a control system can be made to adapt to such conditions even when the mechanism for doing so is initially unknown or unperceived. Shifting from responsiveness to intelligence and adaptability can lead to dynamic, sustainable configurations of high aesthetic value.

Images and video of the kinetic prototype can be found at **www.microhappy.com**

Adaptive Fa[CA]de was implemented through the *MSc Adaptive Architecture and Computation* program at the Bartlett, UCL in 2008–2009 with Sean Hanna and Ruairi Glynn as thesis supervisors. The project was further explored during the Bartlett bolt-on *Advanced Architecture Research Certificate* in 2009–2010 and was included in the *Digital Architecture: Passages Through Hinterlands* publication and exhibition at *Phase 2 Gallery* in London.



The Stratus Project is part of an ongoing body of research investigating the potential for kinetic, sensing and environment-responsive interior envelope systems. The top image is a plan of the Stratus component array and the bottom image presents The Stratus Project v1.0 prototype responding to occupant presence. (Courtesy RVTR)

The Stratus Project 2011

Geoffrey Thün
RVTR; Taubman College of Architecture and Urban Planning, University of Michigan

Kathy Velikov
RVTR; Taubman College of Architecture and Urban Planning, University of Michigan

The Stratus Project is an investigation into a kinetic, self-sensing, environmentally-responsive interior envelope system that develops continual information and material exchange, and eventually dialogue between ourselves and the soft systems of architecture—such as light, thermal gradients, and air quality. The research is embedded in the history of environment-modifying architectures and cybernetic systems while also engaging questions of health and biopolitics. It explores how the technologically mediated spheres that define our existence may be designed materially, aesthetically and operationally, and how interactive technologies can be harnessed to develop more complex relationships between humans and their environments. *Stratus v1.0* is the first installed prototype for a personalized, responsive, light and air-based interior envelope.

The system is developed as a thick, kinetic textile that delivers distributed spatial and environmental adaptation relative to inhabitation. A lightweight tensegrity weave enables spatial deformation, transforming overall volume of space, while also supporting a networked matrix. Physical presence, as well as environmental conditions such as temperature, light, carbon dioxide (CO_2), and airborne pollutants are measured through a network of sensors that communicate with actuators triggering fans to supply localized sensible cooling or extract air through operable cells. A consciousness of the breather's own agency within the air environment occurs through the continual "breathing" and movement of the envelope, as well as haptically through blue LED lights that glow if CO_2 exceeds baseline levels. *The Stratus Project* works to reclaim the environmentally performative domains of architecture—in this case, specifically, interior mechanical delivery and interface systems—to within the purview of the discipline, as territories of material, formal, technological and experiential innovation. The personalized system is intended to minimize energy consumption associated with air delivery, as compared with conventional systems, while providing a responsive and fine-grained approach to air quality provision driven by inhabitation.

www.rvtr.com

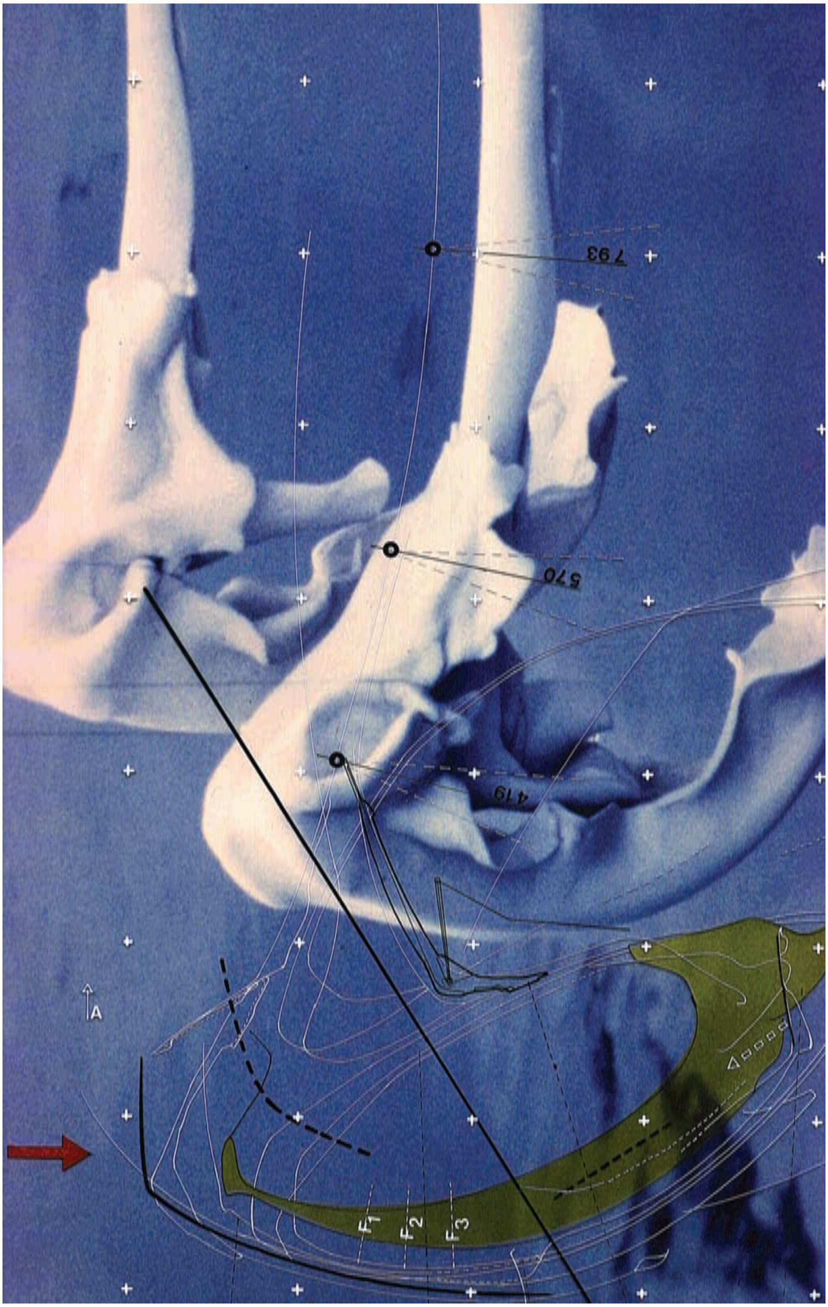
Project Collaborators: Zain AbuSeir, Mary O'Malley, Matt Peddie, Colin Ripley [Design Research], F.Parke MacDowell [Fabrication and Animation], James Christian, Christopher Parker, Jason Prasad [Programming and Actuation], Sara Dean, Jessica Mattson, Dan McTavish, Christopher Niswander, Lisa Sauvé, Adam Smith [Prototyping], Dr. Aline Cotel [Fluid Dynamics and Particle Image Velocimetry], Dr. Jerry Lynch [Wireless Sensor Technology].
The Stratus Project is funded through a Taubman College of Architecture and Urban Planning, University of Michigan *Research Through Making* Grant, University of Michigan Office of the Vice President for Research Small Projects Grant and a Social Sciences and Humanities Research Council of Canada Research Creation Grant.

Q + A

Shaun Murray *with Sneha Patel*

SHAUN MURRAY is an architect, researcher and founder of **ENIAtype**, an architectural practice that explores the nexuses of ecological, notational, instructional and aesthetical design visions and methodologies, collapsing the natural onto the artificial. In 2011, he received his PhD in Architecture at the Center for Advanced Inquiry in Integrative Arts (CAiiA)/Planetary Collegium at the University of Plymouth. Shaun Murray is also Editor-in Chief of the bi-annual international journal *Design Ecologies* (Murray 2011, 2012) published by Intellect Books, which foregrounds the inextricable connection between human communication and ecological accountability in architectural design. Currently a teaching fellow at the Bartlett School of Architecture and a lecturer in Creative Design and Technology at the University of Plymouth, Shaun Murray has written extensively about ecology and design, highlighted by his book, *Disturbing Territories* (Murray 2006).

Exploring the co-existence between people, environment and space, Shaun Murray discusses how an ecological model of thinking and making can prompt an architecture that acknowledges, both broadly and specifically, the interconnectedness of life. Utilizing live data sets within an emerging design process, his work challenges traditional roles and technologies within design practice. To this end, he aims to move beyond the autonomy of building form towards an inventive architecture that maintains an evolving form of communication with its occupants, participants, and the environment.



Camargue Condensations *(1999) A vacillating object in Les Gorge Du Fier, Annecy, France. (Courtesy Shaun Murray)*

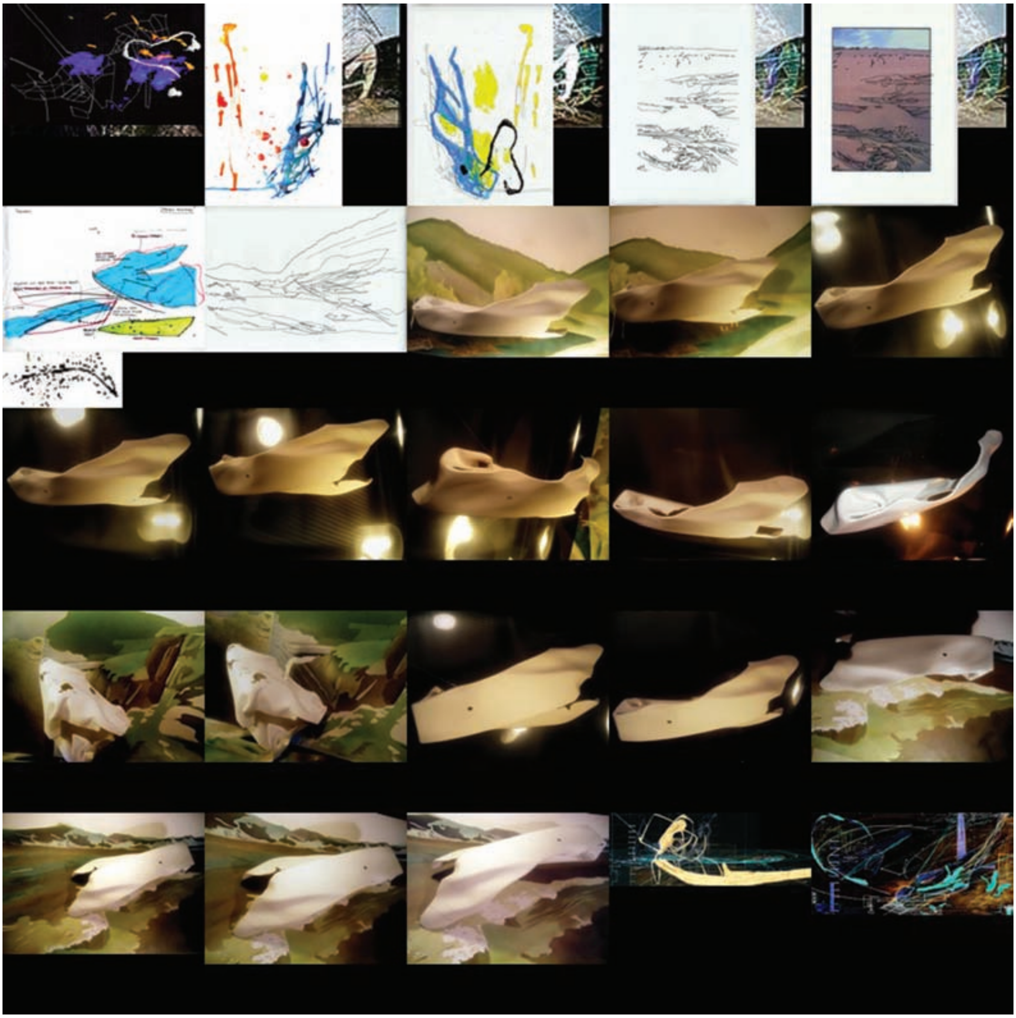
Q1. Sneha Patel: In *Disturbing Territories* (Murray 2006; Murray 2000: 139–144), you describe your work as an attempt to rediscover the "precisely determined, purposeful or inevitable attributes of form." This provides a critique of the ways in which new techniques of drawing, communication, and language have led to a sense of arbitrary formal freedom. Can you expand upon the ways in which you see virtual technologies have both positively and negatively impacted the study and practice of architecture either broadly or particularly in relationship to your work?

A1. Shaun Murray: In my work, virtual technologies have impacted on the study and practice of architecture through *Ecological*, *Notational*, *Instructional* and *Aesthetical* design visions. This has led me to a way of practicing with the idea of open system working drawings (Spiller 2000; Spiller 2008).

The impact of virtual technologies on *Ecological* design visions encompasses our relationship between systems for everyday environments and activities. Through our coming to terms with ubiquitous computing, air travel, global financial markets, and the like, it would be a combination of naiveté and hubris to think that traditional architectural communication could any longer manage mass communication and perception. The physical environment includes the sun, water, wind, oxygen, carbon dioxide, soil, atmosphere, and many other elements and processes. The diversity and complexity of all the components in an ecological study requires studying organisms within their environments. Through an ecological model in architectural practice we could connect many fields and areas of expertise, and in so doing illustrate holistic aspects of components and their relationships to one another within their spatial community. **To view ecology as a model is to integrate the design into the ecology of the place—the flows of materials and energy residing in the community. Architectural practice has been slow to acknowledge the reality of interconnectedness, yet in the past few decades, the message has grown stronger—**from the physical unity of the universe, to the unity of life on Earth, to the interconnectedness of ecological systems, to even the interdependence of our global economy.

The impact of virtual technologies on *Notational* design visions is incredibly important in understanding how living beings subjectively perceive their environments, because most architects use notation to represent and communicate their architectures. Notations are essentially used to mediate the experience of the design toward building; they occupy most working drawings in architectural practice; they can confuse clients, builders, and architects alike and disrupt projects.

Yet architects mostly take them as given, as a neutral code toward the final design. Here I aim to challenge and reverse this well-worn assumption. **We should design notation to suit a new vision of how we can communicate our architectures, spatially and experientially, not to suit the arbitrary specifications of the notation.** The technologies that make this possible are advanced holography, telematic communications, ubiquitous computing and advanced control software. They allow us to define a fundamentally new, radically



Reflexive Thermostat Models *of the communication between participant and environment. (Courtesy Shaun Murray)*

restructured architecture for our notational systems. Notations are used to construct all architectural drawings and have often been studied as whole in space, but never before have they been studied as whole in time. **My interests reside in a synthesis that proposes that notations adapt best when constantly refined and reshaped by their occupants, and that architects can mature from being artists of space to becoming artists of time.**

It is important to constantly question the role of practice.

A1. Shaun Murray: There are many kinds of impacts that virtual technologies have had on *Instructional* design visions, an extremely important one is who communicates with whom and who instructs whom. I envision there could be a network of instructions developed from the evolving interrelationships between the working drawing, participant, and environment. Central to the perceptual shift of a working drawing is the term "system." A system always describes a whole, which in contrast to the elementary, consists of parts. The working drawing is the current methodology of communicating the organizational closure between working drawing and building. The environment is everything that is not part of the system; and on the other hand is not able to influence the current system in a linear manner. It can only trigger temporal structural changes of the system's inner organization and not determine the system's behavior directly. **Can the working drawing become an open system of communication between the working drawing, participant and environment?** This open system should have the ability to respond to perturbations by its environment and changes by the participant, but this is achieved only by structural changes within the system itself. One could then begin to develop an understanding of the complexity and diversity of the methodologies of communication from working drawing to environment. **The working drawing could then become primarily a dance of interacting parts and only secondarily pegged down by various sorts of physical limits that environments characteristically impose.**

The impact of virtual technologies on *Aesthetical* design visions is about appreciating aesthetics as absolutely central to valuing environments. Through integrating descriptive qualities of our environment and aesthetic experience, my work aims to link subjective and objective approaches to aesthetic experience, judgment, and value. Aesthetic experience is one of the most common ways to value our environment. Whether it is having a walk in the park, cycling through a country lane, or just sitting in your garden, **we can appreciate the aesthetic qualities by developing environmental sensitivity through aesthetic experience.**

Through a different understanding of our *Ecological*, *Notational*, *Instructional* and *Aesthetical* design visions, we need to rethink our methodologies of communication through ecological design and understand that **human communication and ecological accountability are inextricably linked**. These pertinent questions induce us to look with new eyes at our own idea of "working drawing." This invites us to see in a wider perspective those inertial habits of architectural design that push us to describe drawing either as a representation of something other than itself for the elaboration of information about building (encapsulated drawing), or, on the other hand, vitalistically, as something ineffable and somehow attached to reality and a larger part of our environment (embedded drawing). To picture this relationship of embedding the drawing within environment, consider it as being like the relationship between a river and its banks—the river molds the banks and the banks guide the river. Similarly, **the embedded drawing molds the environment and is guided by it.**

Open System Working Drawing *from the Building Energy Management Systems (BEMS) data sets. (Courtesy Shaun Murray)*

As the focus of architecture moves from a system of relationships based on objects toward a system based on distributed environmental systems, we also must find the importance in developing an architecture a priori to building—at the pre-planning stage in the development of the site of construction, the architecture before the architecture.

Q2. Sneha Patel: To expand upon the previous question, the current state of digital methodologies in architectural representation often rely on the sophistication and seduction of manifesting the real, recreating the material as an image of itself. Do the tools and techniques you use in your work aim to consciously avoid the pitfalls present in predictable representation and in a

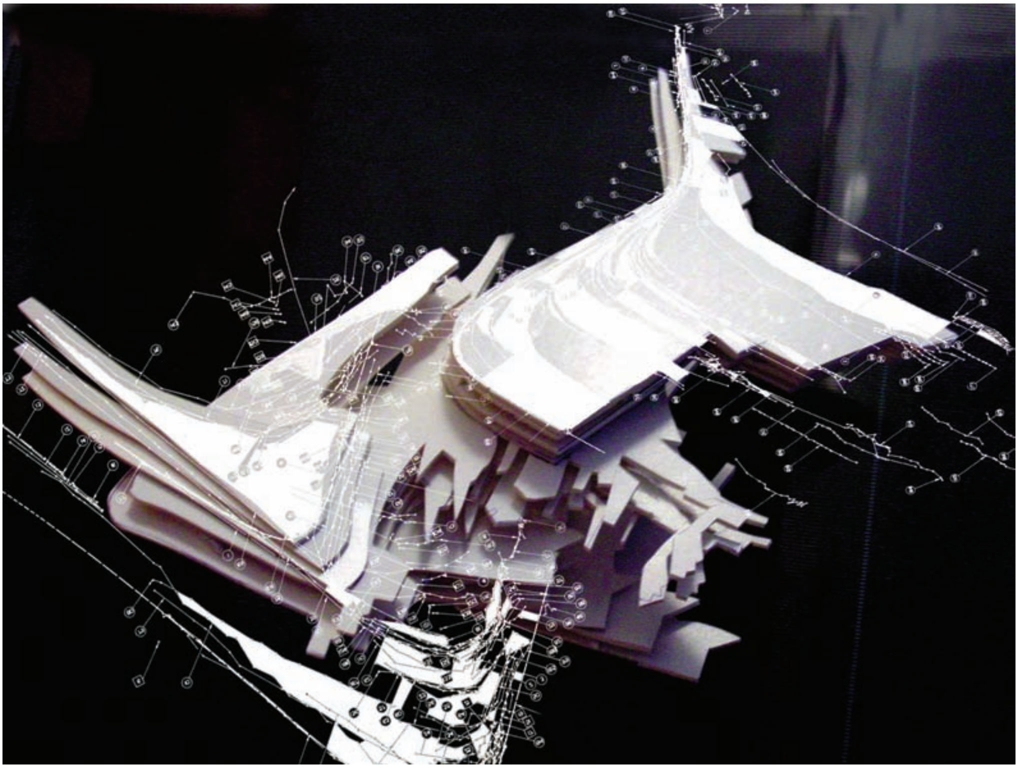
> similar way, how do they allow you to explore the changing and adapting conditions present in the built environment?

A2. Shaun Murray: There is a field of relations we construct between ourselves and the "territory"—the "objective world"—so that what we map is that relationship in which we participate, and not a direct representation of the things "out there." If we can interpret the idea that the map is not the territory within the experience of architectural practice, we might begin to unlock the more fundamental ambition of the relationship between working drawing and environment, that we must "experience it."

Within my practice, for every project I set up an "*Ecotype map*," a map that is characterized by the surroundings it inhabits. For my type of architecture to operate and be engaging with its environment, it needs to assimilate information from its environment and recode it as an actual. To assimilate information from an actual environment means that the design will receive data continually, for example, soil conditions, wind speeds, and zoning or recorded information on seasonal changes. The *Ecotype map* is a series of sensors positioned in the site context, which relay the data, real-time, to a model on my computer. The map becomes a way of thinking about the relationships between working drawing, participant, and environment through context, design, and communication. **It is through drawing these notational systems that I want to examine the state of transfer from one medium—working drawing, to another, as environment, as in a material transfer.**

> **Q3. Sneha Patel**: Your work provokes the question of how architecture can become a fingerprint of the environment as a set of dynamic, interactive, and complex interactions. As such, it intends to define continually changing dialogues between environment, user, and construct in which nature and self are engaged and indivisible—a necessarily holistic understanding of the world at large (Spiller 2002). This ecological approach is definitively distinct from other paradigms of *sustainability* or *environmental conservation* in that it does not aim to maintain or prolong a present, stable, or preserved condition. What do you feel are the most difficult challenges facing architects and designers today regarding the limitations of narrowly defined views on ecology and the built environment?

A3. Shaun Murray: This is a critical moment for architectural designers, who appear to be unable to respond to a problem of the apparent disconnection and the progressive displacement of the participant in reference to ecology. The way that this has been constructed has not only impacted on design solutions but has led to a particular understanding of ecology. **It is the understanding of ecology as *artifact* which has become no longer sustainable and precipitates the crisis.** By revisiting the working drawing as a mutable consequence of designing, it is possible to relieve the problem by opening up the scope for finding new methodological approaches. These can be used to



Recursive Handrail *uses data sets from the Open Source Building Energy Management Systems (BEMS).*
(Courtesy Shaun Murray)

develop design strategies that are sufficiently subtle and coherent in their terms, to engage with the open complexity of future discussions of the distributed and enacted human.

The question of ecology also leads me to think about the issues surrounding practice and the built artifact. There seems to be a constant doubt about what do we do now that it does not seem obvious what "practice" even is, but there is also a lot of ingenuity—invention. We are all doing work that makes a certain kind of sense to us and to each other, and although we are not really sure where it is going, we are doggedly journeying on through a surreal landscape. Hopefully, my practice will be the vehicle to traverse it, outlining a way in which we can encounter designing in the world as a system of strange communication that is complex and involving. The idea of an open system working drawing drives to become ecological and nonrepresentational through the remediation of my methodologies of practice. Over the past ten years **I have been involved in the application of open-source real-time data sets as a tool for unpacking the complexities of designing in a specific context.**

Ecology is about understanding that the world is a complex system in which we all interact. Designing in an ecological way is to unpack the complexities of our relationship with it.

Q4. Sneha Patel: Since 2005, you have collaboratively organized a series of transdisciplinary research sessions including participation from the fields of architecture, 3D design, communication design, performance, digital art and technology, programming and engineering. Each session has utilized technologies (Global Positioning Systems, Nurbs Modeling, OS-Arch [integrated hardware-software systems], Structural Equation Modelling, Rapid Prototyping, etc), as a means of seeking knowledge beyond disciplinary boundaries. What have been some of the most salient outcomes of these sessions?

A4. Shaun Murray: Through *Transdisciplinary Sessions*, we experiment with and forecast potential future use, impact, and value of using different technologies. For example, we use data generated by a building and its inhabitants to recursively influence behavior, creating a symbiotic ecology with a potential for greater environmental awareness. Through the sessions we encouraged the development of an organic list of solutions or potential methodologies for building design. In session 1: *Architectural Ecologies*, these methodologies were based on the study of three main factors: behavior, data, and interaction of participants in the building. The results of the participants were a hybrid of potential methodologies to expand and evolve our physical and conceptual space, wherein the boundaries and thresholds of spaces maintain a dynamic pluralism between contemporary tectonic architecture and abstract environmentally generated data.

Another salient outcome was that **we can now question the autonomy of the building from its participants and occupants**. The session enabled building occupants to reflect on the environmental impact of their interactions, both physically and through the extended social interactions enabled by communications technologies. **Through the acoustic and visual representation of their social activity, combined with live representations of data generated by the electro-mechanical and environmental activities of the building, the participants are able to better understand the complex relationships that exist between each other and their environment.**

Q5. Sneha Patel: Your work proposes a fundamental critique of traditional architectural drawing. Your drawings can be described as palimpsests, embedded with layers and continually adapting and becoming. Can you elaborate on your approach to drawing? Do you anticipate and value varied interpretations of your drawings or is their purpose rooted in their ability to be specifically decoded?

Inside-Outside *(2010) Trans-disciplinary Session (Scanning Electron Microscope/GPS Tracking Master Class), Dartmoor, United Kingdom. (Courtesy Shaun Murray)*

A5. Shaun Murray: Drawing should to be read as a web of relationships connecting different pathways together and act as a mutable transformative model within design. The drawing allows other things to interact with it and for it. **Many architects fail, often deliberately, to recognize that the drawings they produce are, architecturally, more interesting than the buildings they produce.**

In my practice I am using the working drawing as a tool to set up new relationships between the changing status of drawing, participant and environment within context, design, and communication. This might enable one to shift the idea of a working drawing into a spatial and contextual tactic for design practice. Working drawings are a fundamental act within architecture that allows architects to communicate their ideas usually towards building. The working drawing in relation to design has shifted over the past ten years because of the use of computer-aided architectural design systems (CAAD) and the commercial practice of using building information modelling (BIM). Within contemporary practice there are transdisciplinary models of working drawings across all disciplines involved in the built environment from engineers, contractors, and clients.

The visions of working drawings are particularly resistant to interpretation. This is by design, to make sure that what we draw defies readings other than our own. A working drawing is therefore overloaded with conventions (both for the author and the reader), particularly through notational strategies. One might protest that this relates particularly to production drawings but the fact that the conventions allow the same thing to be understood in the same way by the many agencies that contribute to its production means that other forms of architectural representation tend to conform to the same rules. It is very rare to find drawings that stray too far from conventions, when architects draw they do so to study or document an idea. The drawing is trying to discuss an idea while at the same time trying to avoid prescription. **I am looking for drawing that is available to the author for reflection and allow the reader to take possession in a way that does not rely on interpretation. I suspect that the mechanism to allow this is to look at how the drawing can become spatial and embedded so that it requires a direct and phenomenal relationship between drawing, participant, and environment.** Some of these ideas explore the relationship between context, design, and communication by placing drawing in the very heart of environment, and situating the participant within the drawing within the environment as it is drawn; Thereby making the connection of drawing, participant and environment both spatial and experiential.

The traditional methods of representation in architectural practice will come under increasing stress through the increasing demands of real-time 3D applications. As advances develop in the way we communicate with each other and as Web 2.0 extends onto mobile and locative media devices, the need for different methodologies to communicate our architecture is even more assured. In a broader context it is hoped that the concept of my work at *Eniatype* will constitute the roots of a communicative architecture. **The emergence of burgeoning practices within the field of a nonreductionist, nonlocalized and non-anthropocentric worldview opens up the potential for a challenging and communicative**

Camargue Condensations *(1999) Spatial layering and embroidery of a vacillating object, France. (Courtesy Shaun Murray)*

architecture. The potential for an *Eniatype* architecture is to enable us to situate ourselves within the environment. Design should support new methodologies of communication that allow us to understand what the relationships are in our environment and our responsibility in questions of a transdisciplinary practice.

The whole of the architectural process is a performance. We are constantly caught between the act of making and the experience of making—and involved within the doubt of both.

Further reading

www.eniatype.com

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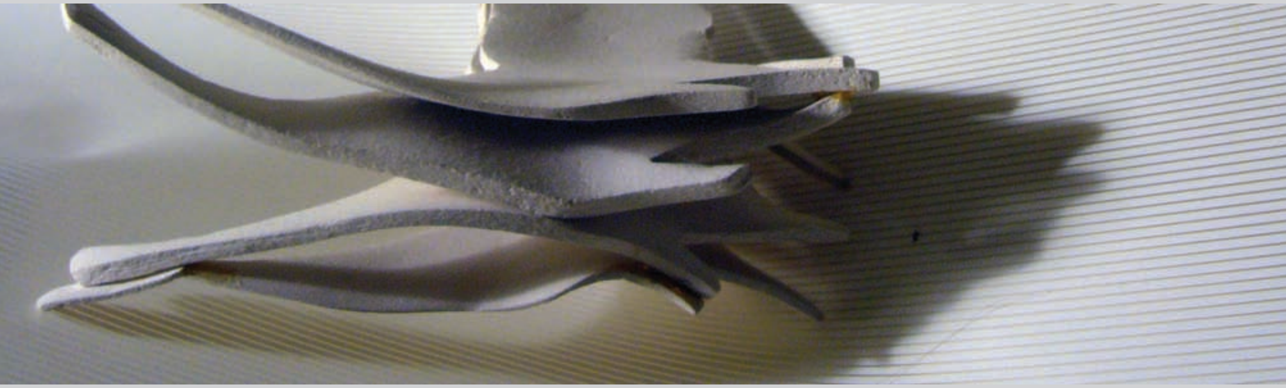
Chapter 5

Material Futures



Recursive Handrail *(Courtesy Shaun Murray)*

fu·ture

• expressive of time yet to come[1]

1 *Merriam Webster's Collegiate Dictionary* (1995) 10th Edition, Springfield: Merriam-Webster.

Speculations of Future Materiality

Rashida Ng

Looking forward to future decades of architecture and design, the maturation of experimental material technologies is poised to contribute to the evolution of practice, research, and the academy. Nascent research originating from multiple knowledge areas suggests a latent potential for the development of performative materials, assemblies, and systems, as illustrated within the series of projects featured in this book. There are many prospects for the evolution of these inquiries, ranging from incremental improvements that fit within the current paradigm of architectural production to radical ones that can incite more fundamental advancement of the field. Even with the prospect of future innovation, technologies with a capacity to threaten the status quo face a predictable and formidable level of resistance. However, critical analysis of these technologies can also serve to assess the validity and promise of the research to evoke more significant and lasting innovation. The confluence of research suggestive of performative materials confronts basic conventions of making, representing, and collaborating within architecture, thereby presenting opportunities to expand these prospects and advance the discourse of design.

While the definitive outcome of such advancements cannot be entirely foreseen, this essay will examine the potential of several significant trajectories poised to challenge established architectural conventions while assessing the opposing forces that stand in resistance of such conceivable change. Firstly, energy-intensive manufacturing traditions are called into question by promising scientific research that offers the possibility for more ecological and judicious means of material making. The influence of these factors, as well as others that have been previously discussed, provoke the development of bespoke material systems that challenge established rules of tectonic development in architecture. Furthermore, the dynamic and participatory paradigm of performative materials confronts the linear and static nature of representation, documentation, fabrication, and construction, while advocating for more interactive and temporal methods of communication. Finally, proposing a working environment for architecture that underscores research, prototyping, fabrication, experimentation, testing and analysis of material systems, this emerging paradigm suggests a repositioning of our alliances with diverse knowledge areas.

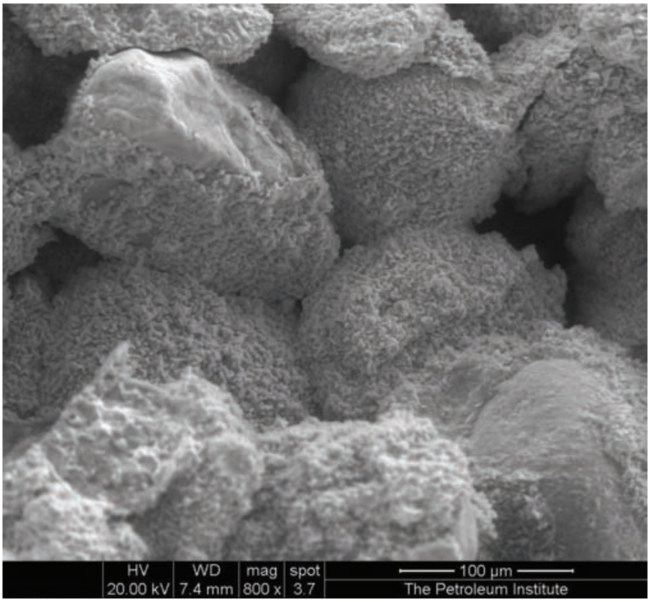
The profession should remain attentive to these pressures and receptive to new ways of conceiving of constructed space.

Scientific Paradigms of Material Making

Scientific research, specifically in the areas of nanotechnology and biomimicry, prompts reconsideration of the means by which materials are both designed and fabricated. As described in the introduction, "Experimental Performances: Materials as Actors," the ability to manipulate the molecular composition of a material proposes the opportunity to embed performative properties directly within customized materials at the molecular scale. Correspondingly, at the nanoscale, technologies can impact both the physical and digital realms of material making. Martina Decker further explored the potentials of nanotechnology in her essay, "New Material Compositions," included in the "Material Elements" chapter of this book, by describing advancements in electron microscopy that have facilitated the production of "multifunctional" materials with potential for diverse applications. As exemplified by Decker Yeadon's research into a Homeostatic Façade, scientific research provokes the design and fabrication of highly refined material composites with performative properties. Similar to nanotechnology, the growing field of biomimicry further enhances possibilities of material making.

An extensive field of scientific inquiry, biomimicry seeks to illuminate the efficiency, beauty, and proficiency of nature's techniques, inspiring a systematic approach toward the evaluation and production of technological innovation. Representing a substantial shift in scientific thinking, biomimicry prompts an expanded characterization of the built and natural world, which rejects the energy-intensive traditions of the Industrial Age in favor of more benign practices of production that are more akin to natural processes (Benyus 1997: 97). This framework suggests an altered taxonomy of fabrication practices that allow for material making without high pressure, extreme temperatures, and toxic chemicals. As an alternative, biomimicry proposes that industrial techniques of casting, cutting, forming, and extruding can be exchanged with less intensive procedures such as growing, propagating, breeding, and cultivating. Biomimetic research provokes the design of scientifically precise ecosystems that encourage the fission and reproduction of matter at the scale of atomic particles.

Although the prospect of the growth and cultivation of building materials poses unique possibilities for customization, it also invites consideration of the condition of permanence and stability within architecture. The use of "intense" environments for the fabrication of materials symbolizes a proclivity toward constant and enduring material states, which traditionally are linked to the intensity of the conditions surrounding its creation. Steel is produced at temperatures upward of 3000 degrees Fahrenheit. Bricks are fired at temperatures in the range of 2000 degrees Fahrenheit. The severe conditions in which these materials are fabricated also implies that the completed material state will be durable and stable in the more typical conditions to which it will be subjected. "Natural" materials, such as granite and marble, can also be associated with these ideals of permanence. In this case, the perception of material resilience is not generated from extreme heat, but rather through a process that requires an extreme amount of time. Therefore, a fundamental question remains, is it possible to produce durable materials in less time and utilizing less energy-intensive means of fabrications?



Scanning Electron Microscopy of successfully calcite cemented grains of aggregate for Biomanufactured Brick. (Courtesy Ginger Krieg Dosier)

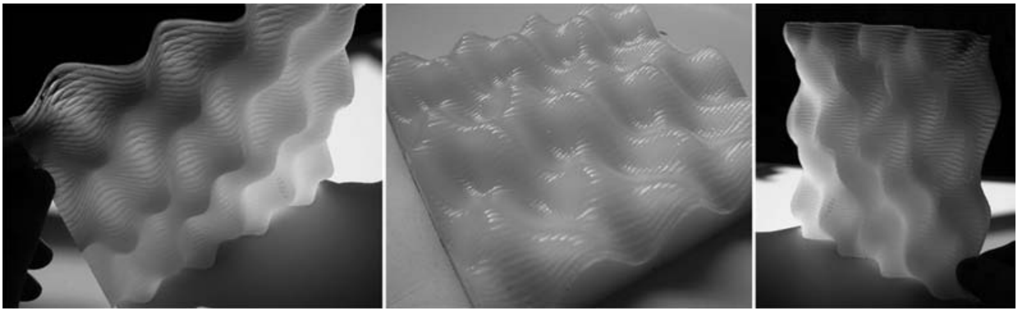
Image of a full scale Biomanufactured Brick. (Courtesy Ginger Krieg Dosier)

Biomimetic research into fabrication processes is addressing the challenge of material durability through technical inquiry into processes of *self-assembly* and *material customization*. As contrasted to the top-down traditions of carving and shaping materials, the process of self-assembly follows basic rules of physics in which materials are manufactured through the bonding of oppositely charged molecules. Processes of material customization, as described by Benyus (1997: 104–105), are similarly efficient to natural processes of growth whereby scientists are able to precisely "sculpt" materials without utilizing elevated temperatures, toxic chemicals, or other extreme conditions. For example, Stephen Mann, a biomineralization professional in England, is developing procedures to "grow" 3D crystalline materials. Inspired by single-celled magnetotactic bacteria, these bio-crystals could produce "a window that is as rigid as glass, yet able to bend and bounce back (Benyus 1997: 114–105)." Similarly, Ginger Krieg Dosier's *Biomanufactured Brick* project, featured in the "Material Elements" chapter, demonstrates similar promise. Fabricated in normal ambient temperatures by a bacterium that thrives in wetlands, this bio-stone exhibits similar structural properties to traditional brick, while being produced with significantly less embodied energy. This promising research serves as an example of the transformative nature of current biomimetic experiments to produce resilient materials through procedurally simple methodologies. The tenets that emerge out of biomimicry suggest a future in which materials are fabricated with the ease, facility, and environmental efficiency of processes of biological growth and reproduction.

Bespoke Materials and Tectonic Disruptions

The experimental fabrication processes stimulated by research in areas of biomimicry and nanotechnology are among numerous factors leading toward the production of materials and assemblies with customized properties. The growing ubiquity of digital fabrication techniques and computational technologies are also provoking research and development of bespoke materials and assemblies. In addition, sustained interest in smart materials continues to reveal opportunities for altered and dynamic material properties and behaviors that shift in response to external stimuli. As compared to more traditional materials, these advances allow for greater command over the specific properties of the material itself, affording the designer an opportunity to script performative material behaviors. Such developments permit the association of previously divergent properties within a single material, such as transparency and thermal storage as proposed by the *Latent Shift* prototypes featured in the "Material Elements" chapter of this book.

The future progression of performative materials extends opportunities for customized and varied material properties and behaviors within diverse settings. This proposition of more flexible logics between form, performance, and material signals a critical departure from established tectonic principles. As Antoine Picon explains in his book *Digital Culture in Architecture: An Introduction for the Design Professionals* (2010: 161), "Tectonic is based



The Latent Shift prototypes utilize phase change material to increase the thermal storage properties of this responsive daylighting panel. (Courtesy Rashida Ng and Sneha Patel, Photo: Point B Design)

on prescriptions regarding the proper use of materials … The properties of composite and smart materials call for the institution of new rules, rules probably very different from former tectonic guidelines." Lacking a set of fixed properties, performative materials instigate an elastic and supple design process, where formal and tectonic decisions are not strictly related. As such, the properties of a material can serve as a point of departure for a particular project, can be manipulated as desired to suit other goals, or can even change in response to human or environmental prompts. Consequently, the new "tectonic rules" suggested by Picon will emerge out of the evolution of both the design process and design product in response to the relaxed contingencies between material properties and tectonics. Similar to biological systems, the interdependence of performative materials requires that discrete variables be considered simultaneously as analysis of a singular variable would by definition be invalid.[1]

Challenges of Representation

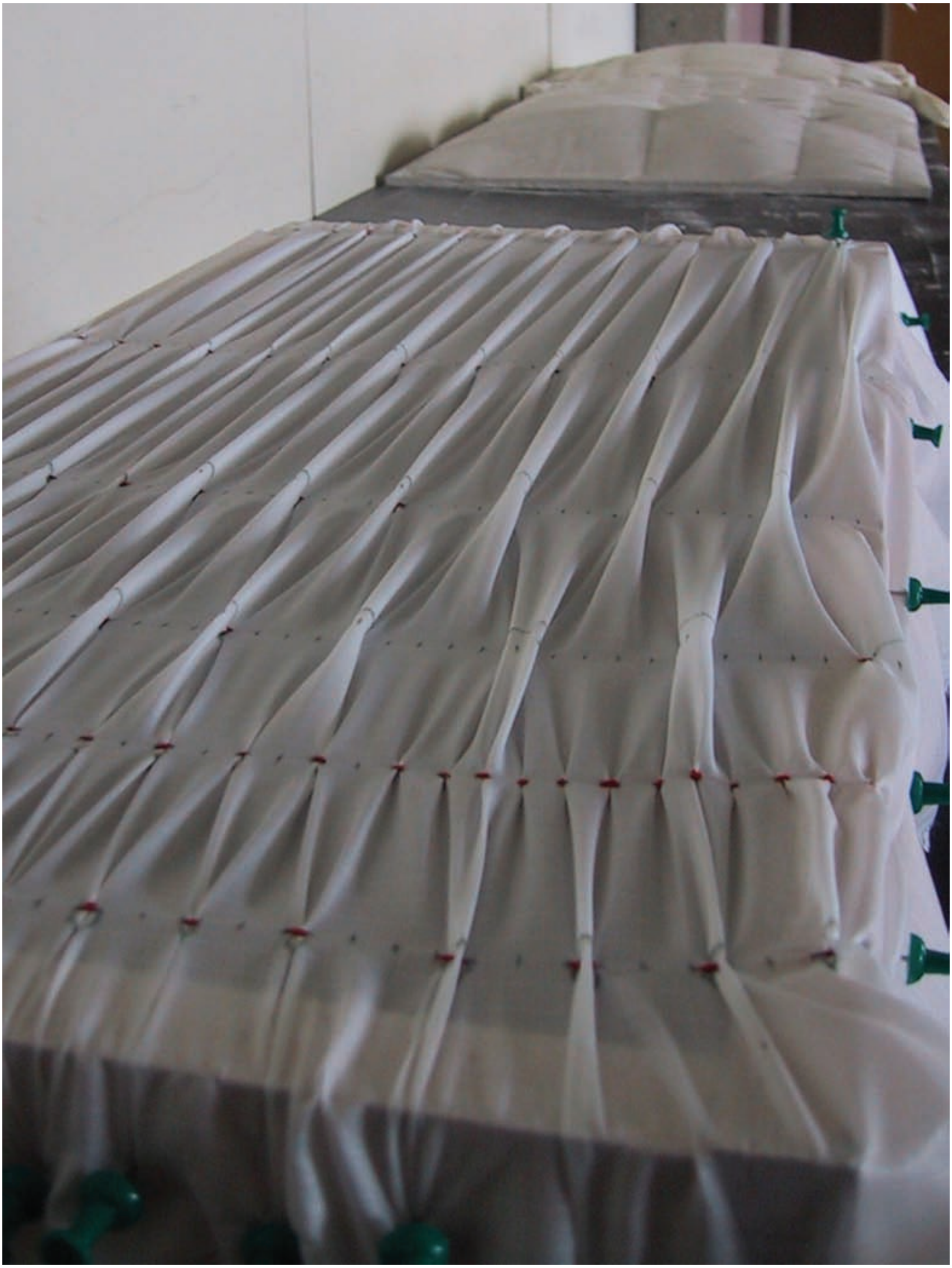
Rather than simply defining the physical boundaries of space, performative materials presume a more dynamic and participatory role of materials to contribute to the overall effect of architecture. Historically, architectural drawings focus on boundaries, connections, location, and positioning—physical characteristics that can be suitably described through the use of orthographic 2D drawings. In contrast, when conveying dynamic conditions, the delineation of the means by which the material assembly behaves within a situated context—its performance—is of far greater consequence than a description of the physical size and profile of the material through the use of projected lines. This presents a fundamental shift in design inquiry that stimulates reconsideration of the techniques by which we signify and communicate the physicality of architecture and its anticipated dialog with its milieu.

This challenge presented by the representation of the dynamic conditions suggested by performative materials is analogous to that posed by the variable properties of smart materials. Michelle Addington (2005: 4) describes this dilemma as follows, "This is an important distinction as our normative means of representation in architectural design privileges the static material: the plan, section, and elevation drawings of orthographic projection fix in location and in view the physical components of a building." Accordingly, the interaction of performative materials cannot be fully described through a depiction of surface or physical border, it compels a probing of relations, exchanges, and interactions that require altered means of visual communication. In the years since Addington published the critical text on the nature of smart materials, considerable scrutiny has been placed on the potential of smart materials and systems, while techniques of representing the dynamic behaviors of these materials and their environments are only slowly emerging.

Similarly, computational processes also challenge the applicability of two-dimensional means of communication as suitable for architecture practice moving forward. As observed by Yasha Grobman (2012: 11) computer-based design and production are leading toward "the architect producing the file from which the real object is produced without any need for mediators." However, the implications of the evolution from a traditional process whereby the architects produce a set of scalar drawings to a new paradigm in which the architect produces a complete and accurate virtual model of the building are not inconsequential. At the root of the issue are questions of precision, tolerance, and professional liability. Antoine Picon (2010: 162) writes of the potential shift toward digital documentation observing, "The need to make design procedures more explicit will be further increased by the evolution towards a systematic constitution of a common pool of data, often referred to as a Building Information Model, to be shared by the various actors involved in a project." The move toward the production of precise data obligates even greater coordination amongst professionals within a design team, thereby elevating the importance of management of the overall *design process*. In contrast to the idealized fluidity often associated with prophecies of digital potentials, the realities of virtual documentation that are emerging begin to challenge that assumption. As Picon (2010: 163) puts it, "In such a context, the designer's ultimate competence becomes more and more about when to make certain states of things irrevocable."

The connections between digital methods of visualizing and analog methods of making occupy a critical intersection within architecture and design. The analog world exists within the realm of human perception as physical scale is distinguished relative to the human body and the observations discerned by the visual acuity of the eye. Conversely, within the virtual realm the perception of scale exists only within the distorted reality presented by the computerized interface. In theory, virtual accuracy is infinite, limited only by the precision of inputs and the functioning of the device. At the same time, virtual materials lack the corporeal resistance presented by physical states. The apparent exactitude of digital surfaces and materials confront their limitations upon entering into physical existence. As explained by Phil Ayres and his colleagues at the Center for Information Technology in Architecture in the chapter 4 essay, "Making a Digital-Material Practice," the translation between digital and physical contexts requires hybridized methods of investigation that

Plaster cast detail, Smocking v3; Smocking explores the potential of a pleating technique on a fabric formed concrete surface, a manifestation of an equilibrium reached between the surface tension and omni-directional hydrostatic pressure. (Courtesy Kentaro Tsubaki)



Fabric formwork, Smocking v5 (Courtesy Kentaro Tsubaki) allow for the negotiation of physical conditions to provide feedback into the virtual realm. Hence, developing modes of representation in architecture are working to close the gap that persists between digital and analog means of material making. *Smocking: Pleated Surfaces*, a project by Kentaro Tsubaki featured within chapter 3, explores the tension between precise notational drawings that signify the design process and a haptic sense of materiality evoked by unpredictable forces within the physical construct.

In addition to interpretation between analog and digital domains, the need to discern the corollaries between multi-scalar effects further complicates visualization techniques associated with performative materials. Future development of these potentials obligates investigation within both scientific and computational fields of study. Ali Rahim (2006: 193) speculates, "Directly inputting the behaviors and properties of smart materials into digital design models, for example, might enable architects to iteratively test the behavior and affects of such substances in a generative design, under various conditions of context and use." Although our ability to simulate sensory aspects of architecture is developing, these platforms typically exist within discrete scalar ranges, rarely allowing for the seamless translation of metrics between multiple scales of research. Furthermore, knowledge of these relationships generally resides in isolated disciplines of biology, chemistry, engineering, materials science, architecture, ecology—each with its own practices and methods of representation and evaluation of critical relationships. As we approach a more holistic understanding of the interactions of matter at multiple scales, it underscores the need for scalable metrics and communication tools, which allow for iterative translation from the nano-scale to the building scale, to the scale of collective environments. It also calls for methods of representation that transcend disciplinary boundaries and transform traditional, isolated modes of practice.

The Experimental Workspace for Design Research

The introduction of experimental research into the discipline of architecture also shifts the nature of the physical workspace. Design processes of drawing, modeling, and documenting are being supplemented with activities such as prototyping, simulating, and testing, thereby altering the setting in which these activities can occur. As the notion of invention is becoming more familiar to design, the place for the production of architecture at times assumes the qualities of a laboratory, such as that utilized by Zbigniew Oksiuta in his work with biospheres, as presented in the "Material Ontologies" chapter of this book. As the ability to fabricate more bespoke materials and systems increases, the traditional space of a design office can assume the qualities of fabrication workshops and production spaces. Finally, as the technical demands of architecture increase, the place of design also necessitates conditions suitable for environmental testing and simulations. The creative physical "space" used for the production of architecture affects the level of inventiveness embodied in the work. As such, places of design innovation provoke haptic interfaces with materials and prototypes as architecture shifts away from the selection of materials from standardized catalogs and toward more bespoke material propositions.

At the same time, experimentation within design provokes the concurrent expansion of the intellectual field of design professions, while presenting a critical challenge for the field. Acknowledging the recent interest of architects in the design and customization of material composites, Picon (2010: 160) questions, "Should designers themselves invest in the field of material design instead of relying on the researches of others?" I would suggest that the response to this question is already emerging. Given the interrelated nature of material customization and the related influence of design decisions at multiple scales, experimental research in this area is beginning to define areas of disciplinary overlap that allow architects to do what they do best, while at the same time benefiting from the crucial expertise of specialists—such as scientists, material engineers, biologists, ecologists, and others. These collaborative environments also extend the influence of design thinking into other areas of knowledge creation as well.

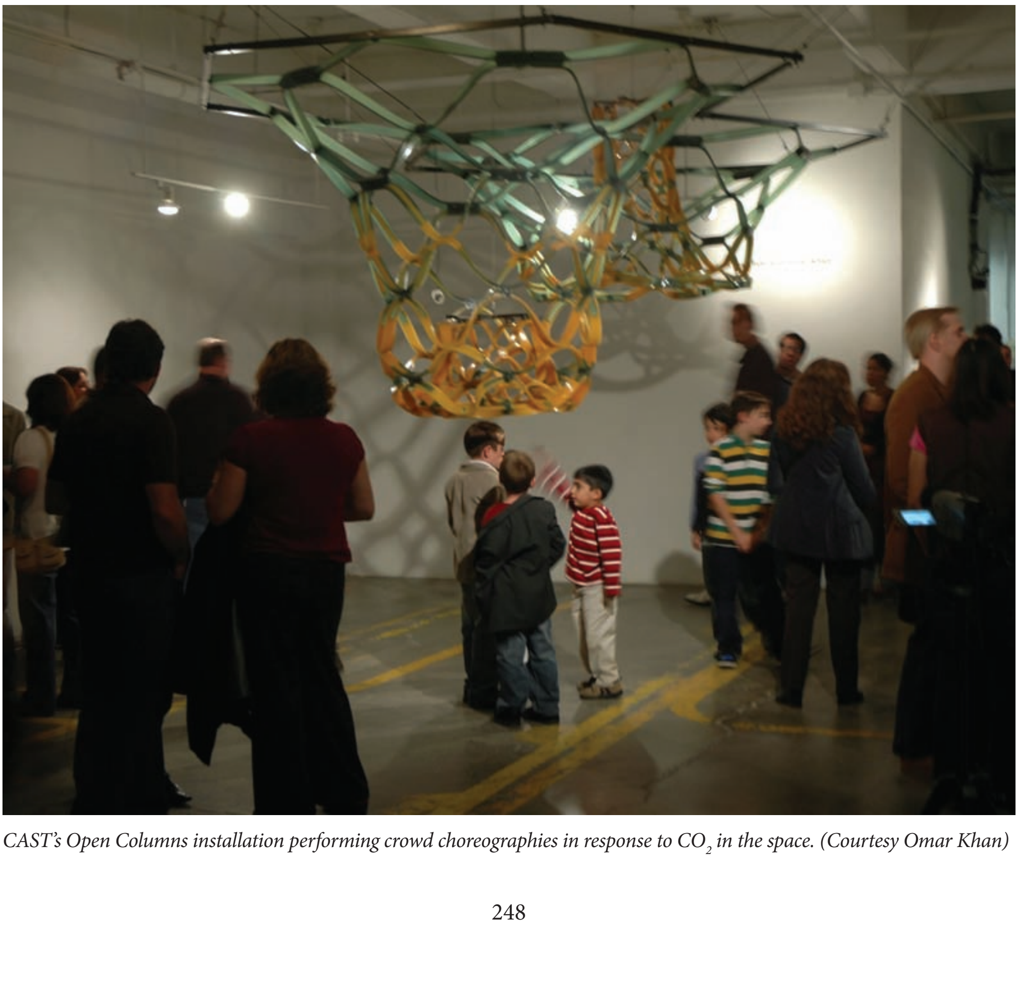
Zbigniew Oksiuta forming an agar layer in the 3D bioreactor and preparing of the biosphere for the growing of organisms within a self-sustaining miniature world. (Courtesy © Copyright by Zbigniew Oksiuta & VG Bild-Kunst Bonn; Photo: Bjorn Podola, Cologne, Germany)

Although architecture enjoys an extensive history of collaboration with other specialists, such as those from various engineering disciplines, current partnerships are distinctly different from previous alliances as they fervently acknowledge the interdependency of divergent knowledge areas and the relationship of this collective awareness to architecture. The current paradigm proposes an expanded field of collaborations with disciplines that were previously perceived as fairly irrelevant to the critique and interrogation of the built environment. As described by Jenny Lovell (2010: 35), in contrast to the more traditional *multidisciplinary* model that allows for distinct roles and professional liability, *transdisciplinary* models require "deep collaboration – idea exchange in an unanticipated way, with a free flow of information." These transdisciplinary environments can assist architects in defining more productive paradigms for research and dissemination of new knowledge. Furthermore, such collaborations present an opportunity for shared knowledge between the academy and practice. Typically the economics of practice will not absorb the expense associated with the development of new material systems; on the other hand, partnerships with academic research centers facilitate innovative work that would otherwise prove economically infeasible. Additionally, the shared goals of such collaborative environments serve to enrich academic pedagogical missions and to stimulate productive design thinking skills amongst the next generation of architects and designers.

An example of such a collaboration is demonstrated through the work of the Center for Architecture, Science, and Ecology (CASE) at Rensselaer Polytechnic Institute in partnership with the architecture firm of Skidmore Owings and Merrill.[2] A partnership of academia and practice, CASE brings together architects with other professionals from a diverse range of disciplines including physics, aerospace engineering, and economics, among others. This intellectually diverse think-tank confronts design challenges at multiple scales from that of ecosystems, such as study into the intersection of coastal mangroves with urbanized areas, to those at the scale of building materials, exemplified by its research into the design of earthen ceramics. Similar to CASE, organizations such as Kennedy & Violich's MATx, Mitchell Joachim's Terreform ONE, and Jenny Sabin's Sabin + Jones LabStudio, provide fertile platforms for collective research and serve to accelerate the production of technological innovation within the building industries.[3]

In contrast to formalized models of direct collaboration with specialists in other disciplines, other designers extend the scope of the profession through the intellectual breadth of their research activities. In 2006, architect and educator Omar Khan, featured in the "Material Elements" chapter of this book, initiated the research collaborative CAST (The Center for Architecture and Situated Technologies) with his colleagues Mark Shepard and Trebor Scholz from the Department of Architecture at the University of Buffalo.[4] This center interrogates the implications of ubiquitous computing, information, and responsive technologies to alter interactions between humans and computers. Although these areas of influence bear directly on the built environment, primary knowledge of these technologies is formed in computer science and engineering professions. Challenging the position of theoretical, technological, and materials research in architectural education, the work of the center operates both pedagogically and as a productive research entity. Through research and design installations, it provides a productive model for the integration of design research in architecture schools. Similar models of expanded inquiry are also emerging in architecture practice, such as in the research and design work of DeckerYeadon LLC that explores the intersection of nanotechnology and architecture, as presented within the essay "New Material Compositions" and Urbana, Rob Ley's firm that queries the potential for responsive architecture as instigated by research within disparate areas of cultural influence.[5]

Over the past decade examples of such collaborations—both as formally defined entities and as loosely delineated alliances—are developing within the context of architectural research settings. Whether through deliberate transdisciplinary centers, as demonstrated by the work of CASE, or through the appropriation of technologies into contexts that are governed by concerns that are primarily architectural, as seen in the work of CAST,



CAST's Open Columns installation performing crowd choreographies in response to CO_2 in the space. (Courtesy Omar Khan) these entities engage in research that confronts the established confines of architecture. Suggesting an expanded sphere of disciplinary overlaps, these models provoke consideration of the evolution of the role of research within design contexts. The coincident effect of these overlapping influences already provokes subtle yet significant shifts in pedagogical approaches, research paradigms, and professional relationships that will continue to influence the evolution of the field.

Conclusion

Evocative of the projected reality represented by the legendary 1968 short film *The Powers of Ten* by Charles and Ray Eames, materials within design are now being considered along an expanded continuum of scales, from the nanoscale of atomic particles to the ecoscale of climatic patterns. At the ecoscale, the intensifying disquiet associated with global climate change has provoked considerable research into the relationship between the materiality of the built environment and its effect on surrounding ecosystems, microclimates, and urbanized environments. While on the other end of the spectrum, at the nanoscale, advancements in electron microscopy have facilitated the visualization and manipulation of the molecular composition of matter, a seemingly immaterial magnitude wholly imperceptible to the naked eye. Nevertheless, these nanoscaled molecules embody potentially transformative macroscaled behaviors and visually perceivable effects. The intricate interactions between molecular matter and macroscaled environments suggest an altered perspective of materiality within design, which compels critical analysis of the unique properties of materials at discrete scales. Approaching the abstracted and perpetual zoom depicted by the Eames' film, the interrelationships that arise along this scalar continuum will bear influence on the future evolution of material practices in architecture.

The interconnectedness of built and natural ecologies as stimulated by the dynamic and relational aspects of materials incites the need to concurrently probe the compound influence of discrete material interfaces on their extended environmental networks. However, the ability to navigate between molecular, material, and environmental scales, translating properties from the nano-, to micro-, to meso-, to macro-, and ultimately eco-scales poses a practical challenge for the discipline, as expertise along this scalar range lies within multiple fields. Furthermore, acknowledgment of the affinity between nanoscaled molecules and macroscaled ecosystems focuses design effort away from scales of normal perceptual interaction toward the scalar extremes—limits that can only be perceived through the use of intermediary devices, either microscope or satellite. Such detached surveillance that prevents direct sensory perception of these extended scales further tasks the designer to translate disengaged realities into the perceptual realm.

The dissonance evoked by these multi-scalar material interfaces presents a critical challenge to the discipline. Innovations stemming from experimental research into performative materials will ultimately be appraised based upon their success or failure within situated contexts—those that are temporal in nature and referential to the body. Although performative materials operate along a scalar continuum, architecture persists within the context of the human scale, which is ultimately characterized by direct sensory experiences rather than exclusively augmented ones. The challenge lies in how we can employ this extended range and leverage the performative aspects of materials to enhance and enliven the human sensory context. Architects should not be content with the orchestration of isolated events at hyper- or nano-scales, as architecture is—and always will be—an experiential discipline. The design of scientific existences or systematic relationships is meaningless without the ability to relate this information back to the middle range—the ones that we sense, touch, feel, and physically embody. In this case, experience should be considered broadly, beyond the long-standing dichotomy between poetic expression versus technical proficiency. More accurately, the experiential aspect of the building referred to here represents the human sensory context, which responds to and celebrates the multiplicity of occurrences that allow architecture itself to participate within cultural settings.

An architecture that participates does so in time. Heightened awareness of the performative potential of materials leads to new empathies of the persistent forces to which a building is subjected. When attentive to this temporal reality, the process and product of architecture is subject to intensified scrutiny and enriched capacities. A time-based interpretation of material contexts invites consideration of variable properties within different contexts. It acknowledges that as time inevitably moves on, material conditions may also shift in response. In contrast to an architecture in search of an unattainable state of rest or equilibrium, the notion of performative is persistent and progressive. Ultimately, performative materials are situated within an expanded time-space reality. In this sense, "space" can be analyzed in various dimensions, from the infinite space surrounding nanoparticles to the collapsed space of ecosystems. Similarly, "time" is understood through a widened lens from the time of day, to the time of an architectural event, to global time of finite resources and changing climatic patterns. As these experimental technologies continue to mature, the implementation of these multivalent insights can be leveraged to promote new means of conceiving and experiencing the performative aspects of architecture.

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Notes

1 See (Hensel, Menges, and Weinstock 2010: 12–16) for a discussion of the evolution of biological systems and materials in architecture.

2 For more information about CASE, refer to <http://www.case.rpi.edu/home.html>.

3 For more information about MATx, refer to <http://www.kvarch.net/>; For more information about Terreform ONE, refer to <http://www.terreform.org/>; For more information about Sabin + Jones LabStudio, refer to <http://labstudio.org/>.

4 For more information about CAST, refer to <http://cast.ap.buffalo.edu/site/>.

5 For more information about DeckerYeadon, refer to < http://www.deckeryeadon.com/>; for more information about Urbana, refer to < http://urbanaarch.com/>.

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Phil Ayres is an architect, researcher and educator. He joined the ranks at CITA (Center for Information Technology and Architecture, The Royal Danish Academy of Fine Arts, Copenhagen) in 2009 after a decade of teaching and research at the Bartlett School of Architecture in London, and completing his PhD in Denmark at the Aarhus School of Architecture. He has also been a partner of sixteen*(makers) since 1998. As a self-taught computer programmer, skilled machinist and maker, his work searches to construct complementary potentials between the worlds of the digital and the material. His teaching and research allow him to bridge the realms of representation, fabrication and interaction, and feed into his interest of developing exploratory design techniques that are often computer mediated, but always lead to physical output. Much of this work has been exhibited and published internationally.

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Rashida Ng's research broadly examines emerging material technologies and their potential within design to provide a sustainable and responsive architecture. Central to this inquiry is the potential for experimental technologies to redefine the interdisciplinary and collaborative modes of architecture and design praxes. Situated within the context of ecological design, this research is rigorously directed by the complex and interconnected relationships of built and natural environments. Her ongoing projects include investigations into new lighting technologies and the development of a responsive daylighting panel utilizing phase change material. Rashida previously won Gimme Shelter, an International Design-Build Competition, for her entry, *Firefly*, designed in collaboration with the artist Nami Yamamoto. She has previously been awarded an AIA Medal, the Paul Philippe Cret Award, a Roothbert Fellowship and a Dales Traveling Fellowship. Rashida is a registered architect and the President and Co-founder of

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Martin Tamke is an Associate Professor at the Center for Information Technology and Architecture (CITA) at The Royal Danish Academy of Fine Arts, School of Architecture in Copenhagen, where he pursues design led research at the interface of computational design and its materialization. After graduating he worked at the Institute of Theory and Design in Architecture at TU Braunschweig in 2003, where he focused upon new strategies for architecture that are concerned with speculative design and their means of realization. He has been a key collaborator in numerous projects of varying scales including an infrastructural hub in Hamburg developed in partnership with Blunck-Morgen Architects, which was awarded Building of the Year in 2010. Martin joined CITA in 2006 and has been instrumental in developing research led projects that investigate new design and fabrication tools for wood production, curved and creased surfaces in a variety of materials and fractal systems. Martin has taught extensively through workshops at Vienna, Berlin, Barcelona, St. Petersburg, Hamburg, Istanbul, Moscow, Copenhagen and Aarhus.

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Index

Note: Page numbers in italics refer to illustrations. Search terms in italics refer to titles of projects.

H

I

J

K

PERFORMATIVE MATERIALS IN ARCHITECTURE AND DESIGN

EDITED BY
RASHIDA NG
SNEHA PATEL

Performative Materials in Architecture and Design addresses the convergence of several significant and fundamental advancements in the ways that materials and environments are designed, evaluated and experienced within architecture and related disciplines. The emergence of experimental and ultraperforming materials, digital design and fabrication techniques, and interactive processing systems has established an interconnected network of technological inputs that has stimulated the development of materials, assemblies, and systems with performative properties. Providing an overview of representative design projects and relevant theories, this volume illuminates both the interaction of these technologies and the role of materiality in research, design, and practice. Emphasizing the value of research as a mode of design inquiry, the work is experimental and provocative of future innovations not yet applied. The breadth of the work suggests a future in which the reductive dichotomies that commonly define the discipline—such as inside and outside, natural and constructed, technical and poetic, even digital and analog—can be matured, redefined, and less distanced.

Rashida Ng and Sneha Patel are assistant professors of architecture at the Tyler School of Art at Temple University in Philadelphia. Together they cofounded SEAM*Lab*, a nonprofit think tank dedicated to research and dissemination of design-based knowledge related to materiality and the built environment.

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