Transformative Research Practice
Architectural Affordances and Crisis

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It is well known that buildings in the United States alone account for nearly 40% of the total national energy consumption. Currently, most contemporary sustainable approaches to the problem offer technological solutions through sanctioned rating systems, such as Leadership in Energy and Environmental Design (LEED), a rating system launched by the U.S. Green Building Council for new construction and existing building renovations. LEED takes into account five key measurements when evaluating new construction projects and building renovations: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. Additional points may be obtained through innovation in design and regional priority. While these measures adequately address issues of resource consumption in buildings, they do not address the systemic ecology of the built environment over the long term. How might we rethink our conceptual approach toward the problem of sustainability in architecture? Are there design research models and methods that may counteract this emphasis upon solutionism in favor of transformative practices that engage a dynamic reciprocity between form and environment, placing emphasis upon behavior over technology? More specifically, are there *affordances* within the environment that we may use as design drivers toward a transformative and sustainable architecture?

In 2010, the National Science Foundation (NSF) within the Emerging Frontiers for Research Innovation (EFRI) Science in Energy and Environmental Design (SEED) umbrella solicited proposals for transdisciplinary research teams that would engage the problem of sustainability concerning building energy and its associated impacts upon our built environment. In an unprecedented occurrence, the teams were to also include architects. Importantly, the program manager for EFRI SEED did not require American Institute of Architects (AIA) licensure as a requisite for architects to submit. This opened up opportunities for both licensed architects and architectural designers engaged in practice and core design research to apply with their collaborative teams across academia, practice, and industry. While the topic of sustainability in buildings may be viewed through the lens of crisis, this article attempts—as the NSF also intimated—to define transformative research models that address the subject through conceptual approaches that do not merely offer solutions but afford new modes of design thinking and research across disciplines. This requires a radical departure from traditional research and design models in architecture and science with a move toward hybrid, transdisciplinary concepts and new models for collaboration. Although there have been tremendous innovations in architecture, material sciences, and bio- and information technologies, direct interactions and collaborations between scientists and architects are rare.[1] All of this is regardless of the fact that science, engineering, and architecture all share the need to comprehend key social, environmental, and technological issues. Four interdisciplinary research practices are surveyed with emphasis upon innovation and architectural prototypes that actuate affordance in the context of crisis.[2] Here, the word "affordance" refers to James Gibson's "Ecological Approach to Visual Perception" and more specifically to the development of his argument pertaining to "The Theory of Affordances." Here "affordance" refers to how context may specify constraints and thus contribute to emergent and transformative relational models for design through notions of feedback and ecology as opposed to symbolic or function-based solutions. Simply put, an affordance gives rise to the possibility of an action or series of actions, a relationship between environment and organism. This article explores four bodies of work that exhibit architectural affordances that emerge through dynamic exchanges between environment, technology, biology, and form. The surveyed practices are Philip Beesley Architect Inc. at Waterloo Architecture, the Sabin Design Lab at Cornell Architecture, the BIOMS group at the University of California, Berkeley, and the Institute for Computational Design at University of Stuttgart.

Rachel Armstrong, who generates near living adaptive materials and is a leading innovator in the realm of sustainability states, "While conservation of energy and frugal use of natural reserves may buy us time to develop new paradigms to underpin human development, they are not sustainable in the long term, as they continue to operate according to the laws of resource consumption."[3] To this end, sustainable building practices should not simply be technical endeavors. They should include the transformation of existing built fabric into sustainable models

Figure 1. Epiphyte Chamber is envisioned as an archipelago of interconnected halo-like masses that mimic human sensations through subtle, coordinated movements. Across each floating island, densely interwoven structures and delicate canopies made of thousands of lightweight, digitally fabricated components are drawn together in nearly synchronized breathing and whispers. Audiences walk into highly sensual, intimate sculptural spaces that support small clusters of activity interlinking into larger gathering areas. This experimental new work explores intersections between media art, interactive distributed mechatronics, and synthetic biology. © PBAI.

that inspire both positive sociocultural change and innovation in design, science, and technology. Professor and architect Michael Hensel, at a recent symposium hosted by the Department of Architecture at Cornell University titled "Sustaining Sustainability," underscored this notion.[4] The symposium featured lectures by a diverse group of researchers and practitioners spanning multiple disciplines from biology to architecture who share a common concern for what Hensel has labeled "sustainability fatigue." This symposium was not centered upon exhausted issues including energy, optimization, and performance, which tend to dominate most conferences on sustainability in architecture today, but was instead focused on rethinking the entire conceptual foundation for the project, one that fundamentally examines our relationship with nature and nature's relationship with humans. Important to this shift is a move away from purely technical solutions to environmental sustainability toward an understanding that our built and natural environments are equally becoming the contexts for thriving hybrid ecosystems. As Maria-Paz Gutierrez, director of the BIOMS research group at UC Berkeley states, "The reinvention of conceptual frameworks and processes of technologies becomes transformative when it situates itself beyond the introduction of new productions. Trans-disciplinary research in building technology can craft new habits of thought; it reorients innovation."[5] Clearly, the design and production of new energy-efficient technologies is crucial to successfully meet goals such as the Net-Zero Energy Commercial Building Initiative (CBI) put forward by the US Department of Energy, which aims to achieve zero-energy commercial buildings by 2025, but as Gutierrez points out, these technological imperatives are largely based upon resource consumption. The discipline of architecture needs to move away from reactionary responses to the problem of sustainability and toward new habits of thought that question, actuate, and redefine relationships between environment and form. Transdisciplinary models afford such a dynamic reciprocity. How do we situate these new conceptual frameworks?

Responsive architecture, a term first coined by Nicholas Negroponte, is a type of architecture that has the ability to alter its form in response to changing conditions, particularly at multiple scales. Popular examples include Galleria Hall West (Seoul, South Korea), Institut Du Monde Arabe, Aegis Hyposurface, POLA Ginza Building Façade, and SmartWrap. Most of these examples, however, rely heavily upon the use of mechanically driven units that communicate through a mainframe and are nested within a building façade system. Additionally, there are now many research groups and experimental practices engaged in the exploration and implementation of existing responsive materials such as shape memory polymers, shape memory alloys or thermochromic resin, to name but a few examples. In the context of the work of Manuel Kretzer or Martina Decker of Material Dynamics Lab at the New Jersey Institute of Technology, for example, prototypes investigate the architectural potential of building materials that not only change but also respond and adapt to environmental stimuli. Decker's speculative Homeostatic Façade System incorporates dielectric elastomers for dynamic shading in double skin façade systems. A building's envelope must consider a

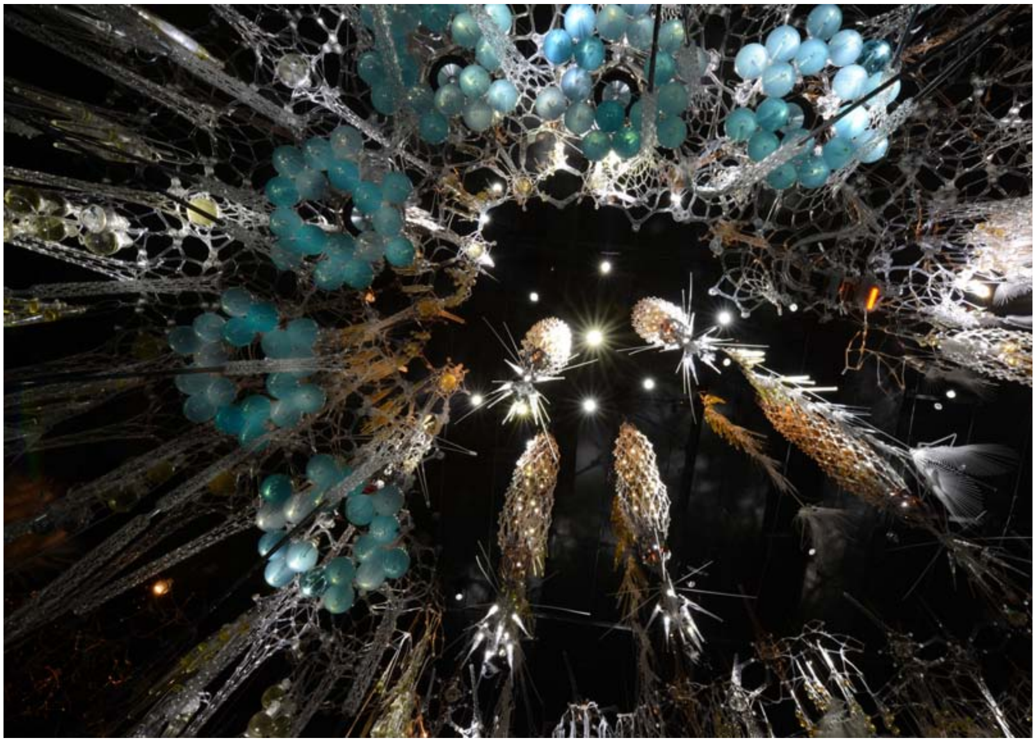
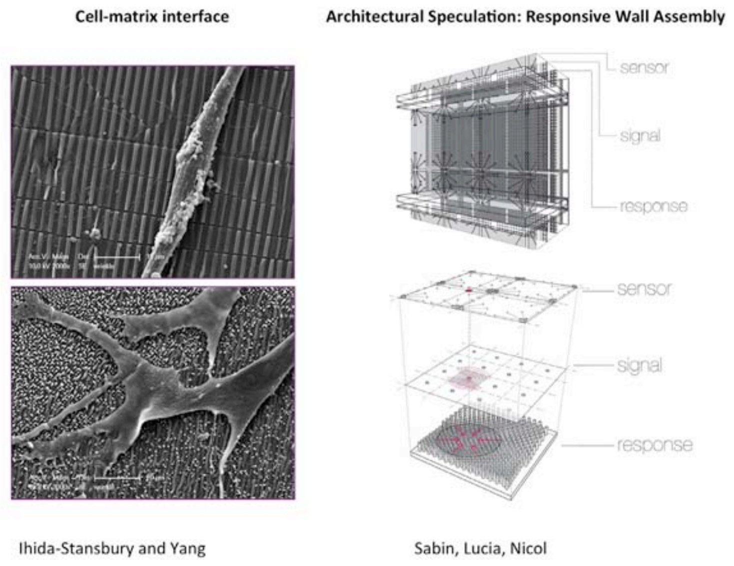


Figure 2. Epiphyte Chamber, an immersive environment erected for the inauguration of the Museum of Contemporary and Modern Art, Seoul, 2014, demonstrates key organizations employed for Hylozoic Architecture group constructions including lightweight resilient scaffolds, distributed interactive computational controls, and integrated protocell chemical metabolism. Photograph: Philip Beesley. © PBAI.

number of important design parameters, including degrees of transparency, overall aesthetics, and performance against external conditions such as sunlight levels, ventilation, and solar heat gain. In contrast to existing examples of adaptive architecture, perhaps we can entertain and embed the role of the human in response to changing conditions within the built environment.

Perhaps the closest example to this scenario is the work of Philip Beesley, whose sculptures and installations such as Hylozoic Ground incorporate layers of chain responses and amplified effects that are the result of highly personal interactions. Feedback loops between these networked mesh systems respond, adapt, and amplify user input, giving rise to emergent conditions that are the result of reciprocal loops between environment, code, and communication. In recent projects, Beesley is examining thermodynamics to as he states, "seek a tangible exchange for the reality of an expanded physiology." Beesley's interest in a design process and form language rooted in what he calls *dissipative structures and diffusion* gives rise to adaptive architectures that are rooted in and generated by the human body.[6] As he goes on to state, "In turn, it suggests a craft of designing with materials conceived as filters that can expand our influence and expand the influence of the world on us, in an oscillating register: catching, harvesting, pulling and pushing." Beesley describes these constructions as "a synthetic new kind of soil." These affordances, which are not features of organisms or the communicative landscape that we entertain, actuate change through emergent forms. These architectural affordances are actors and they are also acted upon. Beesley's thermodynamic environments are in a perpetual state of formation and communication. In this sense, the new soil is both emergent and fully enmeshed in their environments, and both of these attributes may be characterized as affordances. They are *emplaced* architectures that do not merely conserve energy but rather exchange it.[7] His most recent work, titled *Epiphyte Chamber*, which was erected for the inauguration of the Museum of Contemporary and Modern Art in Seoul, builds upon the periodic and aperiodic textile meshworks impregnated with interactive mechanisms that respond and adapt to the presence or absence of people and in turn engage in their type of learning or feedback (Figures 1 and 2). Additionally, this immersive environment is populated with what Beesley calls "Protocell fields," glass flasks that add a stuttering and turbulent atmosphere through the aid of chemical reactions that affect, expand, amplify, and quiet the adaptive and responsive nature of what Sanford Kwinter may call a "hyper communicative landscape."[8] Importantly, Beesley states, "These do not achieve high, efficient functions. Instead they offer a sketch of possibility."[9] Are there models in nature that exhibit similar reciprocity that we may mine?

In the Sabin Design Lab at Cornell Architecture, we ask, How might architecture respond to issues of ecology and sustainability whereby buildings behave more like organisms in their built environments? We are interested in probing the human body for design models that give rise to new ways of thinking about issues of adaptation, change, and performance in architecture. Our expertise and interests focus upon the study of natural and artificial ecology and design, especially in the realm of nonlinear biological systems


Cell-matrix interface

Architectural Speculation: Responsive Wall Assembly

Ihida-Stansbury and Yang

Sabin, Lucia, Nicol

Figure 3. eSkin inputs: cell-matrix interface and architectural speculation as adaptive wall assembly. © Sabin Design Lab, Cornell University; Kaori Ihida-Stansbury, University of Pennsylvania (above).

Figure 4. *ColorFolds*, a recent prototype by Sabin Design Lab, integrates eSkin material features with Kirigami principles and follows the concept of "Interact Locally, Fold Globally," necessary for deployable and scalable adaptive architectures. Using mathematical modeling, architectural elements, design computation, and controlled elastic response, *ColorFolds* showcases new techniques, algorithms, and processes for the assembly of open, deployable structural elements and architectural surface assemblies. © Sabin Design Lab, Cornell University (below).

and materials that use minimum energy with maximum effect.[10] Importantly, our practice and research offer another model for architectural affordance, one that is invested in developing an alternative material practice in architecture through the generative fabrication of the nonlinearities of material and form across disciplines. Together, the studio and lab investigate the intersections of architecture and science and apply insights and theories from biology and mathematics to the design, fabrication, and production of material structures.[11] Seminal references for the work include matrix biology, materials science, and mathematics through the filter of crafts-based media, including textiles and ceramics. Together, our collaborative work attempts an analogous deep organicity of interrelated parts, material components, and building ecology. Generative design techniques emerge with references to natural systems, not as mimicry but as transdisciplinary translation of flexibility, adaptation, growth, and complexity into realms of architectural manifestation. The material world that this type of research interrogates reveals examples of nonlinear fabrication and self-assembly at the surface, and at deeper cultural and structural levels. In parallel, our work offers up novel possibilities that question and redefine architecture within the greater scope of ecological design and digital fabrication.

Since the official public launch in the fall of 2010 of our NSF EFRI SEED project, titled *Energy Minimization via Multi-Scalar Architectures: From Cell Contractility to Sensing Materials to Adaptive Building Skins*, Jenny E. Sabin (co-principal investigator) along with Andrew Lucia (senior personnel) have led a team of architects, graduate architecture students, and researchers in the investigation of biologically informed design through the visualization of complex data sets, digital fabrication, and the production of experimental material systems for prototype speculations of adaptive building skins, designated eSkin, at the macro-building scale (Figure 3). The full team, led by Dr. Shu Yang (principal investigator), is actively engaged in rigorous scientific research at the core of ecological building materials and design. The work presented here is one subset of ongoing transdisciplinary research spanning across the fields of cell biology, materials science, electrical and systems engineering, and architecture. The eSkin project starts with these fundamental questions and applies them toward the design and engineering of responsive materials and sensors.[12] Biology presents useful conceptual models for architects to consider, where form is in constant adaptation with environmental events. Here, geometry and matter operate together as active elastic ground—a datascape—that steers and specifies form, function, and structure in context. Through direct references to the flexibility and sensitivity of the human body, we are interested in developing adaptive materials and architecture where code, pattern, environmental cues, geometry, and matter operate together as a conceptual design space.

The goal of the eSkin project is to explore materiality from nano- to macroscales based upon an understanding of nonlinear, dynamic human cell behaviors on geometrically defined substrates. To achieve this, human smooth muscle cells are plated on polymer

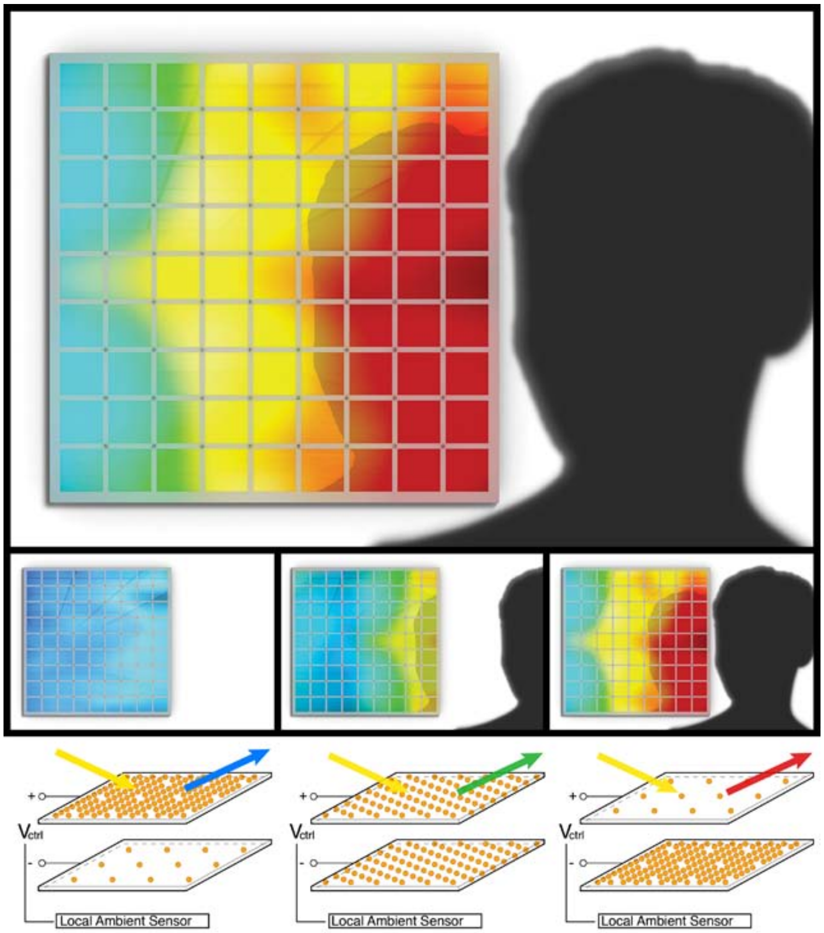


Figure 5. Rendering of eSkin material prototype demonstrating user interaction as an active input with resultant speculative transformation of the material substrate (top). Schematic diagram of circuit design interfacing with nano-colloidal particle solutions through voltage control. Individual sensing nodes interact with the material substrates locally through voltage control via the sensing of changes in ambient light, ultimately affecting the appearance of the prototype components. © Sabin Design Lab, Cornell University.

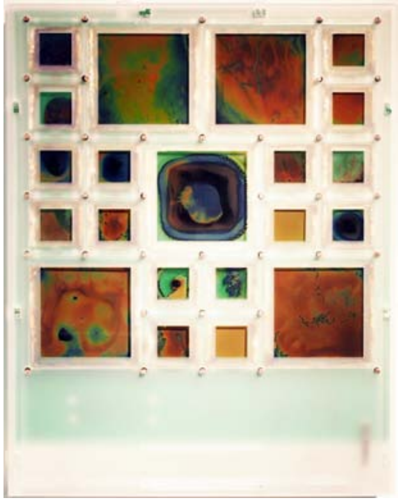


Figure 6. AeSkin interactive prototype. ITO treated glass cells with voltage controlled nanoparticle solution within, housed on a custom-built PCB substrate, and controlled locally via ambient sensing nodes. Component material prototype with local sensing nodes affecting component cells, harnessing user interaction as an active input and resultant transformation of the material substrate. © Sabin Design Lab, Cornell University; Shu Yang Group, University of Pennsylvania; Jan Van der Spiegel & Nader Engheta, University of Pennsylvania.

substrates at a microscale. Sensors and imagers are then being designed and engineered to capture material and environmental transformations based on manipulations made by the cells, such as changes in color, transparency, polarity, and pattern. Through the eSkin project, insights as to how cells can modify their immediate extracellular microenvironment are being investigated and applied to the design and engineering of highly aesthetic passive materials, sensors, and imagers that will be integrated into responsive building skins at the architectural scale (Figures 4–7).

In parallel, the work of the BIOMS group, directed by Maria-Paz Gutierrez at UC Berkeley, takes direct inspiration from nature's skins. Gutierrez is also a recipient of and principal investigator on one of the NSF EFRI SEED grants from 2010. As Gutierrez states, "Self-active matter is the new passive architecture."[13] Taking advantage of the textile as an important architectural element, the BIOMS multifunctional membrane features an integrative sensor and actuator system that is not only designed to answer to many functions through what Gutierrez calls the "synergistic optimization of heat, light and humidity transfer" but is also a closed loop system. Importantly, this system does not require energy input through mechanical actuators, sensors, and a mainframe. As the BIOMS group reports, "If the energy and material flows are synergistically optimized through a material programmed with self-regulation, the enclosure becomes, as in nature, a multifunctional skin."[14] Through an array of pores and apertures, the *breathing membrane* manages multiple functions through zero energy input.

In this sense, the material itself actuates and responds to multiple contextual inputs while optimizing for ideal conditions. The BIOMS group speculates that their breathing membrane, which is digitally fabricated through the integration of polymerization with 3-D printing extrusion, could be integrated with new construction such as in small deployable emergency housing or in public spaces in tropical zones such as markets and schools (Figures 8 and 9). Finally, Gutierrez and her BIOMS group articulate the importance of their research focus in the context of crisis. Rather than focus upon single solutions for conditions of crisis, as in the case of emergency relief housing, they are more concerned with how their research methodology and approach "contributes to a paradigm shift in our

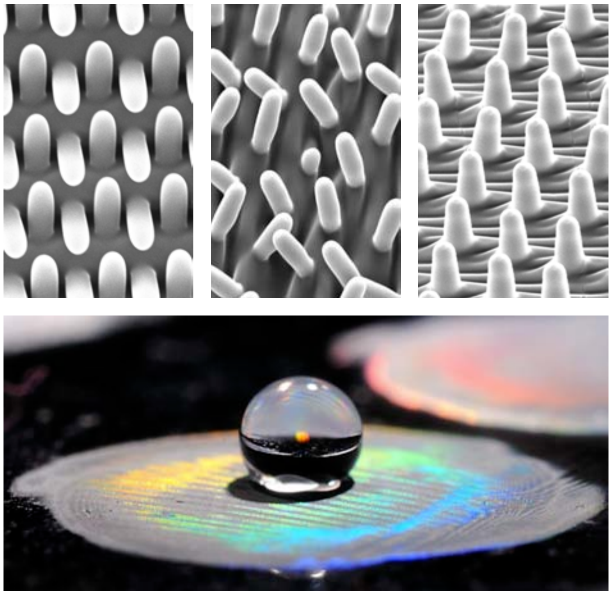


Figure 7. Yang's group at University of Pennsylvania explores biomimetic concepts such as structural color, exhibited here. Credits: By Jie Li, Guanquan Liang, Xuelian Zhu, and Shu Yang, "Exploiting Nano-roughness on Holographically Patterned Three Dimensional Photonic Crystals," Advanced Functional Materials 22, no. 14 (2012): 2980–86. Image was rendered by Felice Macera. © Shu Yang Group University of Pennsylvania.

Figure 8. *Multifunctional Building Membrane: Self-Active Cells, Not Blocks*, M. P. Gutierrez (BIOMS director/lead) with L. P. Lee (BioPoets director), UC Berkeley; BIOMS team (Charles Irby, Katia Sobolski, Pablo Hernandez, David Campbell, Peter Suen); B. Kim (BioPoets team). © BIOMS UC Berkeley.

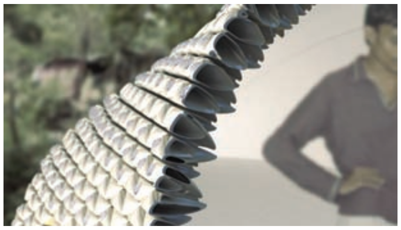


Figure 9. In contrast to many existing adaptive building assemblies and prototypes that require communication from a mainframe and electricity, the BIOMS breathing membrane operates on zero-energy input to self-regulate and optimize for heat, light and humidity. © BIOMS UC Berkeley.

understanding of how to approach resources (human and physical) in crisis and the transformations this entails from the design concept to the production framework from the nano or micro to the building scale."[15]

While Gutierrez and the BIOMS group focus upon the multifunctional capacity of self-actuated 3-D printed material membranes, the work of Achim Menges and his students at the Institute for Computational Design (ICD) at the University of Stuttgart operates at a larger scale through the explicit exploration of natural systems for novel structures in the context of computational matter.

Recently, the ICD and the Institute of Building Structures and Structural Design (ITKE) of the University of Stuttgart have constructed another bionic research pavilion, one of several in a series of research pavilions (Figure 10). Designed, fabricated, and constructed over one and a half years by students and researchers within a multidisciplinary team of biologists, paleontologists, architects, and engineers, the focus of this project is upon the biomimetic investigation of natural fiber composite shells and the development of cutting-edge robotic fabrication methods for fiber-reinforced polymer structures (Figure 11). Architects and structural engineers have historically looked to nature to design and build better shell and spatial structures. Cable nets have been inspired by the high strength-to-weight ratio of the spider web; pneumatic structures by soap bubbles; vaults by shells and eggs composed of hard and curved materials; and geodesics by radiolarian. Models borrowed from architects—such as tensegrity structures and geodesic (structures composed of spheres, triangles, and hexagons) domes—have led to radical new insights into how living systems, including eukaryotic cells, tissues, and whole organisms, are assembled and function, as well as to a new understanding of how the microecology of cells influences the genome. Similarly, models borrowed from biology, particularly regarding self-organization and the emergence of complex, nonlinear global systems from simple local rules of organization, have led to the discovery of new forms and structural organizations in architectural design.[16]

In the case of the new ICD/ITKE pavilion, the investigation of natural lightweight structures was conducted by an interdisciplinary team of architects and engineers from Stuttgart University and biologists from Tubingen University within the Module: Bionics of Animal Constructions led by Professor Oliver Betz (biology) and Professor James H. Nebelsick (geosciences). With an interest in exploring material efficient lightweight constructions, the elytron, a protective shell for beetles' wings and

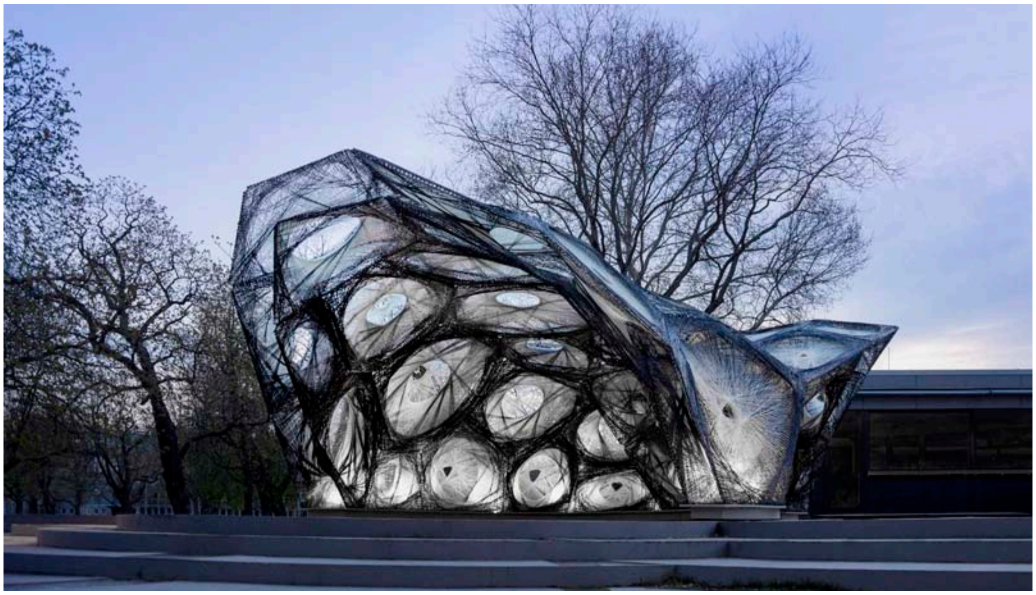
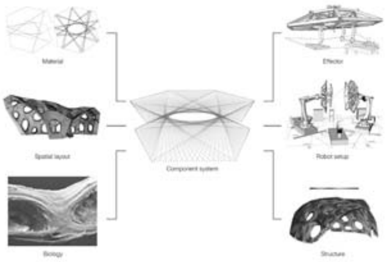


Figure 10. The Institute for Computational Design (ICD) at the University of Stuttgart operates at a larger scale through the explicit exploration of natural systems for novel structures in the context of computational matter. Recently, the ICD and the Institute of Building Structures and Structural Design (ITKE) of the University of Stuttgart have constructed another bionic research pavilion, one of several in a series of research pavilions. © ICD/ITKE University of Stuttgart.

Figure 11. Integration of multiple process parameters into a component-based construction system. © ICD/ITKE University of Stuttgart (below).

Figure 12. The robotic fabrication process involved two interacting six-axis robots to produce doubly curved glass and carbon fiber reinforced polymers through a winding process. © ICD/ITKE University of Stuttgart (left).



abdomen, proved to be an appropriate bionic model for the generation of innovative fiber composite construction methods through biological structural principles.

Through analysis of SEM scans of the elytra beetle, a biomimetic model of the trabeculae, a matrix of column-like doubly curved support elements that is highly differentiated through the shell structure, was extracted, synthesized, and redeployed through the aid of robotic fabrication. With an interest in working with this highly differentiated morphology as a model for a novel composite shell structure through the production of nonstandard unique elements, the robotic fabrication process involved two interacting six-axis robots to produce doubly curved glass and carbon fiber reinforced polymers through a winding process (Figure 12). Through this simple process, which basically entails winding layers of fibers and strategically impregnating the hollow cores with resin, thirty-six unique components were generated for the lightweight pavilion (Figure 13). Overall, these lightweight structures rely upon the geometric morphology of a double-layered system inspired and informed by the elytron beetle and then redeployed through the mechanical properties of the natural fiber composite.

While nonlinear concepts are widely applied in analysis and generative design, they have not yet convincingly translated into the material realm of fabrication and construction, until recently. The ICD/ITKE Research Pavilion 2013–14—Stuttgart 2014 showcases possible design routes and techniques that no longer privilege column, beam, and arch through a broadened definition of architectural tectonics successfully made with advancements in computational design.

Figure 13. Thirty-six unique components were generated for the lightweight pavilion. © ICD/ITKE University of Stuttgart.

How might these advancements impact material practice in architecture, engineering, and construction at economic, technological, and cultural levels? Importantly, the ICD/ITKE is equally committed to the communication, documentation, and public dissemination of their advances in tooling and fabrication to advance the design and production of nonlinear systems via complex geometries.

Central to all of the work presented here is the integration of fields and industries outside of our own in the practice of design research by multidisciplinary teams composed of architects, engineers, scientists, and fabricators active in academia, practice, and industry. A primary thrust of the works is the evolution of digital complexity in the built world in the context of the human. In parallel, this approach aims to make advances in material research and fabrication to affect pragmatic change in the economical and ecological production of complex built form and adaptive architecture.

While the exploration of biological and nano- to microscaled material properties and effects at the human scale form the starting points for many of the featured projects, the disciplinary hurdles that are encountered through the production of projects across scales, culminate in what is perhaps the most potent deliverable: a new model for transdisciplinary collaboration and the formation of new habits of thought. In all four cited design research practices, we are presented with architectural affordances that operate in counterdistinction to the solutionism of sanctioned and typical sustainable approaches to architecture where models based on behavior are favored over the purely technological. In the case of Beesley's work, architectural affordances operate, affect, and interact as environments, entities, and beings. Beesley's thermodynamic environments are in a perpetual state of "catching, harvesting, pulling, and pushing." In this sense, his architectural interfaces are both emergent and fully enmeshed in their environments, exhibiting a dynamic reciprocity between context and form. All of these attributes may be characterized as affordances and can also be seen in the work of Sabin Design Lab and BIOMS. In the case of eSkin or the work of BIOMS, programmable matter and self-actuating material systems operate as dynamic thresholds, interfaces that adapt, learn, and change in response to environmental cues with minimal to zero energy input. Here, geometry and matter are explored across multiple length scales and disciplines, where issues of sustainability are not merely about metrics and technology, but about new paradigms for adaptive and ecological architectural matter through transdisciplinary collaboration and design. And finally, in the work of the ICD, nonstandard tectonic elements emerge through the rigorous investigation of the behaviors of natural models and their corresponding translation into novel material systems where geometry, materiality, pattern, structure, and form are inextricably linked. Resisting postrationalization of complex form, here architectural affordances reveal themselves as evolving flows of force through geometry and matter that are computed, designed, and fabricated through robotic interfaces that dance, collaborate, wind, and weave. The scalar constraints span materials science, cell biology, textile engineering, fashion, electrical and systems engineering, and architecture, which in turn challenge the differences between fundamental and applied research. Through the collaborative production of these applications, we encounter key differences between the conceptualization and materialization of the projects whose success demands that science, engineering, and design meet. The creative navigation of this ambiguous line between science and architecture in turn offers up a unique model for collaboration across disciplines that defines a new future for architecture and the role of the architect where authorship is horizontal, giving way to interiorities, elastic networks, fabrics, and topological meanders that are pliable, plastic, ecological, and open—where geometry and matter are steered and specified by the flexibility and sensitivity of the human body. Perhaps the most important deliverable in the aforementioned examples to date are these new models for collaboration across disciplines where architectural affordances form a bridge and a point of departure toward transformative models that may in parallel provide potent contributions to an era in crisis.

Author Biography

Jenny Sabin's work is at the forefront of a new direction for twenty-first century architectural practice—one that investigates the intersections of architecture and science, and applies insights and theories from biology and mathematics to the design of material structures. Sabin is the Arthur L. and Isabel B. Wiesenberger Assistant Professor in the area of Design and Emerging Technologies in the Department of Architecture at Cornell University. She is principal of Jenny Sabin Studio, an experimental architectural design studio based in Philadelphia and Director of the Sabin Design Lab at Cornell AAP, a hybrid research and design unit with specialization in computational design, data visualization and digital fabrication.

Notes

1 Jenny Sabin, "PolyMorph and Branching Morphogenesis," in *Post Sustainability: New Directions in Ecological Design*, ed. Mitchell Joachim and Mike Silver (New York: Metropolis Books, forthcoming).

2 I use the word "affordance" as it refers to James Gibson's *Ecological Approach to Visual Perception* and more specifically to his piece, "The Theory of Affordances." Here "affordance" refers to how context may specify constraints and thus contribute to emergent and transformative relational models for design through notions of feedback and ecology as opposed to symbolic or function-based solutions. Simply put, an affordance gives rise to the possibility of an action or series of actions, a relationship between environment and organism. See James J. Gibson, *The Ecological Approach to Visual Perception* (Hillsdale, NJ: Erlbaum, 1986). See also Andrew Lucia, Jenny Sabin, and P. L. Jones, "Memory, Difference, and Information: Generative Architectures Latent to Material and Perceptual Plasticity" (Paper presented at the 15th Annual Conference on Information Visualization, London, July 2011). Finally, see Simone Ferracina, "Exaptive Architectures," in *Unconventional Computing: Design Methods for Adaptive Architecture*, ed. Rachel Armstrong and Simone Ferracina (Cambridge, Ontario: ACADIA and Riverside, 2013), 62–65.

3 Rachel Armstrong, "Lawless Sustainability," *Architecture Norway* 1381, December 5, 2012, http://www.architecturenorway.no/questions/cities-sustainability/armstrong/.

4 J. Sabin, "Reaching a Sustainable Symbiosis," *Architectural Review* 1381 (March 2012): 88–89.

5 Maria-Paz Gutierrez, "Reorienting Innovation: Transdisciplinary Research and Building Technology," *Architectural Research Quarterly* 18, no. 1 (March 2014): 69–82, doi:10.1017/S1359135514000372.

6 Philip Beesley, "Diffusive Prototyping" (paper presented at Alive International Symposium on Adaptive Architecture, Computer Aided Architectural Design, ETH Zurich, March 2013).

7 See Beesley's description of emplacement and architecture in his lecture on "Diffusive Prototyping" (note 6).

8 Sanford Kwinter, "Creods" (paper presented at Acadia 2008: Silicon + Skin, Biological Processes and Computation, Minneapolis, October 2012).

9 Beesley, "Diffusive Prototyping" (note 6).

10 Marie-Ange Brayer and Frederic Migayrou, *Naturalizing Architecture* (Orleans, France: FRAC Centre, 2013), 28–29, 142–45. This was published on occasion of the 9th ArchiLab.

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12 Jenny Sabin, Andrew Lucia, Giffen Ott, and Simin Wang, "Prototyping Interactive Nonlinear Nano-to-Micro Scaled Material Properties and Effects at the Human Scale" (Paper presented at Simulation for Architecture and Urban Design (SimAUD), April 13–16, 2014).

13 M. P. Gutierrez (BIOMS director/lead), with L. P. Lee (BioPoets director), UC Berkeley BIOMS team (Charles Irby, Katia Sobolski, Pablo Hernandez, David Campbell, Peter Suen), and B. Kim (BioPoets team), *Multifunctional Building Membrane: Self-Active Cells, Not Blocks*, in prep (team project).

14 Ibid.

15 Ibid.

16 J. Sabin and P. L. Jones, "Nonlinear Systems Biology and Design: Surface Design," in *Proceedings of the 28th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, ed. A. Kudless (Association for Computer Aided Design in Architecture, 2008), 54–65.