Applications of Insights from Biology and Mathematics to the Design of Material Structures

Jenny E. Sabin, Cornell University

For the past 11 years, Jenny Sabin Studio and Sabin Design Lab now based at Cornell University have engaged in work that sits at the forefront of a new direction for 21st-century architectural research practice—one that investigates the intersections of architecture and science, and applies insights and theories from biology and computation to the design of material structures.[i] This talk presents this new field through rigorous multi-directional and multi-disciplinary investigations that are shaping the future trajectories of these material innovations and technologies for architecture. The work aims to advance materials research and digital fabrication across disciplines in order to effect pragmatic change in the economical, ecological and cultural production of contemporary architecture.

It is well known that buildings in the U.S. 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 LEED, a rating system launched by the U.S. Green Building Council for new construction and existing building renovations. 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 towards the problem of sustainability in architecture? What design research models are already in place to address these questions and thus are shaping future innovations and applications in architecture?[ii]

Examples of these forward-thinking research practices include Matthias Kohler's group at ETH, Zurich.[iii] Kohler coined the term digital materiality through the course of their work with industrial robots and as one of the universal tools of the digital age. His more recent *Computational Contextualism* highlights how sensors operate to integrate feedback from both the environment and materials into a robust design process enmeshed with emergent qualities, but always meeting the built environment. Ronald Rael and Virginia San Fratello of Emerging Objects claim that all materials start as powder or end in dust. Their 3D printed work integrates bits of data and particles of light to transform this dust into nonstandard objects and products as future building blocks, challenging the status quo of rapid prototyping by designing the material itself. Researchers such as Rob Shepherd and Maria Paz Gutierez explore architecture applications in programmable matter & materials science. Shepherd works on actuators, sensors, displays, and additive manufacturing protocols for soft wearable robots. Shepherd underscores the importance of iterative complex feedback between material and mechanical design in the development of these techniques and wearables. In parallel, the work of the BIOMS group, directed by Maria-Paz Gutierez at UC Berkeley, takes direct inspiration from nature's skins. As Gutierez states, "Self-active matter is the new passive architecture."[iv] Taking advantage of the textile as an important architectural element, the BIOMS multifunctional membrane features an integrative sensor and actuator system that is designed to not only answer to many functions through what Gutierez calls the "synergistic optimization of heat, light and humidity transfer", it is also a closed loop system. Importantly, this system does not require energy input through mechanical actuators, sensors and a mainframe. Through select research projects from his Institute for Computational Design and Construction at the University of Stuttgart, Achim Menges argues that technological innovation across multiple disciplines suggests that design computation is no longer limited to the binary world of the digital, but is now interfacing the complex realm of the physical. How is this innovative and forward-thinking work leveraged and funded?

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 trans-disciplinary 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 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. Successful project proposals required a radical departure from traditional research and design models in architecture and science with a move towards hybrid, trans-disciplinary concepts and new models for collaboration.

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 non-linear biological systems and materials that use minimum energy with maximum effect. 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. In parallel, our work offers up novel possibilities that question and redefine architecture within the greater scope of ecological design and digital fabrication.

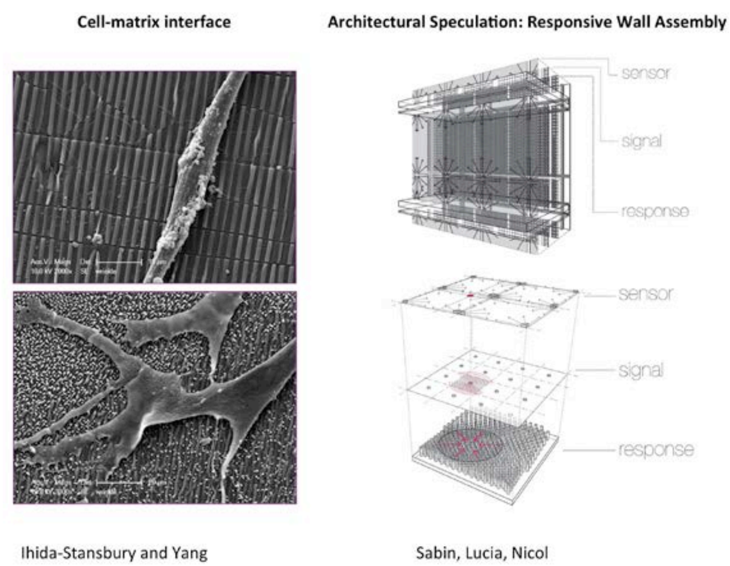

Figure 1 - eSkin inputs: cell-matrix interface & architectural speculation as adaptive wall assembly. Copyright: © Sabin Design Lab, Cornell University; Kaori Ihida-Stansbury, University of Pennsylvania

Since the official public launch in the fall of 2010 of our National Science Foundation (NSF) Emerging Frontiers in Research and Innovation (EFRI) Science in Energy and Environmental Design (SEED) project titled, *Energy Minimization via Multi-Scalar Architectures: From Cell Contractility to Sensing Materials to Adaptive Building Skins*, Jenny E. Sabin (Co-PI) 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. The full team, led by Dr. Shu Yang (PI), 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 trans-disciplinary 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 towards the design and engineering of responsive materials and sensors.[v]

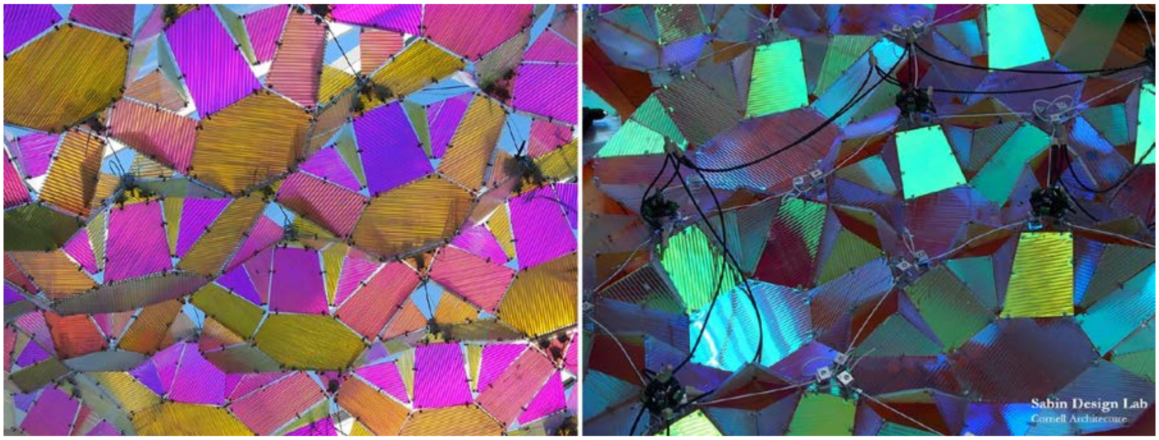

Figure 2. *ColorFolds*, a recent prototype by Sabin Design Lab, integrates eSkin material features with Kirigami principles and follows the concept of "Interact Locally, Fold Globally," necessary for deployable and scalable adaptive architectures. Using mathematical modeling, architectural elements, 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. Copyright: © Sabin Design Lab, Cornell University

Our architectural research with the scientific team operates within a multi-year and multi-phase research plan. Currently, our work is broken down into 3 phases including: (1) The production of catalogs of visualization and simulation tools that are then used to discover new behaviors in geometry and matter; (2) An exploration of the material and ecological potentials of these tools through the production of experimental structures and material systems through digital fabrication, and (3) Generation of scientifically-based, design-oriented applications in contemporary architecture practice for adaptive building skins and material assemblies.

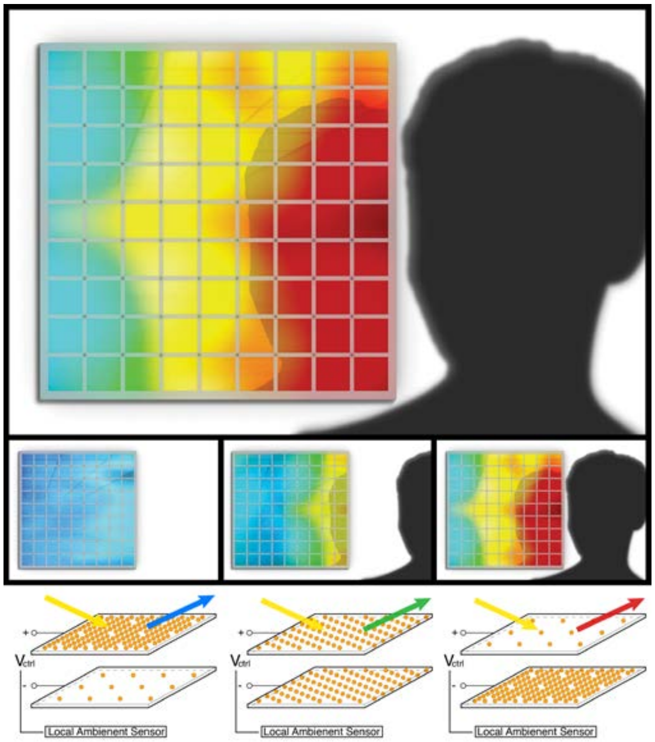

Figure 3 - Rendering of eSkin material prototype demonstrating user interaction as an active input with resultant speculative transformation of the material substrate (top). Schematic diagram of circuit design interfacing with nano-colloidal particle solutions through voltage control. Individual sensing 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. Copyright: © Sabin Design Lab, Cornell University

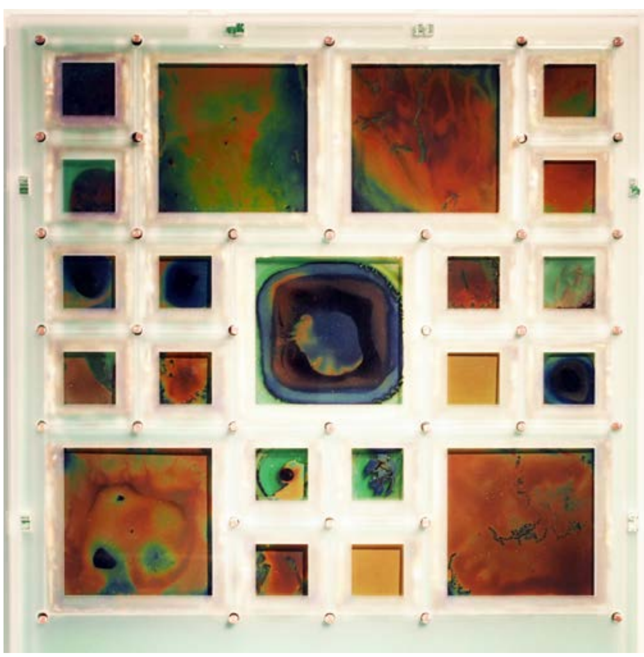

Figure 4 - eSkin interactive prototype. ITO treated glass cells with voltage controlled nanoparticle solution within, housed on a custom-built PCB substrate, and controlled locally via ambient sensing nodes. Component material prototype with local sensing nodes affecting component cells, harnessing user interaction as an active input and resultant transformation of the material substrate. Copyright: © Sabin

Design Lab, Cornell University; Shu Yang Group, University of Pennsylvania; Jan Van der Spiegel & Nader Engheta, University of Pennsylvania

The goal of the eSkin project is to explore materiality from nano to macro scales 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 substrates at a micro-scale. 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.

Overall, our project addresses energy minimization at multiple scales of architecture by working towards challenging goals such as those put forward by the U.S. DOE. We hope that our interdisciplinary work not only redefines definitions of research and design, but will also address pressing topics in each of our fields concerning key social, environmental and technological issues that ultimately impact building design and the built environment.

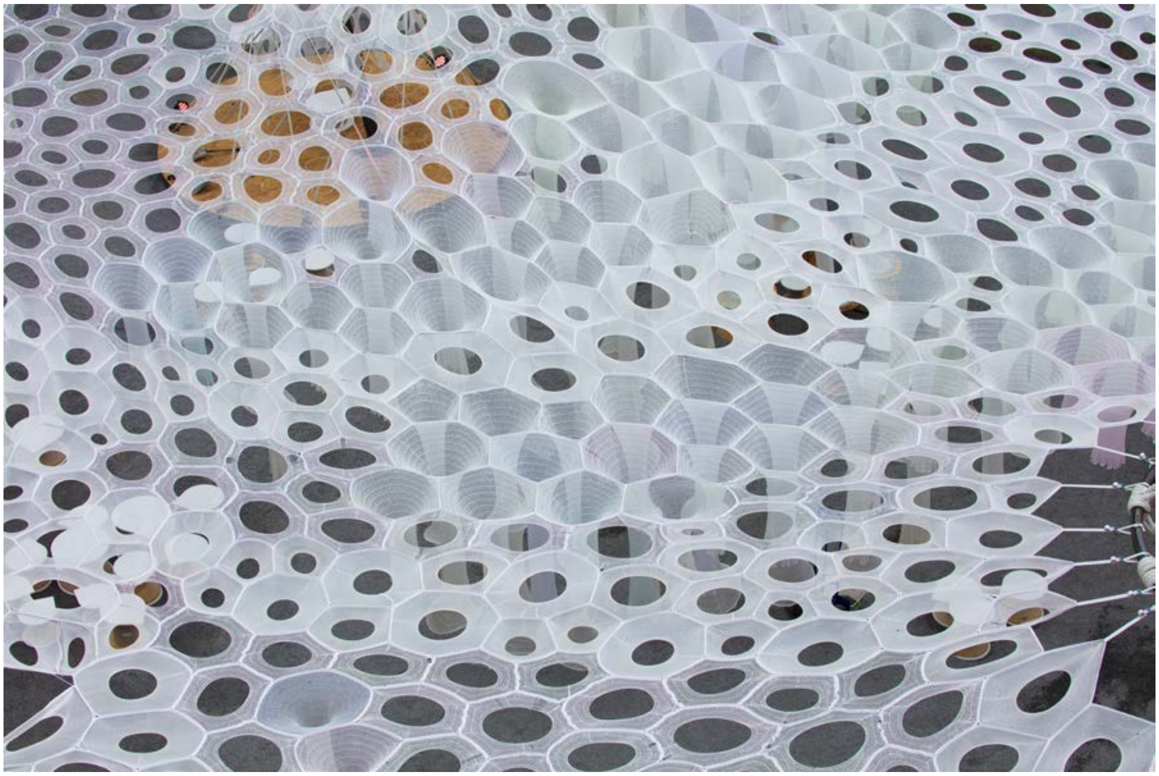

Figure 5 – Lumen by Jenny Sabin Studio, winning project for MoMA and MoMA PS1's Young Architects Program, 2017. Lumen is an immersive, interactive installation that evolves over the course of the day, with responsive textiles that display subtle color in sunlight and emit glowing light after sundown. © Jenny Sabin Studio; photo by Jenny E. Sabin.

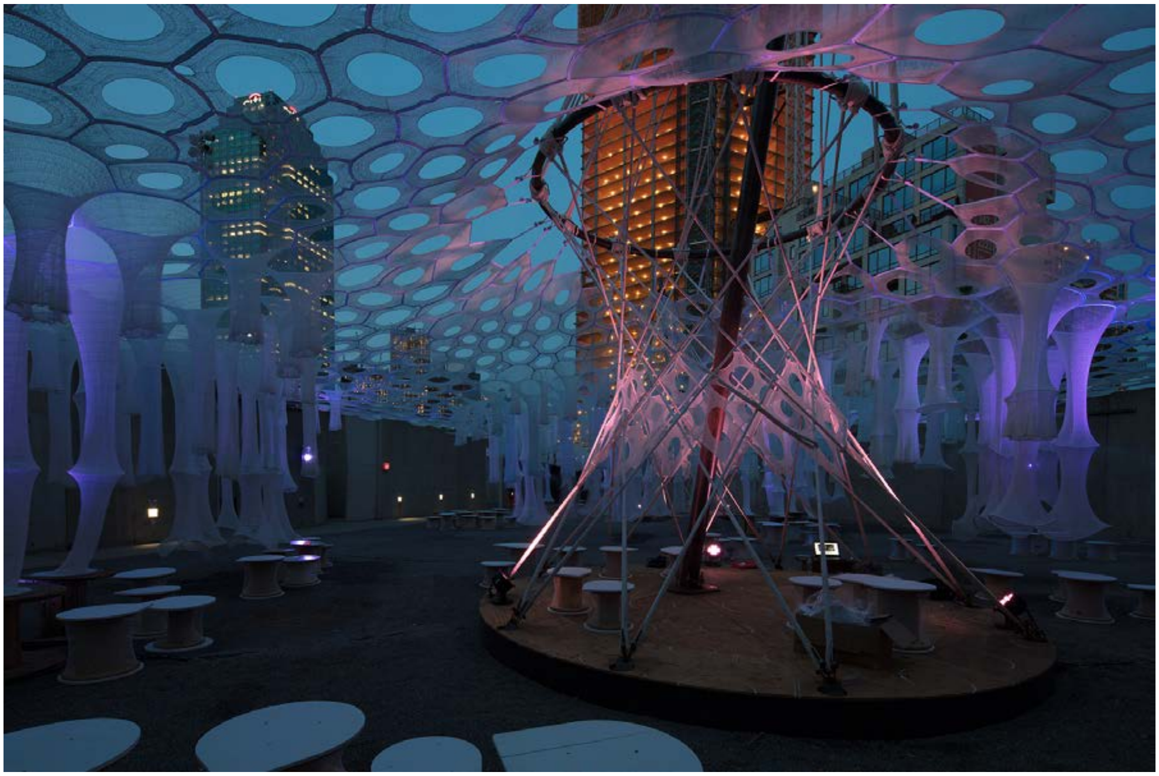

Figure 6 – Lumen engages adaptive architecture and responsive materials at all scales and is the result of collaboration across disciplinary boundaries including in architecture, engineering, materials science, computer science, fiber science, fashion, and beyond. © Jenny Sabin Studio; photo by Pablo Enriquez

---

[i] See Sabin J. and Jones, Peter Lloyd. ***LabStudio: Design Research Between Architecture and Biology***, (London & New York: Routledge Taylor and Francis, 2017). A book on design research across disciplines through the lens of LabStudio, co-founded by Sabin, an architectural designer and Jones, a cell and molecular biologist.

[ii] Portions of this paper have been adapted from Sabin, J. "Transformative Research Practice: Architectural Affordances and Crisis", Journal of Architectural Education, ISSN: 1046-4883, Taylor & Francis, 2015.

[iii] As discussed in the *Matter Design Computation Symposium: The Art of Building from Nano to Macro*, Cornell AAP Preston Thomas Memorial Lecture Series, March 10/11, 2017

[iv] 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)

[v] Sabin, Lucia, Ott, Wang, "Prototyping Interactive Nonlinear Nano-to-Micro Scaled Material Properties and Effects at the Human Scale" in Simulation for Architecture and Urban Design (SimAUD), April 13-16, 2014.