SABIN+JONES LABSTUDIO: NONLINEAR SYSTEMS BIOLOGY AND DESIGN

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In 2006, Jenny E. Sabin and Peter Lloyd Jones founded LabStudio (www.sabin-jones.com), a hybrid research and design unit based within the Schools of Design and Medicine at The University of Pennsylvania. The Mission of LabStudio is to produce new modes of thinking and working in design and biomedicine through the creation and subsequent modeling of dynamic biological systems. Our emphasis rests heavily upon the study of natural and artificial ecology and design, especially in the realm of non-linear biological systems that use minimum energy to maximum effect.

Within LabStudio, architects, scientists, engineers and mathematicians collaborate in a reciprocal and direct fashion to develop, analyze and abstract dynamic, biological systems through the generation and design of new tools and material constructions. These approaches for modeling complexity and visualizing large datasets are subsequently applied to architectural and biomedical research and design. The real and virtual world that LabStudio occupies has already offered radical new insights into generative and ecological design and fabrication within architecture and it is providing new ways of seeing and experiencing how biological systems are formed and operate during human development and disease.

The immediate implementation plan included recruiting graduate architecture students and scientists to collaborate on research projects operating within LabStudio. In the first phase, we chose to focus our projects that examined *Surface Design, Motility and Networking* behaviors in living systems, based upon the unique research potential of each towards application in architecture and biomedicine. The funded work for our awarded AIA Upjohn grant focused solely upon the *Surface Design* research trajectory. This article, however, features architectural projects and outcomes from all three research tracks.

LabStudio operates within a multi-year and multi-phase research plan. Currently, each project is broken down into three phases including: (1) the production of catalogs of visualization and simulation tools that are then used to discover new behaviors in geometry and matter within specific dynamic biological systems; (2) an exploration of the material and ecological potentials of these tools through the production of experimental structures and material systems, and (3) generation of scientifically-based, design-oriented applications in contemporary architecture practice and biomedicine. In part, these applications range from new concepts of materiality to adaptive structures with complex geometries to avant garde diagnostic tools for patients with lung disease. Overall, LabStudio research has already had a significant impact upon hypothesis- and design-driven research in architecture, biomedicine and education.

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Technology has provided architects and scientists alike an extraordinary ability to generate information, yet this has resulted in an ever-increasing inability to organize, visualize, model and most importantly, to comprehend and relate to diverse datasets within dynamic scenarios. While the end goals in science and architecture may differ, there is a driving necessity in both disciplines to spatialize, model and fabricate complex, emergent and self-organized, non-linear systems. How can we intuit, see and understand complex wholes that are often indiscernible from their individual parts? The increased stores of information available within design and biomedical technologies require alternative modes for information mediation, collaboration and ways of "seeing" amidst an increasingly complicated information context. Many of the projects within LabStudio call for an intervention in this technological context through the visualization and materialization of intangible information. Our research is underscored by cell biological studies that are essential to the understanding of human health and disease. By investigating loops that filter datasets through material organizations, many of our design projects seek to empower individuals through matters of knowledge, information and access.

Reciprocity & Design Computation

At the bench side, our research includes the study of the extracellular matrix protein network that surrounds cells within tissues, and to ask how this dynamic network affects tissue behavior at the genotypic and phenotypic levels. Jones has studied the extracellular network described herein since 1992, and his work has helped form a new paradigm in biology that is underscored by the idea that 3-D tissue architecture, specified by the matrix, exerts a dominant effect over genes. Essentially, function follows form since much of the secret of life exists outside the cell within the matrix. We aim to understand the dynamic and reciprocal relationships that exist between cells (i.e. a component), their extracellular matrix (i.e. an environment), and code (i.e. genetic information). This exchange of information between the outside of the cell and its interior environment and back again presents a potent ecological model for architecture based upon an understanding of how context or environment shares a reciprocal relationship with code, geometry, and matter. The advanced digital procedures and generative design strategies implemented within LabStudio to study these relationships at multiple length scales have been fostered by Sabin's expertise in design computation and digital fabrication of alternative materials, and by Jones' expertise in building 2-D environments at the micro scale. Design computation is a relatively new area within architecture and design research. It includes the systematic study and production of formal and contextual relationships through generative processes, which may include custom-designed algorithms and parametric models. Sabin studied under and later taught (at UPenn) with Cecil Balmond, a world-renown structural engineer and pioneer in the practice and production of form through algorithm. Sabin's work and collaboration with Jones have contributed substantially to these new trajectories within architecture and research.

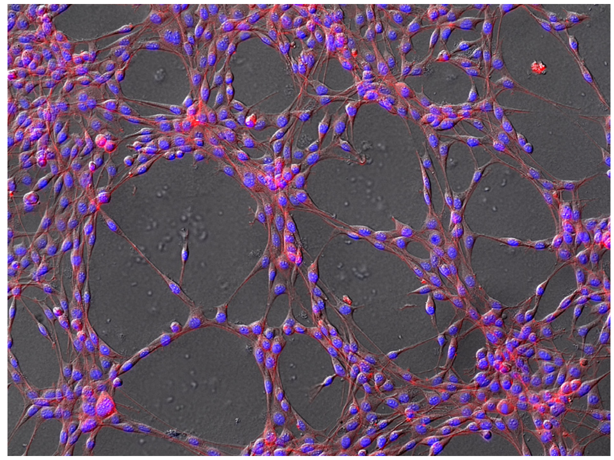


Figure 1: Real-time imaging of endothelial cells, cultured within specialized matrix microenvironments, that either suppress or promote networking, formed the starting point of the "Branching Morphogenesis" project.

Material Technology & Fabrication

One example of material and informational transfer of biological data through geometry and form resides within a public installation entitled "Branching Morphogenesis" (Designed by Jenny E. Sabin & Andrew Lucia with Peter Lloyd Jones and Annette Fierro). Originally exhibited in LA at Siggraph 2008, this work investigates part-to-whole relationships revealed during networking by lung vascular cells in 4-dimensions. Real-time imaging of endothelial cells, which form the lining of all blood vessels, including within the lung, cultured within specialized matrix microenvironments, that either suppress or promote networking, formed the starting point of this project. At the human scale, time-lapse movies of this process are manifested as 5 vertical, interconnected layers made from over 75,000 cable zip ties. Displayed at *Ars Electronica* in Linz (Jan '09-11), gallery visitors walked around and in-between the layers of "Branching Morphogenesis", thereby immersing themselves within an organic "Datascape". At the scientific level, the manifestation of such data as a physical, human-scaled architectural construct has the potential to produce new hypotheses regarding the role of tissue architecture, force and environment in controlling morphogenesis.

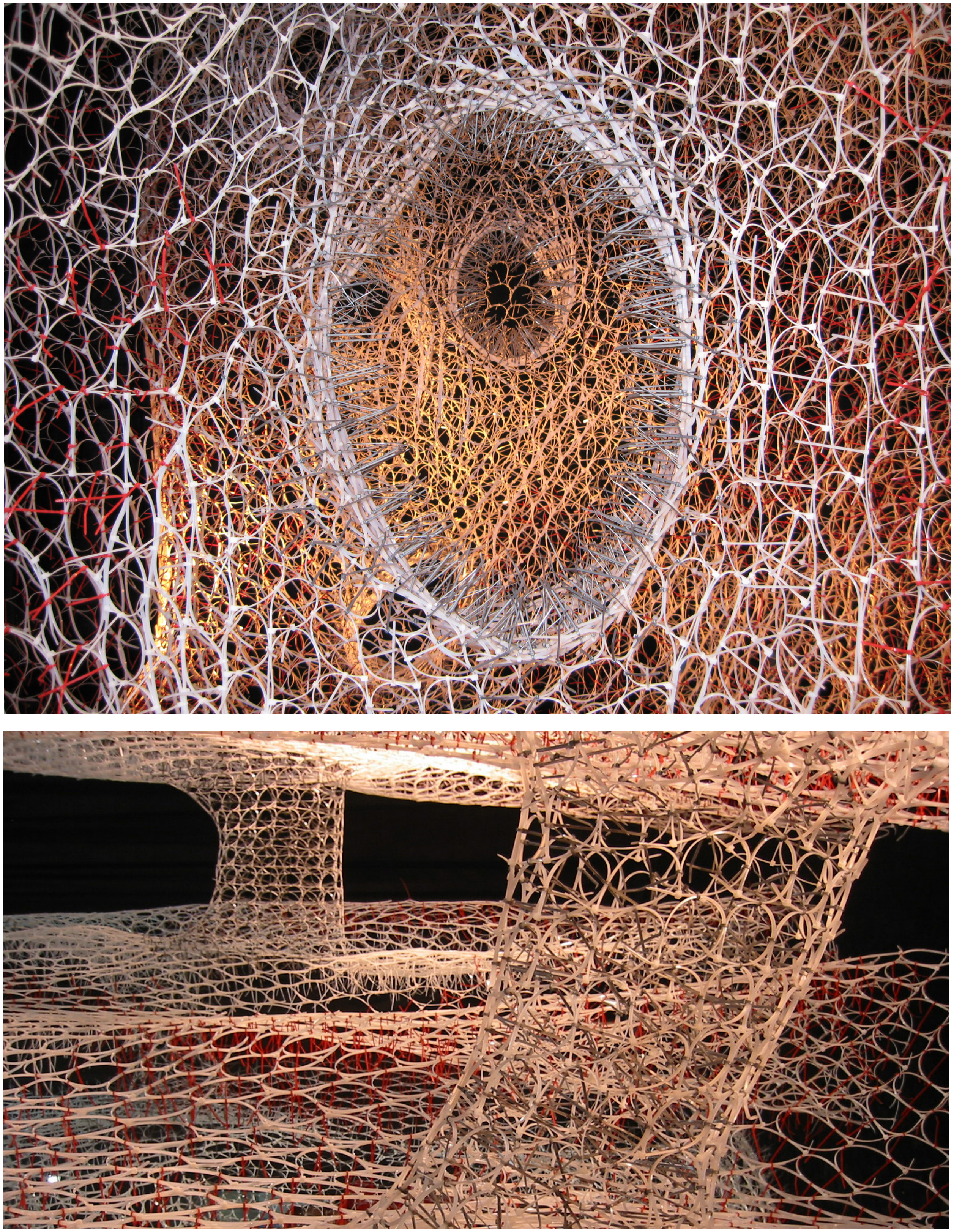


Figure 2: Originally exhibited in LA at Siggraph 2008, this work investigates part-to-whole relationships revealed during networking by lung vascular cells in 4-dimensions.

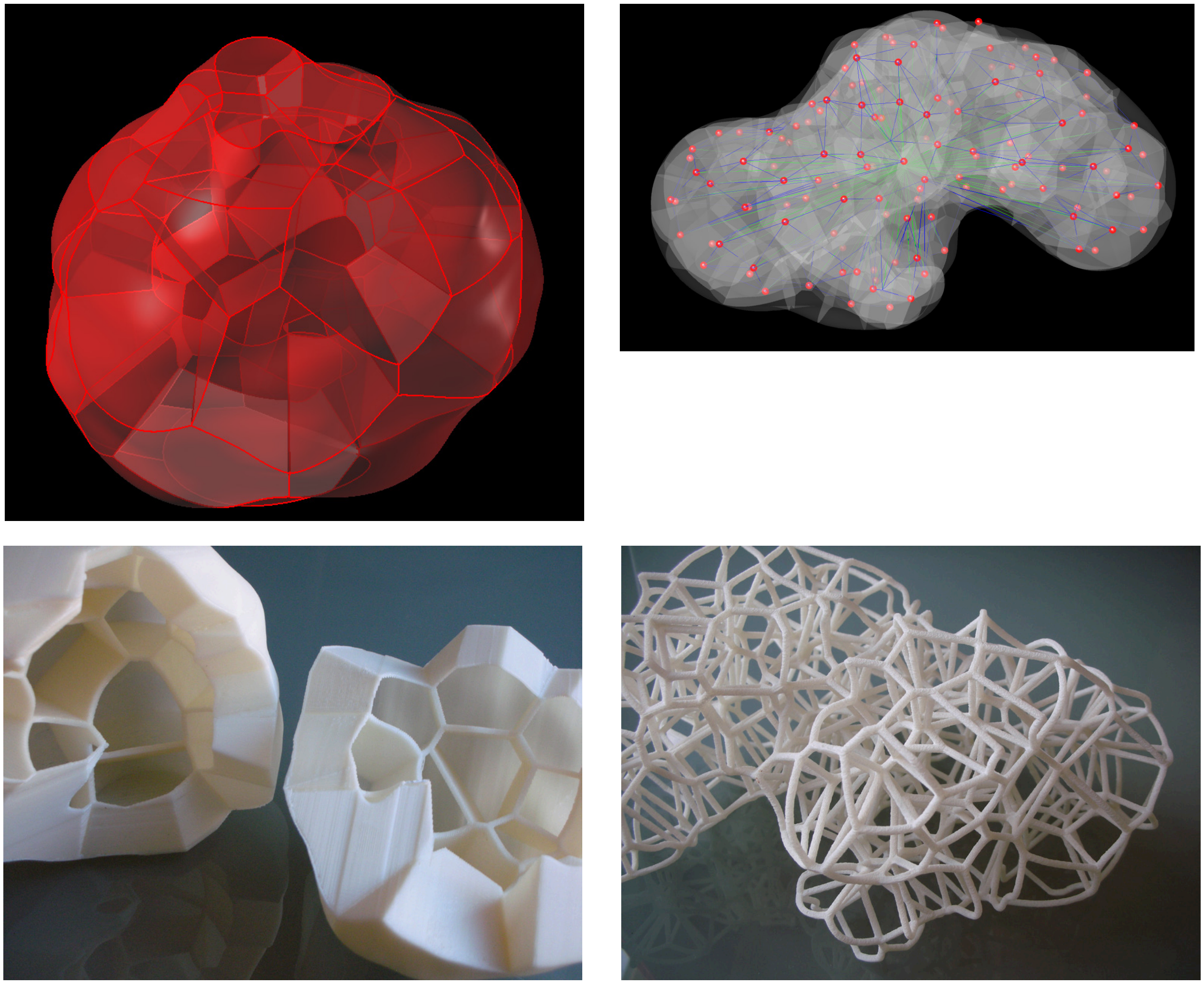
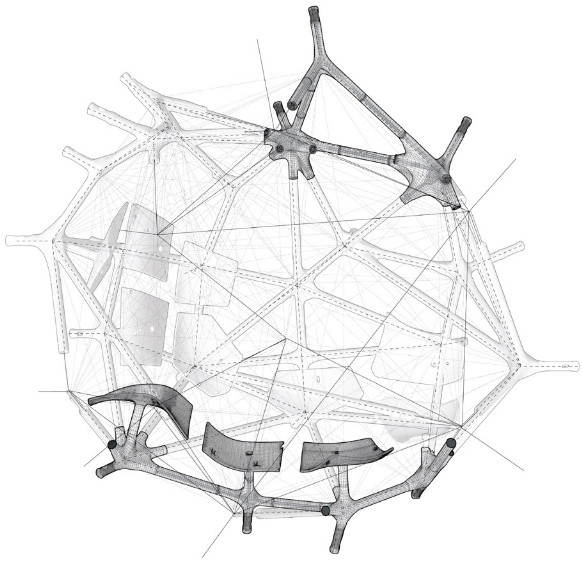
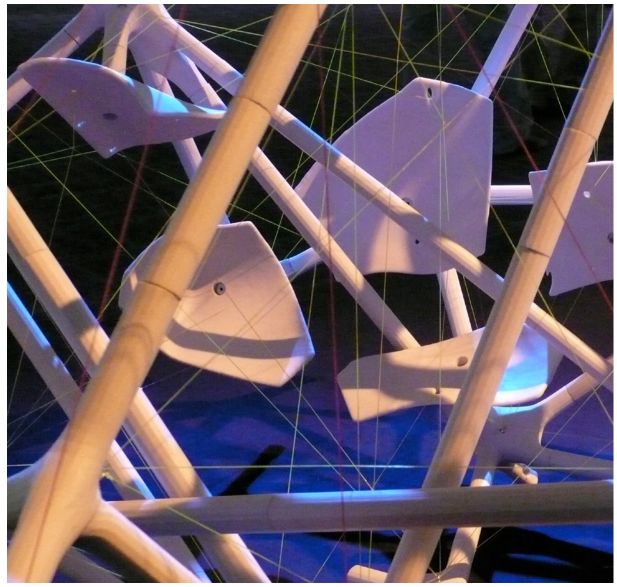


Figure 3: The algorithmic and digital exploration of relationships between interacting cells and their immediate tissue environment gives rise to an abstract, yet deeper understanding of architectural form as it relates to a dynamic boundary condition.

While this example underscores our interest in the material and spatial effects produced by complex biological datasets, the *Surface Design* track highlights the impact of our research upon the production of experimental structures. The funded work for our awarded AIA Upjohn grant focused upon this trajectory. In brief, we sought to quantify and spatialize cellular and tissue contour information using normal human mammary epithelial cells cultivated within a 3-D normal or tumor-like microenvironment. Here, the algorithmic and digital exploration of relationships between interacting cells and their immediate tissue environment gives rise to an abstract, yet deeper understanding of architectural form as it relates to a dynamic boundary condition (see images of digital and 3D printed models and simulations) In turn, this information has provided new clues as to how the tissue microenvironment may control in the genesis of breast cancer.

One project stemming from our *Surface Design* track titled “Ground Substance” (Designed by Jenny E. Sabin & Andrew Lucia with Peter Lloyd Jones and Annette Fierro and recently on view at Siggraph 2009 in New Orleans) may be described as an experimental structure produced through alternative modes of digital fabrication. “Ground Substance” bridges art, architecture and science through a structural and material model that is both natural and artificial. The project embeds biological behavior in material systems through the use of advanced technologies in 3D printing and rapid prototyping. In parallel, prototype studies using 3D printed ceramic modules were also produced. The final fabricated model is composed of 146 unique 3D printed parts connected together with aluminum rod and cable thread.





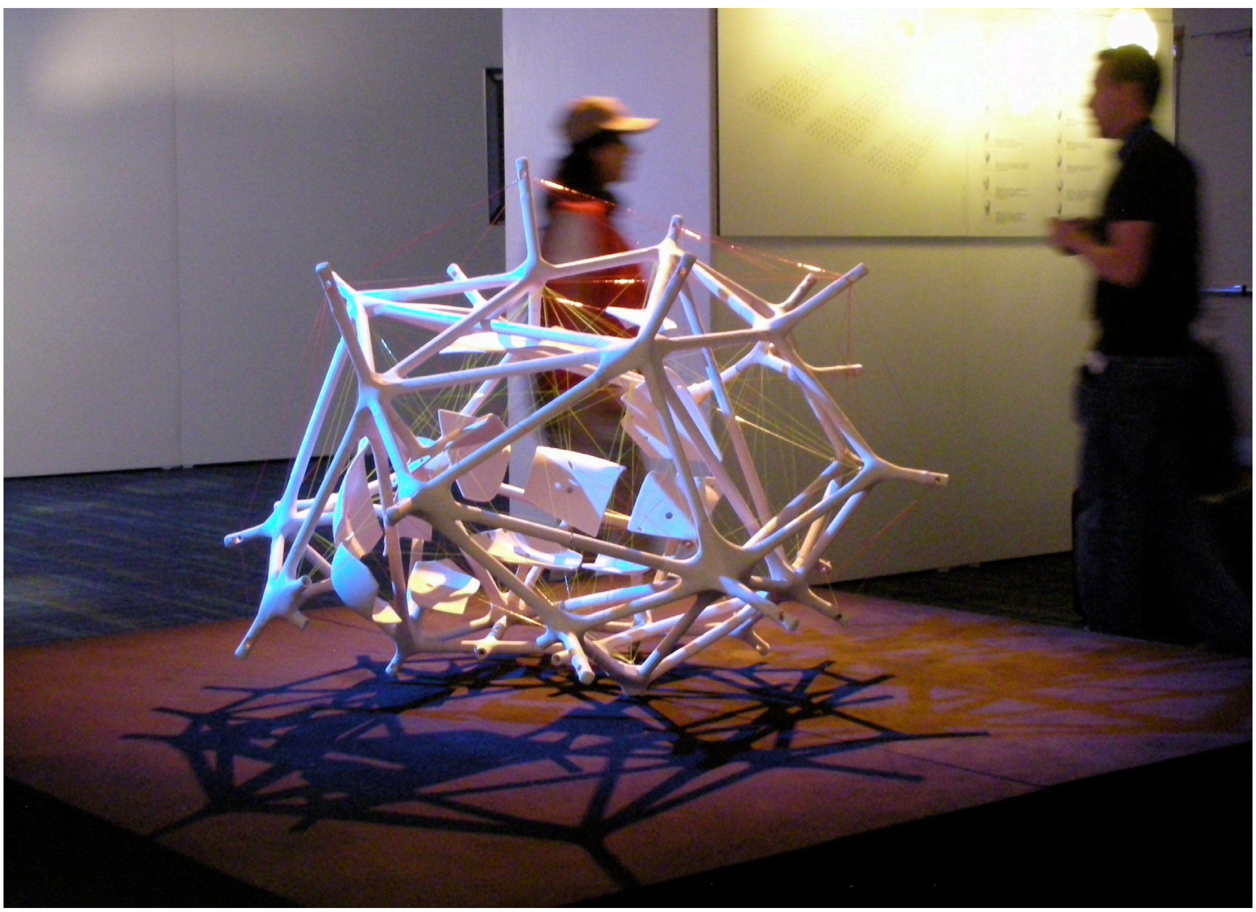


Figure 4: “Ground Substance” bridges art, architecture and science through a structural and material model that is both natural and artificial.

A second *Surface Design* project by Misako Murata (M.ARCH 2009) incorporates the application of deployable structures as a testing ground to better study the junctions between cell surfaces. Deployable structures are composed of three key elements: structure, mechanisms and the programming of such mechanisms. In our case, the information programmed and transmitted through the specified mechanisms comes directly from the biological model being studied. Adherens junctions are specialized forms of adhesive contacts important for tissue organization in developing and adult organisms, including construction and maintenance of the normal, adult mammary epithelium. With breast cancer, however, the stability of these junctions is compromised. When applying the deployable structure model, the varying range, quality and duration of each deployable performance varies within the normal and diseased contexts.

The final stage of this study involved the scalable reconstruction of the embedded biological behavior in deployable systems (described above) to a building and pavilion prototype. The rapid manufacturing of a skin structure composed of water-jet cut aluminum flaps is fused with the intricate design and fabrication of steel struts and mechanisms composed of hinges and pins. Information gained from studying geometry and matter at the cell and tissue level is embedded in the final assemblage alongside architectural constraints of scale, material thickness and fabrication. The final prototype deploys locally and along nonlinear paths leading to a differential and highly local experience at the architectural scale.

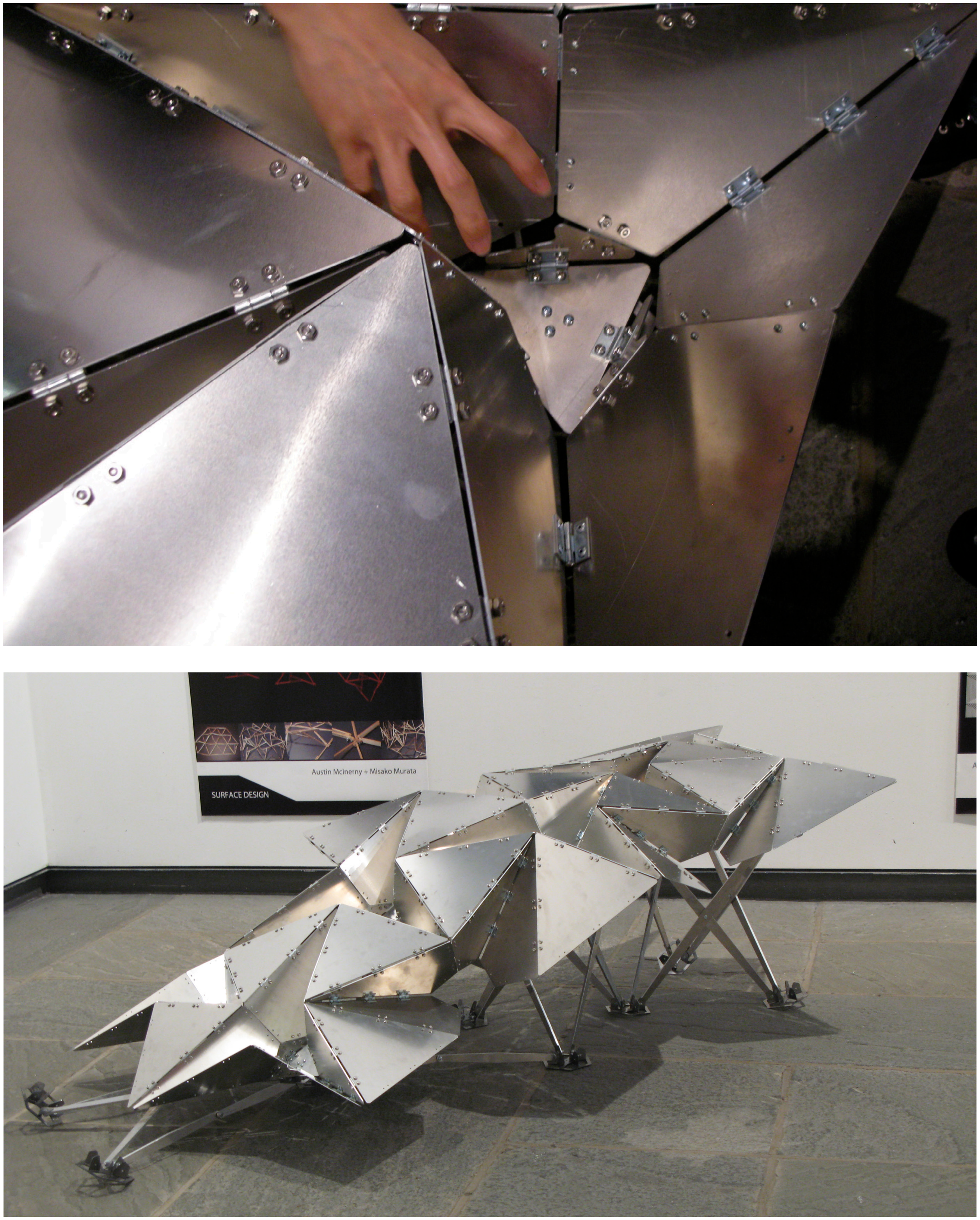


Figure 5: Deployable structures are composed of three key elements: structure, mechanisms and the programming of such mechanisms.

Design Ecology & Tech Transfer

The projects described above underscore our mission to probe the ecological and material import of our collaborative research in biology and architecture. More specifically, the third project track, entitled *Motility*, has led to several unique research paths within design ecology, as well as forthcoming applications at the scale of a building facade.

For this project, visualization tools have been designed and developed by Erica Savig (M.ARCH 2009), Andrew Lucia (M.ARCH 2008) and Mathieu Tamby (PhD) under the guidance of Sabin and Jones for assessing how human smooth muscle cells differentially respond to a normal or diseased 3-D tissue microenvironment. We investigated the role of the microenvironment in controlling cell motility and the shifting geometries inherent in this movement. This study is now being developed as a rapid, accurate and cost-effective diagnostic tool for patients with lung disease.

Concurrently, this project seeks to explore materiality from nano- to macro scales, based upon a quantitative understanding of dynamic cell behaviors cultivated on custom-designed geometric surfaces. This approach to comprehending cell sensing and responsivity to a specific surface condition is now being investigated for the rational design of materials that will form the basis of a building component that responds passively (i.e. without the need for an external energy input) to changes in climate. This project includes co-investigators in the fields of architecture (Jenny E. Sabin M.ARCH), cell biology (Peter Lloyd Jones PhD), material science (Shu Yang PhD), and mechanical and electrical engineering (Nader Engheta PhD, Jan Van der Spiegel PhD). This synergistic, bottom-up approach across diverse disciplines brings about a new paradigm for the design and construction of intelligent and sustainable building materials that engage users at an aesthetic level with minimal energy consumption. The research outcome will also create a significant opportunity to excite the general public about dynamic biomimicry for energy harvesting and sensing, thereby provoking and engaging their interest in science, technology, engineering, and mathematics.

Reliable Standards: Funding

To date, funding for LabStudio has been substantially bolstered by our affiliation with the AIA Upjohn Award. Since receiving this grant, we have garnered funds from a UPenn Academic Enrichment Fund, Bentley Systems (21K via a Nonlinear Systems Organization (NSO) application), an ITMAT- IME Fellowship (100K), a ‘07-08 UPenn Vice Provost Research Development Fund Grant (170K), and a Wharton Interactive Media Initiative (WIMI) Grant (5K).

Other Activities

Since the 1st Annual Nonlinear Systems Organization (NSO; directed by Cecil Balmond) conference at UPenn in 2005, we have participated in a number of collaborations and events at Penn and beyond. We have publicly discussed and/or exhibited our ideas and collaboration including the following highlights: the MAK Center in Los Angeles, The Slought Foundation in Philadelphia, Cambridge University, The American Heart Association, the 2nd & 3rd annual NSO meetings at PennDesign, The Esther Klein Gallery at the University City Science Center, the Smart Geometry Conferences 08/09, the 08/09 Siggraph Design and Computation Galleries, the College of Physicians in Philadelphia, and the "What is Human?" conference at the University of Wisconsin at Madison.

At the University level, Sabin and Jones co-mentor a post-doctoral fellow at the IME, and final year graduate students at PennDesign. We also co-teach a permanent course at UPenn titled "NonLinear Systems Biology & Design", which we developed de novo in 2007. This research-intensive elective explores new directions in architecture and biomedicine based on work being produced within LabStudio. The course involves 14 Graduate Architecture students, (plus researchers from the Department of the History and Philosophy of Science, and the School of Medicine). To date, more than 50 students have been taught within this elective.

In terms of publications, Sabin and Jones are also actively working on a monograph entitled "LabBook", which denotes the beginnings of this highly productive LabStudio collaboration. Other publications related to our research have also been generated in architectural journals, including 306090 (Princeton University Press), The MAK Foundation Gen(H)ome catalog, 10+1, and in VIA, an award-winning UPenn-based design journal. In addition, ACADIA 2008: Silicon + Skin, Biological Processes and Computation published "Nonlinear Systems Biology and Design: Surface Design". Finally, our work was featured in 2008 conferences on Advances in Architectural Geometry in Vienna (Sept), and the American Society for Cell Biology Annual Meeting in San Francisco (Dec) and "Branching Morphogenesis" is currently on view at a second location, Ars Electronica, a nexus for art, technology and design, in Linz, Austria, European Cultural Capital 2009.

In summary, based upon the first three years of work within LabStudio, we have demonstrated a radical departure from traditional research and design models in both architecture and biomedical science, with a move towards hybrid, trans-disciplinary concepts encompassing new ways of collaborating. We believe that this type of environment will continue to provide research models and applications in each of our specialities that address a diverse array of pressing issues. Examples include 1) the development of customized digital tools to visualize large and complex datasets to address how we perceive and use information, 2) lowering our carbon footprint for buildings through dynamic interfaces, and 3) novel diagnostics for lung disease and breast cancer.

Overall, we argue that any future investigation between architecture and biology may wish to consider models that capture and cultivate the dynamic reciprocity of the less obvious organic systems of architecture, and the more obvious living complexities of biological systems. To address this, perhaps architecture can take a cue from biology in matching the complexity of its generative design models to the very dynamic features of the living environment and organic milieu in which the architecture is a part. Or, perhaps architects might learn from these biological models so that architecture acquires 'tissueness' or 'cellness', and is not merely 'cell- or tissue-like'.