Figure 1
Pneumatic screen prototype assembly and array of physical experiments.
ABSTRACT
We have the opportunity to rethink the interrelations that architecture has with the environment and with human behavior. Adaptive systems are gaining traction in the discourse as relationships between the natural environment, the built environment, and their users evolve over time. This project, Pneuma-Technics, investigates pneumatic architectural systems, composite materials and components, computation, physical computing, and sensory actuation. The objective is to advance a developing typology of responsive systems: a breathing architecture that is sensitive to its changing environment. Pneuma-Technics is actuated breath in built form: pneuma, the Greek word for "to breathe," and technê, the Greek word for technique/craft in art.

The project imagines the potentials of a soft, interactive surface that allows for the passage of light, air, and human vision, yet maintains enclosure and insulation as necessary for architectural performance (Figure 1). These innovations project new futures onto traditional methods of architectural production and engage in nontraditional materials to develop unique environments. Pneuma-Technics is a body of research that consists of tangible experiments for the advancement of soft environments. We design for these potential futures as collaborative action, materials, and methods evolve the discourse toward adaptive technologies.
1 INTRODUCTION

The demand for a critical evaluation in this project invokes interdisciplinary questions such as: How are we, as humans, able to interact with our surroundings? How could our buildings react to their situational context and their climatic environment? And, what are the social and performative benefits to an adaptable building system? While the work crafts experiments with these basic questions serving as the theoretical framework, it hopes to consider realistic properties through these interdisciplinary connections. The research operates within the paradigm that human interaction with the built environment is becoming a natural extension of evolving technologies in the industry. The work attempts to explore multiple trajectories for the advancement of material technology within architectural discourse, and to determine which of these futures holds the most potential for real-world applications.

Soft, flexible materials, such as silicone, lend themselves to composite systems and pneumatic adaptation because of their high elasticity and tensile strength. These structural properties help silicone maintain its form despite high levels of fluctuation, or stretching, when inflated. So, by negotiating the human relationship to its context through a soft, pneumatic form, Pneuma-Technics engages architectural properties such as structure, form, and material in addition to projecting innovation in the atmospheric environment those properties produce. Whereas the questions posed at the onset of this introduction attempt to frame the problem, the following questions are hoped to be addressed eventually through research and experiments. How can silicone be formed, and how do various composites affect its material strength and elasticity? How can the geometry of silicone forms and their internal array of air chambers be designed to control pneumatic movement with a high degree of precision? And, more generally, what trajectories can this work project for the future of this material in architecture and how should these potentials be evaluated to determine which have the highest potential for further exploration?

When pneumatic architectures first emerged in the 1960s and 1970s, they primarily consisted of large-scale air-supported structures, whose interiors were hermetically sealed from their context (Herzog 1976). However, contemporary paradigms of building skins focus on the development of adaptive or responsive systems that participate with their context through dynamic exchanges of environmental matter (Velikov and Thün 2012). The Pneuma-Technics research works towards the development of a pneumatic skin system that engages with its context by fluctuating its porosity in order to allow for the passage of light and air. The project builds on recent research by Velikov and Thün at the University of Michigan in nested aggregate pneumatic cushion-based skin systems (Velikov et al. 2014). However, we specifically investigate kinetic silicone-based soft robotic components, for which methods and processes have been learned from recent work in soft robotics underway at Carnegie Mellon University, Harvard University, and ETH Zurich, as well as early work from Stuttgart’s IL (Melendez et al. 2014; Whitesides n.d.; ETH Zurich 2013.; Park n.d.; Bubner et al. 1976). While many of these recent
works in soft robotics explore capabilities without the constraints of program, Pneumatechnics attempts to build on this knowledge by investigating specific performative geometries of soft robotic components for adaptive architectural skins.

2 PROCESS

The process began with controlled experiments in individual soft robotic components to understand how to control characteristics such as range of movement, deformation, and behavior during inflation. The work produced reusable acrylic molds that fluctuated in their position and frequency of air chambers, in the thickness of the resulting silicone cast, and in the ratio between solid material and pneumatic void. These two-part molds were then filled with a specific silicone product (EcoFlex), hardened, and then removed from the larger mold to be cast together for an air-tight seal (Figure 2).

Due to the highly variable behavior of pneumatics based on material, geometry, and air chamber location, it is very difficult to computationally predict the form and movement of the components. However, using generative design software such as Rhinoceros and Grasshopper, we translate the work between digital models and physical prototypes to construct acrylic molds and to build up a scalable array of forms. Moving forward, the work hopes to take advantage of current technologies like AutoCAD 123D Catch to translate inflated pneumatic devices into digital form and compare real-life inflation properties with the simulated output from physics plug-ins such as Kangaroo for Grasshopper. This advancement of the process would allow for more accurate predictions of the behavior of pneumatic devices.

2.1 FORMAL EXPERIMENTS

In order to frame and constrain the experiments, the work developed a specific trajectory of forms (Figure 3). These evolved into a prototype for a tessellated rain and sun screen comprised of an array of pneumatic devices. By researching previous silicone actuators and biological patterns, the design arrived at a leaf-like form, which provided a nesting typology to fit within the scalable array (Figure 4). The screen prototype
developed from a single air chamber cast into a symmetrical diamond, two-chamber device in which each air chamber is individually controlled. Looking forward, a more rigorous biomimetic design process will engage natural patterns such as scales or feathers. With these biological patterns in mind, the pneumatic screen may prove to be more productive with an overlapping array of devices that allow for better enclosure and protection from the elements.

2.2 COMPOSITE MATERIALS

In order to achieve more variable control over component inflation, some of the experiments embedded other materials such as textiles or paper into the silicone forms and combined various degrees of hardness of silicone in later tests. These changes produced material composites whose behavior during inflation varied radically, even though the uninflated forms had similar geometries (Figure 5); the various behaviors were caused
through the strain layer embedded in either the top or bottom layer of the silicone component.

Fiber-reinforced composites are another potential direction for the Pneuma-Technics research. Originally developed by Kevin Galloway at the Wyss Institute for Biologically Inspired Engineering at Harvard University, fiber-reinforced soft actuators allow for a wide range of motions. Modifying the mechanical structure of the soft actuator allows for programming the bend radius and bending axis which, in turn, would allow for varied flexure throughout the arrayed prototype (Galloway et al. 2013). These composites, along with previous experiments, could be translated into digital space with added geometrical and physical restraints in order to simulate physical movement.

2.3 COMPONENTS AND SUBSTRUCTURE
Throughout the experimental process, it became important to integrate the air valve input systems into the device itself in order to achieve a consistent inflation. We began by integrating two separate valves, one for each air chamber in the device, and evolved into a solid component within the silicone cast. The component was designed to fit into a void that was created through the casting process, and was then glued to the silicone cast with a product called Sil-poxy. While this acrylic chassis system developed to be integrated within the silicone for the input valves, it was also designed to attach to a larger structural array that would connect each panel to the next and provide a transparent sub-structure to support the pneumatic prototype (Figure 6).

2.4 FUNCTIONAL PROTOTYPING
This study of pneumatic typologies through experimentation produced working prototypes that often failed through vigorous testing. However, each new experiment advanced knowledge of the pneumatic system at large and helped to maintain a trajectory towards a functional panelized rain-screen. The screen prototype continued the symmetrical diamond geometry discussed above, incorporating a minimal inflation chamber on the interior, which was made from a softer silicone compared to the hard exterior surface (Figure 7).

2.5 ADAPTATION AND CONTROL
The next steps consist of integration of the adaptive componentry, including an Arduino microcontroller connected to a collaborative breadboard that transfers the Arduino code to a series of solenoid valves (Figure 8). These valves inhale and exhale critical air supply from a compressor, through a pressure regulator, to the pneumatic prototype and are necessary to maintain accuracy and control over the system. By connecting sensors to the system, the Arduino can control inflation based on the environment, causing the system to react to a variety of inputs depending on its context. For example, a light sensor opens up the screen for daylight and shading while a proximity sensor allows the user an exterior view.
3 CONCLUSION AND FUTURE PROJECTIONS

This project has begun a line of experimentation in how silicone and soft materials in general have powers beyond those of static architectural elements, how pneumatics can drive adaptive surfaces, and how humans can design a new experience with their context through responsive, elastic membranes. The research to date has concluded little, yet serves to project possible futures for innovations in material systems within the built environment. The work thus far has explored emerging typologies of soft robotic components for architectural applications. In order to control their performance, careful design of their internal and external form and material properties is necessary.

The project began with formal design methods to discover various geometries that could nest efficiently and serve multiple functionalities (Figure 9). Working with soft robotics and material systems has been proven to be a variable and unpredictable task. Through physical experiments and digital design, the work succeeded in finding a potential performative geometry for pneumatic systems. The subsequent phase of work will entail a clearer methodology in which an intense process of formal and behavioral parameters will be tested, prior to their integration into an architectural skin.

Through this initial research, we have found that each solution lays the seed of a new problem, and therefore, a need for various trajectories of research with these technologies. These include a pure formal experiment, a material composite and component design problem, a study of aggregation properties, and exploratory shifts in scale. By
continuing the exploration of soft, composite material systems and by engaging the environment through intelligent sensing and control, Pneuma-Technics has attempted to contribute to the evolving development of adaptive architecture through the advancement of kinetic pneumatic components for architectural skins. Often following paradigms found in the natural world, contemporary adaptive projects respond through programmed logics, i.e. sensors and controllers, or through pre-engineered materials that react based on inherent material behavior, such as shape memory alloys and composites (Brownell and Swackhamer 2015). By mimicking various biological processes such as breathing, branching, or scaling in architectural componentry, research of this type uses experimentation and physical prototyping to project new territories for innovations in the industry that might contribute to growing trends for positive environmental impact.

This research works towards a future of human-robotic relationships where sensory and control capabilities will permeate the built environment and contribute to the advancement of performative and adaptive architecture. By employing biomimetic processes, performance and relationships, such as a leaf’s connection to its branch or a fish scale to its body, soft robotics in architecture envisions a functional relationship between a building skin and its context. Precise control will transition this relationship into a seamless conveyance of data and adaptation between the environment and user, which allows humans to actively interface with their built and natural environments, giving way to an era of performative architectural technologies.

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All images, Figures 1-9, by the authors.
REFERENCES


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Figure 1
Plan view of a prototype construction site robot in stowed position. The machine has an on board computer and video-tracking camera that allows it to identify objects and navigate space.