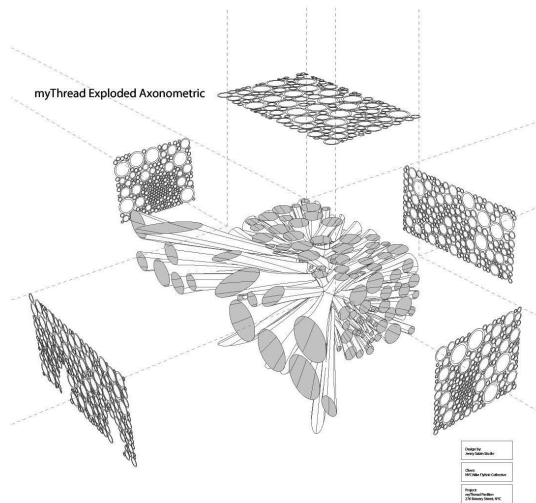
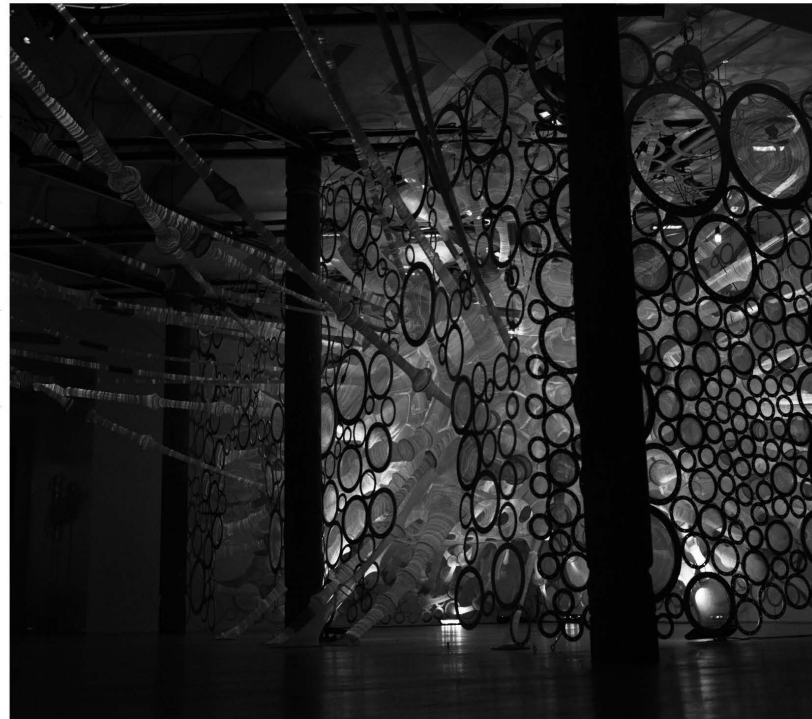


myTHREAD PAVILION: GENERATIVE FABRICATION IN KNITTING PROCESSES

Jenny E. Sabin Cornell University



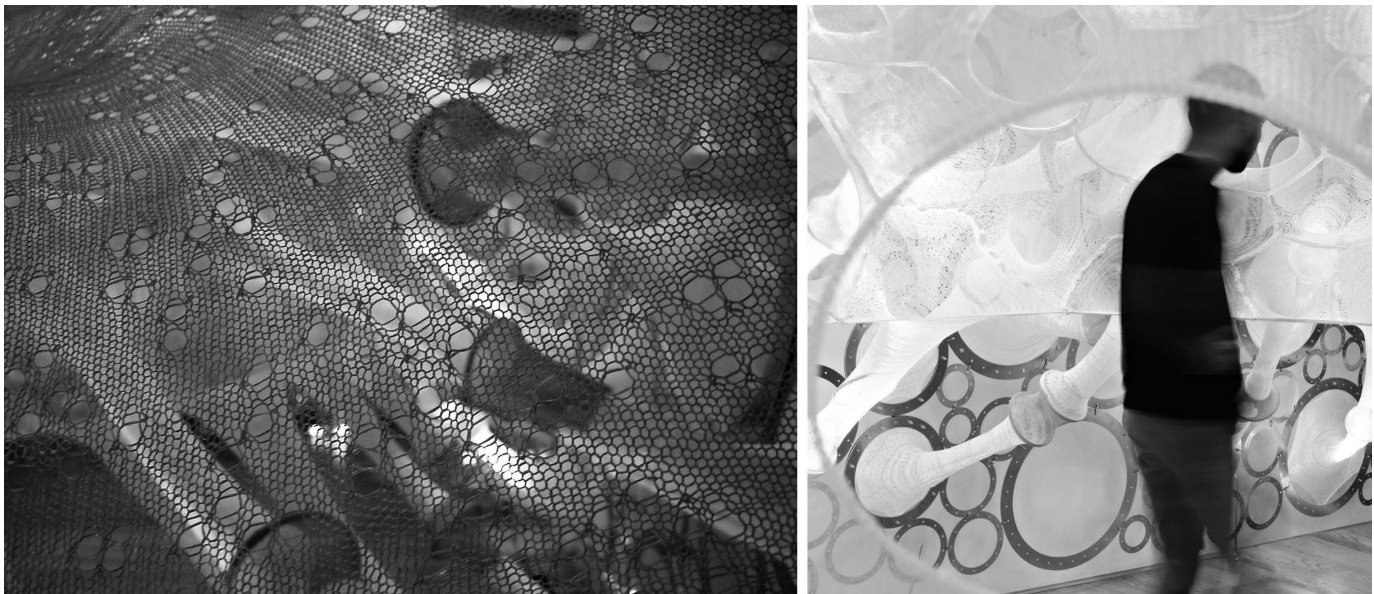
MYTHREAD PAVILION



1 myThread Pavilion for Nike FlyKnit Collective, NYC

ABSTRACT

Advancements in weaving, knitting and braiding technologies have brought to surface high-tech and high-performance composite fabrics. These products have historically infiltrated the aerospace, automobile, sports and marine industries, but architecture has not yet fully benefitted from these lightweight freeform surface structures. myThread, a commission from the Nike FlyKnit Collective, features knitted textile structures at the scale of a pavilion. The evolution of digital tools in architecture has prompted new techniques of fabrication alongside new understandings in the organization of material through its properties and potential for assemblage. No longer privileging column, beam and arch, our definition of architectural tectonics has broadened alongside advancements made in computational design. Internal geometries inherent to natural forms, whose complexity could not be computed with the human mind alone, may now be explored synthetically through mathematics and generative systems. Textiles offer architecture a robust design process whereby computational techniques, pattern manipulation, material production and fabrication are explored as an interconnected loop that may feed back upon itself in no particular linear fashion. The myThread Pavilion integrates emerging technologies in design through the materialization of dynamic data sets generated by the human body engaged in sport and movement activities in the city.



2 myThread Pavilion detail and view to interior

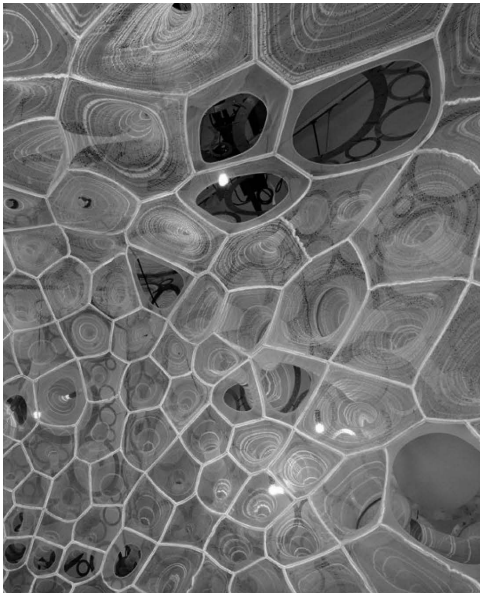
INTRODUCTION

How do you knit and braid a building? Could a building be as lightweight as air? Can sport, in terms of the measurable performance of the human body, influence both design and fabrication and inspire the next generation of buildings? What if we could formfit and enhance architecture with bio-architecture and performance of our own bodies? Turning performance into structure for the Nike Flyknit Collective, Jenny Sabin works at the intersection of art, architecture, design and science. There are instant similarities in this approach to the work of Nike's Innovation Kitchen, where disciplines from different fields are brought together with a view to re-thinking basic principles and approaches to design challenges.

myThread features novel formal expressions that adapt to changes in the environment through formfitting and high-performance lightweight structures. (Figure 1) This project aims to engage a new material practice and next steps in digital fabrication in architecture through the production of models and prototypes via cutting-edge parametric and associative software that interface fabrication technologies in related, but alternative disciplines. By digitally crafting these new formfitting material systems at architectural scales, beautiful formal possibilities emerge allowing for the construction of novel spaces and immersive adaptive environments that ultimately advance textile tectonics in architecture. (Figure 2)

Importantly, this project seeks to communicate, document and make public advances in tooling and textile fabrication towards the design and production of nonlinear systems via complex geometries. Central to this is the integration of fields and industries outside of our own with the promise of advancing the functional, adaptive and formfitting nature of knit material alongside provocative emergent forms and spaces. This is achieved through visualization models of human bio-data — motion data from a large group of runners — transformed and realized as a new choreography of performances in the context of a fully knitted pavilion. Simply put, the generative design strategy is based on prior performances that are translated into present-tense performance through a finely tuned material assembly of knitted threads that respond and adapt to the presence or absence of light. The main goal of this project concerns the evolution of digital complexity in the built world.

Sabin often starts from a molecular point of view where the singularity of a single unit such as a cell or zip-tie becomes a building block for structures of greater complexity. Like Nike FlyKnit, which uses simple threads to create a complex formfitting structure on a performance-enhancing shoe, the fusion of



3 Activated photoluminescent threads from the interior of the pavilion (left) and form-finding digital model (right)

science, architecture, art and technology open the door to new ways of thinking about structure and the relationship of the body to technology. In this project, the human body is used as a biodynamic model to inspire new ways of thinking about issues of performance and adaptation at the architectural scale. Performance, lightness, formfitting and sustainability become immediately relevant architectural criteria.

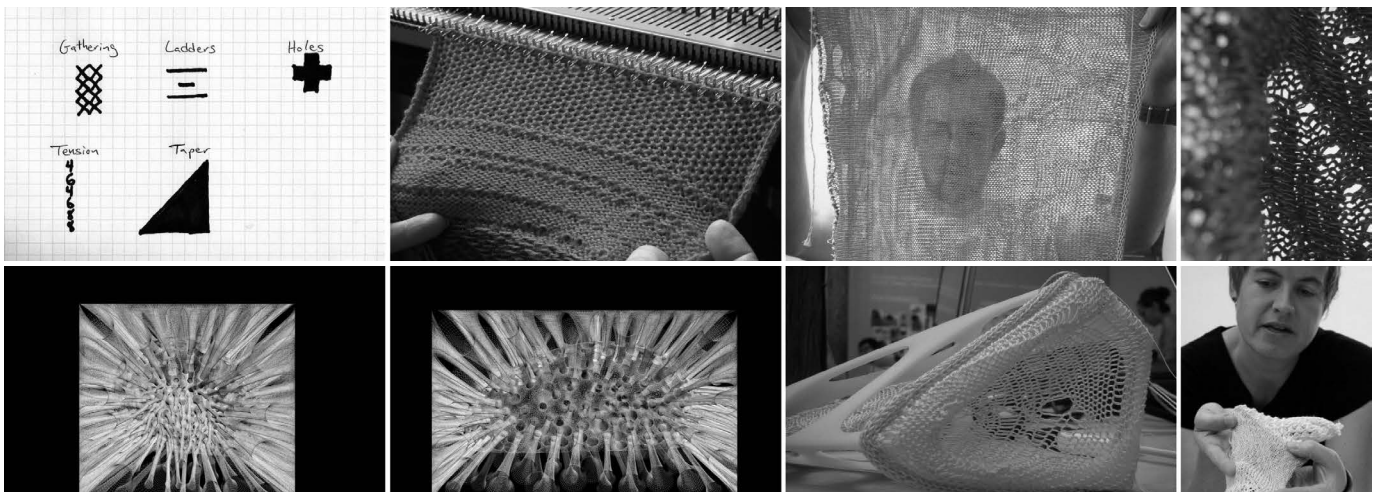
The body, or more specifically the body in motion — pure performance itself — is the starting point of our New York collaboration for this project. Using Nike+ FuelBand technology to collect motion data from a community of runners during an earlier Nike FlyKnit workshop, the Sabin Studio transformed the patterns of this biological data into the geometry and material of knitted structure, based on prototypes developed during workshop sessions. The motion data, collected and organized in Excel files, then linked to geometric features in a 3D modeling environment, forms a material construct for a unique response to the formfitting question delivered in the original Nike FlyKnit Collective brief.

The Pavilion consists of a harder outside construction and softer, organic inner material. Composed of adaptive knitted, solar active, reflective photo luminescent threads and a steel cable net holding hundreds of aluminum rings, the simplicity of knitted geometries meets the complexity of a body in motion. (Figure 3) An inner structure of soft, textile-based whole-garment knit elements absorbs, collects and delivers light as the materials react to variegated light sources and the presence of people through embedded shadows. The material's response to sunlight as well as physical participation is an integral part of our exploratory approach to the subjects of performance and formfitting.

The myThread Pavilion is the result of collaboration across disciplines and industries including architecture, textiles, sportswear and engineering. Linking biology and innovation, technology and tradition, this is an analog manifestation both of the benefits of Nike FlyKnit, and also the activities and performance of the individuals that went into its making. This installation's adaptable sensitivity and flexibility mirrors the human form. It is its own environment, its own community and its own energy. While interpreting and visualizing human data, the pavilion also becomes a body itself by virtue of a dynamic, spatial interiority and the presence of a multitude of actual human interactions.

PROJECT BACKGROUND

Upon receiving an invitation from Nike Inc. to participate as one of six international innovators from around the world in the Nike FlyKnit Collective, the project began with a visit to the Nike Campus in Beaverton, Oregon. There, Sabin was able to spend time with Ben Shaffer, director of the Nike Innovation



4 Knit material studies and prototypes from the NYC workshops; lower left: initial generative models

Kitchen, and his team at the Nike campus. All six innovators were able to see first-hand the design and fabrication process for the Nike FlyKnit shoe. The Innovation Kitchen is composed of labs and creative studios similar to what an architectural designer may engage in, but with altogether different directives and resources.

Recognizing the promise of a material fabrication process wedded to the nonlinear characteristics of the human form — albeit at the scale of a shoe — the Sabin Studio project for New York City took hold. The first task was to assemble a framework for a series of workshops composed for invited participants with diverse backgrounds including extreme athletes, artists, scientists, fashion designers, architects and textile designers that would feed into the final built legacy project in New York City. The starting point for the New York City project by Sabin was simple: link the complexity of the human body in motion with the simplicity, performance and materiality of knitting. Using the Nike FlyKnit Collective as a platform for design research and experimentation, the myThread pavilion incorporates data from the human body to explore nonlinear fabrication processes alongside practical issues such as sustainability and performance in architecture through groundbreaking form-finding and knitting techniques that link sport with architecture.

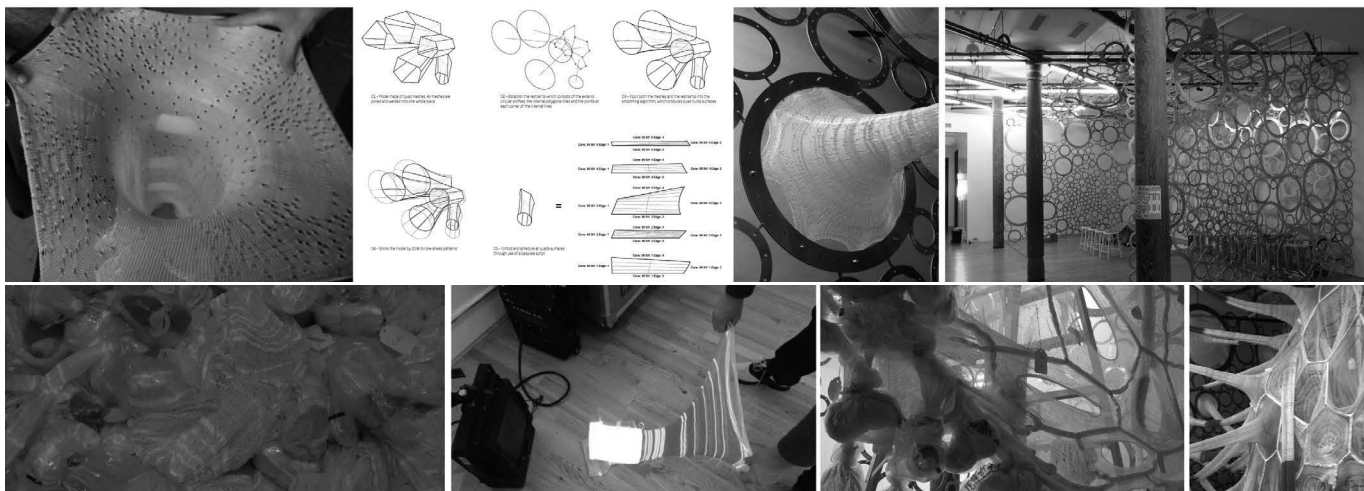
METHODS AND APPROACH: PHASE ONE

Knitting may be described as a line affected by force and, more specifically, as a loop affected by force. Differing from a weave, a system of discrete strings or members, the knit is a continuous system. One single member navigates the system, and in each instance looping its current self through its former self. Knitting takes into account parameters such as stiffness, end conditions, loop length, material thickness, and stitch density as well as more complex variables such as dropped stitches, crossovers, and clusters. Given these links between material, structure, and construction, the knit is rich in architectural potential, both as a literal

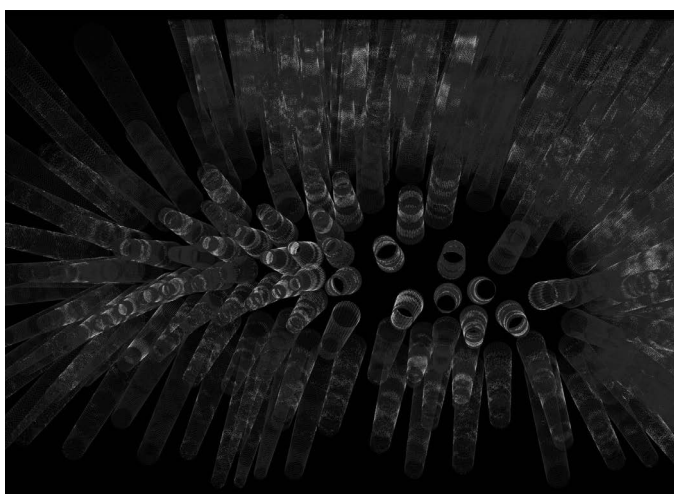


5 myThread Pavilion, exterior view through the front, projected ring panel

translation and as one that works well with biologically informed design strategies that demand generative fabrication techniques. Our first task in the context of the project was to understand the fundamentals of knitting in order to begin rigorously translating these features into a computational environment that may then interface digitized knitting machines. The Sabin Studio initiated a dialogue and collaboration with Anne Emlein, a practicing textile designer and artist who is the Chair of the Textiles, Apparel and Fashion program at the Main College of Art. With Emlein, we developed a series of test swatches and design experiments exploring different types of materials and knit patterns including parameters such as holes, ladders, changes in tension and tapering. We produced prototypes on hand-knitting machines and on a Stoll Flatbed digital-knitting machine at RISD. This catalogue of material swatches formed the basis for our digital modeling exercises and eventually a template for attaching data points collected from



6 Form-finding techniques, beginning stages of installation, and activated photoluminescent yarns



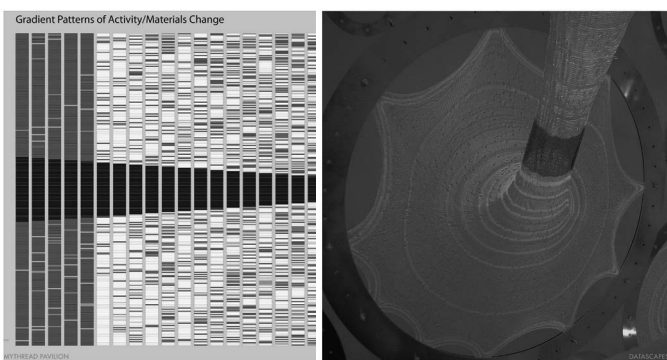
7 Visualization of participant data from Workshop 1 mapped as striation patterns of material change across the population of cones

human motion data to actual knit parameters. (Figure 4) This work simultaneously investigates the potential of the knit system as a whole and the geometry of a single knit loop. The work explored material thickness and elasticity, scale, nesting, and overlay. The process was intentionally open-ended and unrestrained, allowing for experimentation of these intricate relationships.

This also framed the sequence of public workshops leading up to the final legacy pavilion in NYC. The first workshop focused on data collection from participants engaged in various movement activities in the city. Each participant was outfitted with sensing technology to collect movement activity with GPS tags. This data was partitioned into various parameters and dumped into an Excel environment, which were eventually linked directly with our three-dimensional Rhino models. The second workshop focused on making sense of the human motion data through fabrication and modeling exercises geared towards making the intangible nature of the data — its structure, rhythm and form — into organized and tangible material systems. Yarn materials and stations of expertise were carefully orchestrated to opportunistically utilize the workshop format as a test bed for the final pavilion project.

PHASE TWO

With an interest in amplifying the hidden structures and unseen beauty of the data collected from the participants through changes in pattern and geometry with the dynamics of material, responsive and adaptive yarn materials were selected. The intent was to develop a soft material palette that would reflect the complexity of the human data and amplify it through changing conditions reflected in its environment. The pavilion was originally specified to be built outside. Solar active, reflective and photoluminescent yarns were chosen for their integrated responsive behavior and ability to change in the presence of active environmental inputs. For example, the photoluminescent yarns absorb UV light



8 Gradient patterns of participant activity mapped as changes in material within each shaped and knitted cone

throughout the day and glow at night, while the solar active yarns change their color immediately in the presence of bright sun. They also hold shadows in fabric form. Finally, the reflective thread provides immediate bursts of light through a micro-scale bead structure on marled yarns when activated by a flash or beam of light.

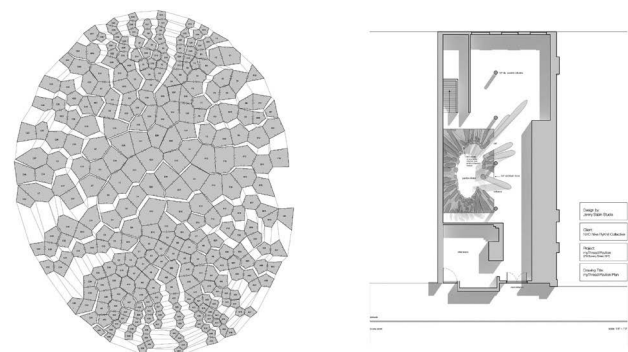
The design experiments produced during phase two were used as model prototypes for moving into the final design and production phases of the pavilion. Schematic strategies began early on in the project, linking the initial knitted material swatches with formal investigations into data visualization. Working closely with the parameters of knit fabrication and the considerable formal restrictions that were presented, our generative strategies took on several linked trajectories. One focused on form-finding techniques through minimal surfaces and relaxation methods in Kangaroo for Grasshopper. The second explored algorithmic strategies for organizing populations of data produced by the individual participants. These individual agents populated the surface studies and were organized based on nearest neighbor relationships. Meanwhile, analog tension tests were conducted in the studio to understand how much the knitted fabric would stretch under considerable stress. Additional structural analysis and form-finding modeling was conducted by the engineer on the project, Daniel Bosia of AKT Engineering, but due to the unprecedented scale and nature of the knit forms, we found that hands-on testing with 1:1 scale material elements, produced the most accurate results. These results fed back into our digital form-finding models. (Figure 6)

With a keen understanding of the dynamics of the knit structure, we began to explore ways to distribute forces and “pull” the pavilion into shape. The lines normal to the interior surface — each attached to one unique agent — were then connected to fields of circles, packed in orthogonal planes to form a rectilinear exterior volume. This wireframe geometry describes a collection of cones or conoids, each one representing a knitted volume pulled into tension as well as a collection of data. In order for the pavilion to be inhabitable, the overall structure would need to behave like an inverted basket with a hovering tension ring at the base, thus allowing visitors to enter the interior of the knitted volume. This required that each individual knitted element be seamed together with its neighbor to form one cohesive surface on the interior. To achieve this, a tessellation strategy called Laguerre tessellation was incorporated, which is different from a Voronoi tessellation where inter-distances between nuclei define the geometry of cells only. Compared to a Voronoi, the Euclidean distance between cells is replaced by a power distance in the definition of each cell. The Laguerre allows for the assignment of weights to nuclei. Thus, we were able to use the circles at the edges of the volume as input, which then defined cells on the interior and the edges of the final seam pattern. At the same time, we were able to make adjustments to the input parameters as new material and fabri-

cation constraints emerged. For example, the knitting machines have a limited base diameter and due to cost we were not able to implement unlimited cone diameters. Thus, the circles on the exterior were optimized to three diameters only. The circle-packing algorithm was run again, as was the tessellation. Overall, the final pavilion form integrates external data sets from the human body as a population of active external forces that integrate with the inherent performance of knit geometries. This generative fabrication process drives the form-finding techniques that describe emergent geometries, where force, material and form are understood to co-evolve with human data.

PHASE THREE

Locating a knitter for production was not an easy task as most knit manufacturers have ceased operating in the States. Time restrictions and a necessity to work closely with the manufacturer prohibited working with a knit manufacturer overseas. Eventually, a collaboration with the Japanese-based company Shima Seiki was formed. Shima is at the cutting edge of what is known as whole garment knitting. This process enables the production of seamless three-dimensional knitted forms as the knitting process is done in continuous tension as shaped elements. The process is similar to additive 3D printing, but in rows of knit stitches. However, Shima had never done a project at the scale of a pavilion before, nor had they knitted responsive and adaptive threads, which tend to have thread counts and stiffness factors that are difficult to knit in tension. The cone elements for the pavilion range in length between two feet to fifty feet. Working side-by-side in their factory, we innovated an entirely new process whereby the complexity of the data populations determined material striations and hole



9 Seam pattern drawing and overall plan of the pavilion at Nike Stadium NYC



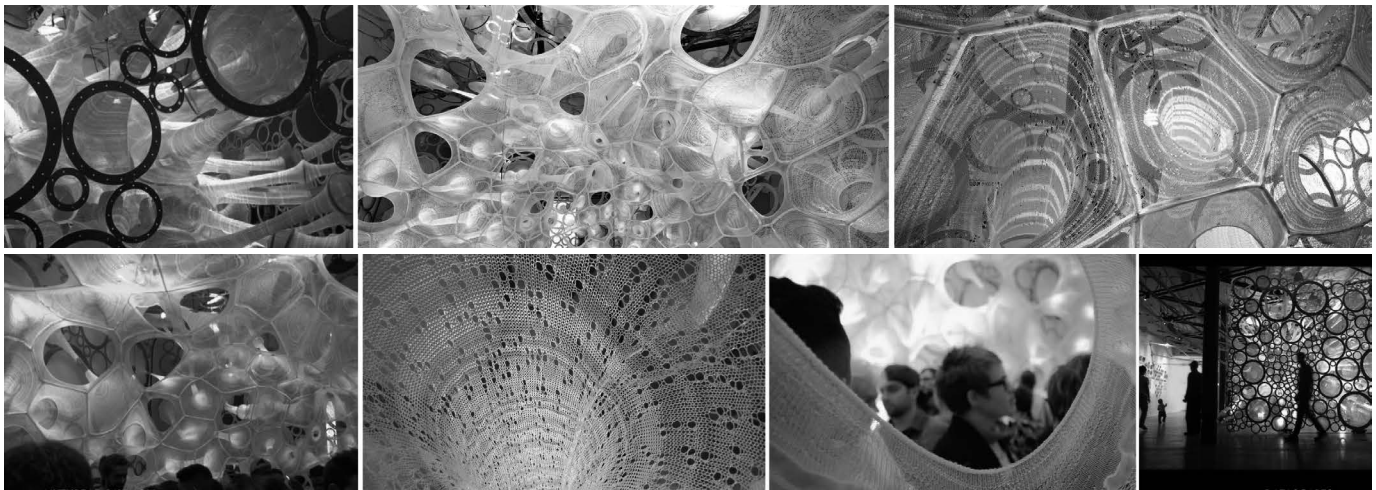
10 Interior shot on opening night. The entire structure is pulled into tension, cone by cone, until the bottom forms a taught elliptical tension ring

patterning in each cone, which then informed the file input for the digitized knitting machine. The knitting process took just under two weeks to complete at which point all of the cone elements were transferred to a fabric finisher, Dazian Fabrics, for assembly and final seaming. (Figure 9) The tagging scheme for each cone remained the same from digital model to knitted cone to the final seam pattern, which was used 1:1 by the finishers to accurately label and sew each edge of the elliptical forms to their neighbors. The final fabric structure weighs less than 170 pounds and fits within a single large canvas bag.

PHASE FOUR

The assembly and construction process operated much like tuning a drum. The first task entailed laying out each circle-packing pattern with the various sizes of laser cut aluminum rings, linking them together and then hoisting them in place. Each ring panel was pulled into tension, utilizing the actual space of the gallery as a frame. The gallery, called Nike Stadium NYC, is located at Bowery and East Houston streets in New York. Although the project had originally been specified to be outside, the final pavilion installation was housed inside due to permit restrictions in New York City parks. Once the rigging was complete, the knitted structure was slowly pulled into tension, each cone receiving its own unique ring panel, with one wall of cones projecting beyond the front panel and anchored to the opposite wall. We moved concentrically from bottom to top to evenly distribute the changes in tension across the overall form. Once all of the cones were fully installed, a tight tension ring emerged at the base of the structure allowing visitors to pass through the door in the front ring panel and pop up into the interior. (Figure 10)

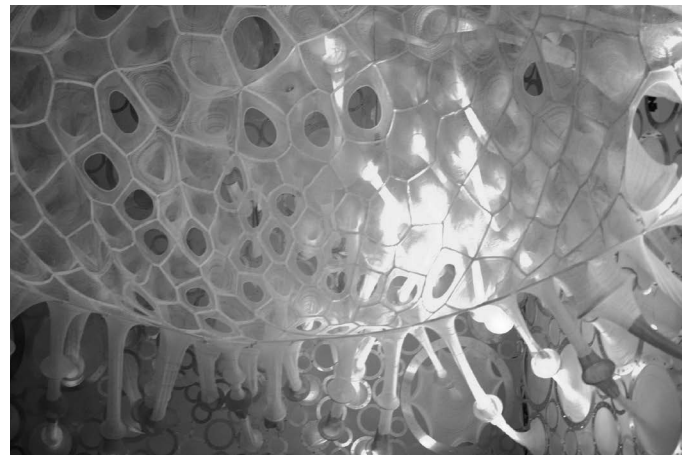
The Sabin Studio worked closely with Benji Kayne, a lighting designer with expertise in theatrical lighting, to choreograph a lighting scheme that would emphasize the performance of the responsive and adaptive yarns in the context of the overall form and user interaction. UV and blacklights were placed strategically around the pavilion and placed on digital timers to simulate an accelerated day-to-night sequence. The affected knit structure changes dynamically to shifts in its environment. Visitors were subsequently inspired to inhabit and use the pavilion in multiple ways from laying down to stretching to simply watching the fabric change over time. Although the carefully controlled lighting scheme provided maximum expression of the responsive threads, the next installation will be outdoors to explore the subtle material changes over longer durations of time. (Figure 11)



11 Detail shots of installed pavilion

CONCLUSION

Through the productive misuse of fabrication technologies in alternate disciplines, namely fashion and sport, this project pushes the boundaries of current scaled applications of knitted surfaces. We believe that the myThread Pavilion is a paradigm shift in soft textile-based architectures. 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. Knitting processes provide material production and generative fabrication processes that work in tandem with nonlinear design concepts, thus closing the gap between design intent and built form. Recognizing the successful and seamless design process that Nike innovated for the FlyKnit shoe that links the nonstandard and complex nature of the human foot with knitted material and formal production, the myThread Pavilion also seeks to explore this example of generative fabrication, but at an altogether different scale. The project opportunistically uses the flexibility and sensitivity of the human body as a biodynamic model for pioneering pavilion forms. myThread features novel formal expressions that adapt to changes in the environment and increase building performance through formfitting and lightweight structures. Whole Garment knitted solar active, reflective and photoluminescent threads in combination with aluminum laser cut rings and a steel cable net compose the overall structure of the pavilion. While the technical and formal features of the pavilion are new to architecture, at least in scale, these are not the most convincing aspects of the pavilion in terms of future promise, but rather, point towards a design process engaged in generative fabrication. This may bring us closer to realizing forms and landscapes that are the products of emerging diagrams over static representations of discrete moments in time. Perhaps, this is what is most intriguing: the promise of a design process that is adaptive in real time. Like cells weaving their own extracellular matrices in order to signal



12 Interior view with solar threads activated; elliptical tension ring visible at base

through their newly constructed environments, which in turn affects the form, function and structure of the cell, myThread seeks to engage a similar active environment of making, where architectural features of the human body are erased and then found again in newly constructed architectural surfaces that also inspire and delight, shelter and embody.

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 assistant professor in Design and Emerging Technologies in Architecture at Cornell University. She is principal of Sabin Studio, an experimental design studio based in Philadelphia, and co-founder of LabStudio, a hybrid research and design network, together with Peter Lloyd Jones. In 2011, Sabin was named a USA Knight Fellow in Architecture, one of fifty artists awarded nationally by US Artists.