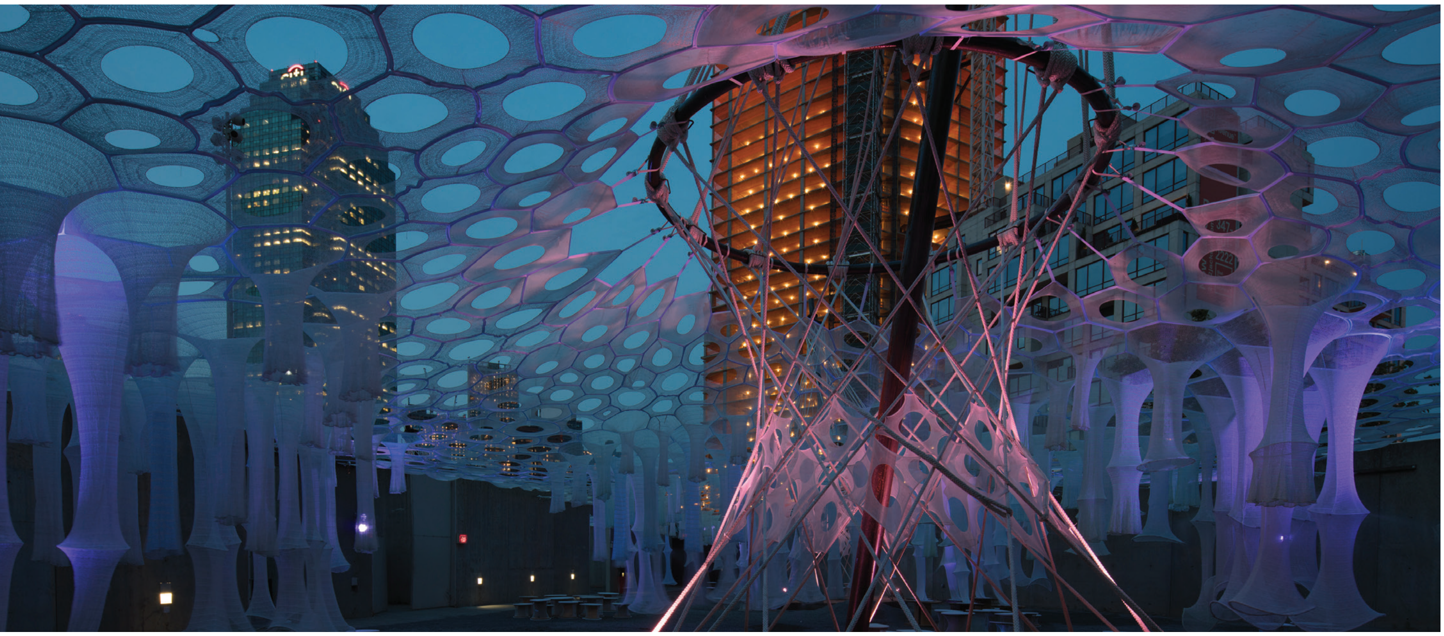
Lumen

Jenny E. Sabin
Jenny Sabin Studio / Cornell
Dillon Pranger
Jenny Sabin Studio / Cornell
Clayton Binkley
Arup
Kristen Strobel
Arup
Jingyang (Leo) Liu
Sabin Lab / Cornell



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ABSTRACT

This paper documents the computational design methods, digital fabrication strategies, and generative design process for Lumen, winner of MoMA & MoMA PS1's 2017 Young Architects Program. The project was installed in the courtyard at MoMA PS1 in Long Island City, New York, during the summer of 2017. Two lightweight 3D digitally knitted fabric canopy structures composed of responsive tubular and cellular components employ recycled textiles, photo-luminescent and solar active yarns that absorb and store UV energy, change color, and emit light. This environment offers spaces of respite, exchange, and engagement as a 150 x 75 foot misting system responds to visitors' proximity, activating fabric stalactites that produce a refreshing micro-climate. Families of robotically prototyped and woven recycled spool chairs provide seating throughout the courtyard. The canopies are digitally fabricated with over 1,000,000 yards of high tech, responsive yarn and are supported by three over 40 foot tensegrity towers and the surrounding matrix of courtyard walls. Material responses to sunlight as well as physical participation are integral parts of our exploratory approach to the 2017 YAP brief. The project is mathematically generated through form-finding simulations informed by the sun, site, materials, program, and the material morphology of knitted cellular components. Resisting a biomimetic approach, Lumen employs an analogic design process where complex material behavior and processes are integrated with personal engagement and diverse programs. The comprehensive installation was designed by Jenny Sabin Studio and fabricated by Shima Seiki WHOLEGARMENT, Jacobsson Carruthers, and Dazian with structural engineering by Arup and lighting by Focus Lighting.

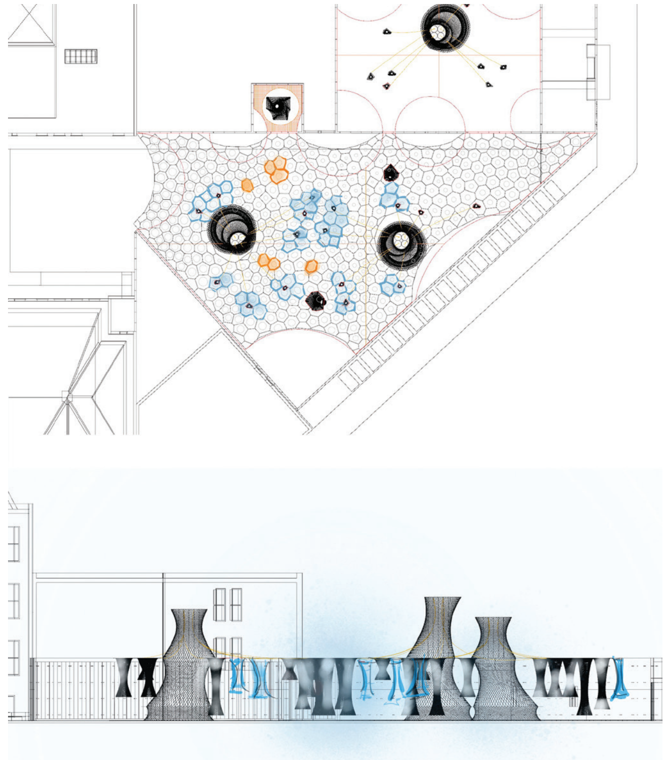
INTRODUCTION

Held in tension within the PS1 courtyard matrix of walls, Lumen applies insights and theories synthesized from 13 years of collaborative work across disciplines including biology, materials science, mathematics, and engineering. Lumen, the largest knitted architectural installation ever erected and composed of over 1,000,000 yards of yarn, undertakes rigorous interdisciplinary experimentation to produce a multi-sensory environment that is full of delight, inspiring collective levity, play, and interaction as the structure and materials transform throughout the day and night. Lumen is a socially and environmentally responsive structure that adapts to the densities of bodies, heat, and sunlight.

The Young Architects Program (YAP) is an internationally acclaimed annual competition hosted by MoMA and MoMA PS1. The project brief calls for a comprehensive installation to serve as a backdrop to summer events held in the PS1 courtyard, including WarmUp. The winning project must provide shade, water, seating, and incorporate materials and design strategies that address sustainability and recycling. In addition to these requirements, the 2017 YAP brief encouraged projects to address the topics of transformation and materiality in architecture. Responding to the PS1 YAP brief as well as the highly constrained nature of the courtyard site, Lumen materializes ideas of performance and adaptation at all scales of the project and specifically through seamless 3D digitally knit and textile-based fabrication processes.

BACKGROUND

Advances in weaving, knitting and braiding technologies have brought to surface responsive, 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 benefited from these lightweight, freeform surface structures. Textiles offer architecture a robust design process whereby computational techniques, pattern manipulation, preprogrammed material production and fabrication are explored as an interconnected design loop (Sabin and Jones 2017). In the last decade, knitting has been explored for its highly dynamic and versatile material behavior in architecture. For example, Sean Ahlquist researches the potential of machine knitting to operate as an information mediating interface for responsive environments for children with Autism Spectrum Disorder (Ahlquist 2015; 2016). Mette Ramsgaard Thomsen and Martin Tamke of CITA, as well as Jane Scott of Leeds, develop simulations and prototypes to imbue material systems with variation, gradation, and the inherent properties of natural fibers for performance and sensing-based architectures (Thomsen et al. 2016;



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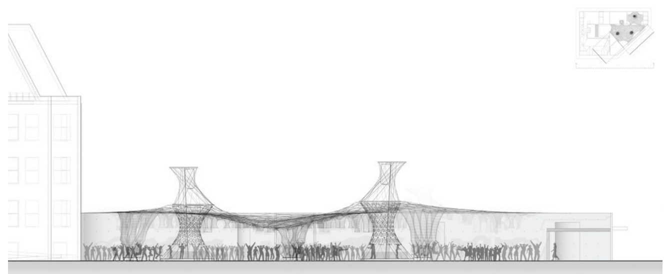

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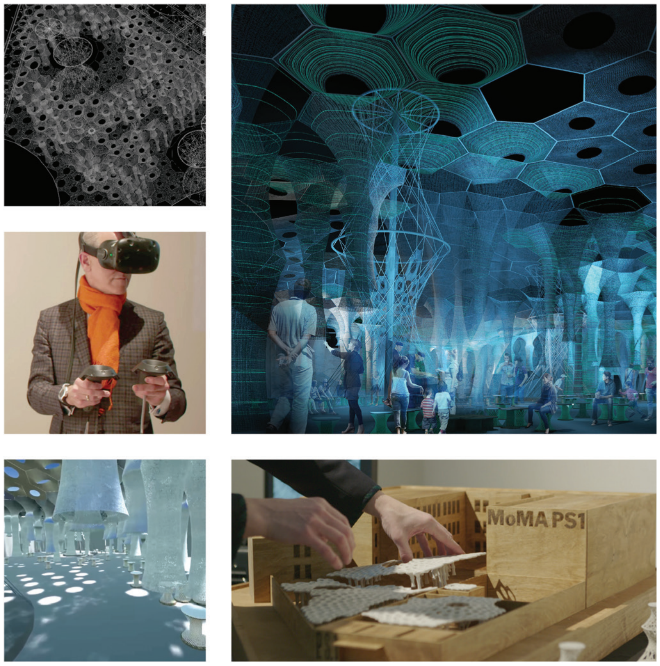
1 Early concept drawings for the tower and canopy design.

2 Elevation proposal drawing; Lumen during WarmUp.

Scott 2013). Composite systems are also possible through the integration of tensile and reinforcement materials and application of prestress and resin impregnation (Sharmin and Ahlquist 2016). Commencing with the myThread pavilion in 2012, Jenny Sabin and her team have explored generative design and digital fabrication in knit and woven structures through multi-sensory responsive environments (Sabin 2013). Drawing synergies with this body of international research and perhaps most closely aligned with themes of responsivity and material performance as shared with the work of Ahlquist, CITA, and Scott, Lumen builds upon six years of design development at the intersections of knitted textiles, bio-inspired design, computation, and architecture.

Design Concept

The primary design parameters for Lumen include: 1) Site-based form-finding, including solar analysis to optimize for



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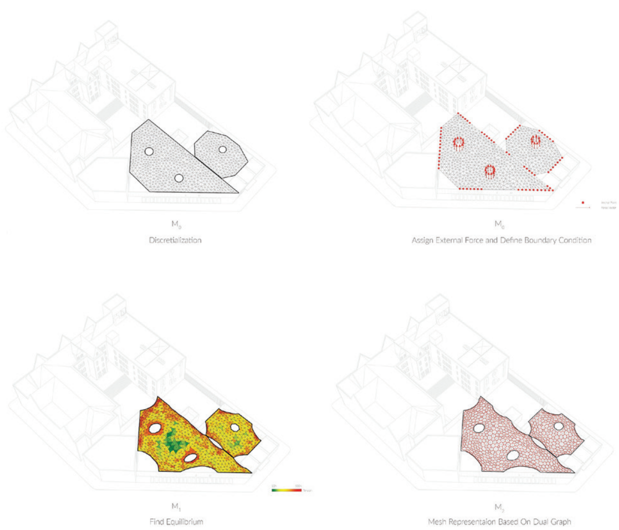

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shade conditions; 2) Generative form-finding methods based on physical and geometric constraints including material, tension forces, and site-based conditions; 3) Explorations of the formal and structural potentials of textile-based structures and active-tension systems at all scales of the project; 4. Materialization at a large scale of ongoing research on the relationships between biology, mathematics, engineering, adaptive architecture, and tensegrity; and 5. Integration of ideas of transformation, materiality, and human interaction into all aspects of the project and its varied weekly summer programs. Overall, the project operates as an adaptive environment composed of two integrated grounds: the courtyards of MoMA PS1 and the upper canopy structures that are connected with the tensegrity towers and responsive conical knitted forms (Figures 1–3). The following sections discuss the computational and technical aspects of each component of the project.

METHODS

Canopy Design and Rationalization

The process of form-finding was based on particle spring systems and implemented via Rhinoceros, Grasshopper and the plugin Kangaroo developed by Daniel Piker (Figure 4). Initially, the NURBS (Non-uniform rational basis spline) surface was generated based on the constraints of the existing courtyard walls. The NURBS surface was then discretized into the mesh network (M0) with defined grid spacing and grid shape based on the circumference boundaries, optimal shade conditions, and constraints of the knitting fabrication process. Triangulation is used as the grid cell network. Nodes of the triangular mesh faces are considered as particles connected by edges which are calculated as elastic springs. We input mechanical properties of the knit fabric—based on physical stress tests of swatches and collected data—by assigning axial stiffness and a damping coefficient to each edge of M0. The length of each edge is collected in a data tree and associative connections between each face are extracted from the mesh M0. We defined two main external force vectors: self-weight of the fabric canopy at each node and tension forces provided by the upward thrust of each of the three nodes where the steel tensegrity towers connect to the canopy structures. Boundary conditions are defined by assigning anchor points to nodes which are attached to the peripheral concrete walls of the MoMA PS1 courtyard. The spring-particle system visualized in M0 is not in equilibrium at the start of the simulation. The form of the two canopies are iteratively computed until each node within mesh M0 reaches the equilibrium position if a solution exists. The form found mesh (M1) is then generated from the node coordinates and their connectivity. From mesh M1, we used the dual graph method to reconstruct a new mesh representation (M2), which is tessellated by polygonal cells. Each node in M2 is associated to a triangle of M1. A given edge in M2 represents a connectivity relationship of adjacent triangles in M1. The cells of mesh M2 are categorized into modular cell types based on their number of edges and dimension for the digital knit fabrication.

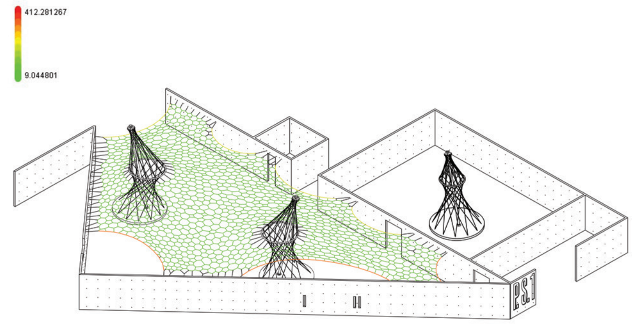
Once initial form finding was complete, the stressed shape of the net was verified by Arup using custom finite element analysis software incorporating additional edge elements and the construction detailing of the anchorages. During this process, the cell pattern was optimized to limit the number of different cell sizes in the entire net.

The form-finding software package is a custom C# plug-in for Rhino that implements dynamic relaxation – a mathematical formulation for solving for equilibrium states of structures. The package relies on two parallel models: a structural finite element model that is used for finding the equilibrium shape of the structure under loading, and a geometric Rhino model that is used to visualize and manipulate the geometry. The software allows the user to modify element lengths while the model is running, allowing the user to alter the geometry during analysis. Once run, the user can query element forces and anchorage reactions to allow for design of the structure and its connections (Figure 5).

The Rhino geometry from Jenny Sabin Studio was used to construct an analysis model and loading corresponding to the weight of the knit structure and wind pressure was applied. While running the model, element lengths were adjusted to regularize the net—minimizing the number of distinct cell sizes. Based on the model output, additional edge ropes were added to increase the tensile capacity of edges under high tension. The anchorages were then sized for the forces from the analysis.

Upon completing the canopy form-finding process, each cell is given a unique ID that follows each component through the entire fabrication and production process. Then, slack and stressed circumference data is organized into an Excel spreadsheet to aid in knit fabrication planning. The canopies are composed of 5 cell types: 1) Grove Cones, the longest knitted cone type connecting the upper canopy with the ground; 2) Misting cones containing the misting nozzles and network; 3) Non-misting cones; 4) Deep windows or cells with a lip and extended knit shaping; 5) Windows or flat cells with no shaping (Figure 6).

Technical files for the digital knit production, in collaboration with Shima Seiki WHOLEGARMENT, are then generated. Having worked with Shima Seiki for over 6 years, a streamlined process for knit production ensures accuracy of each 3D seamlessly knitted part and efficient fabrication planning. Technical specifications for each part are organized into a series of diagrams to be used to program the MACH2XS WHOLEGARMENT specialty Shima Seiki machine, which features 4 needlebeds. In a previous project, PolyThread for the Cooper Hewitt Design Triennial, Jenny Sabin Studio worked with Arup to implement an accurate stretch factor within the design and form-finding process of the pavilion. A matrix of knit swatches, each parameterized with incremental changes to circumference, material type, striation patterning, hole patterning, shaping for 3D seamless knit, and density, were subjected to variable loads to the point of failure to determine an accurate overall stretch



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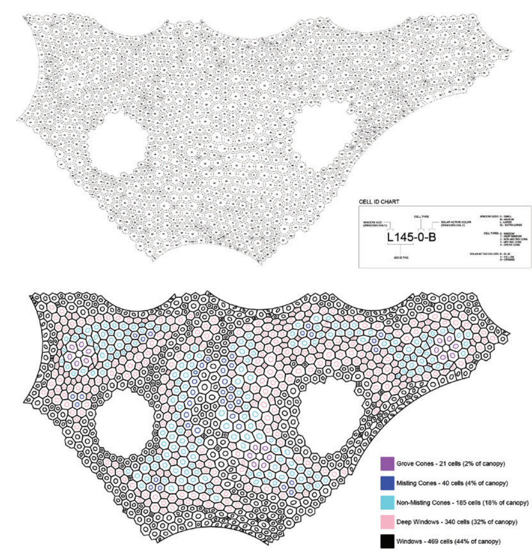

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3 Lumen proposal drawings and model with immersive VR experience.

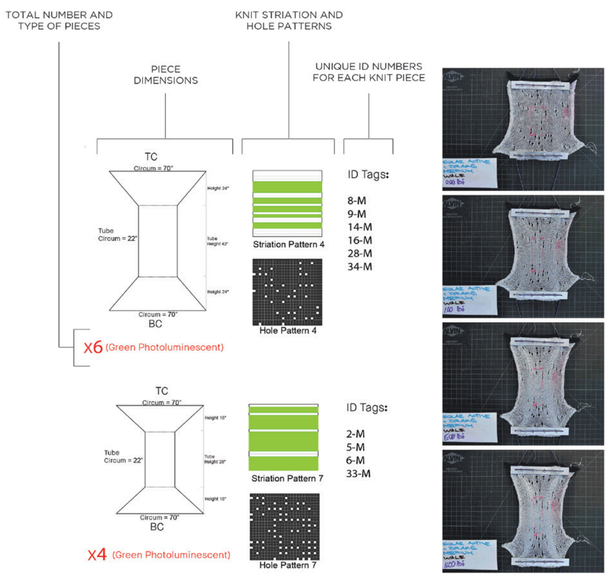
4 The form-finding process of the canopies based on particle spring systems.

5 Force output display of net in custom software package by Arup.

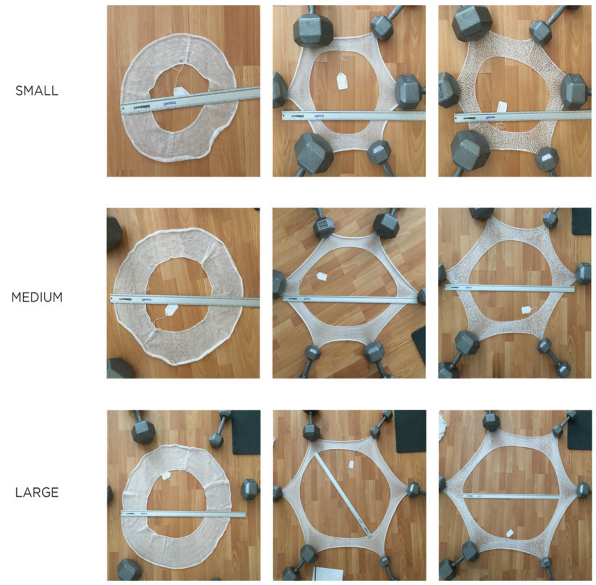
6 Cell and cone distribution within the large canopy in courtyard 1.

factor of 1.5. With Lumen, this was further prototyped and tested for a kit of parts ranging in size from XS to XL, allowing for a more nuanced range of stretch factors from 1.4 to 1.8. This provided a minimum and maximum stretch factor relative to the desired fully tensioned state within the net canopy (Figures 7–9). Due to the bed of the digital knitting machines, the maximum relaxed circumference of each component is 48″ for bulk parts and 68″ for large specialty parts such as the Grove cones.

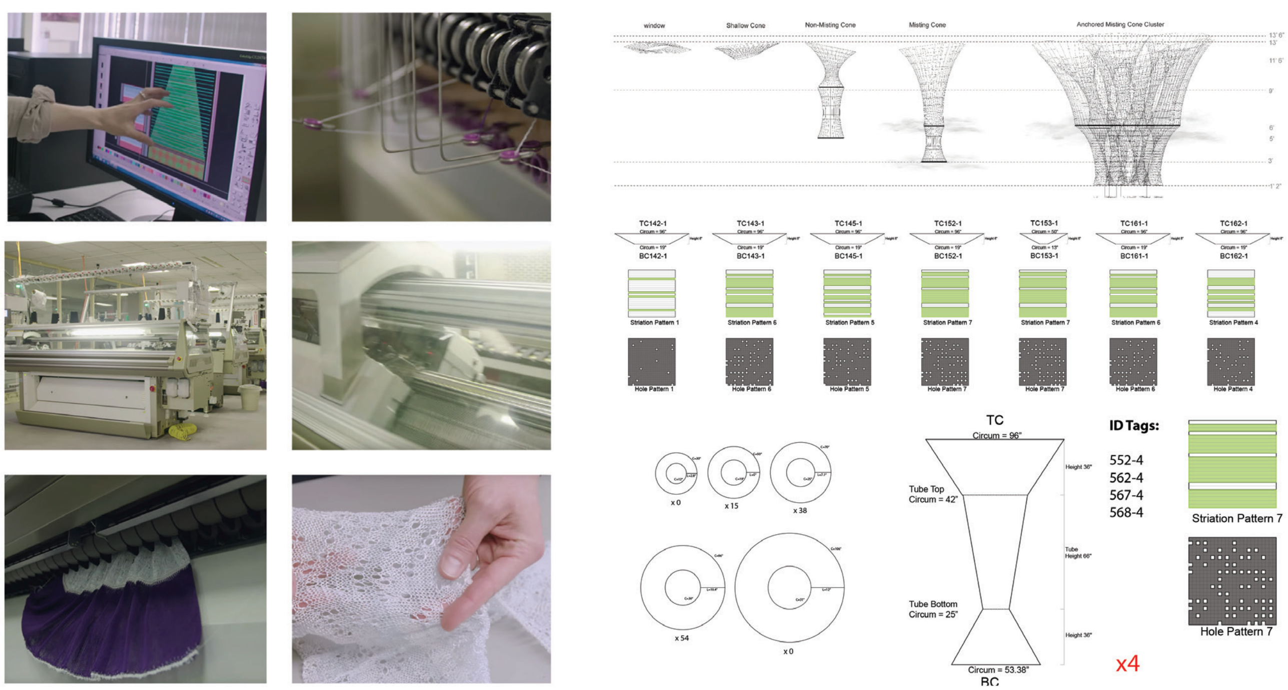
The knit materials include 2 high tech responsive yarns and a white fire-retardant synthetic “fill” yarn. The photoluminescent fibers emit light after the absorption of photons (electromagnetic radiation) from the sun or UV lights. The



7 Previous tests for stretch factor under relaxed and stretched load conditions.



8 Prototypes produced for Lumen to achieve a more nuanced range of stretch factors ranging in size from XS to XL .

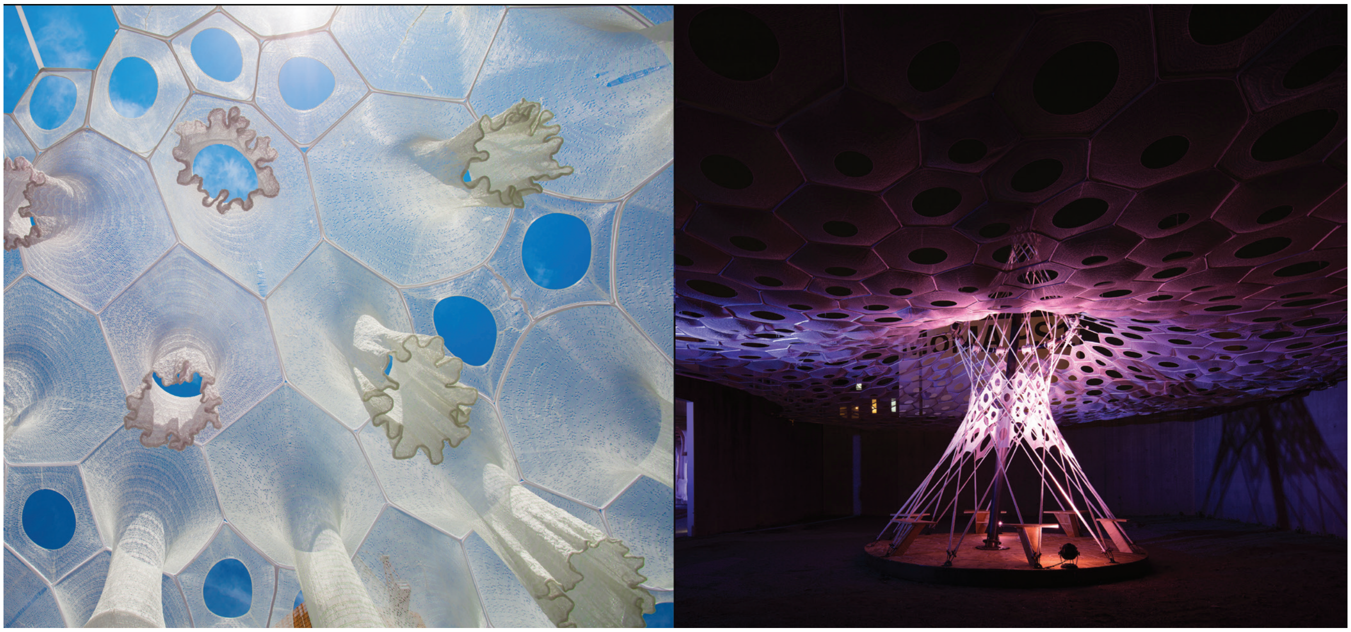


9 Knit fabrication at Shima Seiki (left) and technical specifications for 3D seamless digital knitting of a sampling of Grove Cones and Deep windows (right).

photons within the fiber are excited and then relax and other photons may be re-radiated, causing the glowing effect across the canopy structures. The solar-active threads change color in the presence of the sun. The fibers undergo molecular excitation transition where the molecules in the presence of the sun shift into a range within the electromagnetic spectrum that's visible to the human eye. At a molecular scale, small crystals within the fiber reveal their colors in the presence of the sun (Figure 10).

Tower Design and Rationalization

Three steel-and-polyester rope tensegrity towers were installed to lift the canopy structures at strategic nodes. Each of the towers is comprised of five primary elements: a central steel mast, a suspended steel ring at the mid-height of the towers, a steel base built up from wide flange beams and channels, custom CNC flooring for the base, and 48 1-in diameter custom Cortland and polyester 12-strand ropes. Each of the polyester ropes winds 120 degrees



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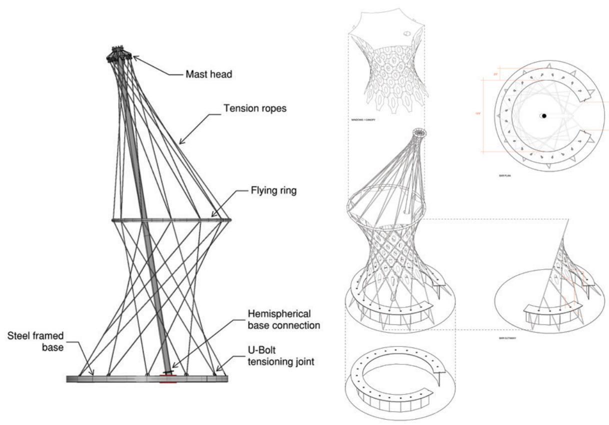
around the circumference, tracing a hyperboloid of one sheet above and below the central flying ring. The towers have a single plane of symmetry about the mast; the bottom of the mast is offset from the center point of the base and leans back across the base (Figure 11). While comprised of the same primary elements, each of the towers is geometrically unique, having varying heights and angles of lean. The base of the towers works in flexure, resolving the tension of the ropes and the compression of the mast through a series of spokes that connect from each of the rope anchor points to the base of the mast. A compression ring around the outside edge braces the ends of the spokes against each other. Overturning under lateral loads is resisted by filling the base with gravel ballast.

The design of the towers, in particular their realization as tensegrity towers, arose out of their relationship with the rest of the installation. The tower's primary purpose is to support two larger tensile canopies that spanned the courtyards at PS1. The tensile net was connected to and tensioned against the tower's flying ring, creating a node in the net that, with the tower, served as a space to be programmed and occupied by the installation's visitors. The towers were originally conceived as woven structures that create spatial, structural, and inhabitable connections between the ground and the upper canopies. They were intended to emulate the nature and form of the hanging knitted cones within the canopy and the dynamic textile-based architecture of the entire project (Figure 1). Early conversations between Sabin and Binkley about the materialization and structure of the towers oscillated between actual woven structures such as the 'hollow ropes' of Robert Le Ricolais and rigidly framed structures similar to Vladimir Shukhov's towers (Le Ricolais 1973; Beckh 2015). As the entire project evolved, we realized that there was an opportunity to construct the towers as tensegrity structures, to literally weave with forces, playing off the tensile character and performance of the net canopies that they supported. The vertical pretension that stabilized the towers added a third dimension to the overall envelope of forces that shaped the installation, thus bringing ideas of performance and adaptation to all scales of the project. Analysis of the tower and the base were performed separately to allow the models to converge more quickly. In the tower analysis model, the mast and ropes were all pinned at the base and these reactions were applied as loads in the base model to determine the forces in the base members and verify the stability of the base (Figure 12).

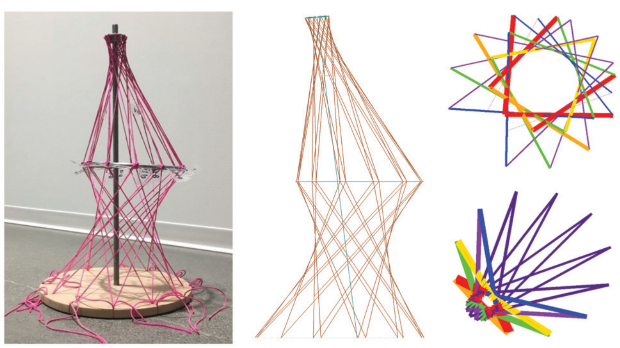
The detailing of the towers is designed around the erection of each tower. The towers are designed to have both coarse and fine adjustments to both tension the entire tower and accommodate fabrication tolerance of the ropes. The limited budget for the project drove unique detailing such as a sliding mast head tensioned with threaded rods and U-bolts instead of turnbuckles to achieve fine adjustment of the ropes.

Misting System and Spool Stools

The project included an interactive misting system capable of responding to human proximity, which informed the rhythm and frequency of the misting (Figure 13). The interactive misting system consists of three key modules: the electronic system, embedded control program, and



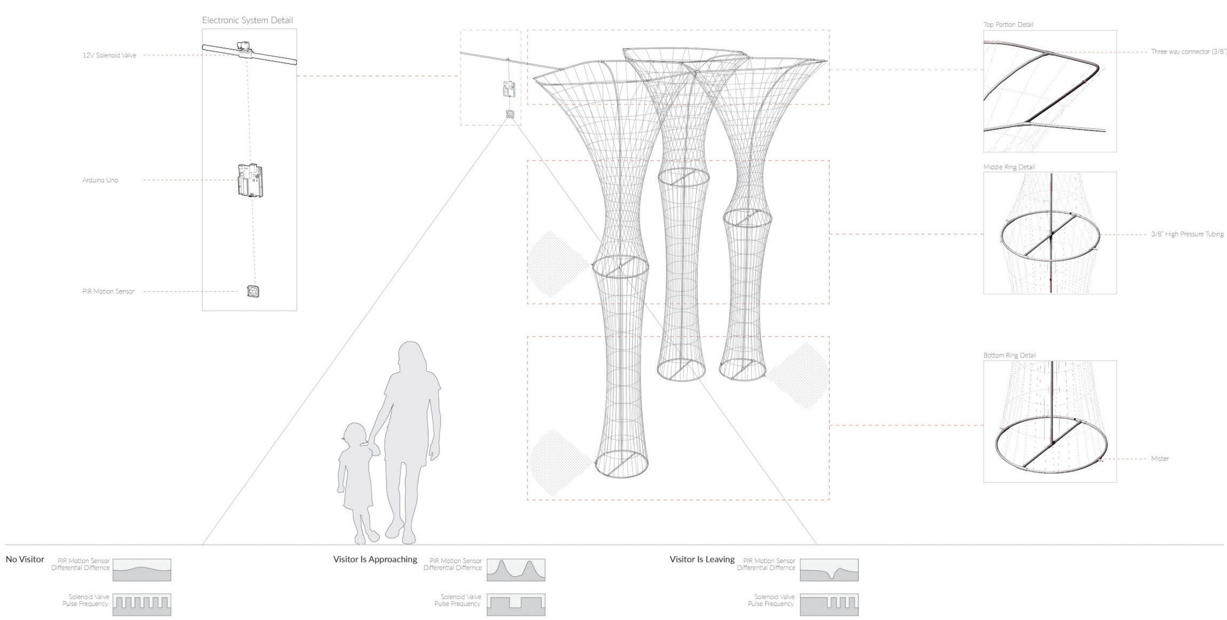
11 Tower elevation and components.



12 Scale model (left); analysis model (middle); variation in rope tensions at top and bottom (right).

solenoid valves. The electronic system is built upon sensors, actuators and a microcontroller. To detect human occupancy, the use of a PIR motion sensor was incorporated. The PIR motion sensor has two sets of infrared sensitive detectors. When visitors approach the sensor, one of the detectors is intercepted, causing a positive differential change between the two halves. When visitors leave the sensing area, a negative differential is generated. The change pulse is then streamed and filtered by the embedded program loaded on the microcontroller. The program corrects for error and noise in the raw sensor data and translates sensor data into three proximity-based situations, "visitor is approaching," "no visitor," and "visitor is leaving." The "visitor approaching" event activates the actuator, a 12v high-pressure solenoid valve that controls the water pressure of the network of misters within the sensing zone. The continually activated valve will increase the pressure of the misters resulting in a continuous misting spray around the visitors. If visitors leave the area or no visitor is detected, the solenoid valve will recover its programmed basic motion pattern, switching between on and off at the frequency of 15 seconds per cycle, which creates a breathing-like rhythmic misting effect. The combination of electronic components and embedded control programs within the misting network generates an immersive and responsive microclimate within Lumen that adapts to human proximity.

Seating was provided by 100 recycled spool stools approximately two feet tall and two feet wide. Locally sourced and recycled from electrical cable manufacturers, the large spools are deconstructed into parts. Grooves are milled



13 Diagram of interactive misting system.

into the edges of the spools by a CNC mill to allow photoluminescent micro-cord to be wrapped around each spool. We augmented our software, RoboSense 1.0, to easily add actuators and sensors to the environment to control the density and tension of the cord wrapping the stool by an ABB IRB 4600 robot (Moorman, Liu, and Sabin 2016). Based on the needs of the stool-winding for the project, we developed a custom winding end effector and four basic nodes: design nodes for creating the movement toolpath for the industrial robot, analysis node for analyzing feedback data, simulation node for planning and visualizing the robot motion, and fabrication node for executing the cord winding routine. We designed a custom end effector with a tension sensor and a control mechanism to maintain a consistent tension range as microcord is deposited around the spool stool for the first spool prototypes, similar in approach and methodology as the ICD's recent filament wound research projects (Yunis et al).

RESULTS AND DISCUSSION

Site as Generator

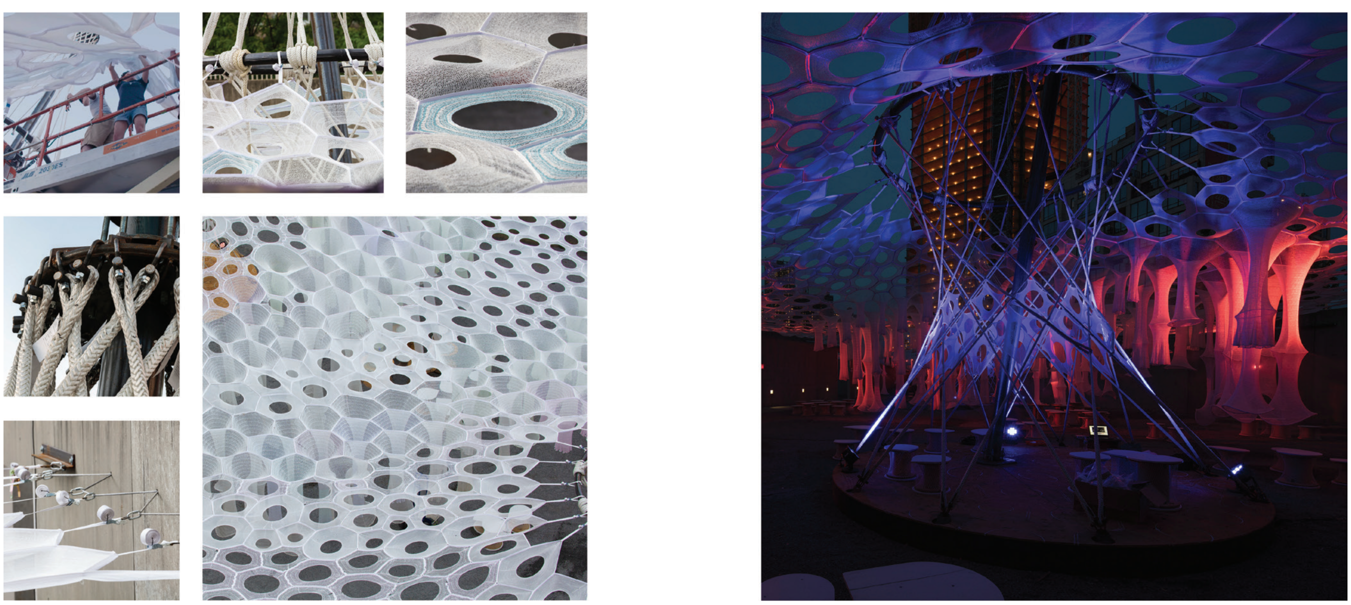
Situated in the context of Long Island City, NY, the significant exterior boundaries of MoMA PS1's courtyard are formed by the acute intersection of Jackson Ave. and 46th Ave. Although limited due to contextual and size restraints, the installation of Lumen relied significantly on the existing conditions of the site as assets for the project. The site served as both a structural component of the project and a physical benchmark for locating critical points in the field. Due to the unique nature of the existing concrete courtyard walls having consistently spaced exposed tie-rod holes, these elements were seen as both a structural opportunity for anchoring the perimeter of the canopy and a condition that offered flexibility in defining the overall canopy surface configuration. Lumen inherently has a large tolerance due to the nature of the materials used to construct the canopy. However, to reduce the amount of deviation between the digital modeling process and physical installation, field measurements were taken to reconstruct an accurate digital model of the site conditions. These measurements provided not only an extremely accurate representation of the site constraints, but also critical benchmark points that were then used in the field for locating physical components of the project (Figures 14 and 15).

Installation Sequence and Results

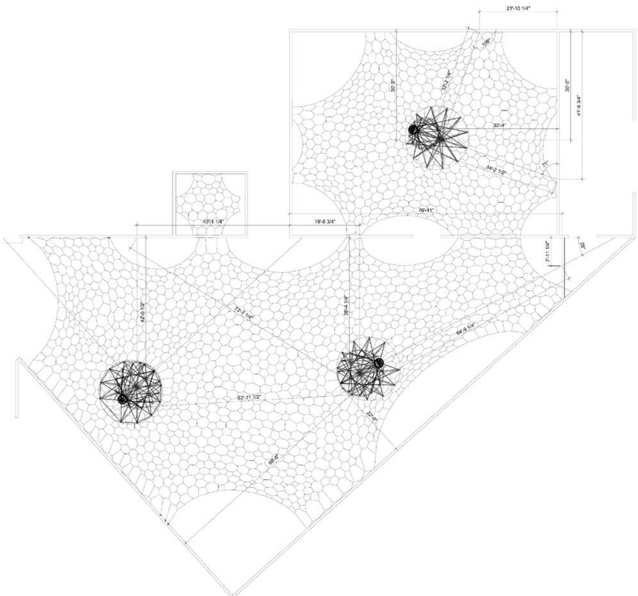
The installation sequence can be divided into three categories: 1) steel tower fabrication and assembly, 2) periphery structure and 3) canopy. Due to the dynamic nature of the project and condensed timeline, the installation required teams to be working simultaneously on different portions of the project and in different areas of the courtyard.

Towers

The two main structural towers consisted in total of 8400 lbs. of steel used for 18 ft. diameter bases and two 46 ft tall asymmetrical steel masts held in compression by 1000 ft of rope each. The center points of the towers and their orientation were located within the site using the northernmost concrete wall on the site as a benchmark. Once located, the towers were erected on site in three stages. Beginning with the base, wide flange beams were welded into a radial configuration using a center piece that was prefabricated off site as a guide. The center piece housed the hemispherical bearing that served as the base of the mast and allowed it to rotate to the correct angle depending

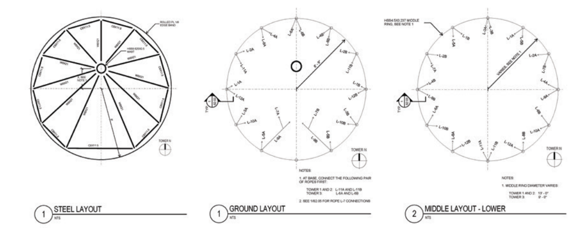


14 Lumen details (left) and at night in the main courtyard with photoluminescent yarns activated.



15 Lumen final plan drawing.

16 Tower and canopy installation.



17 Tower base structure and rope layout.

on the state of stress in the ropes. Once finished with the base, a temporary scaffolding, which resembled a large-scale easel, was built to support the masts at the proper angle relative to the bases. Each mast was erected to rest on its hemispherical bearing. Prior to hoisting the mast into place, a separate steel ring constructed of 4 inch pipe was placed around the mast, which hosts both the structural ropes for the tower and connection points for the canopy (Figures 15–17).

After constructing the base, temporary scaffolding, and mast, a series of 48 ropes were woven around the steel ring and were connected systematically to the top and bottom of the tower, creating a stable condition with the ropes in tension and tower mast in compression. To reduce slack and loss of tension as a result of constructional stretch in the ropes, countermeasures were designed to adjust and re-tension the ropes. Fine adjustments to the top and bottom of the tower was achieved using threaded U-bolts that allowed each individual rope to be adjusted in order to achieve the correct distribution of tension across the entire structure. Due to the asymmetry of the tower, each rope had to be individually adjusted to achieve the correct geometry and a reasonably uniform distribution of prestress. In addition to each point having the ability to be fine-tuned, the top component of the mast was able to telescope vertically as an entire unit allowing for larger global adjustments.

Canopy and Perimeter Connections

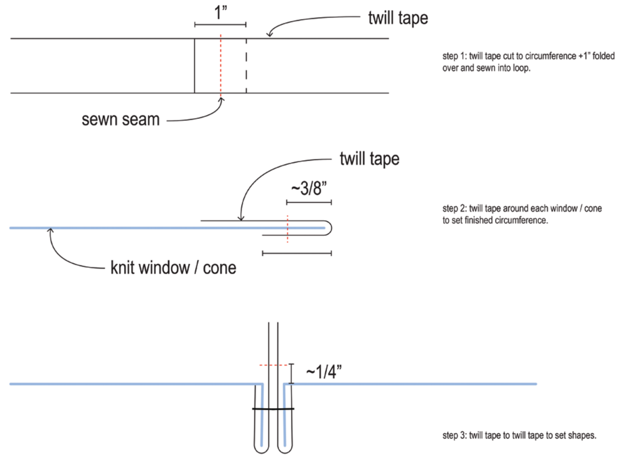
The two canopy structures consist of more than 1000 digitally knit cellular components and nylon webbing sewn together to create two uninterrupted surfaces. Due to the variety of cell types, each part was given a distinct ID label that was associated with the component part throughout the entire fabrication process. The ID labels also played an integral part in coordinating the assembly of these individual cells with the bespoke pattern, circumference, and location in the entire canopy. To reduce lag time and optimize the fabrication of the canopy, knit cells were sent in batches (beginning with cell IDs on one side of the canopy and moving across the entire surface) to the fabric finisher, Dazian, a leader in creative fabric production and fabrication. This allowed Dazian to begin fabrication well in advance of receiving all 586 individual pieces of the first canopy. While each unique ID tag allowed for a general association to be made between adjacent parts, a huge, 150 x 75 ft tiled drawing of the canopy was produced and plotted at 1:1 scale to assist the sewing team with precise measurements for each edge of the individual cells and to reduce the possibility of human error in miscalculation of total circumference. This process led to a greater efficiency in speed of sewing and a reduction in wasted material (nylon webbing) due to miscalculation (Figures 18 and 19).

The primary tension forces are taken through the net composed of nylon webbing and not the knit surface, thus the seam detail and type of webbing are crucial. Two widths of mill spec nylon webbing are used, 1.5 inch for each component and 2 inch at the scallop edges of the canopy where the tension forces are greatest. Six years of research and design through previous projects have produced a highly tested and reliable seam detail innovated by Jenny Sabin Studio and Dazian (Figure 18).

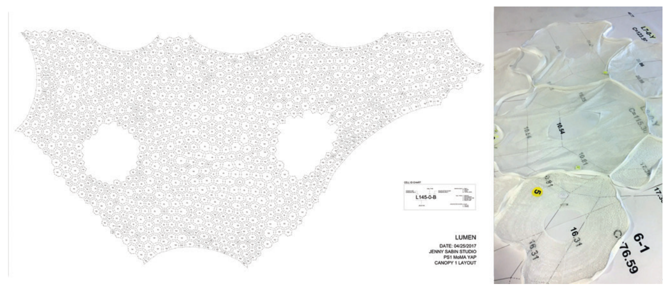
Once sewn together, the ID tags remained on the individual knit cells to aid with orientation during installation. The unpacking of the canopy on site was done incrementally due to its size and delicacy of the material. This strategy also allowed the canopy to be hoisted and attached in segments, thus avoiding excessive contact with the ground and risk of damaging the finished surface. The main canopy was designed with two zippers, which allowed for the surface to wrap around the tower structures like a skirt instead of requiring the surface to be raised to the top of the towers and then lowered down into place (Figures 20 and 21).

Located along all three walls facing the main courtyard, a series of metal brackets and woven rope were strategically attached through existing tie-rod holes at 12 ft above the ground. The metal brackets served as anchor points for the scalloped nylon webbing edges of the canopy, which carried the majority of stress and tension applied by the canopy. Once completely installed in a slack state, the scalloped edges of the canopy were tightened incrementally while moving in a star like pattern to assure stresses were being distributed evenly across the entire canopy. An assembly of tubular webbing, breakaway connectors and ratchet connections with 3,000 lb working load capacity are used at the scalloped edges, and shackles, breakaway connectors, and cam lock buckles with 500 lb working load capacity are used at the secondary anchor connections (Figure 21). Following the tensioning of the scalloped edges with ratchet connections along the perimeter, the secondary anchor points were then tightened to secure the entirety of the canopy's edge and control shaping in localized areas of the canopy. At the tower rings, cam-lock buckles were connected to the rings with nylon webbing loops and the net cells tensioned against them. Repeating this process of continually tensioning the primary anchor points and following with the secondary anchor points was carried out until the canopy reached its final state of stability (Figure 21).

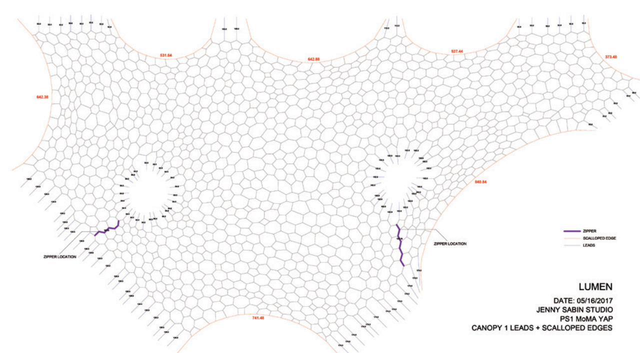
Lastly, the misting network was installed along the edge perimeter of the nylon webbing network, running on top of the main canopy and hidden by the edge detailing. Feeder lines drop from the network to the misting cones, and rings of misters provide a dual function of tensioning the cone and delivering mist. Working closely with Focus Lighting, a lighting system was installed and programmed to accentuate and extend the activation and responsivity of the photoluminescent and solar active fiber, especially during the evening hours and WarmUp events. Lastly, the 100 spool stools were delivered having been prefabricated in the Sabin Lab at Cornell AAP and arranged on site.



18 Nylon webbing cell edge detail for each sewn part.



19 Cell pattern drawing for sewing the nylon net and edge webbing (left) and sewing of each individual cell to its neighbor (right).



20 Edge detailing for the scalloped nylon webbing (red), tails (blue), and zipper locations (pink) for the main canopy.

21 Perimeter edge details (left) and unfolding and preparing the canopy for installation; solar active yarns revealing their colors in the presence of the sun (right).

CONCLUSION

Drawing synergies with current work at the intersection of computation, knit structures, and textile architecture, Lumen celebrates and shares topical themes of responsivity, variation, and material performance as can also be seen in the work by Ahlquist, CITA, and Scott. Having designed, fabricated, and built five previous projects featuring responsive structural fabrics composed of individually digitally knit cellular components, we felt confident that the material system was ready to be pushed to the scale of the MoMA PS1 courtyards and an outdoor environment enjoyed by thousands of people (Figure 22). Although Lumen was not designed or engineered for permanent installation, the project weathered extreme summer rain and flooding and the most well-attended WarmUp events on record at MoMA PS1. Together with Arup, we were able to move from a pavilion scale to a large outdoor tensile installation capable of housing over 7,000 people. Although locally delicate, Lumen's spatial and material systems are inherently variable, adaptive, globally strong, and interactive and are poised to be designed and assembled as permanent inhabitable structures. Currently, we are researching and developing three areas that will allow permanent installation of future projects like Lumen, including: 1) Finer scale manipulation of the responsive yarn to create tunable actuators within the programmed material; 2) coatings of the yarn to protect larger knitted components from extreme weather conditions such as heat, wind, and sand storms in a desert climate; and 3) stress tests with larger gauge yarn (increased to 1500 Denier) to generate more robust parts. Permanent commissions in Abu Dhabi, Portland, and New York are allowing for these new refinements and future installments.

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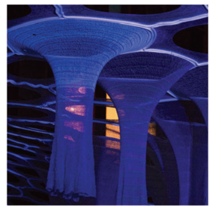
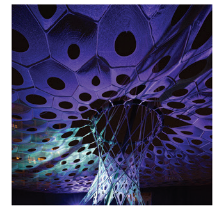
A project by Jenny Sabin Studio
R&D + Digital Fabrication by Sabin Design Lab, Cornell University
Design Team
Jenny E. Sabin, Principal and Lead Architectural Designer
Dillon Pranger, Project lead and manager
Jordan Berta (content coordination), Diego Garcia Blanco, Elie Boutros, Daniel Villegas Cruz, Omar Dairi, Alejandro Garcia, Andres Gutierrez, Jingyang Liu Leo (senior research associate), Mark Lien, Jasmine Liu, Andrew Moorman, Christopher Morse,






22 Lumen during WarmUp with misting system and responsive fibers activated.

Bennett Norman, Marwan Omar, Sasson Rafailov, Steve Ren, David Rosenwasser, Danny Salamoun (production lead), Aishwarya Sreenivas, Raksarat Vorasucha
Video: Cole Skaggs
Photography: Pablo Enriquez, Jesse Winter, Yuriy Chernets
Engineering Design: Clayton Binkley & Kristen Strobel, Arup
Fabricators and Installers: Tom Carruthers, Bo Jacobsson, Erik Grinde, Spencer Whynaucht, Todd Fitcher, Ryan Fitcher, Shannon McElree, Mateo Baca, Jacobsson Carruthers, LLC
Knit Fabrication: Tom Shintaku, Shima Seiki WHOLEGARMENT
Lighting Design: Juan Pablo Lira and Hilary Manners, Focus Lighting
Sewing & Finishing: Wade Wesson & Christine Garcia, Dazian
Misting Systems: Sabin Design Lab & Mist Cooling Inc.

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Jenny E. Sabin is an architectural designer whose work is at the forefront of a new direction for 21st 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 Wiesenberger Professor in Architecture and Director of the Sabin Lab at Cornell University. She is principal of Jenny Sabin Studio, an experimental architectural design studio based in Ithaca, New York.

Dillon Pranger holds a M.Arch from Cornell University where he was also a teaching associate in architecture. Dillon is a senior designer in Jenny Sabin Studio where he works at the architectural scale and manages projects. He has a diverse design background, ranging from KPF to Eisenman architects.

Clayton Binkley is an associate in Arup's Seattle office. He is responsible for design, analysis, and project management on a variety of projects including bridges, buildings, sculptures, and special structures. His work reflects his belief that high quality and holistic design can be achieved through creative engineering solutions.

Kristen Strobel is a structural engineer in Arup's Seattle office. She holds a MArch and M.S. in Structural Engineering from the University of Washington. In addition to working on Lumen, she worked on the Mexico City International Airport as a PE.

Jingyang Liu is a PhD candidate in Carnegie Mellon's department of Architecture. He was formerly Senior Personnel in the Sabin Design Lab. Liu graduated in 2018 as the first recipient of Cornell Architecture's M.S. in Matter, Design, Computation degree. Liu also holds a M.Arch from Cornell's post-professional degree program.