Folded Sun-Shades: from Origami to Architecture

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I. INTRODUCTION

The sunshine that delights us in winter can be overwhelming on a summer afternoon. Because blocking low-angle late afternoon summer sun can mean blocking views, our eyes are eager for a visually compelling substitute. The purpose of the Shaping Light study is to explore how adjustable surface structures can create beautiful sun-shading screens that modulate both heat gain and light levels in response to varying diurnal, seasonal and climatic performance criteria. By cutting apertures and creating folds in 2D sheets, we can shape how light is admitted, blocked and reflected. Origami folds efficiently create structural reinforcement and integral hinges, and folded surfaces change in appearances with varying sun intensity and angles.

This project leverages material manipulation for form-finding with 2D lasercutting, photographic studies, physical daylight analysis and 3D parametric modeling. Each physical or digital process is sequenced to inform the next one. We propose this kind of multivalent design cycle as a way to create results informed by many modes of thinking.

II. PRECEDENTS AND INSPIRATION

Erwin Hauer's Continua screens and sculptures created in the 60's show how continuous curved surfaces can block direct sunlight while transmitting beautiful gradients of bounced light.[1] The inter-reflections in his regular repeating screens have influenced contemporary designers in creating modular structures that respond to input with varying appearances.[2],[3] Material experiments for screening light reveal translucent layered shadows, bounced light and soft vs. sharp shadows to be compelling effects.[4] Design inspiration for folded form came from Polly Verity and Fernando Sierra who have taken origami into fashion, product design and architectural scale applications.[5],[6]

Digital methods to dynamically simulate the geometry of origami folding are readily available online. Compared to our approach of working with a continuous sheet, the work generally centers on cut sheets or modules. Tomohiro Tachi created the Rigid Origami Simulator and gives away software for generating, animating and altering crease patterns.[7] Gregory Epps has created Robofold, a machine with padded arms that automatically folds sheet metal

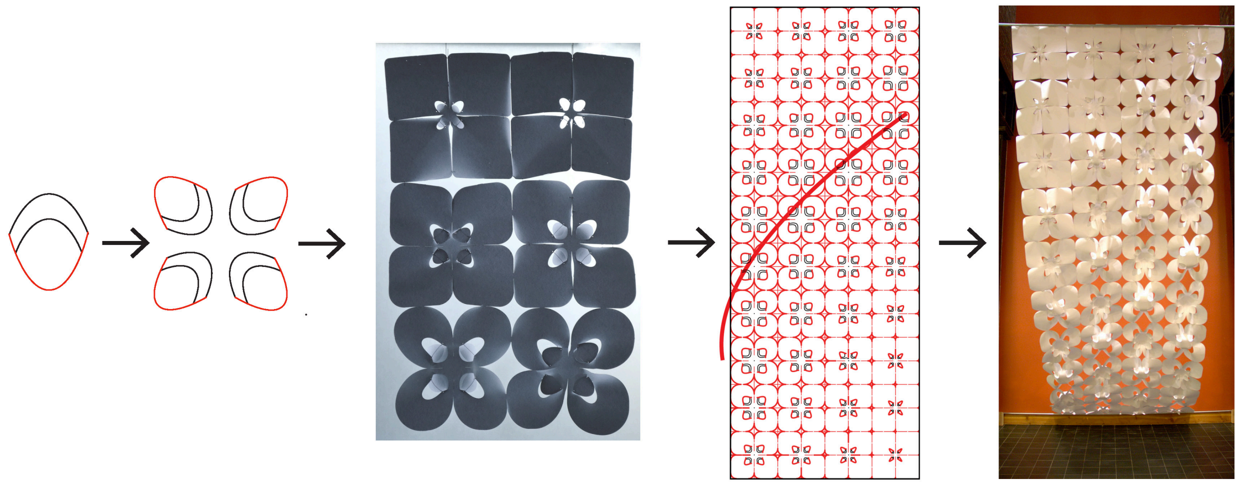

Figure 1. Simple slit motifs (l) were aggregated into repeating patterns (c), then parametrically varied for the Shaping Light Veil (r).

and started a Ning social networking site for digital origami.[8] Daniel Piker has used his Kangaroo 3D live physics engine plug-in for Grasshopper to simulate origami dynamics, including interaction through the Kinect interface.[9] We have tapped into this extensive community both for inspiration and assistance in creating these structures.

III. GEOMETRIC DEVELOPMENT

This study started with a slit and folded opening that bounces light as the cut surfaces were compressed into opposing pockets. We created variations of this flower petal-like pocket, studying the unexpected 3d surfaces that came from aggregating curved folds into regular patterns. In a precursor to the sun-screens, we created a parametrically adjustable 2d cut and fold motif which we demonstrated as a ripple through the gridded 6' x 15' Shaping Light Veil installation cut from a roll of cardstock.[10] This installation taught us that is was invaluable to cycle between physical manipulation, lighting tests and digital modeling. Too much digital time without lasercutting and manually folding meant we did not exactly understand the kind of 3d form that would be generated from a 2d template. At times, this generated patterns too narrow to fold or 3D forms that looked awkward under lighting. Scaling up the design brought complexity to tensioning the folds and brought the unexpected challenge of supporting the Veil's self-weight.

Our goal with the sun-shading screens was to adapt the paper-folding to architectural applications. From a variety of folding prototypes, we settled on an accordion-pleat pattern that provided the best possibilities for a room-size kinetic modular system while still maintaining an interesting visual pattern. Crisp v-folds allow the surface to compress more fully than visually compelling soft curves. Vertically flipping the cut motifs on alternate convex vs. Concave spines make the petals move in the same direction so they can bounce sunbeams together. Adding a secondary inverted fold within the petal creates a scoop that bounces more light, gives the alternating motifs more visual similarity, and reinforces the original fold structure. The dimension of the petal was set by maximizing the openings for light while maintaining enough of the accordion pleat surfaces to create a lattice-like frame. Helmut Koster's documentation of the retro-lux system was particularly useful in helping us understand which angles would be most effective for solar control.[11] He shows how horizontal blind slats with a folded surface can block direct summer sun and bounce winter sunlight deep into a room while maximizing views out. The book illustrates a rigorous approach for creating design applications, with design graphics that suggest how to use the underlying geometry for future applications.

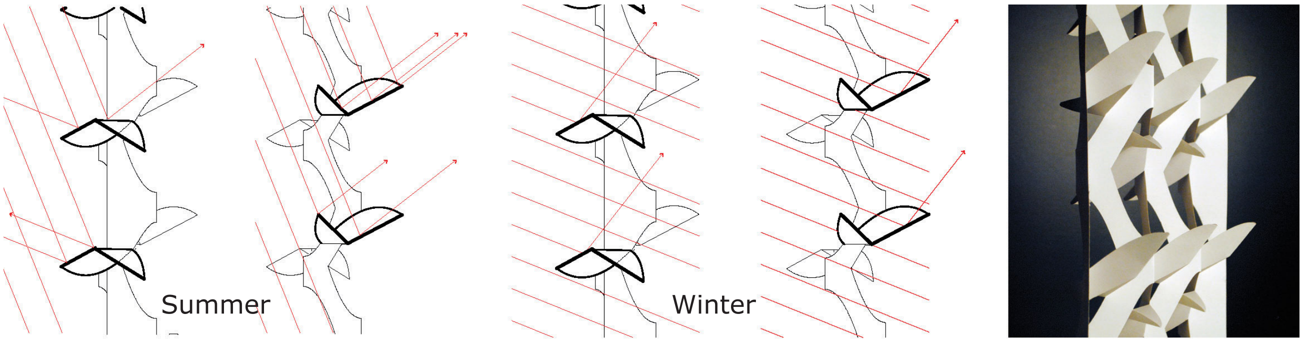

Figure 2. V-Folded petal pattern flips petals on alternating convex and concave folds to reflect summer sun and transmit Winter Light

IV. MODELING DAYLIGHT EFFECTS

After selecting our test pattern, a daylighting model was built in order to test the screens' visual performance in a south facing classroom. Because our need to test the screen prototype in a space where we could eventually test a full scale mock up, our model is based on room 451 of the White Stag Block, a University of Oregon's satellite building in Portland. The model created took into account the reflectivity of the room's surfaces and materials, the size and placement of its window openings, the placement of furnishings, and the room's structure. As the climate of Portland includes sunny, dry summers and overcast, wet winters, we examined the screens under both direct sun and diffuse sky conditions.

To test the differences between the screen when compressed versus when taut, two screens were created using the same geometric cutouts. The screen when compressed is designed to allow in more light, while the tensioned screen is designed to block sunlight. We used the angles of a heliodon to test the screen's shading effects at hourly intervals during three seasons - summer solstice, equinox, and winter solstice. Our photos and videos show that the shadow patterns change in a dramatic way with sun movement, particularly when the sun is low.[12]

To simulate the diffused light distribution of an overcast day, additional testing was done under a mirrored-box artificial sky that simulates the diffused light distribution of an overcast day. Light sensors allowed us to compare daylight factors for the two configurations and see the light fall-off with depth of the room (to test the screen under more "typical" office space conditions, a flat plane ceiling panel was added to the daylighting model for comparison).

V. DAYLIGHTING RESULTS

In the summer and equinox conditions both screens successfully shield direct sunlight, allowing some light into the front of the room, yet reduce heat gain and glare. During the winter, both screens allow sunlight to penetrate deeply into the space, with the compressed screen casting a more interesting pattern on the room's walls and floor. The high-contrast shadow patterns could distract from visual presentations or activities done in a classroom, but would be appropriate as visual stimulation for waiting areas.

Under the overcast sky conditions, both screens block more than half the incoming light. In blocking slightly more light, the screen in tension diffuses it more evenly. In blocking more of the view beyond, the tensioned screen more effectively reduces contrast and creates a more visually pleasing pattern than the compressed screen. Ultimately, the adjustable screen is much more likely to be used in the spring and fall due to the variable sunlight in the season. In the winter the screen is likely to be removed or slid aside in order to maximize light and heat gain.

As currently envisioned, screens of this type offer an exciting possibility for efficient and visually pleasing light modulation that fits the needs of various end users. We are interested in how the aperture shape, fold pattern and mounting system could make it easy to adjust the screen for different facade orientations and functional requirements. Additional geometric optimization is necessary to bounce sunlight deeper into the space for better daylight distribution.

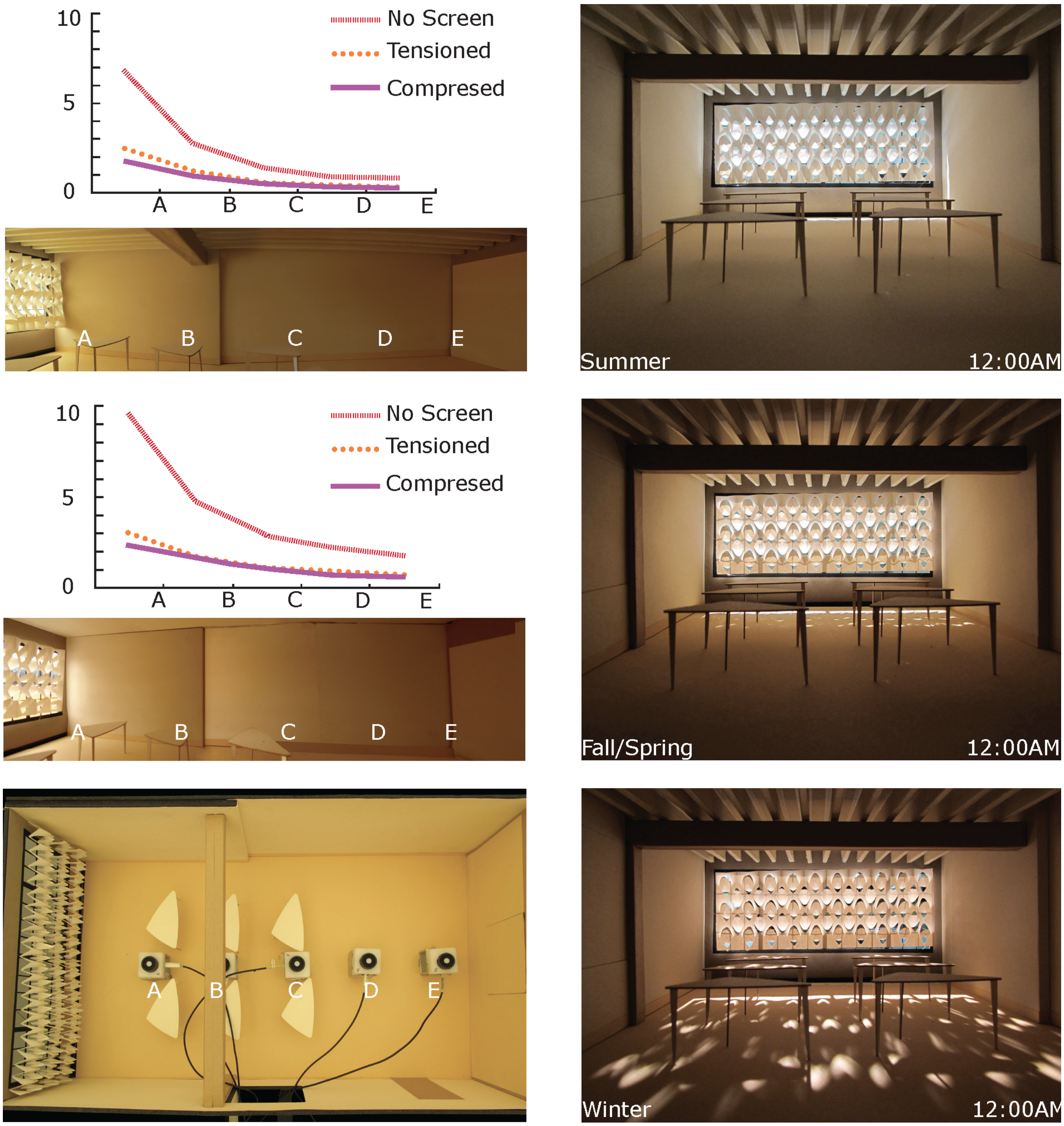

Figure 3.Diffuse sky testing of a classroom (l): measurements from sensors shown in plan (left bottom) compare daylight factors for large aperture Compressed screen and small aperture Tensioned screen for original classroom with beam (left top) and beam removed (left center). Direct sun conditions show Tensioned screen (r).

VI. MATERIAL AND CONSTRUCTION DEVELOPMENT

Geometric development with the computer was complemented with hands-on screen prototyping. Physical construction revealed how rigid and soft materials could be combined, how fasteners could work and how components could be assembled. Manipulating hand-held models clarified the structural loads caused by self-weight and activation,

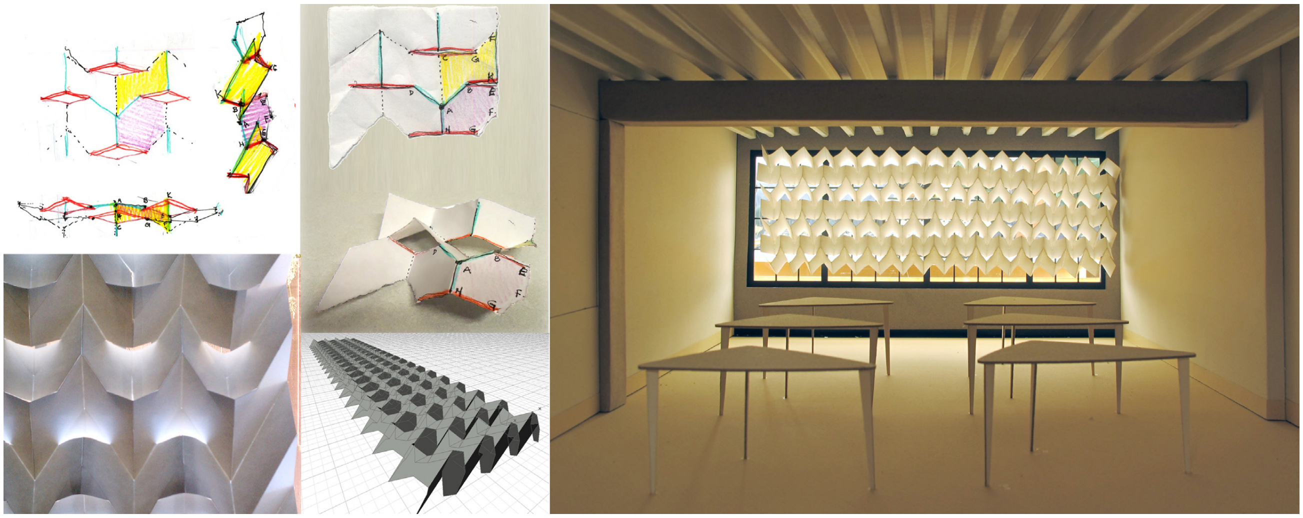

Figure 4. Process from hand-cut screen through sketch analysis, Grasshopper script and daylighting model

crucial for developing ergonomic folding mechanisms. Working with the models fore-grounded the importance of material characteristics. Scaling up the model made component and connection definition drive the design refinement.

Models for material driven research include Extreme Textiles which shows how textiles can be utilized for architectural applications.[13] The Cardboard in Architecture group at TU Delft shows how designers working with material scientists and engineers can adapt cardboard for use in buildings.[14]

Our project showed that laser etching or lasercut perforations can efficiently create self-hinges for folding in many materials. Plastics such as Yupo polypropylene, and materials with non-directional fibers, such as Tyvek olefin and mulberry paper, can sustain partial cuts more successfully than layered paper boards. The latter can become delaminated after repeated folding. Many patterns generated with a laser could be scaled up to efficient production through other technology such as die-cutting.

Constructing the prototypes in different materials made the divergent performance criteria more evident. In addition to having visual properties of high reflectance and moderate translucence, the screen materials needed to be flexible to fold yet rigid enough to hold shape. The original small paper screens were easily self-supporting, could flex at the hinges, retain folds and spring back to a semi-open position.

At the larger scale, no single material could meet all the criteria. To give both structural stiffness and foldability, thicker frame elements were adhered to a flexible layer that could act as hinge and reflective petals. Among materials tested, an acrylic frame laminated to Tyvek provided the most attractive assembly. The Tyvek non-woven construction makes it highly resistive to tearing and its fibers create an organic texture when backlit.

For folding and unfolding the screen, tension cables acting as a drawstring will open up the screen from one side as in a traverse curtain rod. In contrast, local pre-tensioning with elastics allows all folds of the screen to open consistently.

For future development we take inspiration from Issey Miyake's A Piece of Cloth project[15] in which a dress was fully woven into a bolt of material, needing only to be trimmed to scale. In a similar way, the screen material could be woven, printed, embossed or overlaid with patterns of rigid ribs, resilient and reflective petals, and embedded tendons.

VII. ARCHITECTURAL APPLICATIONS AND LIMITATIONS OF ORIGAMI

Combinations of curved folds and cut edges can generate compelling light modulating forms from sheet materials. Many materials can create a self-hinge through folding. Folds can simultaneously create sculptural form and structural rigidity.

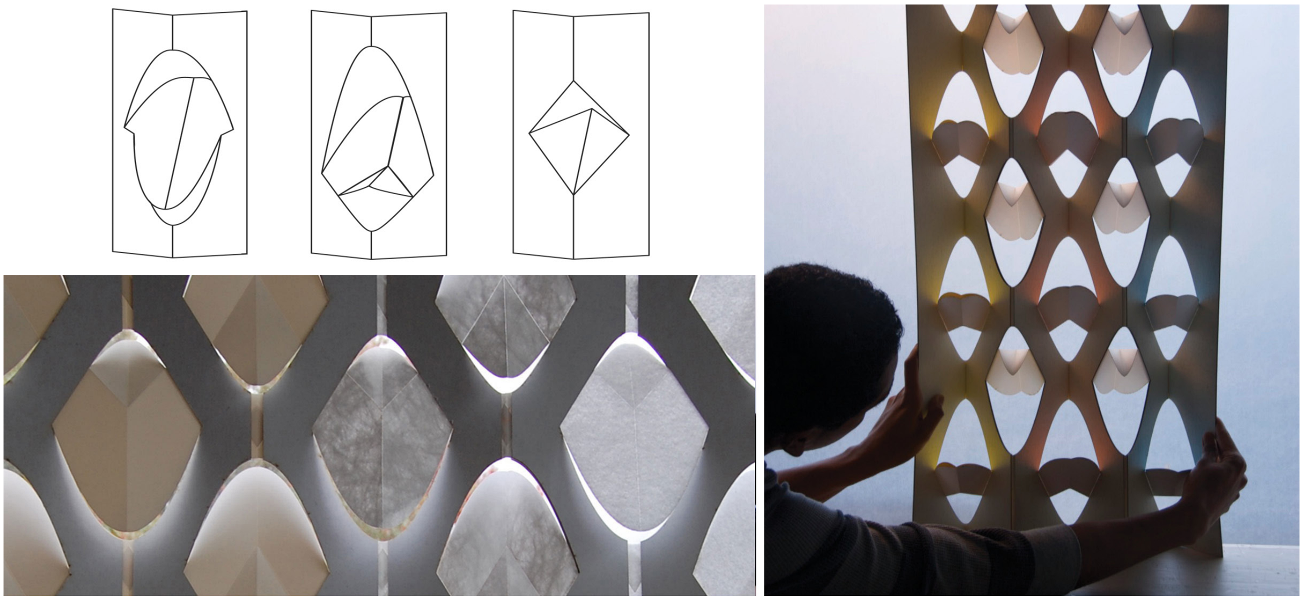

Figure 5. Visual, tactile and digital methods yielded different petal forms (top left). Petals of Yupo polypropylene, Tyvek olefin and synthetic felt within a rigid frame (bottom left), manipulating a screen with reflected color (right)

However, the idea that a single sheet can efficiently be transformed into a compelling and useful form has limits. While the concept works well in smaller pieces, enlarging screen's scale hits the dimensional limit of manufactured goods. While large rolls of materials can be automatically cut, methods for joining components and carrying material weight need to be considered. Shaping and assembling individual 3D modules can be easier than sculpting a large matrix of multiple components. In the case of our screen, scaling up to architectural scale exaggerated the challenges of requiring one material to act as frame, hinge and reflectorVIII. Digital + Analog Design Process

The study that began with looking at the form of paper under light gradually spawned a series of on-going investigations. In defining the inquiry, the questions sharpen over time, with the future investigations (items 7 & 8) the most open-ended.

1. FORM - Cutting and Folding: How can patterns of slits and folds transform a 2D sheet into compelling 3D forms?

2. LIGHT QUALITY - Photography & Video: What visual effects can be created with the artifact under natural and electric lighting?

3. MATERIAL - Prototyping: How can materials improve the screen's visual, structural and kinetic properties?

4. STRUCTURE - Production and Assembly: What system of components and joints can most efficiently and elegantly suspend the screen? How does the system need to be modified to meet site-specific installation requirements?

5. DAYLIGHTING - Heliodon photos and Artificial sky illuminance measures: How well do prototypes block summer sun, optimize daylighting usability and maximize aesthetic delight?

6. PARAMETRIC MODELING: How can the dimensions and angles of the screen be optimized for daylighting usability and aesthetic delight?

7. KINETICS - Manipulation: How much does the piece need to move? What folding pattern fits the daylighting constraints? What screen positions work best for different times of the day and year? What kind of joints and tendons most efficiently and elegantly fold the screen? What manual or electronic mechanism most seamlessly activates the screen?

8. ELECTRICAL LIGHTING: How can electrical lighting be embedded into the screen to generate compelling and dynamic aesthetics?

IX. CONCLUSION

To recap, the screen designs started as 2d sketches that were lasercut into sheet materials to explore 3d form generation. Physical manipulation of these folded laser cut artifacts were key in developing the screen patterns.

Crucial to pushing a project from divergent material exploration to convergent refinement is defining a specific architectural condition to focus the work towards performance in a built environment. By selecting a south-facing window in a room that is prone to summer, we could concentrate on variably controlling summer, fall and winter daylighting. While earlier studies explored radial and organic geometries, the rectangular window aperture limited us to frieze patterns with an underlying accordion pleat. Testing the screens' sun shading patterns in the heliodon and artificial sky pointed out the need to increase openings and reflectance at the top of the screen.

The parametric software has been more effective on this project as a design refinement tool rather than a form generator. Inputting the sun angles for the summer, fall/spring, and winter conditions in Portland, the screens can be optimized using the parametric model to give better distribution of natural light into the space. The parametric model can address inefficiencies revealed by physical model tests of daylighting and material assembly. The parametric models facilitate concurrent digital testing (exporting to analysis software) and physical testing (lasercutting for the heliodon and artificial sky). This can help optimize the screen forms for specific site and climate conditions so that a screen designed for the Portland climate could be adapted to the climate of Alaska or Arizona with relative ease.

Seeing how the project grew according to available talent makes it clear that strategic partnership choices are key to research development. CNC milling of wood and plastic panels in 2007-8 fostered the original light and shadow focus. In 2010-2011, the Shaping Light project developed opportunistically according to available student ability in lasercut paper manipulation, parametric programming, material testing and prototype construction.

In the Shaping Light project, we are seeking a digital + physical pipeline to address performance criteria and maximize creative material exploration. While defining a fluid path through physical prototypes, digital models and lighting analysis sound appealing, our project's non-linear development reveals the serendipitous opportunities of varying from a tight agenda. Design requires a balance between free play and discipline, as occasionally a tangent off-shoot can seed a new branch of exploration. The site-specific demands of both the Veil installation and the classroom sunshade projects lead us on different design process paths to address unique requirements. While we do need easy physical to digital translations and accessible interoperable software, each project will demand a different set of tools. The quickly changing demands of our dynamic society requires familiarity with a wide range of design techniques and ability to find and integrate the appropriate expertise for a specific situation.

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