Folded Sun-Shades: from Origami to Architecture
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The sunshine that delights us in winter can be overwhelming on a summer afternoon. Because blocking low-angle 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 heat gain and light levels in response to varying diurnal, seasonal and climatic performance criteria. By cutting apertures and shaping 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 modelling. 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.

Precedents and inspiration
Erwin Hauer’s Continua screens and sculptures (2007) created in the 60’s show how continuous curved surfaces can block direct sunlight while transmitting beautiful gradients of bounced light. The inter-reflections in his regular repeating screens have influenced contemporary designers in creating modular structures that respond to input with varying appearances. (Perez, Ramaswamy). In our own shadow workshops, we conducted material experiments with screening light and found translucent layered shadows, bounced light and soft vs. sharp shadows as the most compelling effects (Petchek 2011). As we developed the folded forms, design inspiration came from Polly Verity and Fernando Sierra who have taken origami into fashion, product design and architectural scale applications.

Extensive research has been done in digital methods for origami by the large and sharing origami community and the work generally centers on uncut sheets or modules. Tomohiro Tachi created the Rigid Origami Simulator and gives away software for generating, animating and altering crease patterns. Gregory Epps has created Robofold, a machine with padded arms that automatically folds sheet metal and started a Ning social networking site for digital origami. Daniel Piker has used his Kangaroo 3D live physics engine plug-in for Grasshopper to simulate origami dynamics, including interaction through Kinect interface. We have tapped into this extensive community both for inspiration and assistance in creating these structures.

Geometric Development
This study started with a slit and folded opening that bounced 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. (XX, 2010) This installation taught us that it was invaluable to cycle between physical manipulation, lighting tests and digital modelling. Too much digital time without lasercutting and manually folding meant we didn’t really understand the kind of 3D form that would be generated from a 2D template. This generated more awkward 3D forms, patterns too narrow to fold or forms that didn’t look good under lighting. Scaling up 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 the what angles would be most effective for solar control (2004). 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.
Modelling Daylighting Effects

After selecting our test pattern, a daylighting model was built in order to test the screens' thermal and 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 XXX’s satellite building in Xxxxxx. The model created took into account the reflectivity of the rooms surfaces and materials, the size and placement of its window openings, the placement of furnishings, and the room’s structure. As the climate of Xxxxxx includes sunny, dry summers and overcast wet winters, we examined the screens under both direct sun and diffuse sky conditions.

![Figure 3. Tensioned screen under direct summer, fall/spring, and winter sun at different times of day.](image)

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. (Shaping Light, 2011)

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).
Results

In the summer and equinox conditions both screens successfully shield direct sunlight, allowing some light into the front of the room, yet reducing 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 rooms walls and floor. The high-contrast shadow patterns would be more appropriate as visual stimulation for waiting areas, as they could distract from visual presentations or activities done in a classroom.

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.
Digital + Analog Design Process

As previously mentioned, the design of these screen patterns started as a 2D sketch that was laser cut into a flat sheet to explore its potential as a 3D form, with physical manipulation of these folded laser cut artifacts being key in developing the screen patterns. From here we tested the pattern in the heliodon and artificial sky and analysed the generated data. With this testing data we are now modelling the screens in parametric modelling software, redesigning them as we go along to address the inefficiencies that the physical model testing showed us, using parametric software as a design refinement tool and not as 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 models allow us to test the screen digitally (exporting to analysis software like IESVE) and physically (cutting new screens to use in the heliodon and artificial sky) concurrently, allowing us to optimize the screens quickly for use in specific climates and sun orientations. This constant feedback data loop allows us to create new versions of the screens with relative speed and ease. As such we have been testing an alternate (weaved) screen design concurrently with our main design. Parametric software allows us to quickly reconfigure a screen based on changing site and climate conditions. A screen designed for the Portland climate could quickly be adapted to the climate of Alaska or Arizona with relative ease. We’re only beginning to scratch the surface of what parametric modelling can offer us.

![Figure 5. Hand Cut to Parametric Modelling: weave pattern design development.](image)

Future Possibilities

We are eager to see how much of origami’s simplicity can be maintained as we scale up. Material properties are a large part of this. As we found during the Veil installation, a material’s weight and structural properties can be as crucial to a screen’s success as its reflectivity and opacity. Aside from looking at papers and cardstocks, we are researching how fiber, plastic, or composite materials could meet our unique requirements of reflectivity, opacity, flexibility and durability. Procedures for cutting, folding, fabricating and mounting are dependent on these material characteristics and change dramatically with scale. (i.e. laser cutting for prototyping, die-cutting for mass production). While habitable structures will always require connections and components, we are interested in making folds integral to the sheet and maximizing the dimension of the contiguous sheet. We would like to find ways that the screens could be automatically cut from a large roll, folded over a jig, assembled and installed. Since no single material tested is meeting our requirements, we are looking at custom manufacturing a composite material for the final 3D product. Issey Miyake & Dai Fujiwara’s APOC - a piece of cloth project did just that, with positive results (Scanlon, 2004). The material could woven, printed, embossed or overlaid with patterns of rigid ribs, resilient and reflective petals, and embedded tendons. (McQuaid, 2005). McQuaid’s book Extreme Textiles shows that textiles are underutilized for architectural applications. In order to adapt non-standard materials to buildings, we can look to the example of the Cardboard in Architecture group at TU Delft. (Eekhout et. al., 2008) They show how with the aid of material scientists and engineers, designers can adapt cardboard for use in architectural applications. With these material possibilities in mind, we are considering the screens use not only as sunshading devices, but as aesthetically pleasing room dividers and habitable art installations.
Outside of the specific screen product, we want to define a digital + physical pipeline for development and testing of shading devices that addresses performance criteria and maximizes creative opportunities with material experimentation. We need a fluid path between playing with material form, generating digital models and analysing thermal and lighting characteristics. Along with easy physical to digital translations, we need accessible, interoperable software for both accurate measurements and compelling visual representation.

Works Cited

6. Sierra, Fernando http://www.ambientesluar.net/