SURFACE INTO FORM

Nancy Yen-wen Cheng

I. Introduction: Defining space with almost nothing

The Surface into Form project examines how minimal materials can create maximum effect. Every piece is cut from flat sheet material with little waste, and then bent, stretched or draped into 3D. The pieces are designed to maximize sculptural interest, creating light and shadow effects that change with the direction and type of light source. Lighting plays off matte and shiny surfaces to create reflections, highlights and shadows. Soft light to dark gradients on curved surfaces juxtapose with crisp edges. The edges are manipulated to create high contrast, by pulling one surface forward and an adjacent surface backwards.

The shapes are crafted to combine continuous large expanses with fine detail. For example, crossing self-clasps can pull a sheet of material into a three-dimensional saddle, creating vaults that catch the light differentially according to the viewpoint and light source. Reducing the size of the self-fasteners maximizes the surface for light gradients, and the minimum dimension of the self-fasteners depends on material strength and flexibility.

Figure 1. Each pattern with flat circles pulled into 3D saddles is cut from a single sheet of plastic.

Six pieces incorporating the saddle have been designed examining how edge conditions can change perception and meaning. For example, contoured oval and round pieces have been designed to cast changing shadows as they twist from a single suspension point as they move with air currents. Related continuous patterns for architectural applications were created with an awareness of the negative space so that positive and negative compete for importance, with dominance changing according to daylighting conditions.

II. Context

The pieces are inspired by Bauhaus teacher Laslo Maholy-Nagy's light modulator machines and photographic experiments, as well as University of Oregon Architecture colleagues. My classroom assignments build on classic Bauhaus exercises using digitally milled and lasercut materials to generate light and shadow effects.

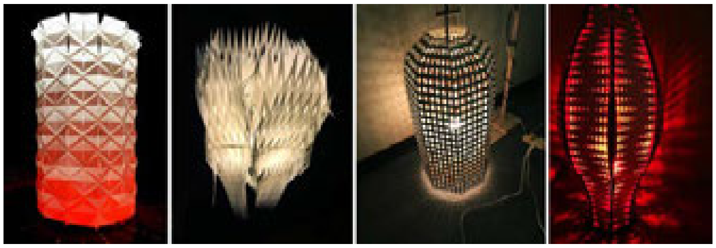

Figure 2. Luminaire designs by Oregon students Nicole Epple, Kevin So, Zach Arino and Zachariah Petett.

The work is a creative counterpart to research on how sculpted surfaces can interact with environmental forces. Understanding how folded geometry affects the distribution of light, air and water could help us create better building envelopes. Textured surfaces improve the aerodynamics of golfballs by creating local turbulence that reduces friction of the ball moving through air. While surface textures and profiles have been engineered to improve hydrodynamics of swimsuits and propellers, they are not well understood for building surfaces experiencing wind. For example, shapes that passively accelerate airflow could enhance the cooling effect of shading screens for hot climates. Furthermore, controlling ventilation in layered facades could reduce fungal growth in wood structures. Towards that end, I have worked with Melbourne colleagues to measure how folded surface patterns affect airspeed[i]. Looking at aesthetic possibilities of these surfaces and understanding how folds affect their structural integrity is an important part of making useful building skins.

III. Exhibit design: window attraction, then a journey with vistas

The exhibit at PLACE, a gallery and landscape architecture studio in Portland Oregon, was designed to create a small journey with particular viewpoints and contrasting experiences. Outside viewers could glimpse fabric stretched between suspended hoops to form a 9' tall nuclear cooling tower shape, pierced by arc-shaped openings. From the front window one could also see a monumental white wavy form deep in the space against a dark blue wall. On the way towards it, one travelled to the back of the gallery between a big woven corrugated cardboard wall and a sculpted zig zag wall, then discovered a small room containing a mysterious red chamber.

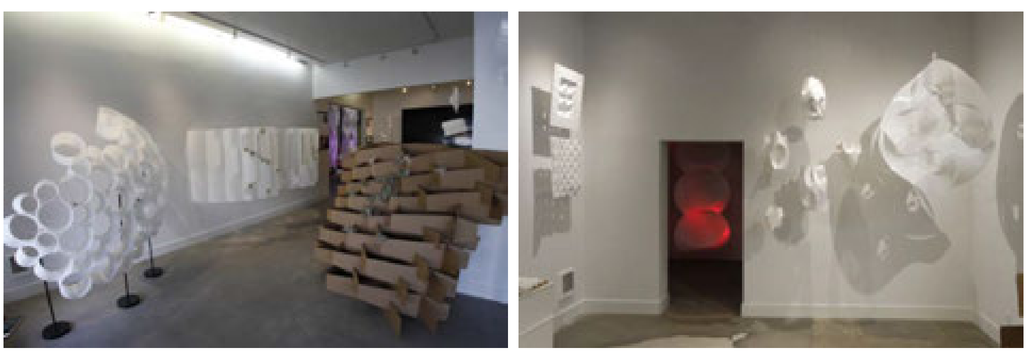

Figure 3. Large pieces create a garden of contrasting geometries (left), small vessels hover in front of a red chamber (right)

Inside the red chamber, curved disks cinched to each other into a totem-like chain. From that corner, suspended lamp forms employing a series of asymmetrical petals to bounce light could be discovered and study models could be examined and manipulated. Visitors could then move into the studio space to see the space-filling pieces, and then return to examine the stretched cylinder and saddle pieces in the window.

IV. Folding and Folded pieces

Two large folded pieces were created from for the Oregon BEST Fest stage. Interlacing Light, created with Marziah Rajabzadeh, demonstrates a flat-pack construction system that pairs zig-zag strips to create structurally stable diamonds, then offsets layers to create a wall with customizable thickness and texture. The wall has an S-curve for structural stability and creates a contrast between deep convex areas that catch the light and shallower areas that appear darker. Lasercut from cardboard for low cost, light weight and easy transport, it could be created in metal, wood or other sheet materials.

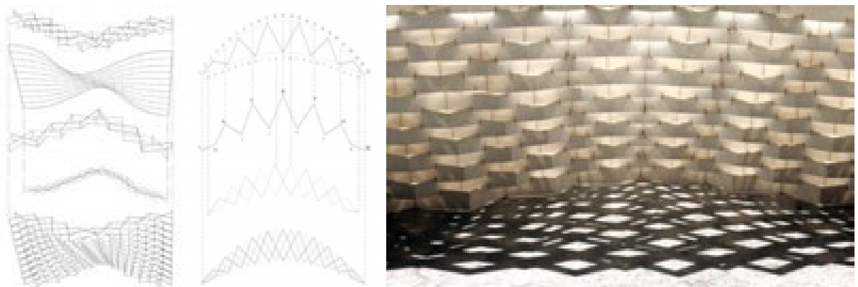

Figure 4. Interlacing Light features a flexible system developed by Marziah Rajabzadeh from a workshop co-taught with Mohsen Marizad.

The 16' high Ripples uses wavy, curved folds to create stable forms evoking large figures, arranged symmetrically like caryatids, the maiden figures of classical architecture. The waves were inspired by the way Oregon BEST Fest expands the impact of good ideas like waves rippling out from the shore. The wavy surfaces create gradients of light and shadow that change in appearance with different lighting and the viewer's perspective.

Figure 5. Ripples have a monumental presence with curves mimicking human form. Left photo by Monica L. Klau

A series of vessel forms illustrate the use of ear-shaped flaps to create organic shell-like forms. Flaps are the simplest way to pull out a surface to catch light. A simple tab can be curled from a sheet or isolated with a fold, with the fold shape determining its curvature and the edges cut freely. Parametric flaps located along a sine curve were used to articulate a 4' x 16' zig-zag wall that was decorated with air plants.

V. Fabric pieces

Fabric forms were investigated with Marziah Rajabzadeh and Mohsen Marizad, as our teaching combines physical form-finding and digital investigation. Inspired by Frei Otto's form finding, they utilize the fact that draped fabrics follow catenary curves and stretched fabric naturally takes on the most efficient minimal surface between tension locations. In experimental workshops, fabric was draped from hoops and rods, as well as tensioned with cables at edges and points. Fabrics required physical prototyping to reveal the behavior of specific materials under loading. Linear supports, edge and point tensioning create different morphologies depending on the stretch of the material.

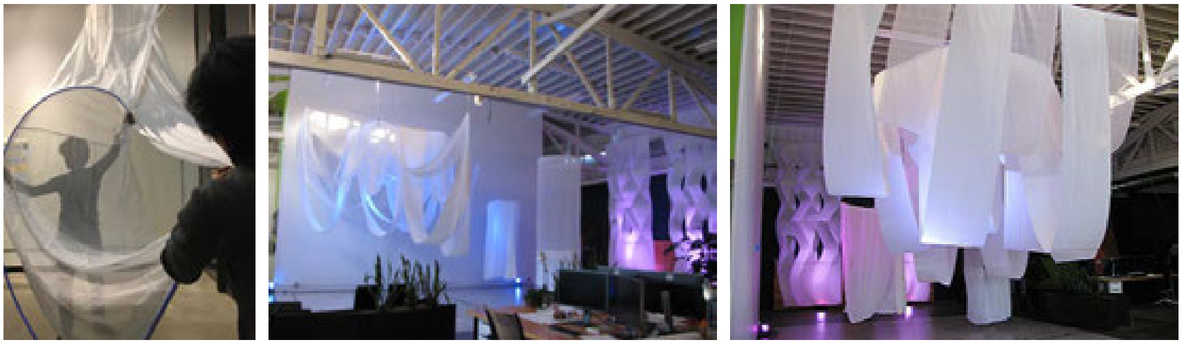

Figure 6. Fabric forms were developed through experimental workshops.

Inside the warehouse-like PLACE studio, we created a large draped piece with fabric strips in catenary curves inspired by textile artist Akio Hamatani's W-Orbit. All strips are suspended from a large hoop and edge cables, with the depth of the catenary dependent on the width of the span. Shorter, filmy sheer strips cast shadows on the longer, more opaque cotton strips. Because all of the strips are hung on the same circular hoop, they have coherence while the strips follow independent curves.

Yardage was also suspended from smaller 3' diameter hoops to create simple split columns, an orderly starting point for further experimentation.

Figure 7. Draped hoops provide a consistent starting point for developing new forms. (Monica Klau photo right)

The cylinder at the front window shows how stretched fabric can create unexpected curved surfaces. Two opposing openings were cut to reveal the interior, with the edge cut in a curve that echoes the edge formed by pulling a tab through the form. It is part of a larger investigation of how continuous surfaces could be inhabited.

VI. Lessons learned

Lighting designed by Paula Barreto gave the pieces a great deal of their impact. The positioning and strength of light sources brought out the forms in relationship to the spaces. Unexpected reflections and shadows became important elements of the exhibit. Static colors and hue-shifting colored light animated the neutral white forms, giving them personality.

Figure 8. Shadows are interspersed with unexpected highlights. (Brian Lockyear photo)

TILING PATTERNS: Experiments show that tessellation patterns vary in their adaptability. Linear patterns and grid-based space-filling patterns are easy to apply to the built environment. Linear repetition is the simplest: a motif can be repeated along a line that is straight or along a curve, with variable densities. The series can incorporate gradients of size and geometric variation, so they are effective for beginning parametric explorations. Grid-based patterns (rectangular, triangular, hexagonal) also have a wide range of application, as they can be geometrically stretched or squeezed over any surface.

Figure 9. Waves with eyelids for light can be stretched into different forms.

Radial systems are simple to propagate and can incorporate rhythms of alternation such as a ABA or BBA. Radial patterns and related spherical and toroidal surface patterns are limited in application because concentric patterns grow quickly in size. Radial folding patterns can naturally distort a sheet to have smaller center and larger perimeter, which creates a saddle, or something similar to a ruffle edge.

Figure 10. Each material needs to tested for properties. Back-lit parts awaiting assembly shows optical qualities.

MATERIALS: For folding surfaces, a range of materials was tested, from stiff acrylic to aluminum and industrial felt. Forms that originated with thick paper work best with resilient materials that have spring when bent, so the larger pieces were CNC milled from 1/16” milky-white High Density PolyEthylene (HDPE). The greater opacity used in smaller models better supports the original design intent of creating dramatic visual contrasts and gradients. While sheet metal has been explored, its shaping process requires different tools (i.e. brake machines or multiple robotic arms[ii]) which would more naturally spur different forms than prototypes created with resilient paper.

Figure 11. Ripples under construction. When suspended, the weight of the lower pieces flattened some of the upper folds.

STRUCTURE: Developing the exhibit required a careful consideration of gravity and structure. Even with lightweight materials, self-weight can distort the form of folded structures, and balance is crucial. The behavior of sheet materials when tensioned or compressed needs to be verified through prototyping because achievable forms will vary according to attributes such as thickness, size and stiffness. While deflections can be estimated, actual material performance need to be observed under loading conditions. Cut components or assemblies can be too floppy or too stiff to create the desired form.

Working at architectural scale typically means building up components with armatures and connections. Creating a good fit between armature and skin requires attention to material pliability and connection tolerances. For example, on the cylindrical vessels, calculating the dimension of surfaces wrapped onto wheel-like armatures was tricky due to the way that the interior and exterior surfaces distort. As pieces are enlarged, joints and connections become more visually significant. For example, connection holes can appear as decorative points of light or shadow and a row of zip-ties can read as lines of stitching.

VII. Conclusion and Next Steps

The exhibit provided an opportunity to review, organize and refine experimental efforts that are contributing to a lexicon of elements and connections. The project has been enriched by workshops inviting collaboration with the spirit of play and discovery. Transforming material from flat to 3D is the most exciting aspect of the work, so folding structures can involve viewers with physical flexing, as it provides the satisfaction of kinesthetic engagement. Interactive lighting, parametric animations or other simulations could further contribute to an enriched experience. New forms of electronic, hydraulic and pneumatic folding actuation are opening up further design possibilities.

Additionally, the opportunity to engineer material properties has emerged through techniques such as compositing layers or 3D printing strength where needed. Because folding can generate structurally efficient demountable spatial systems, there are many potential areas of application.

CREDITS

Contributors: Marziah Rajabzadeh, Mohsen Marizad, Francisco Toledo, Bonnie Jean Dominguez, Jose Toledo, Jonah Jumila, Takanori Mizutani. From PLACE: Kelly Stocklein, Zeljka Carol Kekez, Paula Barreto, J.P. Pauli, Mauricio Villarreal, Lloyd Douglas, Monika Klau, Ayla Palacios contributed to the exhibit.

---

[i] Cheng, N., McCarthy, J.; Khorasgani, M.; Muehlbauer, M. and Burry, J. (2017) "Surface Geometry and Airflow for Ventilated Building Facades" in Kellett, R., Hatten, M.; Duffy, K. et. al. eds. Transforming Architecture: A Festschrift in Honor of Professor G.Z. "Charlie" Brown, University of Oregon.

Muehlbauer, M.; N. Cheng; M. Latifi-Khorasgani et. al. (2016) Breathing Skin: testing and visualization methods for additive folding surfaces. Simulation for Architecture and Urban Design SIMAUD 2016, London, England.

[ii] See http://www.robofold.com developed by Gregory Epps, working with Daniel Piker, the author of Kangaroo Physics, a Grasshopper plug-in.