Parametric Folds

*Using the elasticity of polymers for a light weight structure*

Gernot Riether  
Georgia Institute of Technology.

Abstract. This project takes advantage of a dynamic structural quality found in high-density polymers in the development of a self-supporting lightweight structural envelope for the Nuit Blanche pavilion. The pavilion was developed to display a series of interactive art projects as part of the annual Nuit Blanche Festival in Paris. The project combines concepts from biology with digital design and fabrication methods to speculate on a new relation between structure, geometry, material and appearance. Before discussing the design research of the pavilion the paper will elaborate on our larger research goals in using digital technology to promote more environmentally responsible construction methods and the research values of projects at the scale of a pavilion.

Keywords. Polymer; elasticity; lightweight structure; pavilion.

INTRODUCTION

When comparing architectural systems and natural systems, one soon realizes that in nature the relation between structure, geometry, material and appearance is far more complex than in buildings. A large number of papers published in conference proceedings and books on digital fabrication (such as Lisa Iwamoto’s book on Digital Fabrications or Branko Kolarevic’s books on design, making and manufacturing in a digital age) show the potential of digital tools and methods to increase the complexity of existing construction systems, a change that has capacity to alter the way we think about construction systems and inspire new kinds of construction systems that are far more complex than most of conventional, available systems. The complexity that can be achieved by digital design and fabrication may also allow us to develop systems that resemble complex natural systems, suggesting the potential for a new generation of environmentally responsible building systems that save material and respond to environmental conditions in a more intense and dynamic way.

Our projects focus on modular-based systems and the relationship between module variation and overall form. In a previous project, “coded surfaces” (Figure 1), the variation of folds in the module informs the curvature of a surface. While working on the development of structural envelopes, we started to use the freestanding, full-scale pavilion to speculate with systems that connect digital design and fabrication technology with environmentally friendly materials or new materials by calling attention to material properties. These pavilions are an attempt to synthesize material behavior and digital design and fabrication techniques in new ways, for example, by calling attention to material properties. We often utilize material properties that are typically ignored in the conventional use by the building industry, such as the elasticity of plastics.
Looking at materials in a more dynamic way than usual we are using prototypes and simulations to understand the material performance that usually becomes an essential driver in the design process. However the value of the research in the pavilion is not in its individual design or fabrication technique, material exploration or philosophical statement alone but always in the synthesis of all these aspects. In that way we see the scale of the pavilion as a first step to bring this complexity that is natural to architecture back into the radical digital experiment. Other examples of such efforts might include recent projects such as the ICD/ITKE Research Pavilion 2011 by Prof. Achim Menges’ Institute for Computational Design at the University of Stuttgart or a series of pavilions by the AA, Architectural Association at London’s Bedford Square.

POLYMERS
The abovementioned pavilions are making novel use of wood and concrete. The project discussed here, the Nuit Blanche Pavilion, explores plastics as a building material. Responding to the chemical industry as it changes from fossil fuel based plastics to bioplastics, our research is interested in techniques and methods that reintroduce plastics as a building material in a new form. In doing so, it will also provide new spatial and aesthetic qualities that are essential in changing the perception of plastic from an environmentally-problematic to an environmentally-friendly material.

In her New York Times article “Plastic: Too Good to Throw away,” Susan Freinkel notes, “The problem isn’t the plastic, but the way we use it.” She argues that plastics are too valuable to be wasted on cheap
Figure 2
*Nuit Blanche Pavilion, interior view.*
junk, but should be reserved for the things that can best take advantage of its properties. We have experimented for a while with possibilities for introducing recycled plastics and bio-plastics into architecture. Of the plastics, it is ETFE in particular that is currently enjoying a revival in architecture. However, a closer look reveals that this material only informs a very few types of architectural systems, such as pillow systems.

The Nuit Blanche Pavilion (Figure 2) is part of a research agenda that speculates on alternative uses of plastics in lightweight structures and in systems that hybridize structure and envelope. The project is a result of an ongoing research in the behavior of a large range of available polymers as potential materials in structural envelopes, as already discussed in our paper in last year’s eCAADe conference. The Nuit Blanche Pavilion takes advantage of high-density polymers. Such polymers have much stronger intermolecular forces than regular polymers, resulting in an increase in material strength. Depending on the resin type, reinforcing agents, and processing methods, the material performance in tension and compression can vary from one another by 50% or more. This differs from many conventional building materials, such as metals, where the tensile and compressive moduli are very close. Distinct from most building materials, the behavior of polymers can be highly manipulated through different processing methods and aggregates. Because polymers are easy to recycle, they are increasingly used for bottles and packaging. Polymers have also benefitted from evaluations of possible health and environmental problems caused by PV and Polycarbonates, as well as from environmental advantages over glass, metal and cardboard. The industry is in the process of changing its production to bio-polymers that are based on starch, sugar, cellulose or synthetic materials. Though its original production is petroleum-based, the material we used is fully recyclable. The larger goal of the project is to provide an aesthetic and technique parallel to a positive development of the materials’ availability and affordability.

FABRICATION
This project started by testing the behavior of different high-density polymers. A series of studies tested possibilities to shape the material and experimented with different means of connections. Polymers are usually formed into final shapes through processes of cold bending and heat bending and thermoforming techniques such as vacuum forming, draping and drape forming. Instead of using only the materials malleability this project also tested techniques to use its elastic qualities. Using it similar to a bent tent pole we experimented with different techniques to use the natural elasticity of the material to self-stabilize a structure.

Instead of pre-tensioning a surface by bending the envelope as a whole, a strategy that we tested in one of our previous projects, the AIA Pavilion in New Orleans (Riether and Jolly 2011) or tensioning and connecting a series of individual sections such as in Achim Menges’ Bending-Active Pavilion (Ahlquist and Menges 2011), the surface of the Nuit Blanch Pavilion builds up tension within the individual cell and the cells’ varying relationships to each other. This was achieved by developing a cell in two parts that once connected to each other formed a double-layered surface. As the diagrams in Figure 7
explain, the flanges of both parts were first bent and then connected to the neighboring cells. We therefore had to find a method of bending the material in such a way to keep its original physical properties in tact after bending the material. The material would then over time try to reach its original flat stage causing tension between the modules.

To achieve this effect different bending methods have been investigated. Usually polymers are heat bent. In this case the material would keep its structural properties but would loose its memory. Polymers can also be cold bent. This weakens the material and consequently compromises its structural performance. For the modules of the Nuit Blanche Pavilion we chose to cold bend the material but instead of using a sharp edge that would be usually used we bent the material around a beveled edge with a radius of 1/8". In that way we kept the physical integrity of the material as well as the materials memory. The modules would stay in the bend position during assembly but then over a longer time would try to go back to its original flat state. Once all the modules are locked in place a tension was built up within the surface by all flanges collectively trying to go back to their original position.

GEOMETRY
We investigated different base geometries for the cell in relation to the overall form, such as different triangulations and Voronoi patterns. From Buckminster Fuller’s dome, we know that altering hexagons and pentagons in two directions is the most structurally efficient way to generate a sphere. A single curvature therefore is a result of altering hexagons and pentagons in one direction, as we can find in nanotubes. We concluded that optimizing a surface that changes from a double to a single curvature is therefore likely to result in different distributions of geometries. Buckminster Fuller’s dome uses a geometric principal to optimize a structural system that can also be found in nature in form of molecules composed of carbon. We were looking for other examples in nature that use more complex geometrical patterns to optimize structure. We found that the structure of the exoskeleton of beetles uses a Voronoi pattern that changes in its formal complexity. The green beetle, Chrysina Gloriosa, possesses an exoskeleton that is made up of hexagonal cells (~10 μm) that coexist with pentagons and hexagons. Figure 4 shows a Voronoi analysis of an optical micrograph of the exoskeleton of a beetle. The diagram to the right shows a decrease in the fraction of hexagons in the pattern as a consequence of an increase in curvature.

For the pavilion we adapted these same principals. We tessellated the surface into a cellular system of altering hexagons and pentagons. To optimize the distribution of pentagons and hexagons, we defined three relationships: first, the size of modules was determined relative to the degree of curvature; second, the Voronoi pattern was determined relative to the shape of a surface area, and third the size

Figure 4
Voronoi pattern to optimize the structural performance of exoskeletons of beetles (Ahlquist and Menges 2011).
of modules was determined relative to the depth of the envelope. Collaborating with Sabri Gökmen and consulting with Matthew Swarts from Georgia Tech and Ursula Frick from [UTO] we used Rhino-Script and Grasshopper to develop the geometry of the pavilion. The script tessellated the surface of an overall form that was derived from the spatial requirements of the program of art installations. After tessellating the surface of each cell its flanges were constructed by extruding the surface in relation to its curvature. In addition to the differences in geometry to optimize structural performance, we also varied the size of the different modules based on curvature and program. The size of a module decreases with a decrease in curvature. The size of each cell as well as the size of the cell’s aperture also depended on the program of each cell. Two kinds of program were inherent in the pavilion: the infrastructural requirements for interactive art installations as well as an architectural program, including such things as doors or windows. Both types of programs were translated as an additional set of attributes in Grasshopper. This allowed for a single system to simultaneously respond to a wide range of attributes.

**FABRICATION AND ASSEMBLY**

After the cells were generated in Grasshopper the 640 parts of 320 individual cells were numbered. To be able to know the final orientation of each cell

1. Unfolded cells are routed from 4’ x 8’ sheets of high density PE.
2. Cell components are stabilized by folding the edges and pretensioning the surface.
3. The two parts of the cell are first connected to other half cells. By connecting the two halves additional tension is introduced into the surface.
the edges had to be labeled as well. The cells were then unfolded and all the connection details were added to the unfolded geometry. The final geometries were nested on 4’x 8’ sheets of a high-density polymer. CNC was used to cut all 640 outlines of the pavilion’s cells.

To make the assembly process more efficient the pieces were grouped in topographical layers that reflected the sequence of the assembly process. Putting the numbers of pieces as well as edge numbers in the sequence of the assembly process allowed for a completely self-guided assembly that didn’t require any additional diagrams or drawings. It was therefore possible to ship all the pieces of the pavilion from the United States to Paris and involve a local team of students with the assembly process. The entire assembly by a team of six people took less then two days.

**FORM AND FUNCTION**

The pavilion was selected by the Cultural Ministry of Paris for Nuit Blanche 2011, an annual art festival in Paris, France. The pavilion had to serve as an infrastructure for different interactive art installations that were part of the Nuit Blanche Festival. The project was one of a series of selected installations that were displayed throughout Paris to transform the city into an art landscape for 24 hours. Strategically located within the city these projects drew people to spaces within the city that were often normally inaccessible. The challenge for this specific pavilion, located at 23 Passage De Ménilmontant, close to the Rue St-Maur and Ménilmontant metro stop, was to create a space as a display or infrastructure for two video installations by Damien Valero, Jérôme Cognet and a sound installation by Jérôme Pougnant. The work of these artists is interactive in nature and
The pavilion was characterized by an extensive use of digital media that challenged the convention of a typical art display or gallery space. In addition, the goal was to build the pavilion as a deployable structure that might be used for other events to come. It was further required to allow for easy transport and assembly without large equipment.

The analysis of the beetle’s exoskeleton and the understanding that we could already successfully use to optimize our geometry towards structure and program was now used again in a different way. We found that its Voronoi texture not only provided the basis for the morphogenesis of the beetles’ exoskeleton but also created its color. Research papers in photonics revealed that, similar to that of butterflies and certain sea organisms, the beetles’ color is generated by its cellular structure as light scatters within its Voronoi texture. Given the program of a display space for video installation, we started to test different lighting effects in relation to the cell geometry. The most promising was an inward orientation of each cellular surface that made it easier to relate different lighting effects to the individual cell. Taking advantage of the polymer’s semi-transparent quality allowed us to use LEDs to light the individual cells from inside.

Each cell could be programmed differently based on the needs of the individual artist. The cell served as sound box or as container for sensors or small video projectors. The two parts of each cell that were connected through bolts along the aperture allowed for each cell to be opened and closed to access the cell’s interior at any time after the pavilion was assembled. The double-skin system formed by the two parts of the cells provided an opportunity to run an infrastructure of cables between the layers. Sensors and display devices could therefore easily be networked by opening and closing different cells after the pavilion was completed.

CONCLUSION

The paper uses the Nuit Blanche pavilion as a case study to explore an alternative method of using polymers for a lightweight structural envelope. In the context of an industry that is changing its production to biopolymers and increasing material recyclability, this paper calls attention to the material’s potential to constitute a more dynamic and complex architectural system. The pavilion combines the elastic characteristics of a high-density polymer with the possibilities inherent in scripting and CNC to integrate structure and envelope into a single material system with a dynamic expression. The project demonstrates how digital design and fabrication techniques can be synthesized with a program of display to generate an interactive art installation that is affordable, self-supporting, deployable and easy to transport.
ACKNOWLEDGEMENT
Architect: Gernot Riether; Design, Geometry, Fabrication, Assembly: Gernot Riether, Sabri Gökmen, Crimson Changsup Lee; Artist Collaborators: Damien Valero, Jérôme Pougnan, (sound), Jérôme Cognet (video); Special Thanks: Ursula Frick [UTO], Andres Cavieres, Matthew Swarts, Aaron Coffman, Suhee Oh, Anthony Payne, Freya Schlemmer, Kasia Życinska.

The Nuit Blanche Pavilion has been fabricated at the DFL (Digital Fabrication Lab) at the School of Architecture at the Georgia Institute of Technology. The pavilion currently serves as a travelling exhibition within Europe. It was last exhibited as part of Traverse Video, an art festival in Toulouse, France.

REFERENCES
