Solar Textiles For the Home

SOLAR TEXTILES FOR THE HOME

A Thesis Presented

By

BRIENNE ELIZABETH COSMAN

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To Rufus McDirtrock, whose sweetness
and
insatiable appetite powered me
through it all.

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Thank you to all my friends and family whose support and friendship is ever and always appreciated, I would not be where I am today without you all.

ABSTRACT

SOLAR TEXTILES FOR THE HOME

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BRIENNE ELIZABETH COSMAN, B.A., WILLIAM SMITH COLLEGE

M.S. UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Kathleen Lugosch

Solar Textiles came out of the idea that everyone has windows in their homes which need to be shaded. The question was simple, why are we not utilizing the sun's rays which are hitting the shades throughout the day. The project explored the idea of creating solar curtains which would collect the sun's energy and put it back into the curtain itself. Solar power, solar sensing, fabrics, shapes and movement is what this thesis is intending to explore. How to bring all of these aspects into a simple curtain that could be put into any house hold; making the world a more beautiful and ecologically friendly place.

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CHAPTER 1

SOLAR CURTAINS FORMULATING A CONCEPT

1.1 Introduction

I started off the year planning to create solar powered curtains. The concept was that the fabric itself would act as a solar cell. The curtains would harvest the sun's energy and then would use this energy to open and close themselves. I envisioned the curtains to be lacelike and organic with beautiful apertures that would create interesting shadows and dynamic forms. When they would open and close it would look like a living organism in your window. Just as the sun is the food source for flora and fauna so it would be for my curtains, powering them to move and grow. I ended the year with curtains that were a version of what I first envisioned. The final results were different than I expected and this paper is about the journey I took to get to the curtains I have today.

1.2 How Solar Power Works

Solar powered curtains seemed like a novel idea. First I had to understand how a solar cell works. A typical solar cell is made up of special materials called semiconductors. These are typically made of silicon, which is doped to create a more powerful current. Electrons within the doped silicon have an uneven number making them unstable and looking to move around. When sunlight hits the cell, the semiconductor absorbs some of the energy of the rays. The energy then knocks electrons loose, allowing them to flow freely.

“PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use, say, to power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.”[1] A solar cell with silicon was not going to work for what I had in mind. This would be too bulky and hard, I needed to have the semiconductor and metals either be fabric or threads woven into a fabric.

[1] http://science.howstuffworks.com/environmental/energy/solar-cell.htm

CHAPTER 2

PRECEDENTS

2.1 Soft House

I wanted to see if anyone had tried this out before. The precedents I looked into gave me hope that solar fabric would be possible. I first took a look at Sheila Kennedy of Violich Architect's "Soft House"

[1]

"Soft House"

The firm was commissioned by the Vitra Design Museum to create a household curtain which harvests the sun's energy. The team went above and beyond and created a house that has moving textiles for optimal sun exposure. Organic photovoltaic nanotechnology is being utilized to imbed the textiles with solar capturing devices. The house is proposed to be able to capture 16,000 watt-hours of electricity which is about half the needs of an average household in the U.S. This research got me excited however, her curtains seemed too generic for me. I liked the idea of the textiles being imbedded with devices but the overall look of the curtains seemed too typical. Kennedy's curtains had to be thick and cover large areas to collect as much energy as possible. I wanted something more delicate which did not need to power an entire house, but just enough to put back into itself.

2.2 Slow Furl


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"Slow Furl"

I next looked to Mette Ramsgard's "Slow Furl" for both beauty and technology. "Slow Furl is the making of a room size textile installation that acts and reacts on its inhabitation. The installation exists as a soft and pliable skin that lines the Lighthouse space. The skin shifts. As guests enter and move within the foyer, the skin moves imperceptibly at deep time frames. The skin also acts as a sensory system. Active patches are embroidered into the skin. These patches act on touch. As the skin moves, it activates the micro-controller. The simple shift between self activation (through the movement cycles of the armature) and interaction (through touch and movement of the users) allows the organism to engage an inherent indeterminacy. The architecture is behavioral rather than interactive, mobile rather than animate."[2] This was a step in the right direction. Both sensors and the armature moving intrigued me and I would come back to them from many different angles eventually incorporating both in my final curtains. I wanted my curtain to be able to sense when it needed to open and close and this installation was doing just this with fabric. The overall design of the curtain was still too bulky looking for me so I went in search of something more delicate.

2.3 Fashion

Fashion design was the next step in my process.

[3]

"Crochete Dress"

I became incredibly interested in the designs of Sandra Backlund. She uses geometric shapes to create beautiful contours on the human body. The lines she creates

[2] http://www.ruairiglynn.co.uk/curation/slow-furl/

are delicate and over the top all at once. I liked the idea of using geometric shapes to make the canvas that is the window frame come alive just as she does with her garments. “The handicraft process is also very important. It is a freedom to be able to make your own fabric while working. For me it is the absolute challenge. All the levels of skills you have to pass before you can even think about starting to improvise. I am interested in almost every traditional handicraft methods and I do experiment a lot with different materials and techniques, but it is my three-dimensional collage knitting that is most significant.”[3] The fact that Backlund actually makes her own fabric was important to me. I sewed my curtains together by hand and this brought me closer to the work than if I had used a machine. Actually placing each loop together and feeling the way they moved with each other was a very necessary part of the process for me.

She also does not feel relegated to just the human contour even though she is making clothes for the body. I started to think about how I could manipulate the curtains out of the window frame. I believe that the movement in my curtains in every dimension is in large part due to studying her work

2.4 Branching Morphogenesis


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[3] http://www.sandrabacklund.com/index.php

“Branching Morphogenesis”

Another study into the form for my curtains brought me to Sabin+Jones LabStudio. “Branching Morphogenesis” is a sculpture of a slice of a lung’s interacting cells. This is an in-depth investigation into how architecture can mimic the branching forms of cells in a three dimensional environment. They used 75,000 zip ties to show how the connections would work. People could walk in and around the sculpture and really get an idea of the cellular make up of a lung. The innovation with the zip tie connection was such a simple yet elegant way of making the links from one cell to another. I wanted to incorporate this system of a stable yet tenuous connectivity into my curtains.

I enjoyed their approach to art through science and architecture. “Within the Sabin+Jones LabStudio, architects, mathematicians, materials scientists and cell biologists are actively collaborating to develop, analyze and abstract dynamic, biological systems through the generation and design of new tools. These new approaches for modeling complexity and visualizing large datasets are subsequently applied to both architectural and biomedical research and design. The real and virtual world that LabStudio occupies has already offered radical new insights into generative and ecological design within architecture, and it is providing new ways of seeing and measuring how dynamic living systems are formed and operate during development and in disease. Overall, the Mission of LabStudio is to produce new modes of thinking, working and creating in design and biomedicine through the modeling of dynamic, multidimensional systems with experiments in biology, applied mathematics, fabrication and material construction."[4]

2.5 Magnetic Curtain


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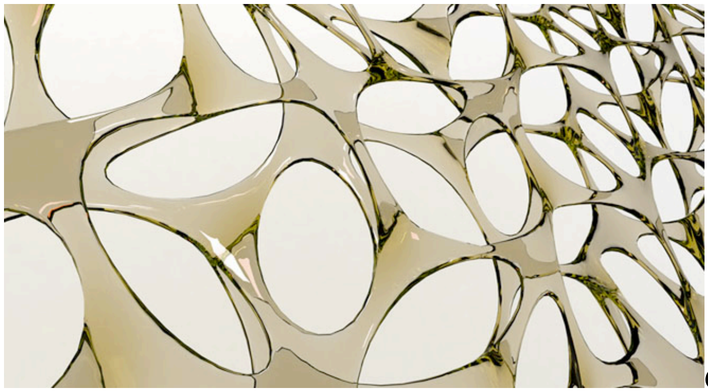
"Magnetic Curtain"

As the cellular form of my curtain began to take shape I was still interested in making it move in a way that could either be done through motors or by the owner themselves. I used Florian Krauitli's "Magnetic Curtain" as a wonderfully simple and innovative example. He created a curtain that you can shape to any form at any time. This curtain is a number of triangles with a magnet at the center of the triangle's meeting points. Through the incorporated structure and magnets, it stays in the shape you put it in. This allows the owner to regulate the look and light let into the room. I took note of the bendable aspects of this curtain and tried to use the idea multiple meeting points to aid in optimal mobility in my own curtains.

2.6 Lattice

[4] http://www.sabin-jones.com/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"Lattice"

The final precedent I looked into was a screen made by the design firm, Kokkugia. This team uses scripting and cellular matter to generate beautiful conceptual models. I really enjoyed the interplay of the cellular pattern and the undulating forms. "This project is an experiment in the affects created by morphogenetic algorithms. These algorithms are designed to generate ornamental distortions within geometry through the internal logic of cellular automation. A technique where an element in space continually changes its state based on the states of those around it, giving rise to emergent patterns." [5] The very basis of their work was exactly what I wanted my curtains to be. When the sun's light hit the curtain would move and with it the patterns of light and shadow would move and undulate. The firm was using software to generate forms that appear logically impossible. I wanted to create a script that would format how my cellular curtains would bend and twist.

[5] http://www.kokkugia.com/

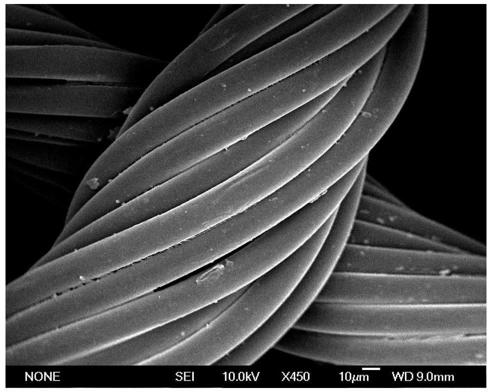
CHAPTER 3

SCIENCE AND ART

3.1 Pedot

After the precedent studies had given me ideas as to the direction I would be taking it was time to get started on "solarizing" my fabric. I teamed up with the polymer science department at the University of Massachusetts, headed by Alex Briseno to work on the solar power aspect of the curtains. I knew how solar cells worked, it was now a matter of switching out the typically silicon layer to the fabric of my choice. We came up with a system of dipping different fabrics and threads into a substance called Pedot. "Pedot: PSS or Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (see figure) is a polymer mixture of two ionomers. One component in this mixture is made up of sodium polystyrene sulfonate which is a sulfonated polystyrene. Part of the sulfonyl groups are deprotonated and carry a negative charge. The other component poly(3,4-ethylenedioxythiophene) or PEDOT is a conjugated polymer and carries positive charges and is based on polythiophene. Together the charged macromolecules form a macromolecular salt." [6]

[6] http://en.wikipedia.org/wiki/PEDOT:PSS



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"Scanning Eclectron Microscope Image of Thread Coated with Pedot"

In theory this would metalize the fabric making it conductive. Pedot is a very ductile polymer so we thought that it would bind well to a fabric, which could potentially be bending, stretching and twisting. "A traditional bulk hetero-junction organic solar cell (Figure 1) consists of an anode as transparent bottom contact, a photoactive light absorbing layer and a cathode as metallic top contact. Poly(3,4-ethylenedioxythiophene): poly(styrene sulfonate) (PEDOT:PSS), a macromolecular salt, is used for improving the surface properties of inorganic conductive oxides (ITO, FTO, etc) in organic solar cells. PEDOT:PSS films have some advantages such as flexibility, uniformity, transparency, cost and ease of processability in comparison with ITO layers. ITO which is generally used or transparent bottom electrodes in organic solar cells is too brittle and a quite expensive material to be used on flexible substrates. Additionally, good conductivities are only reached when ITO is sputtered onto substrates at temperatures that investigated." Pedot seemed to be the perfect solution. However, after many different trials and errors it soon became clear that the Pedot method would not work. The materials I wanted to work with were too elastic and the connection would break just when we thought we had conductivity. The threads and yarn that I dipped into the pedot just did not seem to adhere whatsoever. Perhaps with time, years, this would be a viable option but I only had six months to create and finish the curtains. It was a good learning experience that I feel will benefit the future of solar fabric but until the connections are solid this would just not work out for my curtains powering themselves. Worst case scenario if I really wanted actual solar power I could sew a few smaller solar cells into the fabric and have them harvest the light.

CHAPTER 4

CURTAIN STUDIES

4.1 Introduction

I started to focus more directly on the look and sensory movement of the curtains, which I knew I could complete in a timely manner. I took a very broad approach to the look of the curtains in that I wanted to test every option I could think of. I studied layers, materials, shapes and structures all at once in an effort to make up for the lost time I had spent trying to make the "solarized fabric".

4.2 Layers


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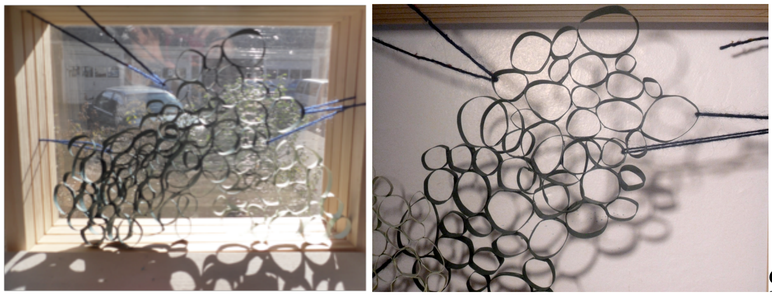
"Layer Study, Wood, Plastic Sheeting and Marker"

For the layers I constructed wooden frames with three slots in them that I could slide thin plastic sheets through. This way I could see what would happen with movement of layers from side to side. The great part about the plastic sheeting was that it served much like a dry erase board so if I did not like the way something looked, I could change it with ease. This allowed for many different options to test out.

[9]

"Layer Study, Wood, Paper and Yarn"

I was trying to figure out a way to create a system that could move easily from opaque to transparent both quickly and beautifully. Layers were a great way of moving between the two. If the layers had an openings in them that were at different intervals and then crossed each other not only were the shadows intricate and beautiful but the opacity changed in an instant. The window frame seemed like it might not have enough room for multiple screens though.

The constraints for my curtain were pretty obvious, I would be making something that would fit into a rectangular shape that was about three inches deep with varying heights and widths. I wanted to allow for movement up, down, side to side as well as forwards and backwards. This is when I started playing with materials to get an idea of how far I could really push the boundaries while still remaining inside the sill.

4.2 Materials

I found elastic materials to be the most dynamic looking. No matter what shape I started with the results always were interesting as the fabric was pushed and pulled. I tested out all sorts of materials from elastic to static just to make sure that I was not leaving any stone unturned. In all the fabrics the warp and weft were clearly visible when the material was pulled taught. "In the literal sense, warp and weft are the technical terms for the two types of thread used to create a finished woven product. The warp is the tightly stretched lengthwise core of a fabric, while the weft is woven between the warp threads to create various patterns. In order to weave any kind of textile, the weaver needs to start with the warp threads. Warp threads tend to be stronger and more coarse, because they must be able to withstand tight stretching. They also provide a core of support for the finished piece, giving the textile body and form."[7] I made my own loom to see how I could manipulate the warp and weft into different forms other than standard weaving. I found this interesting as you really got to see how the fabric was constructed. It also helped me to figure out how to cut into fabrics as I knew which way the holes would get larger or longer depending on how the threads were woven.

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"Perforation Study Material Coated in Plastic"

4.3 Perforations

I started cutting holes in the material so that when it was layered up there would be openings which could move past one another like I had been doing in my previous screen experiments. These holes were both random and logical. The random cuts created

[7] http://www.wisegeek.com/what-are-warp-and-weft.htm

a beauty that was unpredictable and exciting. Each time I pulled the fabric a new shape would emerge. Organized rows and columns were good for bunching out into another plane while not going too much out of the constraints of a sill. I wanted something that was inbetween organized and random though.


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“Nylon Perforation Study”

4.4 Voronoi

As I was cutting the perforations I started to think about ways in which it could be both chaotic and logical at the same time. This made me start to think about Voronoi patterns. “In mathematics, a Voronoi diagram is a special kind of decomposition of a metric space determined by distances to a specified discrete set of objects in the space, e.g., by a discrete set of points.” [8]

[8] http://en.wikipedia.org/wiki/Voronoi_diagram

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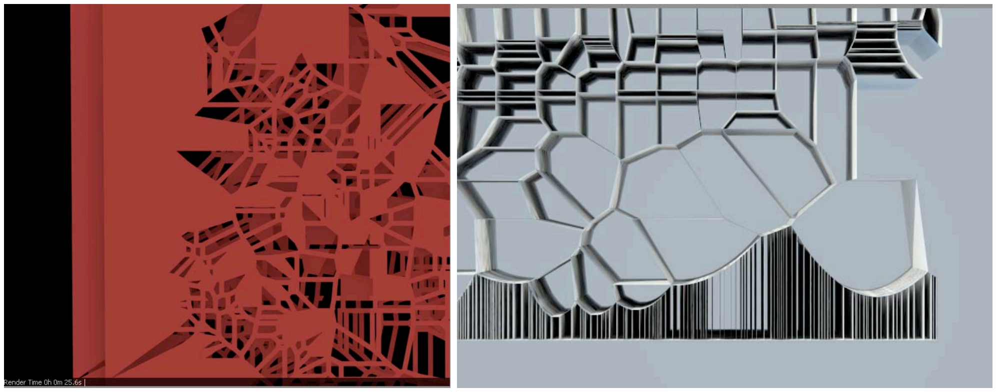
“Voronoi Diagrams from University of Massachusetts Elevations”

Voronoi diagrams are a great way to map almost anything and I had been interested in mapping as an original thesis concept. This seemed like a great way to incorporate the general idea of mapping into my curtains. I started using elevations of the University of Massachusetts and breaking them up into interesting Voronoi diagrams. I then tried the same idea with electrical and solar companies in Massachusetts and drawing the links between them. These forms were beautiful and incredibly intricate. I figured the only way that I would be able to use them accurately was if I had a laser cutter which could systematically etch out the patterns. This was not an option at this time and so and backed off of the concept to simpler forms that I would be able to cut out on my own.



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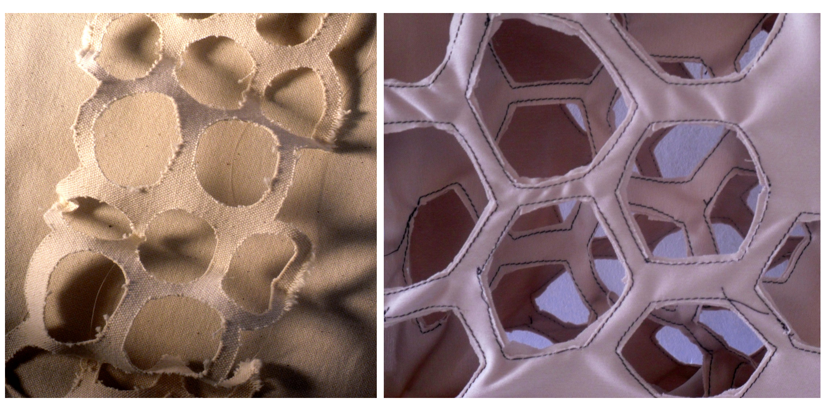
“Voronoi Diagrams from University of Massachusetts Elevations”

4.5 Nylon

I tried a series of more regulated holes and shapes in hexagonal patterns and circular cut outs in non-elastic materials. These did not hold up to the beauty of the elasticity so I decided to stick with stretchy fabrics. This meant that I would just be using circular forms any other shape got lost when stretched. After many different types of elasticity were tested, I settled on nylon. I started with actual stockings and eventually moved to the lining for leotards which was a nylon polyester mesh blend.



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“Layer Studies Canvas and Nylon”

4.6 Nitinol

So now I had narrowed down the material but I was still trying to figure out what type of structural support to use. I wanted something that would both fit into or around the nylon and be able to move the curtain in a dynamic way. I had been thinking about using Nitinol, a shape memory alloy that would effectively open and close on its own when heated and cooled.

"Nitinol alloys exhibit two closely related and unique properties: shape memory and superelasticity (also called pseudoelasticity). Shape memory refers to the ability of nitinol to undergo deformation at one temperature, then recover its original, undeformed shape upon heating above its "transformation temperature" Superelasticity occurs at a narrow temperature range just above its transformation temperature; in this case, no heating is necessary to cause the undeformed shape to recover, and the material exhibits enormous elasticity, some 10-30 times that of ordinary metal."[9] I ordered a couple feet of the nitinol wire to test out the strength and try to see how I would put the metal into the fabric. The nitinol had to be bent into a form that you wanted it to go into when heated then dipped into boiling water and promptly into ice water. This process had to be repeated several times so that the wire would remember the shape. Once this was done I sewed it into the nylon. I soon found out that the nitinol would not be strong enough to hold the curtain's apertures open for any extended amount of time.

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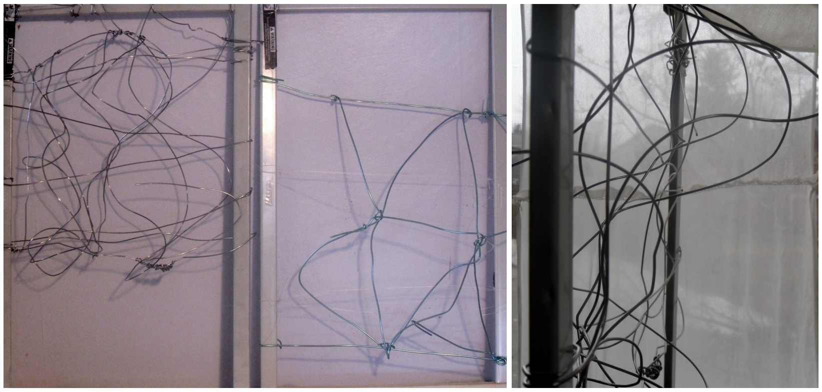
[9] http://en.wikipedia.org/wiki/Nickel_titanium

 15

“Wire Studies”

I realized that when imbedded in the fabric the heat had to be higher than it would get on the inside of a window made today with any sort of proper solar heat gain coefficient: “The SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower a window’s solar heat gain coefficient, the less solar heat it transmits.”[10] The windows in my apartment are new with an estimated SHGC of .4 based on our climate and the fact that they were recently installed. This is great for my heating and cooling bills but not when you need temperatures of 230 F to expand a metal alloy. One discovery that I did make with the nitinol is that I liked the way that the wire moved. I decided that I would have a go at regular old wires and see what kind of shapes and movement I could get out of them.

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[10] http://www.efficientwindows.org/shgc.cfm

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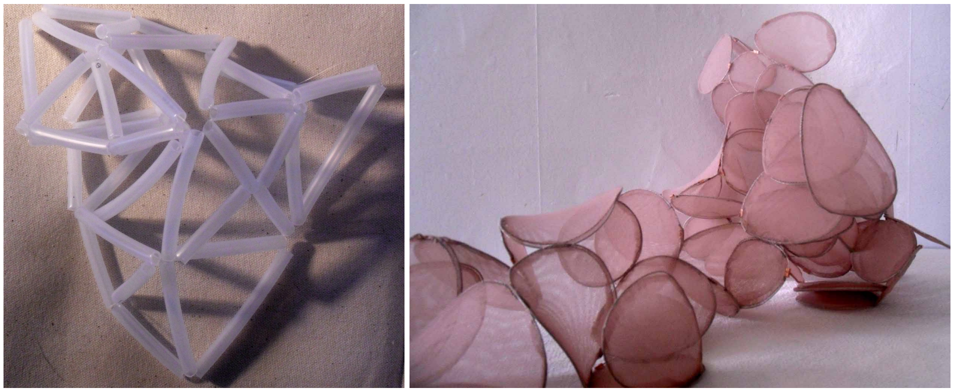
“Wire and Fabric Studies”

I started out with chicken wire and made my own version of a chain link fence as well as a simpler lattice piece. I thought that both of these would lend well to bending and twisting and I liked the way that the repetitive shapes created their own pretty forms while at the same time providing support. The trouble seemed to be when I tried to put the structure into the fabric. I could not seem to figure out a way to make it look delicate and unique. Rather it came out bulky and heavy looking. The wire could not be placed in between two layers of fabric without sewing directly around the structure. This made for a very regulated boring look as well as rather rudimentary looking as it had to be sewn by hand because the wire was too thick to work well with a sewing machine. I knew that wire had the strength and structure I needed, I just had to figure out how to make it look as delicate and organic.

 17

“Tensegric and Tensile Studies”

4.7 Tensile Loops

I had been researching tensile and tensegrity structures at the beginning of my research and came upon one of my older models. “A **tensile structure** is a construction of elements carrying only tension and no compression or bending. The term tensile should not be confused with tensegrity, which is a structural form with both tension and compression elements.”[11] I had made a simple circle which was stocking pulled taught around wire. The wire bent in a curved way due to the tension put on it and I liked the way it looked. I started playing around with multiple models putting them together and taking them apart seeing which way worked and looked the best. I ended up securing the wire into loops. The two ends being held together by a copper ferrule, then covering the loops with fabric. This provided the most stable conditions where I had somewhat of an idea of what would happen when I pulled and compressed the structure. Taking cues from my precedents I knew that if I attached the loops at a single point then when I bent

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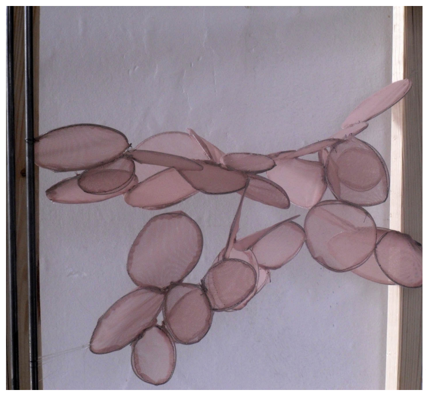
[11] http://en.wikipedia.org/wiki/Tensile_structure

and folded them interesting shapes could be formed. I put many of these pieces together and pushed and pulled and loved the results. I put my own twist on the single point by sometimes attaching multiple loops at the point. This made the loops have an added dimension but restrained them from going too far apart based on the point which held them together. I had finally found my curtain shape, now I just needed to get the frame locked down.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"Tensegric and Tensile Studies"

4.8 Rails

The window frame itself was a clear jumping off point. The tricky bit was versatility within the windowsill. I started out thinking about curtain rods. I new that the "curtain loops" would have to have a certain amount of tension on them so I started out very simple. I used a single rod which the curtain would hang from. The weight of the fabric and metal loops proved not strong enough to create the necessary tension the curtain needed. I put a second rod at the bottom and pulled the two apart and knew right away that this would work. I did not like the rod dangling on the bottom though, this seemed to cut into the structure in an odd way. I ended up turning the apparatus on its side. This made for a much more dynamic bottom and I realized that I could slide the loops up and down the rails and the shapes that were created were wonderful. I ended up feeling that two rails spaced about an inch apart on either side would be the perfect way to move the curtain both up and down and out of the same plane but keep it within the windowsill. This was the marriage of multiple layers I had been looking for. The loops sewn together could go out and come back into the same plane without actually having to be in literal different layers. As long as there were the two rods on the sides pulling the loops away from one another it appeared as layers.

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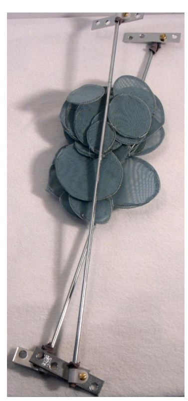
"Rail Studies"

 20

"Rail Studies"

Now I just had to figure out how to get the curtain to move up and down on its own.

4.9 Motors and Sensors

As the title suggests I wanted the curtains to be solar powered. Now that the photovoltaic cells were not involved I thought that solar sensors would be the closest thing to solar power. When the sun would hit the sensor the curtain would move to a closed position. When the sensors were in shade then the curtain would open up. I decided to use a solar sensor that was connected to a servo attached to an arduino board.

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“Servo Motor”

Servos: “A common type of servo provides position control. Servos are commonly electrical or partially electronic in nature, using an electric motor as the primary means of creating mechanical force. C servos are composed of an electric motor mechanically linked to a potentiometer. A standard RC receiver sends Pulse-width modulation (PWM) signals to the servo. The electronics inside the servo translate the width of the pulse into a position. When the servo is commanded to rotate, the motor is powered until the potentiometer reaches the value corresponding to the commanded position."[12] I ended up deciding to use a regular servo that I would modify to continuously rotate. This was so that the motor would be powerful, small and not overly expensive. Modifying the servo gave me a chance to crack open the case and see how the gears worked and gain a better understanding of the apparatus. I like the idea that eventually solar cells could be attached as the power source to the servo, but were not necessary for the initial trial. The servos would be powered by an electrical outlet which most houses tend to have near windows until actual solar cells became involved.

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"Close Up Servo Motor and Curtains"

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[12] http://en.wikipedia.org/wiki/Servo

I ended up using four sensors on the frame which in reality would be the windowsill. These were attached to the servo motors which I placed a pulley system onto. The pulleys would allow for the curtain to go both up and down. I found the right amount of torque needed was not that much as the curtains were light and the motors were strong. This meant that the pulleys did not have to be large nor the chord that would be wrapped around them.

I had a friend write up a program for the arduino board which controlled the sensors and servos. After a few trial and errors many of them resulting in the pulley system I had created running off the tracks, we figured out the speed. The pulleys moved the servos every 15 milliseconds. Any faster and the speed created too much force for the servos to handle. The movement occurred only when light hit the sensors. When there was no light the servo stopped spinning and the curtain remained still. The sensors placed on each corner of the frame gives maximum coverage and exposure to sunlight.


[23]

"Photoshopped Images of Curtains in Various Scenarios"

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"Photoshopped Images of Curtains in Various Scenarios"

At first the curtain's movement appears to be imperceptible but then the viewer notices that apertures change and shift as do the shadows. I felt it was like watching a time-lapse photo image of a flower opening up. This is exactly what I had been hoping for, an organic looking curtain that moved on it's own. The fact that it was not powering itself was a minor blip on the radar, especially as it is a distinct possibility for the future.

CHAPTER 5

CONCLUSIONS


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"Photoshopped Images of Curtains in Various Scenarios"


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"Photoshopped Images of Curtains in Various Scenarios"

5.1 Beginning to End

My struggles with the curtain project have come full circle. I started out wanting to invent a solar fabric that looked organic and cellular. I ended with a curtain which was indeed organic and cellular but instead of being powered by the sun it is controlled by the sun. I struggled with the fact that I could not create my original concept. There were times when I thought that I would have to give up completely and then I would have a breakthrough. The delicate movement of the curtains has been the constant thread in the project and I am very happy with the results.

The beauty and novelty of the curtain make it a piece that could work in many applications. From the typical neighborhood household, to a hospital or large scale piece in an airport. The materials used in the prototypes could all be scaled and modified and I feel that this could potentially cover a very broad range of products. The organic looking curtains could be used as screens, room dividers, hanging ornamental art, it could be used both indoors and outside. Both motorized and manual options could be made available which would give a broad range of price points. The structure is wire and copper which means that the curtain could have conductive qualities. This will be incredibly helpful when the solar power aspect becomes available. I will also continue to work on this in different mediums from magnetic loops to rubber and plastic and glass. There are so many possibilities with these curtains because of their simple yet elegant shapes that it is an exciting time to finish the year as it feels like the beginning of something amazing rather than a project coming to the end.


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"Photoshopped Images of Curtains in Various Scenarios"


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"Photoshopped Images of Curtains in Various Scenarios"

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