

CARBONskin

IIT College of Architecture

Seminar Course: Digital Fabrication

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Location: Chicago, Illinois

Photo Credits: Mina Rezaeian

3rd Party Collaborators: [Fiberworks](#)
[Chicago Composite Initiative](#)
[Polynt Composites](#)
[Composites One](#)
[Gougeon Brothers, Inc.](#)
[Hexcel](#)
[Hawkeye Industries](#)
[Vectorply](#)
[Soller Composites](#)

It's been one year since my former students and I designed and fabricated the [FIBERwave Pavilion](#). Since then I've witnessed a large growth of composite applications in architecture. Last year while designing and fabricating the pavilion we were inspired by the work of Greg Lynn and his pioneering use of composites. His [RV PROTOTYPE house](#) takes advantage of carbon fiber's light weight allowing a robotic armature to rotate the house in two directions. We also extensively researched the work of cutting edge composites fabricator Kreysler & Associates. In fact, it was the [Kreysler & Associates](#) fireproof composite facade panels for the San Francisco Museum of Modern Art expansion by Snøhetta that inspired this semester's carbon fiber project.

In the IIT College of Architecture exists a relic, a 1990's full scale two story glass and steel curtain wall mock-up that was used for teaching architecture students about curtain wall design and construction. The mock-up has fallen out of fashion and has been left untouched for a number of years. This semester's plan was to retro-fit a portion of the facade mock-up with carbon fiber. Specifically, I was interested in how we could transform the flat static facade into a dynamic one full of motion. My current students were tasked to design and fabricate one

full scale facade panel that was 9'-11" tall by 4'-5" wide to be installed on the existing mock-up. Using three layers of carbon fiber the panel will be 1/16" thick.

Students began the semester working in teams of two and three on a full scale Ice Structure as a means to introduce them to the idea of composites. They were first asked to produce small scale prototypes of their Ice Structures out of carbon fiber, resin, and hardener (fig. 1). For the full scale structures, in lieu of working with carbon fiber, resin, and hardener students used open weave fabric, ice, and cold temperatures. This also gave students an opportunity and feel for fabricating at full scale (fig. 2).



(fig.1) Carbon Fiber Prototypes



(fig.2) Ice Structure

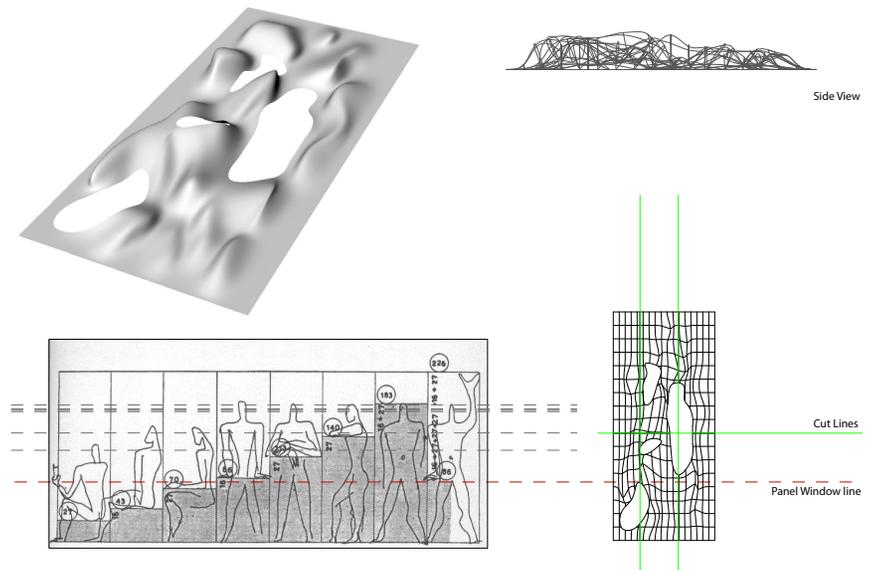
Their next assignment was to design and fabricate a scale model of four carbon fiber panels for the existing facade mock-up (fig. 3). Working in the same teams students researched and discovered that composites are actually being used in architecture and that this wasn't some radical idea of mine that I was imposing on them. They discovered: Arup and GXN Innovation's [Bio-composite facade panel](#), Greg Lynn's [Metyx Facade Mock-up](#), and Justin Diles's [Plastic Stereotomy](#). I think the idea that after they graduate there is a strong possibility they will work with composites and they would be ahead of the curve made them excited. My goal was that students would walk away from this assignment with lessons learned that they could apply to the design and fabrication of the full scale panel.

Students presented their scale model carbon fiber panels at midterm to Rick Pauer from [Polynt Composites](#). Rick has 42 years of experience working with composites and I met Rick from his online comment on the Architect's Newspaper FabriKator blog post on the [FIBERwave Pavilion](#). Meeting Rick was a major breakthrough in continuing to introduce students to composites. After the midterm presentation Rick sent an email to his contacts in the composites industry asking if they were interested in supporting the fabrication of the full size facade panel and the result was overwhelmingly positive. To go from the FIBERwave Pavilion project which was funded mostly through a [kickstarter campaign](#) with no material donations to the possibility of receiving actual material donations was an amazing step forward.

Next it was time to figure out what we were going to build at full scale. We met on a Sunday morning to discuss full scale fabrication techniques, challenges, and constraints. The student teams were given three days using the lessons learned from the scale model assignment plus the results of our discussion to design a facade panel. Then after the deadline we would vote for the winning design. As a group we felt that the winning design successfully conveyed the idea of dynamic fluid motion (fig 4). It captured the possibilities of working with a material that starts out as a cloth that can be formed to almost any shape. It also appeared to be the most challenging to fabricate thus making it exciting and intimidating at the same time. Now that we had a design to build at full scale it suddenly became real. No one in the class including myself have ever fabricated a full size facade panel so this was one of those moments when there is a sense of excitement followed by many moments when you are scared to death that it might not work out.



(fig.3) Scale model of four carbon fiber panels



(fig.4) Winning Design

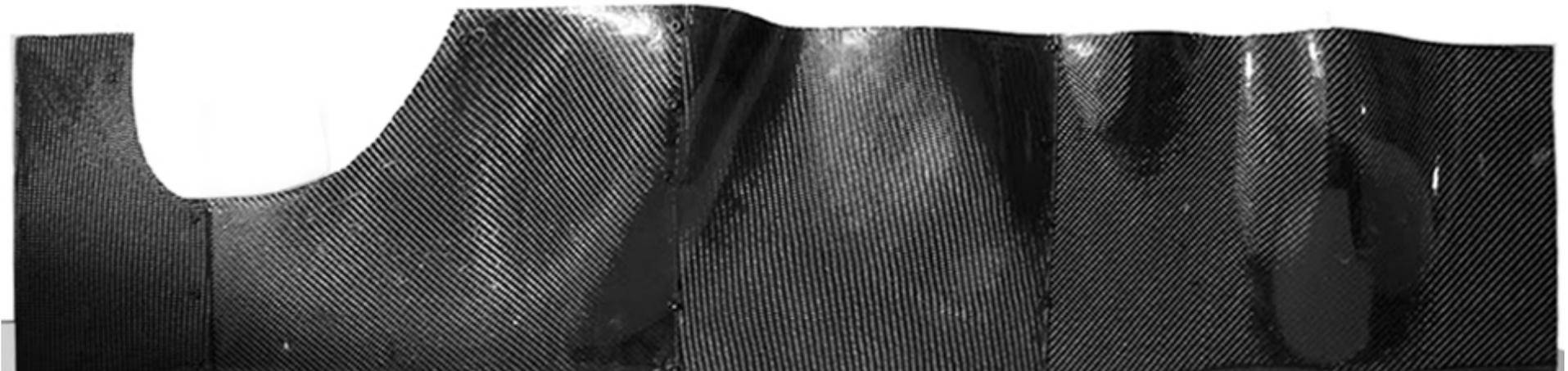
Setting students up for success has always been a catch phrase of mine and it's something that I work very hard to do. With our design selected and six weeks left in the semester we needed a plan to ensure success. Earlier in the semester students designed and fabricated small scale prototypes that provided them with valuable lessons to apply to the full scale panel but it wasn't enough to just begin the full scale fabrication. It was necessary to start by fabricating a scale model of the winning design using as many of the techniques to fabricate the full scale panel as possible (fig 5 a, b). For example the panel had to be fabricated in several smaller sections that would later be mechanically fastened together. Next, I asked the students to build a full scale 1' tall mock-up section of the panel to see what potential challenges we might face. The mock-up came together beautifully and we were ready to move on to the final panel (fig 6).



(fig.5 a) Scale model



(fig.5 b) Scale model



(fig.6) Full Scale 1' tall mock-up section

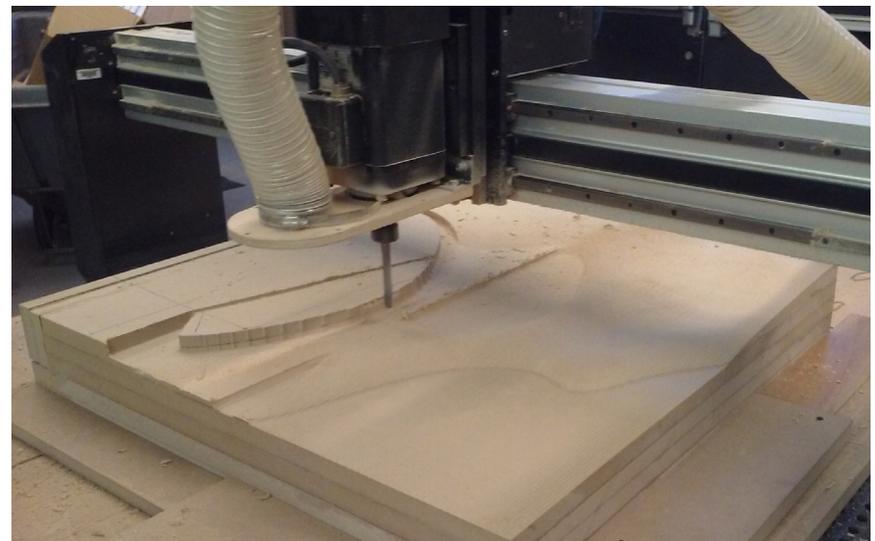
Sometimes keeping some of what goes on behind the scenes from the students is another part of the strategy for success. As we were ready to begin fabricating the full panel it was important that I assess the situation before moving forward. I mentioned earlier the major breakthrough being the possibility of material donations but with three weeks left in the semester donated material procurement was taking longer than expected. This made it necessary to re-strategize and push forward with an achievable goal planned out. The revised plan was to build 3' of the 9'-11" tall panel at full width with the idea that the remaining height of the panel could be completed by future students during the upcoming semesters. Using three layers of carbon fiber cloth it was estimated that we would need 14 yards. We are grateful to [Soller Composites](#) for providing us with the 14 yards at a discounted price.

As we prepared to begin full scale fabrication one more challenge was in front of us. Up until now we were vacuum forming polystyrene plastic over our MDF wood molds to create a non-porous barrier between the carbon fiber and the mold. The molds for the full scale panels were too large for the vacuum former, which we had been aware of, but the alternative to the vacuum formed plastic had not been tested on the scale model or the 1' tall mock-up. The alternative was to spray a specially formulated primer that would not breakdown from the high heat that is generated during the curing process. We worked closely with Brad McCumber from [Hawkeye Industries](#) who introduced us to a primer under the Duratec product line that is perfect for this application. [Composites One](#) generously donated a gallon of the primer for our project. Discovering the right product for the job is one thing but knowing how to work with it can present its own challenges. For this we can't thank Matt Locaciato of [Fiberworks](#) enough. Matt came to our school shop to prime our wood molds and give us some valuable lessons in how to work with Duratec primer (fig 7).

The full scale fabrication began with using a 3 axis CNC router to mill female molds out of glued-up layers of MDF wood (fig 8). There was a total of five molds made, three molds for the carbon fiber sections and two for the PETG window. The molds being used for carbon fiber were then sprayed with primer (fig 7). The primed molds were left to cure for 24 hrs and then they were sanded to a smooth finish. Next the carbon fiber layup process begins by first applying a layer of wax to the mold, allowing it to dry, and then hand buffing it smooth. A layer of

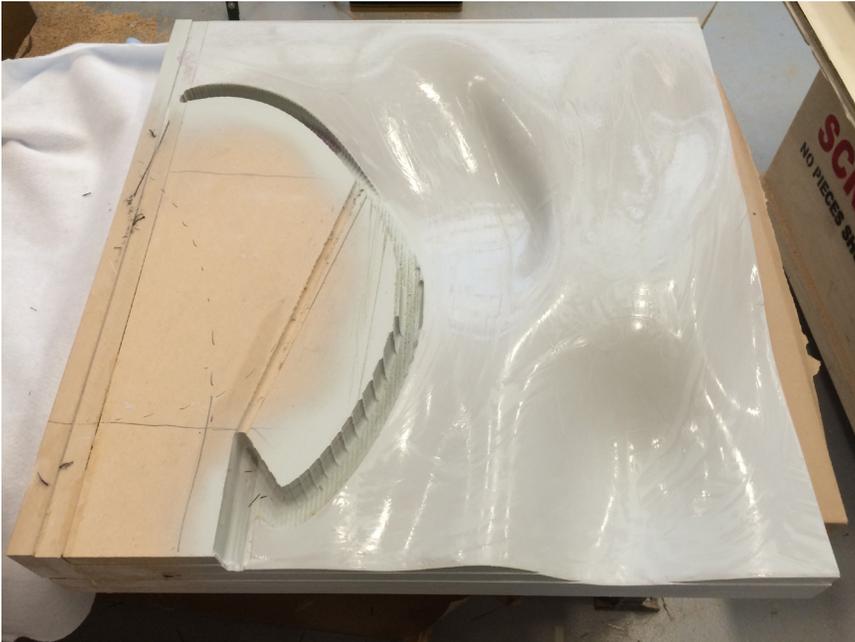


(fig.7) Primer application to female wood mold

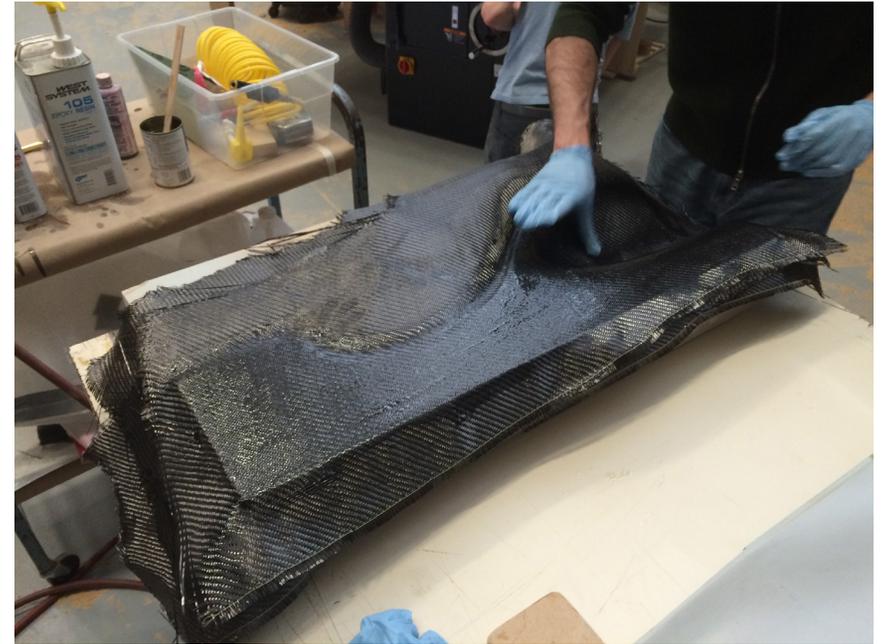


(fig.8) CNC milling of female wood mold

poly vinyl alcohol (PVA) mold release is then applied to ensure proper de-molding of the cured carbon fiber (fig 9). Next, three layers of [West Systems](#) epoxy resin, hardener, and 2x2 twill weave carbon fiber cloth is layered over the mold (fig 10). Then a layer of polyester peel ply is applied to keep the bagging material from adhering to the carbon fiber. The final layer is a breather cloth used to soak up the extra resin while under the vacuum. The mold and all of the applied layers are placed inside an airtight bag and a vacuum is applied removing all air from the bag. The mold stays under vacuum for one hour and then is left to cure overnight (fig 11). After the carbon fiber is cured it can be removed from the bag and released from the mold.



(fig.9) Wax and Poly vinyl alcohol mold release applied



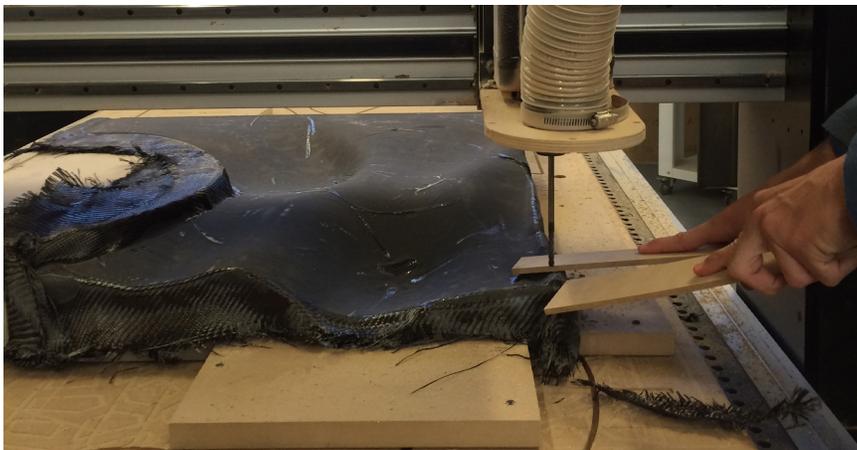
(fig.10) Three layers of resin, hardener, and carbon fiber cloth is layered over the mold



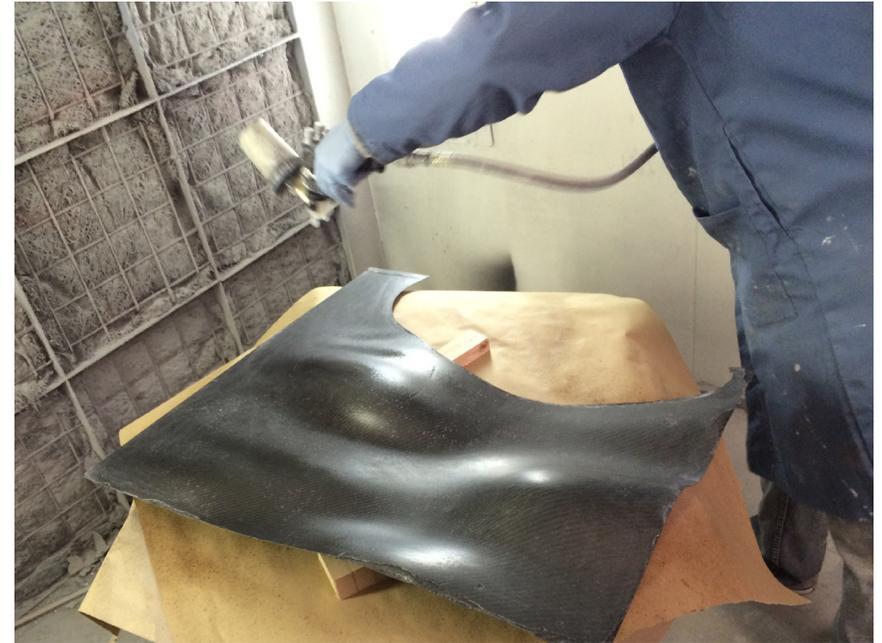
(fig.11) mold inside airtight bag under vacuum (vacuum bagging)

The carbon fiber is then placed back on the mold and trimmed to size using the 3 axis CNC router (fig 12). After trimming, the surfaces and edges are sanded and cleaned. Next a Duratec clear top coat is applied to fill in small voids in the surface finish. The top coat is then sanded to level the surface finish. After sanding, another layer of Duratec clear top coat is applied to bring out the depth of the layered carbon fiber (fig 13 a,b).

As the project and semester came to a close we were able to procure donated material that will be used this Summer by a new group of students who will continue fabricating the full size facade panel. In the near future I look forward to working with students on advancing and experimenting with new carbon fiber techniques, processes and materials. [Hexcel](#), a manufacturer of carbon fiber cloth, generously donated 14 yards of 2x2 plain weave carbon fiber cloth. I'm excited to experiment with plain weave, first because I haven't worked with it yet, and second because you see it used on so many Ferrari and Lamborghini cars. [Vectorply](#), a manufacturer of high performance cloth, sent us a sample of a specially woven high strength cloth that could reduce the number of layers we use. Additionally, thanks to a new Duratec primer that can be applied to foam molds by creating a barrier that protects it from the epoxy resin and hardener we should be able to save in material costs over MDF wood molds. We would also save time since it is faster to CNC foam molds than it is wood. Finally, I would like to try the vacuum infusion technique where epoxy resin and hardener is evenly infused into the mold and through the layers of carbon fiber by vacuum versus being applied separately to each layer by hand.



(fig.12) Trimming of panel on CNC



(fig.13 a) First coat of Duratec clear top coat being applied



(fig.13 b) Panels after sanding first layer of Duratec clear top coat

The final panels turned out well (fig.14 a,b,c,d). I continue to enjoy the carbon fiber fabrication process and how it shifts back and forth from machine made to hand made. I've also been given renewed enthusiasm about what my students and I will accomplish in the future with the support of so many in the composites industry who are interested in our work and are supporting us on this project.



(fig.14 a) Full size panel in front of historic S.R. Crown Hall



(fig.14 b) Full size panel detail



(fig.14 c) Full size panel detail



(fig.14 d) Full size panel on facade