Wind & Water: Material Tectonics in Digital Fabrication

COREY SAFT

COLLABORATORS: SCOTT ENGE, CHARLES DUVALL, MATT FLYNN, BENGI BEAU, DAVID JAUBERT

University of Louisiana at Lafayette

In the spring of 2004 I ran a two-part workshop resulting in two, built installations based on material investigations. The two parts of this project were:

1. A steel rib component, designed in *Rhino* and fabricated with CNC technology
2. A fabric surface component, physically modeled and hand fabricated

The steel fabrication process receives more attention in this paper because of its ability to elucidate the overlap of digital technologies with the fabrication processes, material considerations and the tectonics of construction. The two systems, however, allow for a comparison that brings many issues related to digital fabrication into a useful focus, including notions of arbitrariness, the balance of physical site with its digital recreation, and thoughts on ways to reconcile the idealistic precision of the computer with the invariable interpolation of digital design. The function and form of curves play a prominent role in this paper as well. Digitally generated curves rely on the establishment of a few known points, and then there is a spline or a Bezier curve, or some other mathematically based notion that interpolated between them. There is a basic conflict between precision and interpolation, between the engineer/material specialist and the artist within the architect. The digital technology highlights and will eventually transform this conflict.

A traditional, manual fabrication process created the fabric structure while the steel structure emphasized digital techniques. There are similarities and differences in these methods and while they appear to be divergent in form they can, nonetheless, be spoken about with the same language. My intention is not to mark deficiencies in the steel process or the fabric, but to compare the two processes in a dialectical manner in hopes of suggesting a next step for further investigation. I am not looking for a universal solution but a simple process that could be the next installation.

BACKGROUND

In the spring of 2004 the University of Louisiana at Lafayette School of Architecture and Design initiated a national design collaboration titled: *Fabricating Modernism*. Its outcome was to be a semi-permanent installation of fabric and steel that would create a student lounge area on the upper terrace at Fletcher Hall, the home of the UL School of Architecture.

By the end of the project over 75 people in four different states conducted design and fabrication with representatives from all three disciplines inside our School: Architecture, Interior Design and Industrial Design, with the core group coming from a UL Lafayette second year Physical Systems class. The projects were experiments to explore emergent and traditional technologies from the most immediate, intuitive physical modeling and on-site decision making to extensive 3-D computer modeling that directed remote laser cutting of steel. The larger community, from the greater Lafayette area to New Orleans, Texas, California and Maine came together in finding and donating the resources and helped to make the project happen.

STEEL PROCESS - THE WATER

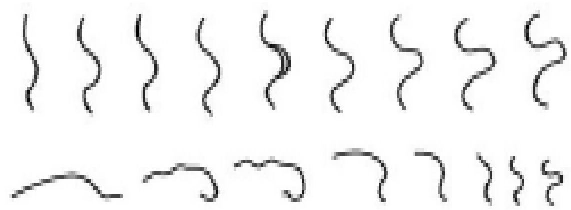
The steel workshop was conducted under the guidance of our guest Scott Enge, who runs Marmol Radziner & Associates in-house architectural metal shop in Los Angeles and has long been involved with emerging fabrication processes. Our process began with three sheets of donated stainless steel and a generous offer to use a local fabrication shop's laser cutting technology. It quickly became apparent that we would be modeling in *Rhino* and forming the steel with CNC technology - any predisposition towards straight lines would be a vestige assumption. Yet, as we began the design process our questions revolved around a search for a language and the biases of our chosen technology.

There is a strong argument for the efficiency of the digital process in its ability to skip over the construction documentation phase in the traditional architecture sequence. CNC technology represents the ability to fabricate three-dimensional designs without having to go through this CD phase where the designs are drawn out in detail – and the majority of an office's mistakes are made. The CNC process allows digital designs to go directly from computer to fabrication, thereby skipping the time-consuming steps of manually drawing and describing the assembly of the component pieces that have traditionally made many designs cost prohibitive.

The technology's efficiency is certainly one of its advantages, but so also did it seem self-evident that the technology pushed for complex curves – largely because this is what CNC technology can do easier than other technologies. Curves are traditionally difficult to induce, both in terms of fabrication and in terms of form. In removing a limitation such as assumed orthogonal geometries, the design process can be opened, while at the same time decisions can become more difficult. Because we had limited our scope, we knew the why–– in this case simply because we could. The difficult question was the what – what was the form language. The iterative quality of the regional landscape offered a relevant template for the project's formal expression.

The landscape of Southern Louisiana is defined by the dissipation of the Mississippi River into the Gulf of Mexico. The slow unfolding of the river through bends, curves and oxbows, stutters and stumbles and repeats itself as the river opens up into its delta. The river is a study in curves. The region is a study in the river. The iterative curves of the region became the template for our project.

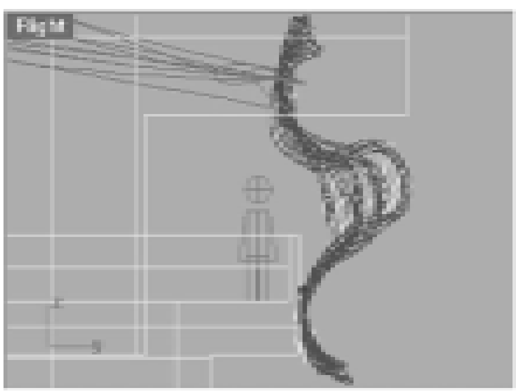
The curves of our project began as a screen system along the edge of the terrace which doubled as ground points for the outboard ends of the soon-to-be-fabric structure above. At this stage the design had developed into a time-lapse sequence of the formation of an ox-bow (the 'U' shaped river formation that is found, among other areas, throughout southern Louisiana). The ribs showed a measured progression of the natural transformation of the river, over the course of, perhaps, centuries. The equivalent meander in the Mississippi River literally defined the delta landscape within which our School sits. About this time the engineer who had been helping us for several weeks suddenly had a change of heart and almost without explanation called to tell us that'"it" wouldn't work and that for unrelated reasons he was leaving town.

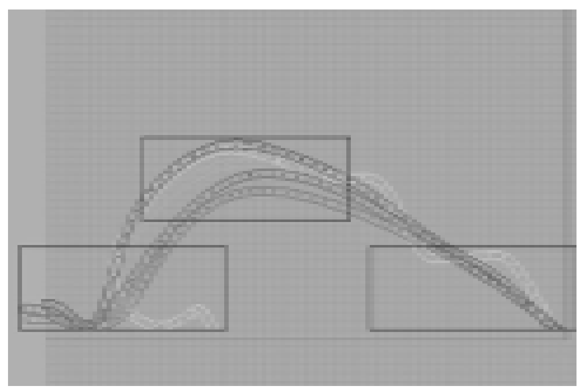


Anuradha Mathur and Dilip da Cunha. Mississippi Floods. Hong Kong: C&C Offset Printing.

We started out wanting to say something about our landscape by tracking the formation of an ox-bow in our ribs. We did this but apparently couldn't stop the design's own meander as the curves of our installation found themselves no longer as a screen at the edge of the terrace but as an island in the middle of the terrace. When our engineer left us we had to begin to think of our project as a piece of furniture with nothing structurally dependent upon it. The relocation of our ribs from edge of terrace to its center oddly paralleled the formation of an ox-bow. Our steel ended as an inland island disconnected from its original source. While the final form of our project resisted our original intention, this act of resistance fashioned it into an oxbow nonetheless. The steel lost its role as outrigger for the fabric and became an object in the open field of the terrace; a key relationship was lost and our form began to seem arbitrary.

At each stage our discussions revolved around what form the steel was to take. Anything was possible but we wanted to use this opportunity to investigate the medium. Our discussions kept going back and forth between the form (read: the complex curve first generated in the computer) and the structure (read: the ribs we needed to support these curves). In the end, our difficulty seems to be in our inability to reconcile the “ideal form” of the computer model with the dynamics of actual site conditions. Once our engineer pulled out, our intervention became conceptually untethered and physically floated in the space of the terrace.



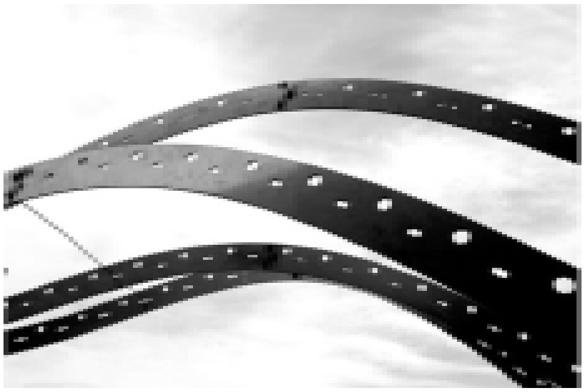


CONSIDERATIONS

Our process began with creating curved surfaces in *Rhino*. In order to map the surfaces into planar sheet goods, we abstracted the model into a series of singular sectional moments. These became lines of structure. Later, these singular, known moments would be interpolated with weaving members to recreate the original complex surface. There was a play between what we wanted to know and what we needed to know to make an estimation. We wanted to know the original complex curve that had been developed in the computer; we needed to know a minimum number of ribs to estimate this form. The necessity of estimation in the manual weaving of the rods provided one of the few moments where the idealistic precision of the computer was tempered by input that did not begin within the computer. There is an evident conflict between the idea that interpolation is the way the computer works and the human desire to try to use the comprehensiveness of the computer to control as much as possible (ex: endless efforts to facsimilate the qualities of the destined site within the computer).

Locally, the ribs made for a series of site forces that had to be responded to which ultimately helped to determine the rods’ locations. The balance between the ribs as control and the weaving rods as interpolation seems to describe the psychology of our project. Once we had done enough work to look back over it, the bias of our working method seemed apparent. Clearly, the organization of the computer model was based on a technique of construction as well as design intention. The model was about two things: 1. The ribs, which are where the moments of a complex form are sectioned to become lines of structure, and 2. Weaving members that interpolate between these known moments (ribs) to form space and reconstruct the original form that was created in the computer.

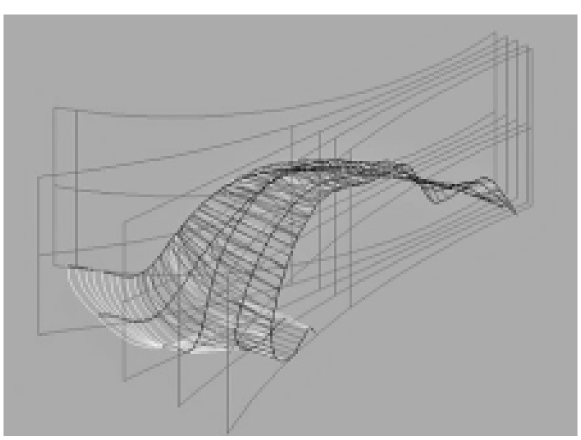
Although radically different from traditional forms, this type of construction continues a simple tectonic logic: there are ribs and weaving, space defined and the tectonic needed to support that definition. The ribs were always about how to fabricate, the weave about the space. This structure/enclosure relationship is part of a long history dating to Semper’s observations about a Caribbean primitive hut. Traditional tectonic principles remain in a digital age – except here there is beginning to



be an elision between fabrication and design. The computer model is not only facilitating both processes but also acting as an apostrophe and abbreviating both into one step. The distinction between the traditional architectural stages is being lessened through the potential of digital tools and the method is falling somewhere between analogy and elision.

Design and fabrication were related by the information in the computer model. The digital model played two roles, and this is evident in its appearance. The role of the ribs was to determine a constructible correspondence between the complex curve and the material. The role of the weaving, on the other hand, was to interpolate between the ribs, creating a closer form of constructible analogy to the original forms of the computer model. The original content of the curves first generated in the computer is in the interpolation, not the structure.

The section in this project is both an analysis of form and an element of fabrication. It is the section, or the abstracting of three-dimensional space into a flat plane, that gives us our ribs and brings us back to our 3 flat sheets of stainless steel. Our constructional starting place is the mode of operation of our technology - planar but not orthogonal. We see the rib as the elision joining the structure in the design with the sheet-goods needed to fabricate it.



FABRIC PROCESS - THE WIND

While the steel portion of the project evolved from the technological means at our disposal, the fabric component developed from the empirical nature of manual production. The difference can't be more marked'– from digital to analog, from precision modeling to on-site design, from theoretical to empirical. The similarities can't be more obvious – folds, curves and a language that derives from a larger natural order. Together these projects are a study in comparison. They ask to be talked about together yet resist equivalency.

Like the steel, the material choice was largely a pragmatic one. Charles Duvall, a noted fabric designer, was to be a guest lecturer and, opportunely, he had previously taught at ULL some 15 years ago. Through donations we were able to confirm a bolt of polyethylene mesh, a material developed in Australia to protect agriculture from the sun blocking 70-95% of its rays. In its own category this mesh was as ideal for the second installation as the stainless was for the first installation. Charles, like Scott with the steel component, was very accommodating to our request to spend nearly a week in the Bayou working on an installation - they both embraced our experiment with much good will.

From the earliest conversations Charles introduced a different attitude from Scott towards his medium. To get too specific was almost burdensome – it would come. To try and predetermine too much engendered quizzical responses – I seemed to be missing the point. But he would always talk about the materials, about their maximums and minimums, and about possibilities. His way of thinking was experiential and as one would expect from this attitude, the working method for the fabric was primarily empirical. While the forms in the first project had strong elements of intuitiveness, we were clearly working with a different kind of intuition in this process. The idealistic precision of the computer was traded for an, almost, assumed lack of control. And as we shall see, there was no original curve we were trying to reproduce, the equivalent to the ribs in the fabric structure came last rather than first, and it was the interpolation that drove the formation of the project rather than its structure.

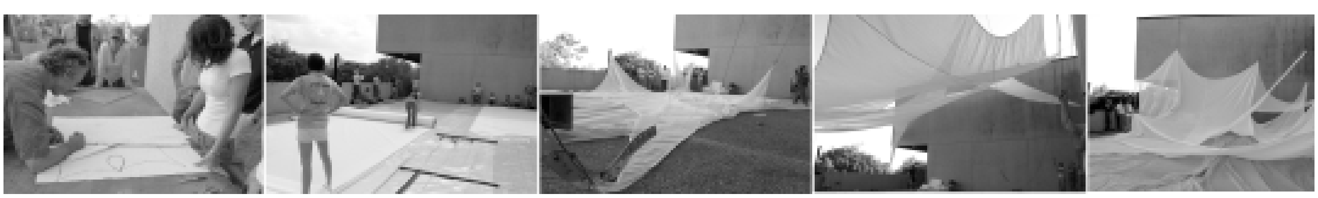
To prepare the building, we sank 12 eyebolts into the walls of the terrace destined to receive the ends of the fabric, and we also developed a kind of outrigger to catch the fabric on the outboard side of the terrace. The eyebolts were estimations between the existing layout of the terrace walls and a distribution that might prove useful for the fabric. They could have been placed anywhere, but this does not matter. It is in fact the point. The fabric, as much as it was pre-designed, had to come into balance with the actual location of the eyebolts—which were located for site–specific reasons. Once the bolts were established these were then the known moments among which a further series of approximations could be made. The fabric became an instrument that expressed the balance of these competing forces, and this allowed us to tune it. The fabric had a life that could not be known before its installation; it was a process that actively resisted a heavy hand by the designer. As is often said to a student: if you know the form your design will take, you have negated the process—with the fabric as an example the idea of process was expanded to extend throughout construction.

The design process for the fabric was a series of acknowledged estimates and often an issue of scaling. Students experimented with the fabric, mocked up versions, and slowly began to work a 1/2" physical model of the terrace. The form evolved from a series of iterative adjustments. Each adjustment was part of a slow and somewhat laborious process of fine-tuning the fabric to offer no resistance to what it had been stretched into – it was a process of tuning not controlling. The template was cut and re-cut as the design and the designers pushed back and forth. Curves were slowly adjusted, let in and then taken out. Lengths grew and shrank, and arcs developed and waned, each time reading the fabric to determine if the last adjustment was successful. Finally the negotiations exceeded the scale, and we shifted to full-scale.

The fabric template was gridded, registration marks identified and the whole thing scaled up from 4 sq ft to 2000 sq ft. It was a vector operation, as we re-struck the curves from reference points. This process allowed us to resolve the inaccuracies endemic to the small model with which we had begun. Interpolation provided more facts with which to describe the surface. We had more information as we scaled up because we had a larger field on which to see it.

CONSIDERATIONS

We can track the curved lines of structure in both the steel and fabric installations and see that they articulate moments of rationalized force. The steel ribs and the reinforced fabric edge describe how force is translated across each structure to a point of support. These lines of force express moments of knowing in a much larger field of estimation. These known lines of force are then woven together with a second system that interpolates the tendencies of a larger field. From these known moments, described by rib and edge, the woven rods and the stretch of woven fabric fill in a field between the lines of force - a field not previously described.



Like the steel, the fabric's form evolved from its bias. The weave of the fabric exerts an equal pull when organized along its diagonal'– a condition literally called its bias. As lines of force are identified at the edges, the field begins to move from a loose description (lufts and ripples) to a precisely described complex form (taut). The surface disturbance in the fabric registers its closeness to its ideal form, given its edge condition. The fabric provides feedback.

For both the steel and the fabric installations, the natural order became the template for how to use technology. In the steel component we abstracted a landscape condition; in the fabric we established a measure for site conditions. In terms of its fabrication and installation the fabric became an instrument for its own accuracy. The empirical method of manual fabrication offers a type of precision that computer modeling missed. This precision, however, is a product of the process, not the medium. The digital process seems to have something to learn from the fabric process: not to control everything. This lesson seems to point directly to the construction process and how to balance the computer's tendency towards precision with its ability for interpolation.

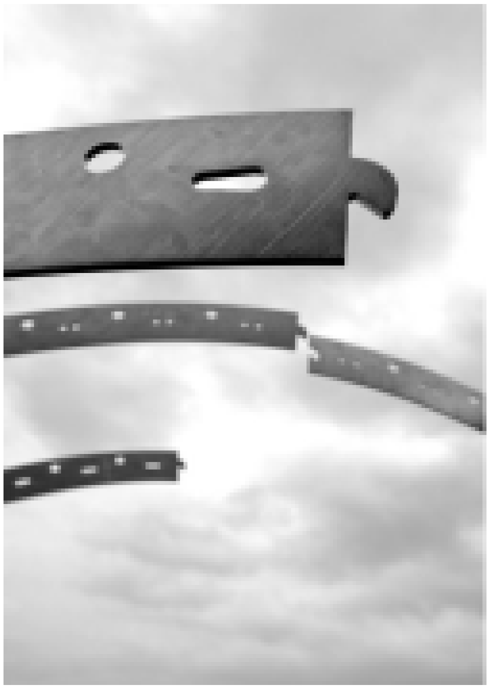
The introduction of a slack joint into the digitally driven construction process can allow it to mediate the abstraction in the computer model with the actual site conditions. In construction, the precision of the computer usually proves to be optimistic and does not match the reality of the site. At that point we are left to change the reality because the computer has already cut its pieces. A systematic means to negotiate the precision on the one hand and the unpredictable reality on the other is what needs to be devised and it seems that the construction process holds the greatest potential to accommodate this.

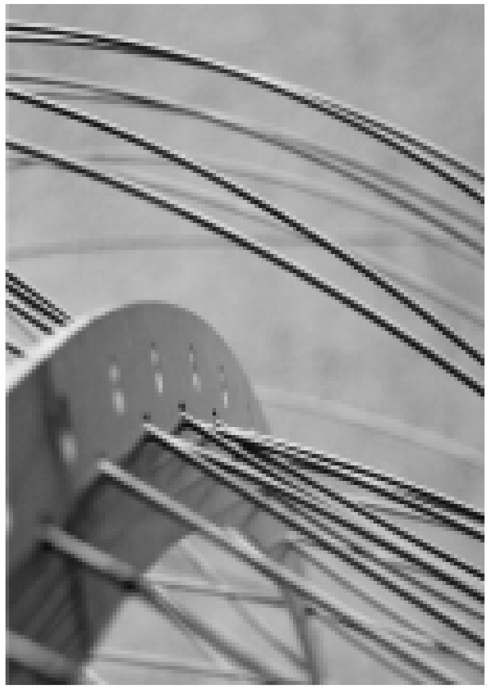
CONCLUSION

It is within the final forms that questions are raised and possibilities lost. The contrast between these two final forms, fabric and steel, demonstrates some of the consequences of each of their working methods. Computer models generated in design development can go right to the fabricator. It is a relatively new way of working and a new way of thinking. Work is front-loaded from the typical Herculean effort of construction documents to design development. The ability to work intuitively at this point is potentially overburdened with more requirements such as the needs of final construction. A reductive pull is potentially established with many ill consequences: spontaneity and complexity are established often without a corresponding sophistication of order. This arbitrariness is a design concept that needs to be ideologically addressed in the digital age. The material and local condition of the site can become estranged from the design process. Or, designs are generated from something that already has a 'unique', but not designed character'– crumpled paper for example. These are conditions that the digital design process can subtly encourage. As the medium becomes more abstract, the project is reduced to how it looks, not what it does, facilitates or engenders. Because the criterion of judgment becomes indeterminate, the consequences become potentially suspect—all are issues of judgment, however, not particular to the technology.

The computer is a means of bringing design and fabrication together with little means of establishing any kind of empirical confirmation. In the same way that a computer model can go directly to a fabrication shop without the production of separate construction documents, so can the translation of a computer model go directly to a built object and skip the tectonic logic that provides a system of measure and relationship.

The question is how to tie what happens within the computer to the world outside of it. The temptation of the computer is to believe that the world





created within it can be complete. Perhaps GPS technology or other potential real-time/real-space input might be an alternative direction but the conceptual need to negotiate the precision and the interpolation of digital design offers more immediate alternatives as well. By leaving an element of the building assembly variable, there seems to be the possibility for a dynamic, site-defined and digital process.

For our project we did not digitally take construction into account except for one very central element: CNC outputs. Our assembly was not tied into the digital process, save for the directions that we were able to laser-etch onto the steel. I am suggesting having a purposeful, determinate piece of the process located outside of the computer. In the fabric this occurs first by the placement of the eyebolts, but these fall far short of a constructional system. Our need to push and pull on the steel in the process of erection was the product of our inability to precisely locate the pieces as they had been in the computer. So, while the assembly of the steel did offer resistance in taking its form (or the form we wanted it to take) just as the fabric did, this type of resistance is clearly of a different sort—it didn't provide more information, it just made us work harder to reproduce what we had in the computer. It is a negotiation from both of these ends, the computer and the site, that is required. I don't believe the idealistic precision of the computer is attainable in any sustainable way, and I am looking to introduce a kind of slack joint into the process that both allows for this incomplete precision as well as potentially ties the process of construction to the site in a more intimate way. It seems we either 1) have to absorb assembly into the digital process - which might be as easy as designing jigs in *Rhino* that would prevent the type of assembly struggles we had; 2) provide some space for 'slop' that is also an active part of the construction, so assembly is not simply a matter of reproducing the abstract condition from the computer; or 3) struggle,•• as we did.

The contrast between the steel and the fabric projects is in the processes they encourage but there is not a difference endemic in their technologies. Digital design highlights the designer's ability to control information and consequently has often been suspected of being arbitrary. While the computer allows for systematic actions, it requires the designer to be more cross-disciplinary and open. The architect must now understand the materials, techniques, and processes of fabrication as an equivalent empirical knowledge. The differences among the architect, the engineer, the artist and the fabricator are evaporating as the demands of technology are reshaping our fields.