30 Pieces of Plywood: Exploring Digital Processes of Making

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INTRODUCTION

For the past three decades, the integration of digital technology has evolved from the replacement of the drafting board with an emphasis on production and efficiency to an essential tool for visualization. It is at this point that the practice of architecture is beginning to critically examine the implications and opportunities that digital design and fabrication technologies offer in contrast to the established method of architectural design, production, and delivery. Within academia, schools across the country and abroad are beginning to recognize the need redefine the "woodshop" to include CNC devices, i.e., CNC routers, laser-cutters and 3D printers. It will be implementation and application of the "digital fabrication shops" that will define the next step for computers in a digital era. Investigating the relationship between architectural design and a digital means of production will provide a material understanding to a new digital practice of architecture. Alicia Imperiale describes in her book New Surface Flatness that, "Digital technology has not only ubiquitized media, image and communication. It also poses a radical shift in the material, technology and communications involved in the construction industry." This has lead architects to search outside their own discipline for inspiration. (Imperiale 2001).

This renewed interest in understanding building materials and assemblage methods coupled with the digitally facile designer will challenge the traditional role of the architect and the project delivery process. Establishing a relationship between the designer and fabricator will allow for new avenues of collaboration. Exploiting the opportunities inherent in a digital design process, whereby information can be exchanged between collaborators from conceptual design to fabrication, allows the architect once again to be immersed in making. Understanding of the fabrication process and the translation of digital design models to the Computer-Aided Manufacturing (CAM) software for the generation of control data to drive numerically controlled fabrication equipment will allow designers to be part of a feedback loop that can now inform the design process. Where once the computer provided solely a digital representation of the design intent, it now provides instructional data sets for CNC fabrication.

This paper describes the process and conclusions related to the implementation of a digitally fabricated installation within the context of an undergraduate third-year architectural design studio, entitled "Thirty Pieces of Plywood." The "thirty pieces of plywood" referred not only to the material (plywood) under consideration but the scope of the installation (30 pieces) as well. The installation served as the final four-week project in the fall term for a group of 15 students exploring the potential of using a digital "medium" for design, collaboration and construction. Various components of the project were divided among teams in the studio that became responsible for design, coordination and the fabrication of their respective components of the installation planned for the courtyard space adjacent to the architecture building. The "thirty pieces of plywood" installation required the design teams to tangibly realize a digital form, understand the material nature of architecture in both a digital and material realm and interrogate digital fabrication of a process of design. Fabricating reality became the process of reconciling the digital and the material. Students sought to exploit the exchange of information afforded by a digital medium, allowing the digital model to become the vehicle for design, fabrication and assembly.

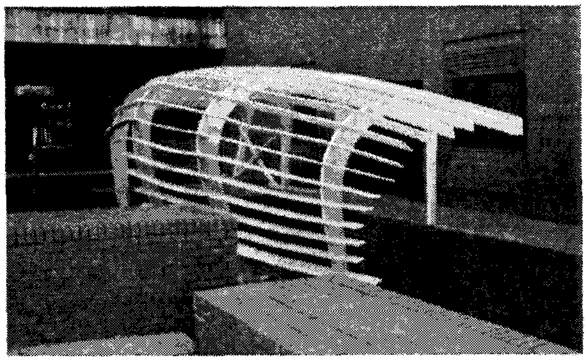

Figure 1. *Completed Installation in the Courtyard.*

DIGITAL PROCESS

The representation of materials in the immaterial realm of the computer has brought about a fixation on image over that of an object's true physical properties. This fixation on image limits the role of the computer as merely a tool for visualization. Advances in software technology have provided the designer with the ability to accurately represent a material in an immaterial digital world. Material properties in the digital world are assigned, characteristics such as reflectivity, incandescence, transparency, diffuse, specular, shinyness, eccentricity, and color all of which represent a visual component of a physical object. The true properties of a material like strength, stress, and texture can only be experienced in the physical realm. Digital design has also taken on a new vocabulary and method of form making. As Joseph Rosa describes in Folds, Blobs and Boxes: Architecture in the Digital Era the differences in vocabulary in contemporary architecture verses that of a pre-digital era where "beauty, scale and proportion... have given way to adjectives like smooth, supple, and morphed." (Rosa 2001)

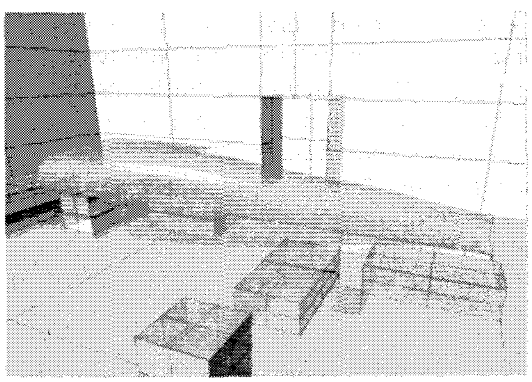

Figure 2. *Design Intent: Surface Model.*

Digital media has brought about a blurring between what is real and what is virtual. Due to this blurring between the digital and the real, designers are becoming further removed from the material, that which is physical, to explore the intangible, ephemeral accepts of virtual space. This project seeks to bring a material understanding to a digital design process and allow a digital craft to emerge. The blending of design and fabrication via the computer is providing opportunities for architects to return to a previous era of the "master builder".(Cheng 2000) Computer-numerically controlled devices allow architects to share in the process with fabricators and to understand more the act of assemblage and fabrication.

DIGITAL DESIGN

This project began as a digital exploration investigating the process of translating a digital representation into the realm of real materials. The studio was provided with a digital surface that served as the design intent for the project and became the standard by which each of the teams would generate their respective components. The teams were divided into the various structural components; the primary structure of the ribs, secondary structure of the slats, and the final component of the skin. The digital process was centered on the ability to exchange data between individuals within each team and between teams. Using the digital model as the single source for design and construction allows one to visualize potential areas of conflict. The intent of the project was to translate a "digitally born" surface into a materially analog equivalent. (Kolarevic 2003) The benefit of a digital medium is that the process of moving from conceptual design to fabrication, through a "file-to-factory" process, is collapsed and the time allotted to design is extended into the fabrication process. (Kolarevic 2003)

COORDINATION

The ability to coordinate between the teams quickly became critical to success of the project. Teams could not work within a vacuum as is sometimes the case when working independently as the sole author. Within the first week of working together the coordination between the rib team and slat team began to breakdown due to a lack of communication. The digital data shared between the teams needed to be coordinated. Simple naming conventions and common areas on the network made accessible to all teams and team members needed to be established. Work schedules between the teams and among the team members varied leaving the most current file hidden within a field of data. As the week progressed, certain students from each of the respective groups emerged as a point of contact and the responsibility of coordination fell on their shoulders. Miscommunication between the teams demonstrated the need for a project manager. By the end of the second week, one student took on the responsibility to ensure the coordination between teams, final fabrication instructions and final assembly.

DIGITAL DESIGN DEVELOPMENT

Design development takes place within any project and the "Thirty Pieces" project was no different. As the "surface" began to be realized materially, the teams needed to understand the limitations of the selected final material, plywood, and the limitations of the 2D cutting process. Once the final shape had been established for each individual component, whether part of the ribs or the slats, further analysis of how the component would be fabricated from a 4'x8' sheet of plywood needed to be explored. In many cases the component at full scale would be greater than the length of the plywood. The design development needed to materially explore each of the components at full within the model space of screen.

For example, the primary structure of the ribs was created by slicing the surface at regular intervals. This slicing method produced the desired profile but not the actual material component needed to support the structure. The fabrication of each rib would require three layers of the plywood to ensure the seams or joints would be staggered over the length of the rib. This staggering of smaller pieces to construct a larger member had an added benefit in that it conserved the number of plywood sheets for the project. Reducing the radius of the components allowed the pieces to be nested more closely together thereby reducing waste. "Nesting" is the process of closely compacting items together. The nesting required some forethought as well. The 2D Cutting process using a CNC router with a ½" router required the students to consider a 1/2" kurf to compensate for the amount the bit would remove around the boundary of each component. Once each of the components had been successfully broken down into its respective smaller elements the task of nesting multiple pieces on to one sheet of plywood and labeling each of the components to ensure coordination was the task at hand.

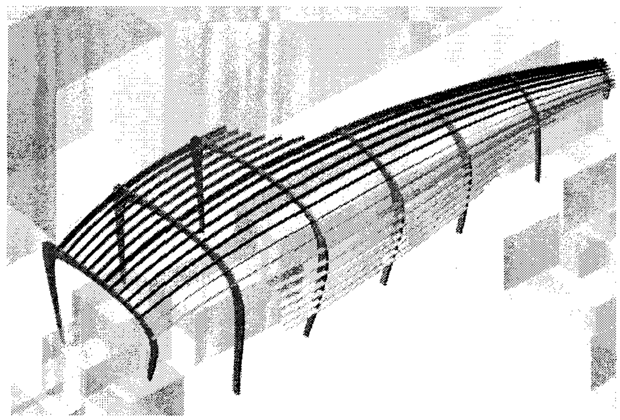

Figure 3. *Digital Design Development Model.*

COLLABORATIVE PROCESS

The success of any collaborative project hinges around the ability to share knowledge and communicate it well. Whether using a digital medium or implementing a more traditional method of design, students needed to find a way to communicate with one another. This would require each of the students to develop the ability to understand and work with the dynamics of a group. Unlike many of their previous studio projects, ownership was not entitled to any one student. Design decisions were made collectively and the original design intent served to focus discussions and parameters for the project. By focusing on the common problem, resolving the surface in a material sense, the mentality shifted from the individual to the collective.

The use of digital media did in fact change the design process and impact the collaborative nature of the project. The exchange of digital information meant that each team did not have to redraw the previous team's components. Through the use of the digital model teams could freely share their respective components and provide the needed updates to the other teams. In many cases the members of the same team needed to be able to share a master file and distribute the work load.

The exploration of the digital to the real became apparent after the more forty slats had been modeled and ready to be transferred to the ribs team for coordinating their location at each rib. This presented a problem after the students realized the actual size of ½" plywood is 15/32". The slats' location and dimensions needed to be exact to provide the needed friction joints between each of the ribs. The coordination between teams became a skill that holds as much value as did knowing the 3D modeling software. In some cases there seem to be an unwillingness to collaborate due to the time constraint of the project. This unwillingness to take the time to stop working and ensure that everyone was up to date and each of the components were coordinated as the design developed manifested itself in the final product.

FABRICATION PROCESS

As the complexity of architecture increases the need for collaboration between designer and fabricator becomes more apparent. Exploring new design and fabrication methods will lead to a fundamental understanding of their implication on revising traditional design processes. The "30 pieces of plywood" project served as an introduction to 2D Cutting method of fabrication. Prior to this project the only experience with digital to analog method was using a laser cutter. The laser cutter provides the ability to construct small scale models from basswood, chipboard and acrylic within a limited range of sizes and thicknesses. The small scale models, while valuable, do not accurately convey the real-world conditions of building at full-scale. The process of fabrication began by using the two-dimensional information created in AutoCAD. This 2D data was then assigned a toolpath that would direct the CNC router to cut along a designated line or curve at the appropriate depth. This direct link to fabrication allows the students extent the use of their digital design data.

The 2D cutting process was not without its share of problems. Due to the humidity, the ½" plywood began to warp, in some cases as much as 4" in four feet. Attaching the material to the CNC router bed would mean using a mechanical fastener. This presented a problem by placing screws in the potential path of the cutter. The warping problem arose again as the individual components were in the process of being cut. As the cutter began to release the component from the stock, the internal pressures of the plywood cause each of the individual components to warp and curl. This presented a problem for the router as it moved across the bed. To resolve this problem, students fastened each individual component prior to the final cutting pass that released it from the material.

The final task in the 2D cutting process was the annotating the pieces as they were removed from the table for final assembly. Due to the nesting process, the components on one individual sheet of plywood did not necessarily correspond to the adjacent pieces. This required a level of coordination and a method of marking the material prior to be removed from the table. Establishing an annotation system allowed multiple students to assist during the 2D cutting process and extend the cutting times based on student availability outside of class.

The off-site assembly process required the careful coordination of all the individual pieces that made up each of the seven ribs and forty slats. The assemblage of the ribs and slats began by distributing each of the necessary parts for each component. This became an interesting task even with the annotated pieces and required consulting the original digital model when clarification was needed.

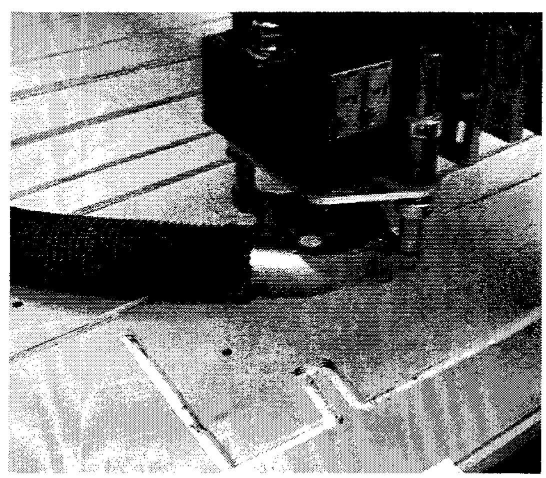

***Figure 4**. 2D Fabrication.*

Due to the large number of individual components comprising the slats, the coordination of each of the horizontal members became difficult to layout. While each of the slats had been marked as they were removed from the table, identifying the adjoining ends and their respective orientations became problematic. The slight curvature of each of the slats in the 8' dimension compounded the problem making it difficult to visually layout the components end to end.

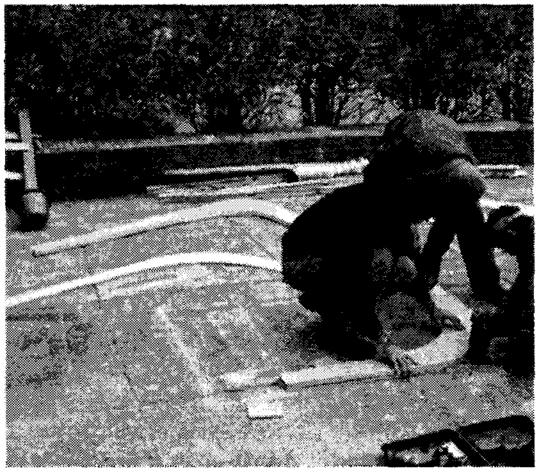

Figure 5. *Off-site Assembly.*

ON-SITE FABRICATION

The on-site fabrication process became just as challenging as the previous design and off-site fabrication processes. While all of the components had been assembled and hand-delivered to the site, the location and method of erection was still to be determined. During the shakeout phase, understanding the numbering system at the site and the physical location of the individual components became problematic. Locating the exact location for the ribs to be erected presented a problem until the courtyard site had been marked and annotated for the task. It seemed that there was difficulty understanding the construction sequencing from the scale of a table top laser cut model to the full-scale installation on site.

After the layout work was complete, thoughts turned to how the ribs would be lifted into place and anchored without mechanical fasteners. This was resolved not by using temporary bracing by the solicitation and employing of the student bystanders who had gathered. Once the ribs were aligned, the four slotted slats were lifted into place that corresponded to their respective rib slots. This created a connection that would lock the ribs and slats together without the use of fasteners between the components. Once the four slats were in place the installation began to take shape and stabilize the structure while the remaining slats were installed. As the remaining slats were put into place, it became evident that without the use of a mechanical fastener to hold the ribs to the ground plane, the internal stress of the plywood would create torque in the tale portion of the installation. The smallest rib of the project required 20 slats of plywood to mate in a relatively small radius creating uplift on the rib. An on-site decision was made to cut the project length back to reduce the torque on the remaining structure. After cutting the slats back to the next rib and pressure was reduced and structure gained stability.

It became evident during the construction process that there was an error or an omission in the measuring of one of the brick seating areas. The design and fabrication of the installation was based on the assumption that the measuring of the existing conditions was correct. Where in fact the measuring was erroneous in one area and led the group to field modify the one of the ribs by attaching a portion of the rib removed from the tale. Until that point a folding chair had served as a prop for rib. The students also learned about the precision and levels tolerance required when linking digital design and numerically controlled cutting. This became evident in the field when it became clear the some of the slot dimensions had not been revised in the digital model and not adjusted prior to writing the toolpaths. Those slots then needed to be resized and cut by hand in the field with a jigsaw.

Figure 6. *On-Site Fabrication.*

Another area where the collaboration between teams needed to have been more closely aligned is in the connection between the slats and the ribs. The ends of each of the slats needed to align to one of rib bays to ensure that each end of the slats were held in place by one of the ribs. The slat team worked from the original surface model and the rib locations provided by the rib team. During the design phase, the rib team determined it was necessary to revise the spacing of the ribs. This change was not communicated to the slat team and did not become evident until the construction phase. Had each of the teams re-assembled their respective models back into the final construction model, this error would have been seen before the components were fabricated and delivered to the site.

CONCLUSIONS

The role of digital technology needs to re-define itself, returning to a notion of craft and a material understanding within a medium that is inherently not material. Computers have evolved from production devices to conceptual modelers to exploratory tools and now a tool for fabrication. This early investigation has allowed students to understand the translation from digital to physical and the limitations of materials and fabrication processes. During the "30 pieces of Plywood" project, students were required to engage the computer as a tool for making. The pedagogical implication for introducing CADCAM to architecture design students creates not only an interesting challenge but an opportunity as well. That opportunity seeks to merge the digital facilities of today's students with a true material understanding of architecture. The blending of the digital and real or the material and the virtual holds the potential for the future of designing in a digital world. The creation of digital information, i.e. our digital models, no longer have to be relegated to a representative images but can offer a material understanding that can instruct in its own making.

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