Fabricating – Design – Research: Examining the Integration of Digital Fabrication Technologies into the Architectural Curriculum

Luis Eduardo Boza
The Catholic University of America, School of Architecture and Planning
620 Michigan Avenue, NE
Washington, DC 20064
USA
E-mail: boza@cua.edu

ABSTRACT

This paper examines the roles that Digital Fabrication and Manufacturing technologies can have on the ability to Fabricate Design Research. In particular, it examines the ability of digital fabrication technologies to stimulate, initiate and integrate design research of various areas in the architectural curriculum. The paper explores the inherent relationships between fabricating, design and research and how one should understand their meanings in his/her own design process.

As a primary case study, the paper will present student work from a course titled "Introduction to Techniques in Rapid Prototyping", in which students were introduced to various digital fabrication tools and software. The student work demonstrates the interactive design process in which fabrication, design and research are interwoven in order to investigate new design methodologies based on new technologies.

1. INTRODUCTION AND HISTORY

In 2001, The Catholic University of America's (CUA) School of Architecture and Planning (in Washington, D.C.) began an initiative that examines Computer-Aided Design and Manufacturing (CAD/CAM) in architectural education and the profession. The intent was to integrate notions of building technologies, digital media and material imagination in a progressive and innovative way. Since the inception of the initiative, CUA's architecture program, already nationally recognized for design education and physical model making[5], passed a resolution that would require all incoming freshman to purchase a laptop computer and appropriate software. This requirement would, in turn, require numerous revisions to the existing curriculum, including the introduction of various digital media courses at the entry level, coupled with additional advanced seminars and graduate concentrations in Digital Media and Digital Fabrication. In addition, the requirement would foster the development of higher-end output and peripheral labs to augment the increase and interest in the area of computers in architectural design.

The school initially purchased a Universal X-660 45-watt CO2 laser cutter and engraving system, a Microscribe 3D digitizer, and a vacuum-forming system. In addition, the School made a number of software purchases, including Rhinoceros 3.0 (NURBS modeling) and Solidworks (parametric modeling). During summer 2005, a 4'x8' Techno-Isel 3-axis milling machine, as well as Mastercam (CAM software), will be purchased. Together, these tools will make up the Digital

[5] The Catholic University of America School of Architecture and Planning was featured in an exhibit entitled "Modeled Space, Space Modeled" held at the National Building Museum, Washington, D.C. (2002). The exhibit demonstrated how the process of architecture advances through various stages, from recording and analysis of existing conditions through presentation of a design proposal.

Fabrication Lab, an annex to the existing Wood & Metals shop. The intent of these labs will be to support student design work and research, as well a foster a renewed interest in the culture of making.

In order to support and introduce students to the concept of digital fabrication, an undergraduate seminar entitled "Introduction to Techniques in Rapid Prototyping" was introduced. There were three goals for the course. The first was to teach the techniques and processes associated with the design and fabrication tools. The second goal was to educate students on how to integrate digital design and fabrication tools into their own design methodology. It was crucial that the course require students to learn by making through a process which would consistently provide feedback, thus informing the development of a design. Thirdly, to produce work that generated interest and excitement about the potential of Digital Fabrication and to communicate the notion of how digital tools are beginning to redefine existing conventions of building technology, material understandings and professional practices. The ability for the subject to spawn new avenues of research for students to pursue is critical for the ongoing success of the initiative.

2.0 COURSE CONCEPTION: FABRICATING – DESIGN – RESEARCH

In the introduction to "Versioning: Evolutionary Techniques in Architecture," Sharples Holden Pasquarelli (SHoP) uses the term *"versioning"* as an operative term that describes "the way in which architects and designers are using technology to expand the potential effects of design." Versioning implies that emphasis is placed on technique rather than image. The technique advocates an iterative process of design in which the computer becomes an indispensable tool that provides feedback during the design and fabrication phases. It becomes an attitude rather than an ideology, which allows the designer to think "across practices" as a way of problem solving.[6] The notion of "versioning," coupled with the ability of digital fabrication technologies to quickly test and re-test a design scheme, creates a more methodical design process that is more closely aligned with established scientific, historical and statistical methods of research. In turn, the design process becomes an iterative research process, creating a case study or default test case and constant testing procedure. (Fig.1)

We can say that the above-mentioned process consists of three parts: fabricating, design & research. The *Oxford English Dictionary* defines fabricating as the act of "constructing, or manufacturing." It defines research as "the act of searching (closely or carefully); to search again or repeatedly," and design as a method of "form(ing) a plan or scheme; to conceive and arrange in the mind; to originate mentally, plan out, contrive," as well as "to have in view, to contemplate."

The three words become descriptive of a design methodology in which new technologies are integrated as a means of generating both design and production data. The designer mediates between the virtual world of the computer and the physical world of the artifact, learning from each successive phase. The process is by no means linear; it can be described as a continually narrowing cycle as the designer begins to question relations between the three. How does one fabricate a design and what is its relationship to designing the fabrication technique? How does one design his/her research versus researching his/her design? And ultimately, how does one research fabrication and what avenues of research are fabricated given this process? By asking these important questions during the design phase, not only does a design develop, but it also enables one to generate avenues of research for further study, within the original scheme or outside of it.

The relationships between fabrication, design and research became the framework for the development of the course. (Fig.2) This framework would require students to continuously and iteratively make associations between design and fabrication, between fabrication and research,

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[6] Sharples, Holden, Pasquarelli (SHoP), *Versioning: Evolutionary Techniques in Architecture*, AD Architectural Design, Vol. 72, No 5 September/October 2002, Wiley-Academy.

and between research and design. The intent was to provide a methodology in which students could question their work in a productive fashion for design development, but also allow students to consider areas of research that could be applied to other courses, studio work and/or graduate studies.

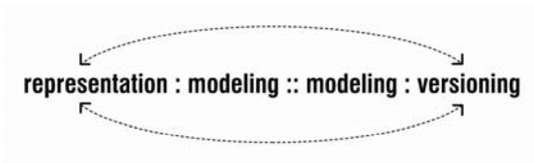


Fig. 1 SHoP's diagram of "Versioning"

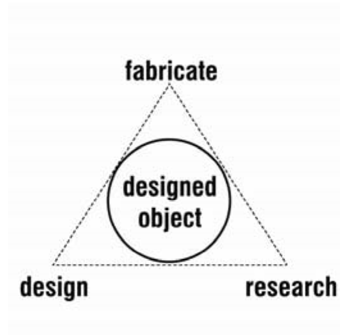


Fig. 2 Fabricating Design Research Diagram

3.0 COURSE DESCRIPTION

Given the above-mentioned notions of fabricating, design and research, the course outline for "Introduction to Techniques in Rapid Prototyping" was developed that addressed three objectives; technique and process, thought through making and research development.

Rather than continuing the centuries-old process of distancing the architect from the physical construction site, CAD/CAM and Rapid Prototyping applications demand that architects immediately participate in very real issues of material manipulation, fabrication and assembly. Rather that liberating the architect or allowing for ever-greater degrees of abstraction in design, CAD/CAM places necessary limitations and makes demands on the designer to clearly think about construction issues during the design process. The interplay between digital tools, virtual and physical models and their applications represent very rich opportunities for architectural development. This course serves as an introduction to issues as they relate to design processes, materials, fabrication and architecture.

Students were introduced to Rhinoceros, a 3-D NURBS modeling program. In addition, students learned the use of a 3D Digitizer as an input device and a CO2 Laser Cutter as an output device.

A total of five projects were assigned during the course of the semester. A number of design problems were assigned in which students investigated the potential of the computer's ability to rapid-prototype assemblies in quick succession. The first four projects were designed in a way to teach the software and tools, as well as technique. During project five, students were asked to further develop their schemes by proposing avenues of research, supplemented with precedent studies in fabrication and design. Students focused on how this process can inform the design and construction of architectural elements.

Although this class is a 3-credit seminar for 2nd and 3rd year architecture students, the mode of instruction more closely resembles a design studio. This allows a student to follow through with a semester-long design investigation fully engaging the software and equipment, honing his/her skills and knowledge to develop a project that he/she can become passionate about.

4.0 PROCEDURE / INTEGRATION / APPLICATION

4.1 Project 1: Base Prototype 3D Model

During the Project One, students were asked to select an object from a provided list made up of architectural objects or products, such as bricks, shingles or joints, as well as door knobs and pulls, light diffusers and containers. Students were asked to create a virtual model of their chosen object using Rhinoceros. This exercise served as a means of introducing the software to the students. The objects were modeled in great detail and the students created high quality rendering that represents existing characteristics they observed.

For the purposes of this paper, the work of two students will be presented. They will be referred to as Student A and B. Their designs will be used as examples of the methodology followed during the course.

Student A chose a lamp with a carved wooden base and a traditional fabric lamp shade. (Fig.3,4) Student B chose a cast metal cabinet pull with a curved form. (Fig.5,6)

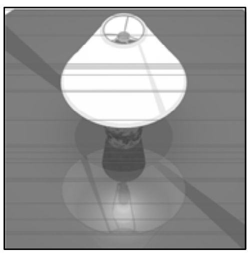


Fig. 3 Student A

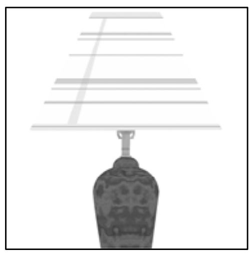


Fig. 4 Student A

Fig. 5 Student B

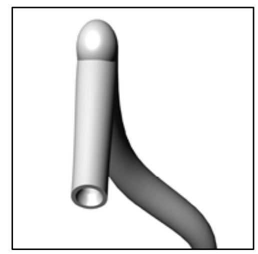


Fig. 6 Student B

4.2 Project 2: Digitizing Physical Qualities

In Project Two, students were introduced to the Microscribe 3D Digitzer. 3D scanning (or 3D digitizing) involves the creation of a digital model by translating points in physical space into virtual 3D space, in turn creating a digital version of a physical object.

Instead of digitizing the objects chosen in project one, students were asked to create an “analogue object model,” which became a physical representation of a characteristic or quality inherent in the original object. This exercise forced the students to look at their objects in a new way. Students considered notions of materiality, translucency, opaqueness, weight and form. The intent of the analogue object model was to physically capture these qualities to serve as a transformative tool given the 3D digitizer. In other words, with the use of the digitizer, students were asked to capture the physical properties of an object that were next to impossible to model virtually. Digitizing allowed a copy of the physical object to be represented electronically and eventually allowed the electronic version to be manipulated in ways the physical version cannot.

4.2.1 Student A: Material and Gravity

After discussing the initial object with Student A, he chose to investigate how the formal properties of one material can translate to another material. In the initial object (the lamp), the fabric material was considered to be a fluid, dynamic material with light-filtering characteristics. In contrast, the base of the material, a solid, carved-form of wood, was considered to be static and heavy. For his analogue object model, Student A chose to represent the idea of a solid material, which will respond or transform its formal properties relative to an applied force and gravity. Student A chose acrylic as the default material that would be deformed. Prior to deforming the material, he drew a reference grid over the surface. Using a heat gun, the sheet of acrylic was melted over a form. (Fig.7) The resulting form was an extremely complex geometric form that was directly related to the process by which it was created. (Fig.8) This object was then digitized by plotting the points along the reference grid in order to create a virtual model. (Fig. 9,10)

Fig. 7 Production of model
Model

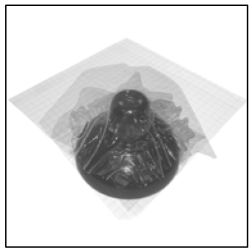


Fig. 8 Analogue Model

Fig. 9 Digitizing Process

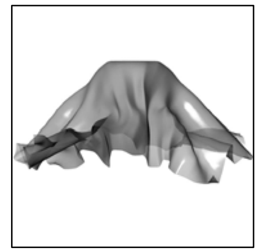


Fig. 10 Virtual

4.2.1 Student B: Form & The Human Touch

The door pull which Student B selected during the first phase suggested the idea of the human touch. The form of the door pull made a weak attempt to respond to the human hand. Student B pursued an investigation into customizing architectural components based on user specifications, or the human form. In order to create his analogue object model, Student B produced a casting of his hand in the position in which it would grasp a door pull. (Fig. 11,12) This object was then digitized to create a virtual model. (Fig. 13,14)

Fig. 11 Production of model
Model

Fig. 12 Analogue Model

Fig. 13 Digitizing Process

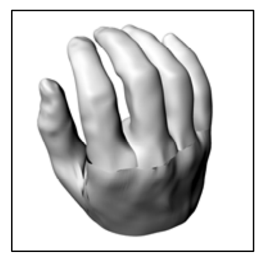


Fig. 14 Virtual

4.3 Project 3: Fabrication Drawings

During Project Three, students developed their virtual models from the previous exercise into fully constructible virtual assemblies that considered all details, connections and materials. In addition, fabrication drawings were created from which the physical model would be cut using the Universal CO2 Laser Cutter. The drawings were created directly from the 3D virtual model.

The process in which the students disassembled their virtual models required them to envision the final form of the object. To create the drawings, a thorough understanding of the assembly process was required prior to disassembling the model. This thought process required students to revise their constructs as necessary. Students began to understand the notion of how CAD/CAM processes place necessary limitations and make demands on a designer to think clearly about construction and assembly issues during the design process.

For the fabrication drawing portion of the course, Student A chose to create a light-filtering device. In order to create the fabrication drawings, a series of contours were cut through the object that allowed for alternating materials to create areas of translucency and opaqueness. (Fig.15) Cut templates were nested and prepared for cutting. (Fig.16). Student B produced a virtual model of a schematic door pull that would be incorporated into a stock cabinet door and/or drawer. (Fig.17) The solid wood insert would serve as formwork for a finish veneer to give the impression of a continuously curving wood surface. The object was then contoured to provide cut templates for wood to be cut and stacked together to imply the form. (Fig.18)

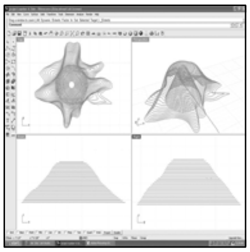


Fig. 15 Student A: Contours


Fig. 16 Student A: Templates

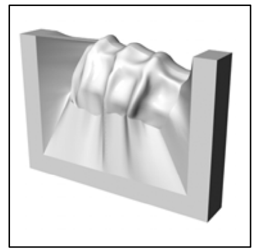


Fig. 17 Student B: Solid Model

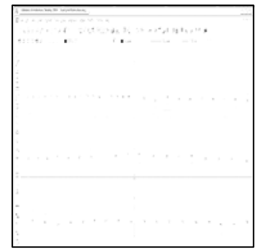


Fig. 18 Student B: Templates

4.4 Project 4: Laser Cut Model

During Project Four, students were introduced to the Universal CO2 Laser Cutting machine. Components of each design were cut and assembled into the final proposed fabrications.

4.4.1 Student A: Light Diffuser

Using the CO2 laser cutter, Student A cut multiple layers from wood and acrylic. (Fig.19) The layers were then assembled by stacking them about a center reference point. (Fig 20,21) When a light was placed below the object, the form glowed with a soft light. (Fig.22) Due to the undulating form of the object, the light was brighter at areas where the perimeter of the acrylic layer was closer to the light and was dimmer as the acrylic layer distanced itself from the light. Although the object, produced an interesting effect, the means of disassembly was simple a result of cutting multiple plan cuts through the form. Critiques of Project Four suggested a departure from the light filtering properties in order to focus on technique rather than effect.


Fig. 19 Student A: Laser Cutting


Fig. 20 Student A: Assembly

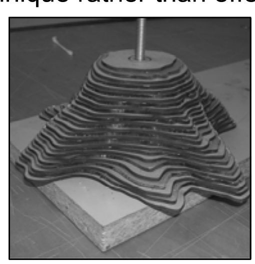


Fig. 21 Student A: Model

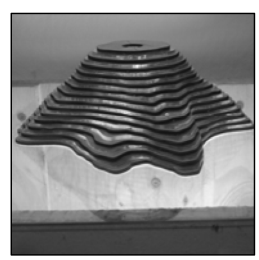
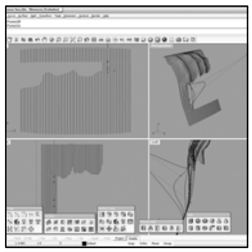
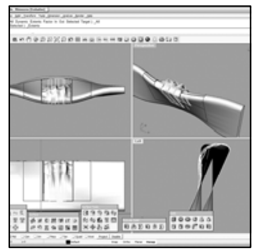


Fig. 22 Student A: Model

4.4.2 Student B: Door Pull

During Project 4, Student B fabricated the door pull insert using the CO2 laser cutter. A mock-up revealed that the expansion and contraction of the material produced an undesirable warping of the veneer over time. This unexpected result led Student B to think about how he may integrate the pull into the drawer/door itself. By prototyping the object, Student B was informed about his design in a way that would not have been possible in its virtual state. Design began on the next iteration; the integration of a customized handle into the face of a cabinet door and/or drawer. (Fig. 23-26)





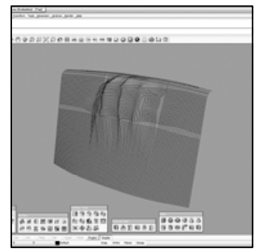


Fig. 23 Student B: Sketchbook Fig. 24 Student B: Virtual Model Fig. 25 Student B: Virtual Model Fig. 26 Student B: Virtual Model

4.5 Project 5: Final Project "Fabricate-Design-Research"

During project five, students were asked to revisit their design schemes given their newly found knowledge of digital design and fabrication. Students then proposed avenues of research that were generated as by-products of the preliminary design process. To support their research, students investigated precedents into their chosen topics providing necessary information that would be folded into the development of the final scheme.

It is important to note that during this phase an emphasis on the cyclical nature of design was stressed. Students were encouraged to move freely in the design process, between all phases of the previous exercises, allowing the processes to inform the design. Given the ability to rapidly prototype assemblies, the students employed a design methodology that allowed them to quickly test and re-test their design scheme while asking the questions related fabrication, design and research.

4.4.1 Student A: Technique and Craft

Referring back to the analogue object model, Student A became interested in the reference grid applied to the flat acrylic sheet prior to deformation occurred. These lines, once straight, now appeared to be warped, twisted, and random. Student A chose to explore how these lines could be fabricated rather that replicating the form of the object itself.

The avenue of research that Student A chose to pursue had to do with issues of "craft." He began to look into traditional means of wood bending. Charles and Ray Eames' work provided valuable insight to use of a form onto which a wood member is shaped.

Prior to fabrication of a physical form / bending armature, a "trench" was subtracted form the virtual object along the grid lines that had been digitized in Project Two. (Fig. 27) This model was then contoured, fabrication drawings were generated, and a physical model was produced. (Fig. 28) Once the physical model was ready, Student A soaked a number of wood members in water. The members were then fit snuggly into the trenches along the bending armature. After the wood members had dried, the wood was removed from the form and studied. (Fig. 29,30) Although, the members did not entirely keep the form of the object, the ability to control and predict the three dimensional curvature of a line-like member in space was successful.

Many often criticize CAD/CAM technologies by stating that they erase traditional notions of craft. What was interesting about Student A's project was that it attempted to use technology to inform a traditional craft. This overlap became very exciting area to investigate. Critics of this project directed Student A to look into other crafts which allow thin members to retain their shape. The craft of weaving was proposed. Although the final project did not address notion of weaving fully, Student A became interested the ability to form wood while applying the techniques and patterns of weaving to help the material keep its shape while gaining strength.

Student A is currently in his second semester, fourth year. He had indicated that he is extremely interested in pursuing further research into notions of craft and materially as related to CAD/CAM technologies.

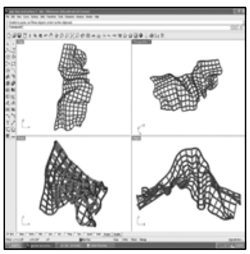


Fig. 27 Virtual Model

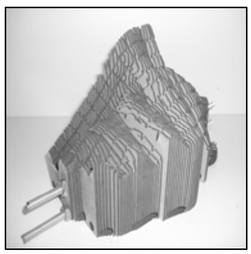


Fig. 28 Bending Armature

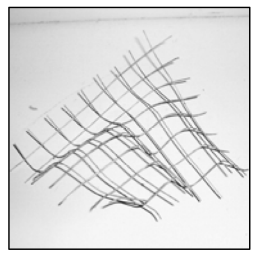


Fig. 29 Final Wood Model

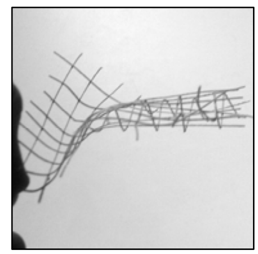


Fig. 30 Final Wood Model

4.4.2 Student B: Integration of Product

For the final project, Student B chose to examine how the integration of an accessory product into the form of, in this case, a cabinet door could create new possibilities or programmatic uses. Student B researched the Harvard University Graduate School of Design admissions office millwork design by Office dA (Boston, MA). In this project, layers of medium density fiber board were stacked together and sanded in order to create the desired, undulating form. The form was then veneered using a vacuum-forming bag. Cabinet pulls were integrated into the undulating form, thus disguising the required pull and push locations. Student B examined the potential to take this idea a step further. He became interested in adding value to the form by allowing one piece to affect the piece above and/or below by serving as a locking device. Student B began to research millwork hardware systems and components from manufacturers like Hafele. For this design, the idea was to eliminate the application of hardware but to integrate it into the design, in turn informing and legitimizing the form. (Fig.31,32)

Although the final design was not physically mocked, the ability of the computer to animate the movement of the pieces suggested how the pieces would work. Student B plans to continue the development of this system during independent research course over the summer. He plans to spend the time fabricating full scale working prototypes.

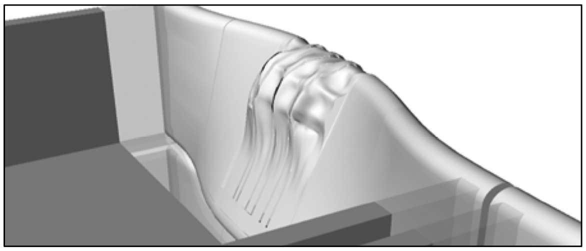


Fig. 31 Student B: Virtual Model of Drawer

Fig. 32 Student B: Elevation of Drawer Front

5.0 SUMMARY AND CONCLUSIONS

“Introduction to Techniques in Rapid Prototyping” stressed ideas of fabrication, design and research by focusing on technology and technique in order to develop a design methodology. It focused itself squarely on these issues without being tied to the development of program. The work presented was successful in that the participating students have proceeded to pursue areas of study at the graduate level that require more detailed, rigorous investigation related to issues in CAD/CAM processes. The intent of the course was achieved in that the students have taken the knowledge gained directly from the course back to their studios and continue to synthesize their modes of working, the techniques and the technology by questioning the relationships between fabrication, design and research.

6.0 FUTURE DEVELOPMENTS

As of the fall semester (2005), The Catholic University of America’s School of Architecture and Planning will be offering a graduate level concentration in Digital Fabrication. Courses in this concentration will include studios dedicated to the investigation of CAD/CAM processes in the design and construction of architecture and architectural projects. Through a design-build model, students will gain first hand experiences of real world issues when constructing and/or fabricating building scale structures. In addition, students will be required to take a number of concentration electives. These electives will range from instruction of various software platforms and CAD/CAM machining processes, to architectural theory (in digital design and computation) and professional practice. The intent is to provide students with a well rounded Master’s level education while allowing them to pursue thesis research and design work in the specific area of digital fabrication.

“Introduction to Techniques in Rapid Prototyping” has been successful in the way that it has generated much interest in the subject. Given this success, the course will remain at the undergraduate level. Its position in the undergraduate curriculum is intentional and will serve as a feeder to the graduate level digital fabrication concentration. As of March 2005, approximately 10 students have registered for the graduate level concentration, all of which had been enrolled in “Introduction to Techniques in Rapid Prototyping.”

Having explored this teaching model for the last two years with the limited resources available at the time, the instructors can speculate that the model will need be to be revised as new tools and resources become available.

Next steps in the integration of digital fabrication technologies into the architectural curriculum will investigate larger scales of design and production to engage building-sized proposals while exploring more complex assemblies made from component parts. The instruction of parametric modeling will be an important inclusion as the software allows students to rethink and revise his/her design process based on production techniques and constraints, providing a more efficient way of moving between design and fabrication. Other areas of investigation will include more thorough research of manufacturing methods in other industries.

Although the content of “Introduction to Techniques in Rapid Prototyping” will require revision as new tools become available, the basic notion of “fabricating design research” will continue to be a framework for future iterations of this introductory course. The subject continues to generate a high level of work and thought, which the is filtered out to design studios for all to learn from.