The Y Model:
Simultaneous Instruction in Digital Fabrication and Representation

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Abstract

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Digital media and tools are now integral to architectural education and the design process. Nevertheless, much of the pedagogy related to digital media is grounded in, and relies upon, traditional design educational approaches.

The relationship of the practice of architecture to digital technology is in constant flux. Recently, university departments of architecture have seen a greater emphasis on technology integration, and have witnessed significant upgrades in hardware and software technologies. These shifts in technologies "have game changing implications for the future of the profession" (Design Intelligence, 2013).

Changes in architecture curricula to accommodate new design technologies and modes of professional practice, as well as students' time and skill limitations, make it challenging for departments of architecture to provide their students with the knowledge base necessary to address the concerns of design professionals as they move from the academic environment into professional practice.

Bearing in mind the following three points:

1. It is not possible to teach the students everything they need to learn (in terms of either design or technology) while they are in school.
2. Students enter departments of architecture generally having achieved a high level of computer literacy that they assume they will be able to apply or build upon in their education (Design Intelligence, 2013)
3. Because of financial constraints, differences in geography, faculty, facilities, academic modus operandi, and whether the institution is private or public, every department of architecture has a different curriculum (Design Intelligence, 2013).

We can pose the following question:

In the context of design education, what should an introductory course in design computing accomplish in terms of topics, tasks, and theory? To which we may answer: Literature states that, at the end of an introductory design computing course:

1. Educators and practitioners in architecture believe students should have the ability to face and adapt to changing technology. They need to learn how to learn technology (software and hardware) in order to become competent practitioners of architecture.
2. Students should be exposed to fundamental design computing concepts that will be useful now and into the future. An introductory course should address fundamental principles and approaches to technology and design that we hypothesize will persist despite rapid changes.
3. Students should have the ability to generate and communicate ideas utilizing multiple processes (approaches) and media.
4. Students should understand, perceive, and be able to act upon existing affordances of digital tools.

This thesis examines teaching methods, curricula, and pedagogical approaches that assist in achieving those goals; it reviews literature regarding the need for a course addressing the abovementioned concerns, and it summarizes case studies that have attempted to address these needs.

The central effort of the thesis involves an exploration, in the form of a course, in which the author attempted to address the needs described above, via the utilization of a learning theory approach known as the "Y" model. This model proposes the acquisition and buildup of a logical progression of skills and knowledge as a foundation for students to pursue further, similar, yet possibly divergent outcomes.

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Chapter 1.
Context

In 1963 Ivan Sutherland developed Sketchpad for his PHD thesis at MIT. Sketchpad is widely considered to be the first computer-aided drafting (CAD) program, as well as a major breakthrough in the field of computer graphics. Additionally, the Graphic User Interface, as well as modern object oriented programming, was derived from the Sketchpad. Graphic User Interface (GUI) is a type of interface that allows users to interact with electronic tools (in this case, computers) utilizing images and icons as opposed to inputting text commands.

Fifty years after Sutherland's developments, computer based tools are ubiquitous in architecture, in both academia and practice. Academia is faced with the question of how to develop ways of harnessing the power of this hardware while still respecting the design process.

Design Tools

Tool:

"An implement, esp. one held in the hand such as a hammer or, saw, file, etc.. for performing or facilitating mechanical operations (Webster College Dictionary, 1982)."

Tool:

1. A handheld device that aids in accomplishing a task
2. The cutting or shaping part in a machine or machine tool (2): a machine for shaping metal : machine tool
3. something (as an instrument or apparatus) used in performing an operation or necessary in the practice of a vocation or profession <a scholar's books are his tools>

4. An element of a computer program (as a graphics application) that activates and controls a particular function <a drawing tool> (Merriam-webster.com, 2013).

Tools give humans the means to manipulate and control their environment. Tools have always been extensions of human hands or abilities. The two definitions above illustrate three points:

1. The definition or outcome of what a tool does has remained constant.
2. The definition of what a tool is has expanded to include digital tools such as software, and sundry digital NC devices, such as the ones described in this thesis.
3. The computer has become widely accepted as a tool over the last thirty years.

Designers have always utilized and relied upon tools. Historically, as the process of design evolves from ideas and concepts, to sketches, to prototypes and drafts, and into planning and production, designers have tended to use the right tool for the right job. Some tools are utilized throughout the process, whereas others are more specific to particular moments in the design process.

One of the oldest, and arguably the most powerful tools, is the mark maker. For the sake of simplicity, hereafter the term “pencil” will refer to any hand held two dimensional marking tool such as the pens, markers, paint brushes, mechanical lead holders, charcoal, etc... Like all tools the pencil has been subject to secondary and tertiary inventions, from the knife to the quill to the Rapidograph pen, from fresco to tempera to oil to acrylic. The power of the pencil is its accessibility and its freedom. Any child can make marks in order to express ideas. Each child has a unique vocabulary with the pen. Architects, unlike toddlers, have a shared graphic language, which can be learned and shared with others.

Malcom McCullough, in his book *Abstracting Craft, The Practiced Digital Hand,* writes that in many refined practices, the perception of a medium surpasses any perception of tools. If a medium represents the dimension of capabilities for any tool, or toolset, then any awareness of the tool being used can become secondary to the more esoteric awareness of the medium itself. For example, expert skiers think about skiing the slope, not their skis, a tennis player thinks about the ball, the net, and their opponent, not his racquet. Tools should allow an expert to focus on their work, essentially going unnoticed. Cognitive psychologists, and athletic trainers both agree that with practice, certain sensory-motor activities can become automatic, or part of one's muscle memory. Even once something becomes automatic; it still requires adjustment when exposed to a new tool's subtleties and performance. With practice, it should be possible to subconsciously utilize a tool without its interfering with one's active intent (McCullough, 1996).

This is an example of how a tool can be referred to as "transparent". When a hammer hits a nail, the primary focus and awareness should be on that nail, not the way the hammer feels in one's hand. More sophisticated tools can be as transparent as a hammer. A good painter should focus on the work she is creating, not her brush. The fact that she is holding a brush at all should be completely transparent.

I have taught drawing to both artists and designers at the University level for over 10 years. In order for students to gain transparency with the pencil, they are first of all required to undergo fundamental changes in the way they see. For example, in order to understand the concepts of perspective drawing, and learn to draw things in "proper" perspective, they must not only be exposed to the information, but are required to practice creating their own drawings until they can demonstrate, via the physical artifact (medium) of their drawing that they understand this concept. During this process their mark making and ability to manipulate the subtleties of the pencil can improve, especially with proper guidance.

One of the reasons hand drawing is still taught in University Art and Design programs is because the pencil is still a valid tool for the early (conceptual) stages of design work. It requires a minimal effort to use, and ideas it conveys can be quickly discarded or developed. One of the obstacles that undergraduate designers face is that they are not familiar with the full range of tools available to them. Further, mere knowledge of a tool's existence does not necessarily mean that a young designer can utilize it. It is not until we are unencumbered by the tool (transparency) that we can use it freely. A small child does not feel constrained by only having a red crayon. A student in the 20th century did not feel constrained by the pencil. Their constraints were internally related to their ability to use the tool, not the tool itself. They learned how to use the pencil; they used it for several things, drafting, sketching, isometrics, and parallel projection. The pencil also played an important part in the making of physical models. Students needed to visualize the parts, draft them out, cut them out, and assemble them. The pencil was a primary tool.

The skills we learned from the pencil transferred quite well to the pen. The rapid, confident movements we learned from the pencil gave us the confidence and knowledge to traverse napkins, Mylar, and vellum. Although many designers consider the pen to be liberating, it still has constraints. By its very nature of being a tool, it becomes a constraint because we are limited by its affordances. It is a constraint because it defines how we perceive the work. It is a constraint because it can only make marks in a certain way. Furthermore, it structures the approach the designer takes and is a determinant as to the amount of energy it will require (Stanley Abercromie, 1997). The term constraint is not synonymous with weakness or negativity. Architects work with constraints all the time: dimensional lumber, material qualities, building codes and even client desires are constraints. A constraint could be merely a parameter that contributes to the general requirements, notes, and assumptions of any given project.

Abercromie and Glaser point out that our workplace is shaped by the tools we use. The addition of a new tool to a workplace has the potential to transform the workplace, the working conditions, and even the workflow. They state that the introduction of the computer into the world is certainly the most dramatic change we have seen since before the industrial revolution, hence the term, digital age, or digital revolution.

The Computer as a Design Tool

Just as the digital camera and Photoshop have essentially replaced film photography and photographic processes, so too have the computer and digital representation software changed the process of architectural design. In CAD, Computer aided drafting, keystrokes and mouse movements replaced line strokes. CAD's and other software's Graphical User Interface placed a keyboard and mouse, instead of a mechanical lead pointer and a triangle, between the users of this new tool and the designs they created.

The computer gives us access to tools that the contemporary architect uses and needs, tools that draft, model, simulate, negotiate, and fabricate. CAD simulates the 2d conventions that architects drew, and contractors interpreted. CAD is a tool that simulates the two dimensional conventions that were previously hand drafted. This set of working drawings has typically consisted of 2D plans, sections, elevations, and construction details. CAD allows the architect to create a set of working drawings that sufficiently conveys design intent to the contractor. These documents are a legal contract, yet they are not a set of instructions on the techniques and methods of construction. The actual method of construction is left up to the contractors. In order for a design to be effectively and accurately interpreted and constructed, it is necessary to have effective communication between the two parties (Loebel, 2008). BIM eliminates much of the interpretation, providing accurate and editable information to the parties involved in the design and construction of buildings.

The computer has several advantages over its purely analog predecessors:

1. Control: The designer now has the potential to control the design from the concept stages into final construction. It has been widely mentioned that the computer as a tool may make it possible for the architect to return to the role of the master builder.

2. Elimination of the mundane: Many tasks that may have been considered extraneous, repetitive, and/or mundane are now done by the computer.

3. Simulation equals control: The actual scale and tolerance of digital models allows for near perfect work in many cases. This allows components to be fabricated in different locations, by different vendors, shipped to the site, and fit perfectly. This type of accuracy was not expected in the era of purely analog tools.

4. Workspace flexibility/transformation: No longer is the scale at which one designs determined by the size of a drafting table. Digital models allow for nearly unlimited detail and experimentation when appropriate (Knorig, 2008).

Although not everyone agrees, according to Schneider and others, the dissemination of digital design tools to the untrained masses has led to an overall degradation of the quality of existent design, which can now be considered a mass phenomenon. Knorig claims that because everyone has access to tools that allow them to "design" they all think they can do it, and many of them do (Knorig, 2008). For example, it may no longer be necessary for a small business owner to hire a graphic designer. Many companies claim to offer easy to use graphics programs and templates at a reasonable price. Although the dilettante may be able to produce a tidy and "acceptable" piece of work, the chances of their work equaling that of someone trained in typography and graphic design is slim. Another example of this is smart phone photography; everyone can take a picture, but that does not make them a photographer. These design tools can make anyone think they are a designer. A design student at the beginning of their education does not possess much more training than a dilettante. When designing using the pencil and other analog techniques, a student's inexperience is evident not only in the quality of their design, but in the mark making and overall craftsmanship of what they have created. The obviously poor craftsmanship can assist in informing the creator that their design requires refinement. Conversely, the uninitiated can be seduced and "satisfied" by a final tidy, straight lined project produced by a digital tool. Many students in the early phases of their design education tend to cease exploratory design work when they believe they have discovered a solution. Digital and visualization tools provide a polished representation of ideas, regardless of the quality of that idea.

A digitally assisted design process can present particular pitfalls to architects. Elliot Felix observed, because of the tool's ability to delete and reconfigure lines, "each action is less consequent than it would be on paper…each will be less carefully considered (Sennet, 2008)."

Contemporary Design Tools

Contemporary digital design tools that an architect might utilize fall into one of three broad categories. The tools tend to be (CAD) visualization/representation, (CAAD) performance/simulation, or (CAM) fabrication tools (Sorguc, 2009).

Digital tools

The term "digital tool" is a wide umbrella that can include the computer itself, visualization, communication, and simulation software applications as well as (physical) fabrication tools. The term "digital tool" in this thesis, unless otherwise noted, will refer to software applications for graphic representation, (Adobe suite), or documentation (AutoCad), three dimensional modeling programs, (Rhino, Sketchup, CATIA, Solidworks, 3D studio Max, or Maya, their rendering plugins such as V-Ray, Kerkythea, Flamingo) parametric plugins (Grasshopper for Rhino or Generative Components for

Bentley) Building Information Modeling (BIM) (Revit)or simulation software (Ecotect). Below are examples of processes that would involve the use of digital tools, in this case, software.

1. Representation/Graphics (Adobe)
2. Documentation/Drafting
3. 3d Modeling/Rendering
4. Parametric Design
5. Building Information Modeling
6. Simulation (lighting, acoustics, etc…)
7. Web based tools
8. Animation

Fabrication tools and techniques

Digital fabrication tools can certainly be considered digital tools, but for the purposes of this thesis, they will henceforth be described as fabrication tools. Fabrication tools typically require some sort of digital model derived from an application similar to the ones mentioned above. Depending upon the final desired materiality of the object, a model created in one piece of software is output as a Dwg. or 3dm, is typically manipulated again by yet another piece of software such as Mastercam, Torch mate, or Rhinocam, and output to the physical fabrication tool before the final object is created.

Fabrication tools to which Architects may output include 3D printers, 3-, 4-, or 5-axis CNC routers, laser cutters, plasma cutters, water jets, etc… These tools require an additional piece of software.

Lisa Iwamoto, in her book Digital Fabrications, Architectural and Material Techniques, lists 5 basic techniques:

1. Sectioning

2. Tessellating

3. Folding

4. Contouring

5. Forming

Iwamoto clearly states that projects need not utilize a single technique; indeed these techniques are often combined in a single project. However, Just as the final technique utilized in a pencil drawing (shading, hatching, stippling, etc…) influences and constrains the artist's technique, tool configuration, and materials/mediums (type of pencil, lead, H or B, sharp point, dull point, hot or cold pressed paper, tooth, etc…), so too does the designer's understanding of the final tool, techniques, and materials to be utilized for fabrication, influence the approach to said project (Iwamoto, 2009).

The designer will need to balance "a satisficed" design, intent, digital product, etc… with a project- dependent need for specificity. Understanding the workflow, the constraints of tools, materials and techniques, will aid in this process.

DIGITAL FABRICATION TECHNIQUES (the physical)

Unlike digital design, or even physical models, which are, or can be, ubiquitous in the design process, digital fabrication is typically not utilized until the final phases of the design process. According to Lisa Iwamoto, upon whose book, *Digital Fabrications, Architectural and Material Techniques*, this section is partially indebted; digital fabrication can be defined as: "a way of making that uses digital data to control a fabrication process. Falling under the umbrella of computer-aided design and manufacturing (CAD/CAM), it relies on computer driven machine tools to build or cut parts (Iwamoto, 2009, p. 4)."

There are four digital fabrication techniques commonly being used by in the field of architecture today, throughout the remainder of this section, these will be explained in depth. In her book, Iwamoto describes a fifth technique, forming, a multi-step process that utilizes fabrication and mold making and casting processes. The complexity of the forming process, the relative scarcity of equipment necessary for this process in schools of architecture and private practices, make it beyond the scope of this section.

1. Sectioning
2. Tessellating
3. Folding
4. Contouring

Many of the projects discussed herein will not utilize a single, pure technique; rather they may combine several techniques in order to best realize their vision. Regardless, these definitions are necessary to the structure of this writing.

SECTIONING

Sectioning, sometimes known as contouring, is a technique where the surface of the object is described by constructing a series of profiles, each of which follow the geometry of an object's surface at predetermined points. Prior to being utilized in digital fabrication, this technique has been common in architectural landscape models.

TESSELATING

A tessellated plane is one that is tiled with a pattern that fills it with no gaps or overlaps. M.C. Escher utilized the technique of tessellation after viewing Moorish mosaics in Southern Spain. In architecture, tessellation has always been utilized, in Byzantine mosaics, Gothic stained glass windows, Italian intarsia, marquetry, Islamic tile work and screen walls, just to name a few.

The time-intensive nature of the handcrafted, tessellated pattern has made it cost prohibitive as a technique in contemporary architecture. However, tessellation is once again a viable technique; its affordability and increased utilization is due to digital design and manufacturing practices.

FOLDING

"If there is a single effect produced in the architecture of folding, it will be the ability to integrate unrelated elements within a new continuous mixture."

(Lynne, 1993)

The roots of folding as it applies to 20th century architecture can be traced back at least as far as the paper workshops at the Bauhaus. A single 90 degree fold in a sheet of paper changes it from a 2D plane to a 3D geometric and self-supporting, structural object. A fold adds strength to an object and allows it to increase its span or cantilever.

"In all cases, folding, or pleating allows new spaces or territories to emerge without losing the native characteristics of what is being folded. It is already understood that architectural aspiration for the fold lies in its potential for manifesting cohesion and a continuity of competing spatial, social, programmatic and contextual conditions within a single language."

"As a Material technique, however, folding is not limited to being a secondary system of articulating the larger building diagram. The operation of folding material is also a generative design tool that has gained currency in digital-fabrication processes."

(Iwamoto, 2009, p. 63)

CONTOURING

Contouring is a reductive process that reshapes an otherwise two-dimensional surface, such as (stacked sheets of) MDF into a three dimensional object. Architecture has long utilized the process of carving or contouring - Greek columns, capitals, and ornate friezes are all examples of this process. The craft of carving has been considered overly expensive and labor intensive since the industrial revolution. Digital fabrication is removing carving from the exclusive world of hand craft, and allowing it to be a viable and affordable solution to problems of detail in architecture. Ornate details such as were considered expensive in Arte Nouveau details of the past have the potential to become commonplace, thanks to digital contouring methods.

Because of the reductive nature of contouring, it is extremely time consuming, and produces much more waste than other forms of fabrication mentioned in this section. Contouring, more so than any of the processes mentioned thus far, has the potential to turn an ordinary material into an extraordinary object

Another realm that contouring may soon dominate will be that of the (physical) architectural model. Contouring is often utilized in the creation of models, as the CNC can easily model and reproduce the architectural and landscape surfaces created by N.U.R.B.S. programs. Other process already mentioned can abstractly represent these surfaces, but only contouring can duplicate them.

3D Printing

Although 3D printers are widely utilized for the production of smaller, industrial rapid prototypes it also has great potential in the realm of furniture design. An example of this potential can be seen in the work of the 2006-07 VIA Grant winner Ammar Elouini. His winning entry, known as CoReFab#71, is basically a 3D snapshot of a single film frame of an animated pattern as it travels through the volume of a chair. The captured frame is exported as a stereo lithography file and the chair is then printed in 3D.

MACHINES (TOOLS) USED FOR DIGITAL FABRICATION

A 3D model can be exported to any number of fabrication devices such as a 3D printer, laser cutter, or CNC (computer numerical control) machine. These machines, once programmed, can create different variations of the same object (e.g. a masonry unit) as easily as it could produce identical units. This is the primary reason that constructing something from identical units will be less of an economic necessity. Mass production could potentially give way to mass customization. CNC milling facilitates the seamless workflow between the digital model and the physical product.

Digital fabrication, like sculpture, is really a result, or combination, of an additive or subtractive process. According to Jacob Kraubel, in his book, *Contemporary Digital Architecture: Design and Techniques*, There are several different types of CNC machines, but they can all be grouped into three main categories:

CUTTING:

CNC creation of 2d elements is the most commonly used technique. Flat sheets of nearly any material can be cut into nearly any shape. Water jet, and plasma cutting are the most common types of CNC cutters, their use is dependent upon the type of material to be cut.

SUBTRACTIVE FABRICATION:

This involves the removal of material from the original stock in order to arrive at the desired design. The removal can be done chemically, as in etching, but is most often done mechanically with a milling machine. Milling machines are available in two and one half to three axis mills, or five axis versions. The number of axes refers to the amount of movement available to the machine while cutting. For example, a three axis mill is able to move simultaneously in the directions of the X,Y, and Z directions. Basically, a three axis mill can cut in any direction laterally, as well as up and down. A three axis mill is extremely efficient at creating any type of low relief, draftable object, such as a coin, but cannot cut anything with undercuts. In order to cut out a fully three dimensional object, a five axis machine needs to be utilized.

ADDITIVE FABRICATION

3D printing, stereo lithography (SLA) layered fabrication, and solid freeform modeling are processes that fall under the category of additive fabrication. These are all unique technologies and processes, but follow the same principle, that of building up the model, layer by layer. The amount of detail available is dependent upon the thickness of these layers, SLA and 3D printing can print layers as thin as .1 mm. It is even possible to use the additive process to “print” a concrete foundation. These processes can produce extremely complex, zero tolerance, exact forms. Labeling of individual objects is essential should this, or any of these processes be used in a project involving mass customization (Kraubel, 2010).

Research Questions and Goals

Based on the preceding observations, this thesis addresses the earlier question: and proposes a research methodology that would allow future researchers to pursue and answer this, and similar questions:

Some answers to this question include:

1. Students should have the ability to face and adapt to changing technology. They need to learn how to learn technology (software).

2. Students should be exposed to fundamental concepts that will be useful now and into the future. The course should address fundamental principles that we hypothesize will persist despite rapid changes.

3. Students should have the ability to generate and communicate ideas utilizing multiple processes (approaches) and media.

4. Students should gain a transparency of the tools, and learn, in terms of design, what is the right tool for the right job, is there a way to teach design simultaneously with tool use?

This thesis proposes that the Y Model, an educational approach adapted from the American Association of Snowboard Instructors, when its content is sufficiently tweaked, and modified from snowboarding to architectural design, is a valid approach to teaching design computing to undergraduate architecture students. The Y model is a pedagogical approach that assists instructors in the delivery of skills necessary for students to best utilize their tool (snowboard) for a desired outcome, freestyle or racing, or a combination of the two, known as freeriding. The Y model consists of 4 parts; the base, the foundational, the developmental, and the applications. The Y model will be explained, in depth in chapter 6.

This thesis provides an example (case study) of a Y model introductory course in design computing that attempted to address the preceding statements. It is important to note that the proposed course's effectiveness is based upon the fact that it happens at a certain point in time in a certain curriculum. It was developed as a contextual response to the above-mentioned considerations.

Chapter 2.
Literature Review

"The modern trouble lies not in the use of machinery, but with the abuse of it, and the hope of reform would seem to be in the direction of a return to the spirit which animated the workers of a more primitive age, and not merely to an imitation of their method of working."

Gustav Stickley

The following review investigates the current role of design computing within the context of architectural design education, experiments, and outcomes.

Architecture is experiencing a shift from completely manual production of drawings and models to a completely digital, or, at the very least, a digital manual hybrid approach to production. As the computer is now an accepted tool utilized during the design process, schools of architecture, educators, and researchers, have begun to explore opportunities for linking CAD with material outcomes via a variety of digital fabrication approaches, techniques, and practices. The numerous ways to describe and experiment with technology within the context of design education indicates a need to understand its impact on student learning during the design process.

Asanowicz argues that the computer can be, "…treated as a medium, which lets students explore different spaces of architectural design. It is an extension of our creative possibilities. While traditional tools enable architects to work only on objects, the computer gives them access to the processes and sources of creative activity. They can use it at early design stages for searching of idea" (Asanowicz, 2007)

The integration of the digital has created a need to determine new and suitable educational approaches for the design process. A review of current literature points to the fact that, due to the ubiquity of computers in design education, they are now thought of as more than just a tool. (Iverson, 2009) (Asanowicz, 2007) The use of technology is allowing the computer to be considered a partner in the creative process. This partnership in the design process necessitates exploration of previously accepted pedagogies and learning theories, as they apply to design and vocational instruction. This review will attempt to provide a proposed area of research intended to reveal potential approaches to introductory undergraduate architectural design computing courses, via the integration of technological and analog, through an analysis of research reports on the integration of the digital into design education, and a variety of pedagogical approaches and summaries.

DIGITAL TOOLS IN ARCHITECTURE EDUCATION

In recent years, investigations into design instruction have posed and addressed the following questions:

1. How can one effectively teach the design process? (Demirka, 2007) (Uluoglu, 2000)
2. How do students' effectively learn the design process? (Yunyan, 2005)
3. Should students be trained primarily using traditional or digital media? (Mao Lin Chiu, 2008) (Hyde, 2000)

Technology is changing rapidly. Digital media are simply too new for there to exist an abundance of formally prepared evidence on their teaching. It has been suggested that educators need to approach the teaching of digital media not by pushing buttons, but by addressing the contextual frameworks informing the software which will inevitably remain in constant flux. The nearly endless possibilities discourage the utilization of a single teaching methodology. It is therefore necessary for educators to employ improvisation, which combines intellect and skill. (McCullough, 1996)

New tools should bring with them a correlating response in our procedures, approach, and tactics. Much computer education has been limited to "how to", technical training manuals. This puts the impetus on learning software as opposed to learning how to apply existing skills, or develop new ones. (McCoulogh, 1996), (Ataman, 1999) (Campbell, 2006) The utilization of digital tools in education has led to some understated changes to the design objectives and results. (Bharat Dave, 1989) (Carrher, 2011) (Chiu M. , 2006) Understanding the underlying concepts of digital media can contribute to the analytic process and contribute to a student's conceptual development (Columbia) (Carrher, 2011) (Ataman, 1999)

For the most part, in computer (software) specific courses, the application of concepts and the wide breadth of features of digital tools are not applied in the design studio. Most agree that current CAD systems are invaluable for production, as opposed to design. There are numerous models that have explored the integration of computers into academic design studios; the earliest of which were reported by (Goldman and Zdepski, (Goldman, 1991) Richardson (Richardson, 1993), (Sapene, 1994) Miranda and Gribou (Gribou, 1993) Akin (Akin, 1990), and several others.) (Ataman, 1999)

When introducing design computing, we should bear in mind that we are teaching design students. When it comes to education of designers, as opposed to most other disciplines, the biggest difference is designers are taught that there is no single correct solution. (Yaşar, 2006)

When teaching the digital, the students' learning styles and preferences, which differ by age, current GPA, gender, and experiences must be considered. There is no single approach to disseminating information. A learning style is "a biological and developmental set of personal characteristics that make the identical instruction effective for some students and ineffective for others" ((Honigsfeld, 2006)

Assessment in design studios, laboratories and shop environments is difficult. Competency is a "dynamic, evolving status that must be sought and maintained throughout a professional career, rather than a single milestone achievement to be attained at a given point in time" (Leach, 2002). How are students to be assessed? Is a simple completion of duties sufficient or is something more necessary? “Because the emphasis is on competency, applying a numerical score to performance or completion of a duty is complex.” (Hamel, 2001)

Now and well into the future, providing students with a solid grasp of the fundamentals of design computing is crucial. This promises to be an ever-evolving concern that must be constantly monitored and updated. (Akin, 1989) (Chiu M. L., 2003) How can we naturally integrate digital design into the architectural curriculum? How can we provide a curriculum that allows students to utilize these tools to their most creative end? How can we measure our effectiveness in disseminating this information? Chiu, Aken, Leach and Caraher suggest that design process and curriculum will necessarily undergo continuous and radical changes once designers attempt to fully utilize the power of the computer.

Akin asserts that due to the digital, instruction is bound to change. Leach and others suggest that due to abundance of digital tools in use by designers, the increased material may necessitate longer or additional courses. Issues related to the process of design will change. “Design problems that capitalize on the advantages of computing will be preferred over others.” (Leach, 2002)Medium specific instructions will have to be included in the curriculum; therefore, more time must be allotted.

Neil Leach states: “We are witnessing a new generation of designers operating within the digital domain, who are not simply using these technologies as a sophisticated tool for testing out designs conceived in a more traditional paradigm, or as a technique for assisting in construction calculations, but rather as a medium through which to pursue design itself.” (Carrher, 2011, p. 103)

MISUSE OF THE DIGITAL

Richard Sennet writes that "machines can be misused". Modern machinery, or, in this case, software, can be considered misused when it deprives people of learning from repetition. Software, such as CAD, can separate an individual's "understanding from repetitive, instructive, hands on learning. When this happens, conceptual human powers suffer. (Sennet, 2008, p. 83)"

When CAD began to replace hand drafting, one thing it is said to have sacrificed for the sake of speed was the intimate knowledge one gets from manually inserting every contour, tree, or joist, into a drawing. When tracing and retracing a drawing, one understands a building in a way that is simply not possible by refreshing a computer generated model. The arduous and time consuming process of hand drawing has long been utilized as a vehicle for slowing down, truly observing, learning, and owning an object, idea, or concept. Classically trained artists have drawn from plaster casts, and students of architecture have drawn Roman ruins since the time of Brunelleschi. Drawing is a process that trains the eye and the hand simultaneously, although not necessarily at the same pace.

Sennet and others describes architectural sketches as "pictures of possibilities". Repetitive hand refinements allow a designer to more easily become absorbed in their process. It "matures their thinking about it." The design becomes "ingrained in the mind".

In a recent *New York Times* editorial, Michael Graves wrote that the computer is now the primary tool utilized by students during the design process, but there is something lost when they draw only on the computer.

Renzo Piano explained his own procedure as: "You start sketching, then you do drawing, then you make a model, and then you go back to reality-you go to the site-and then you go back to drawing. You build up a kind of circularity between drawing and making and back again." He also commented on practice and repetition, "This is very typical of a craftsman's approach. You think and you do at the same time. You draw and you make. Drawing …is revisited. You do it, you redo it, and you do it again." (Robbins, 1994)

Sennet and others argue that it is entirely possible to bypass this CIRCLE when using CAD. This misuse is described as occurring if the process is closed, or simply a means to an end. Misuse makes it possible for the computer to understand the model, but not the designer (Turkel, 2009).

Several researchers write that skills and concepts should become the content of the lectures, as opposed to "button pushing". The students can then be cognizant of the differences, strengths, and weaknesses of the tools and media. (Campbell, Abdelhameed, McCoulogh, Asanowicz)

DIGITAL CRAFTSMANSHIP

In order to bring together skills and intention, it is necessary to practice. It is essential to know how tools work, and how they work with each other. It is imperative to know what tools are for. It is important to practice with the tools. Practice leads to a lasting and satisfying form of knowledge, that of ownership (McCullough, 1996, p. 62). Mastery comes not only from the tools, but from practice and understanding, not just of the tools, but of the tool's function. For example, a good renderer will have the ability to see and compose as well as a deep understanding of the rendering medium, be it paint, markers, or digital (Cameron, 2012) (McCullough, 1996, p. 248).

A tool can be defined as something "that depends on us to control the scope, the pace, and the focus of its work; mere machinery does not." (McCullough, 1996, p. 68) Tools are a vehicle for working a medium. CADCAM, for example, is a single tool that can work several media. The correct approach to tools may help to lead towards more equivocal positions regarding technology. It is essential to investigate and understand the fact that there may not always be a clear distinction between the tool and the medium, between analog and digital, or manual and mechanized.

McCullough believes in that in order to pursue this reality with digital tools, it will first be necessary to master the technology to the point where it will become transparent. Only then will it be possible to use this *"paradoxical freedom"* effectively. He stresses that this transparency must be arrived at with a thorough understanding of the principles that inform the software, and not just memorizing which buttons to push, thereby becoming a "mouse potato". He states that Paz is correct in suggesting that what is missing in work, in the making artifacts, is "contemplation". He believes we need to develop good habits in letting one piece of work inform the next (McCullough, 1996, pp. 50-55). Chiu claims that approaches by certain institutions that focus on digitally enhancing curriculum are indeed promoting the use of certain software and hardware, but this is not necessarily contributing to innovative design (Chiu M. , 2006).

Additionally, McCullough shifts focus from the teacher and the student to the manufacturer of the software. He believes they should do more to reconcile direct with indirect actions. Computers have the power to be logical; they have the power of calculation. It is the user that has the power to see. It is the combination of seeing correctly and utilizing the tools transparently that leads to what he refers to as craftsmanship.

PEDAGOGICAL APPROACHES

Literature has suggested three different approaches that incorporate the digital into the design curriculum:

1. Curriculum designed for computability: A Curriculum designed for computability is one in which the course objectives do not differ from other, technology-free studios.

2. Parallel processes of design and digital fabrication: digital design and fabrication are taught simultaneously. This provides opportunities for students to design and fabricate projects that stress the limitations of the tools in terms of materials, construction, and digital design (Carrher, 2011).

3. Digital evaluation through simulation: Kalay advocates applying technology to segments of the design process as opposed to process as a whole, the logic being that computability and support are a more likely outcome. (Kalay, 2004) Design specific literature suggests a need to more clearly define, and consider, new instructional methods, that can positively affect the role that digital technologies play in education. Discussed below are several attempts by educators to assess the impact of technology on students. This suggests a need to explore the relationships between traditional (analog) and digital tools and education, as well as the search for an integrated curriculum whereby educators could utilize the two methods in concert, thereby creating a curriculum, which could lead to a new way of making (Iversson, 2010).

One of the earlier studies that explored the integration of digital tools into the architecture curriculum was by Aken in 1989. The time required for the acquisition of a new medium was an additional, time consuming block that was added into a pre-established course curriculum. Aken concluded that although the students became more or less self-reliant, in terms of utilizing the software, there was an overwhelming need for them to understand the design process, and develop the skills necessary to adapt that process to what the computer offered, in terms of its being a new tool. Aken noted several changes in the students' design process. The changes in student behavior lead Aken to assert, regarding the instructor, "Perhaps the most critical change in the educational context is needed in this category…to learn about the functionalities of the computer and design operations compatible with computation" (Akin 1989, 315).

During the 2009 Taiwan CAADRIA Hesmath and Bonnestetter, of University of Nebraska-Lincoln, still urged educators to redesign instructional methods in order to increase student engagement and learning. They called for an implementation, development, and evaluations of inquiry-based projects that would align the classroom with technologies necessary to stimulate an essential knowledge base. It was suggested that an inquiry-based CADCAM pedagogy model, as opposed to problem-based education models had tremendous potential. The inquiry-based approach model's primary concern is to address a problem utilizing prototyping. It was stated that the emphasis was more on solving a problem utilizing a specific process, than it was with a specific design outcome. The need to solve the problem drives learning on multiple levels, integrating interdisciplinary ideas into the problem and solution. It also encourages diversity and flexibility by allowing students to look at problems from multiples perspectives (Hemsath, 2009).

Oxman proposes that new design theories will emerge from the visualization capabilities of digitally designed architecture, driving design to explore the "formative, generative, and simulation aspects of design" (Oxman, 2008). It has been proposed that model based, parametric design will begin to replace traditional design approaches (Oxman, 2008) (Corser, 2013). Solution specific inquiries will yield to material experimentation and research into form making; thereby transforming the design process in yet unexplored ways (Oxman, 2008). These emerging avenues will necessitate new pedagogical approaches in order to provide designers with the ability to script and manipulate complex data streams, while still respecting traditional theories of architectural design.

This speculation points to a need to appropriately incorporate design computing into the architectural curriculum. These predictions reveal two young avenues of design computing that have the potential to change the way design is approached: digital fabrication, and parametric design. This suggests a need to develop appropriate methods, and logical progressions for teaching the appropriate use of digital tools to designers.

In order to narrow the scope of this review, the focus will move to fabrication education during the early phases of the academic career, and possible approaches to developing an appropriate curriculum.

PARALLEL MEDIUMS

Simultaneous exploration of mental and physical activities has been shown to teach relationships and limitations between representation and fabrication. Laboratories that utilize both types of modeling supply two modes of feedback, and address visual and kinesthetic learning styles. The technological foundation supplied via this approach can allow the curriculum to transition more smoothly and logically to evaluative or parametric simulations. For Sorguc et al., fabrication and modeling were utilized in order to facilitate an understanding of digital/physical fabrication processes and concepts. (Sorguc et al. 2011).

In 2010, Cameron Campbell taught a course at Iowa State University that focused on fundamental concepts that were applicable to both digital and physical mediums, and how they related specifically to the digital tools. The rationale was that the aforementioned concepts were applicable regardless of the medium in which they were applied. The assumption was that historically, foundation courses have been taught using analog techniques and these principles are not typically revisited when introducing a digital pedagogy.

The approach to this course allowed the students to become critical of how they used each medium, and its respective effectiveness as a communication tool. “The future emphasis in digital design education should be in the digital ground rather than just the outcomes, i.e., the integration and implementation of the design process digitally, including design information and knowledge management, collaborative design, CAD/CAM, and resource management (Cambell, 2006).”

It has been suggested that working in parallel media is a positive strategy when the academic goal is maximizing understanding in CAD education. (Chiu 2006). Other studies suggest that educators introduce students to digital media gradually so that they are allowed sufficient time to "gain the qualitative components of their visual design process performed in these digital environments." (Abdelhameed, 2011)

Synergy in Media

Researchers suggest that it is necessary for the instructor to demonstrate how tools can work together in concert. It has been stated that it is important for students to use the digital tools in a complementary fashion in order to understand their respective potentials and pitfalls. Working in parallel media can reinforce both the contrasts and shared principles, thus contributing to a greater understanding of common approaches and organizational strategies of the programs. (Chen) Peter Szalapaj, Abdelhameed, Hesmath and Bonnstetter have all proposed a similar process that integrates physical prototypes with CAD processes. (Szalapaj, 2005)

Malcolm McCullough stated that computing has the potential to become the medium that will reunite a craftsman's practiced knowledge with (manual) dexterity and visual thinking. (McCullough, 1996, p. 50) He hypothesizes that because it can model and manipulate both objects and the processes by which they are produced, CADCAM is recasting the relationship between representations and objects. This in turn creates a feedback loop similar to the one described earlier by Renzo Piano, whereby each step of the process informs the other.

Higher quality design has always been grounded in the realities of fabrication. McCoulogh insists the best design approach is to use manufacturing criteria as the basis for variations and constraints. When this is done correctly, the result can be a *"close-coupled loop"* in which both design variations and fabrication can drive one another. The essence of this coupling is that the input to physical fabrication operations is symbolic, and the output from geometric derivations is tangible."

Bridging the gap between idea and object, (conception and execution), has the potential to merge design and fabrication, often times thought of as mutually exclusive activities (McCullough, 1996).

> "Design worlds will gain credibility from coupling with the realities of production. Besides framing intangible worlds, we can apply symbolic manipulations to physical manufacturing; we can extend the idea of mechanism in software to a reality in hardware. And conversely, we can make the process of production become workable in the abstract, and manipulate process abstractions together with the objects of design. This is not a new idea, but it has gained a lot of ground lately." (McCullough, 1996, p. 186)

Arzu Gonenc Sorguc has written of the computational design process: Utilizing laser cut models informed decisions on the building sequence and assisted manufacturing, construction, and visualization. By integrating a modeling and manufacturing process, it was necessary for students to "learn rules and precision of the machines as well as features of the materials to be used" (Sorguc, 2009).

Many institutions agree that a mix of traditional and digital approaches should be taught (Brandon, 2001) (Knight, 2010). (Ankerson, 2013). Because the media are not mutually exclusive, this leads to a multitude of follow up questions, of when, how, and how much. (Abdelhameed, 2011)

This exploration is still underway; at the ACADIA Regional 2011 Conference Proceedings Erin Carraher stressed the importance of integrating both the tools and concepts into the early phases of a designer's education. Virginia Tech is currently wrestling with the question of how the digital is amalgamated into their curriculum while still maintaining the benefits gained from hands- on learning.

Carraher asserts that the inclusion of a physical requirement in a computation course "forces a slowness and resistance to the seeming ease and fluidity of the software." It facilitates an understanding of the interconnectedness between the digital and physical. (Carrher, 2011) The students experience and understand that being able to draw something on the computer does not mean they will be able to physically realize the design.

According to Nancy Chen, working in multiple media, in this case digital and physical (3d model making), can achieve the following:

1. Reveals advantages and disadvantages of the processes to the students.
2. Provides new insight into the relationship between process and content.
3. Demonstrates how “translating media” has the potential to enrich the design process.

Manipulating a model digitally is only one form of design development. The same model, when 3d printed, allows its form and scale can be appreciated on a different level. It is important to understand the potential of the respective technologies. For example, hand assembled, laser cut models stimulate another type of thinking, not only of form, but of material concerns (Chiu M. &., 2006).

There have been a number of explorations into digital/analog/physical hybrid courses in recent years; Martens, Marks and Cheng explored contrasts between the media and attempted to describe common opportunities and issues in their respective courses.

In an interdisciplinary design course at University Lincoln, Nebraska, Hesmath and Bonnstetter utilized what they referred to as an “inquiry based CADCAM pedagogy model”. This was an approach that was less concerned with the specific design project than it was with analyzing the process of problem solving utilizing the “vehicle” of prototyping. They claimed that this approach had three substantial benefits:

1. The need to solve the problem facilitated learning on multiple levels. It successfully integrated interdisciplinary ideas into the problem and solution.

2. The problem facilitated a positive interdisciplinary environment through inquiry knowledge building in team exercises.

3. It encouraged diversity and flexibility by allowing students to look at problems from multiples perspectives and points of view.

Hesmath and Bonnstetter believe that the 5E Learning Cycle Model (Engagement, Exploration, Explanation, Elaboration, Evaluation) (Bonnister, 2013) provides clarity to the students. Their desire to solve the assigned problem actuates learning on multiple levels, thereby integrating interdisciplinary ideas into both the problem and solution. A process oriented, CADCAM and the prototyping requirement is able to bridge gaps between disciplines via "inquiry knowledge building". They, like others, refer to the framework of this exploration as cyclical or circular. Peter Szalapaj proposes a similar process that integrates physical prototypes with CAD processes (Szalapaj, 2005).

Carraher asserts that prototyping requires and involves several stages of "design inquiry" in order to problem solve. In their model, students began with a "traditional hands on recipe" in utilizing 3D modeling software in the design of what would be a working prototype. As the students gained familiarity with the software and the object they were modeling, they moved on to the next phase design where they refined the prototype. Refinement of the original prototype allowed the students to gain ownership of the processes and allowed them to focus on their intrinsic motivation for discovery.

Carraher has written that through the experiential process of fabricating their designs in tangible materials that students can discover new ways of making (tools) still have ties to traditional design principles and construction techniques. This in turn can facilitate an understanding of the "affect of digital tools on both the 'product' of design – the thing itself – as well as the 'process' of design – the making of the thing."

Utilizing a digital to physical approach encourages the "development of a durable knowledge".

This is the type of knowledge that, once understood, will remain with them for the remainder of their lives (Carrher, 2011).

In 2003 Chiu asserted that utilizing digital tools affects the processes and outcomes of both the digital and physical design. Digitally designed physical projects are important and are influencing the practice of architecture as studios begin to shift to physically grounded projects. “The design process that can integrate both becomes critical for education.” (Chiu M. L., 2003)

Summary

Based upon the literature review, it is possible to infer (according to the authors) the following:

1. The introduction of digital tools has changed the way we teach architecture and design, thereby changing what students are learning.
2. Users, more specifically, students do not fully understand the digital tools they are using, either in terms of conceptual understanding or practical how to.
3. Because of the understanding, or lack thereof, of the digital tools, the RDM or cyclical design process has suffered.
4. Research into new pedagogical approaches that integrate the process of design and understanding of the new tools should be undertaken.

Chapter 3.
In the beginning…

Introduction to Design Computing at Carnegie Melon University

One of the earliest writings on the subject of introducing Design Computing to undergraduates was in 1989. “Computer Modeling: A First Course in Design Computing” was written by Bharat Dave and Robert Woodbury, Department of Architecture faculty at Carnegie-Mellon University. Although it is nearly a quarter century old, this paper remains significant for that very reason. Several concerns, approaches, and discussions raised in this paper are significant in that:

1. Many of them still exist today.
2. These were concerns when the architectural education process was still largely analog. In a sense, they were teaching design utilizing these analog processes, and teaching “computing” as a separate, autonomous, element.

In this paper, they describe computer modeling in terms of the context, issues and topics it represented, the tasks it required of students, as well as questions and opportunities it raised. The original language of the authors is quoted more often than might be deemed acceptable in this description. Unless otherwise specified, all quotes in this chapter are by Bharat Dave and Robert Woodbury (Bharat Dave, 1989). This is done in order to illustrate and draw attention to the evolution of the semantics currently used to discuss such processes. It also serves to emphasize the consistency of the underlying theories and concepts over the past quarter century.

The course they developed was primarily about concepts, about ways of not only understanding design, but its relation to computation. It was about models, design processes, computation, and computational design. Student acquisition of algorithmic design problem solving and procedural skills were secondary. The goal of the course was to create a “structure that can be used as a framework, around which students can continue to develop an understanding of computers in design."

The intellectual underpinning of the course was the notion of a model which was {Echeneique 1972} defined as: "a representation of reality, in which representation is made by the certain relevant characteristics of the observed reality and where reality consists of objects or systems that exist, have existed, or may exist." (McCoullough, 1990, p. 164)

Their entire course was presented as a "conscious exercise in model building and explanation." The concept of rational decision making (RDM) was central to their course. The notion of RDM is a cyclical and iterative process. It contains several unique actions that are repeated in a consistent order in each cycle. The actions are:

1. The generation of alternatives
2. Performance prediction
3. Simultaneous evaluation of predictions
4. The selection of alternatives

This model is conducive to many processes, design being one of them.

RDM was then paired with an abstract model of human cognition (Newell 1972) that claimed the human mind necessarily supports only certain ways of designing. This is done by searching in what is referred to as a state space, (In this case, state space (model) can be defined as a mathematical model of a physical system.) moving from one model or alternative to another. At each step of this process, humans are said to apply the last three steps of RDM. Since humans have a limited ability to store information cognitively, this implies that they will always use some sort of model, abstraction, or representation when designing. The model need not be limited to the object being designed, but can extend to the design process itself or even the parameters, constraints, or program requirements.

They describe human design as requiring thinking (cognition) decision making, and spatial representation. They asserted a course on design computing needed two additional models. The first was a model of computation (the machine, processor, memory, etc…). The second model was described as "an augmentation of the basic model of human cognition to include these computational agents."

For the course, they asserted that the goal of utilizing computation in design was to be "supportive of humans in areas of strength and provide new capabilities in areas of human weakness."

The Computer Modeling they claimed was an explanation of the five models. They believed that taken together, they created a platform upon which they could build a solid understanding of design computing. Utilizing explanations, demonstrations, and sets of practical applications their goal was to assist students in the learning and application of said models. The assignments were designed to emphasize the concepts of the five models and *to* "exercise the student use of them." As the communication of ideas was the primary goal of the course, they "stressed a conceptual approach." During the lectures, (50 minutes, once a week) students were introduced to the concepts, and in the labs (80 minutes, once a week) they were given a "minimal amount of procedural instructions."

Course Content

The course was structured around examples of models, which they referred to as "spatial representations"; these models functioned to introduce, represent, and explain the other four models.

1. Graphic Pictures
2. Graphic 2-dimensional
3. Graphic 3-dimensional
4. Databases
5. Parametric Models

Each of these was designed to support information in a different manner. For each representation they provided a series of lectures and computer exercises utilizing software existent at the time.

Graphic Pictures

Graphic Pictures were simply bitmaps, raster data that that were seen as larger elements such as lines, surfaces, planes, textures, etc…

These graphic pictures introduced the students to polygons that they were then required to transform in some way. Transform is an apt description as the acts they were required to perform on these polygons would typically be found under a *"transform"* menu in much software used today (2013). Students were required to rotate, scale, and mirror the polygons.

They chose to elaborate upon the notion of state space in these early exercises by introducing "notions of rule, semantically meaningful operations." To show that "rule discovery and search are two inseparable aspects of state space search." Each altered polygon had an effect on the overall composition of numerous polygons. Students generally began to compose these polygonal patterns, which provided the instructors with a "natural opportunity to discuss the RDM model."

The primary digital tools for these exercises were paint programs. One of the underlying concepts they were trying to communicate to the students at the time was the synergy of the pixel, and the role each pixel has in creating higher order representations such as lines and polygons. The notions of logical orders and procedures were also introduced in this section as well. Because it was labor intensive for a human to utilize the paint program, the instructors believed they were fostering an environment where the students were motivated to understand and use proper procedures.

Graphic 2D Models

They believed that graphic 2D models made use of geometric concepts. They also insisted that when they were applied to the "domain of architecture they gained further semantic structure by concepts and conventions of that domain."

This provided the first opportunity for students to design an interior layout and create a set of scaled drawings. The goal at the time was to "develop a spatial composition using a set of familiar objects and their relationships." The RDM and state space search was "made more explicit by requiring students to record intermediate design layouts and sketches."

The utilization of, and logical progression into, 2-dimensional drawing programs served to "introduce additional computational notions". They stressed that when working in traditional mediums such as paper, the "articulation of design intentions and their realizations as a design solution are the primary responsibility of human agents." As the students transformed the pixels into recognizable elements the authors claim that they were also creating their first" parametric operations". As simple as we may consider the specification of two vertices to make a square today, it can still be considered parametric. "By seeing and realizing that interpretations and actions as procedures can be encoded in computer programs, students are exposed to further possibilities of computers augmenting the design process."

Graphic 3D Models

In order to make the 2D representations, plans, sections, etc… "consistent" with literal spatial environments, they then introduced 3D models. They introduced the volumetric notions of solids and voids. Based upon what they called the "parametric nature" of the "objects" they could create different volumes, cubes, spheres, etc… "Based upon certain parameters, volumes can be categorized into classes, e.g., cubes, cylinders, spheres, and others. By using these parameters, a small number of parametric definitions can be used to generate and represent a large number of instances and of volumes."

In order for these instances to function like architecture, they needed to possess specific attributes and relationships to the model. They give an example of an instance of a cube functioning like a wall. Clearly some sort of conceptual leap needed to be made at the time.

These ideas were introduced via a project that required students to create a simple 3d model of an existent design. The emphasis was to be on the representation of elements of the design, not recreation of the object. "By taking apart and modeling a design project, students are expected to understand design projects as assemblies of physical and qualitative elements brought together in order to satisfy some design context. The underlying model, of design as a set of purposes and their realization in the form of volumetric compositions becomes more articulated in this exercise." This project was also used to help the students infer additional information regarding spatial relationships such as adjacency, scale, and rhythm.

The authors went on to note that "on a secondary level" programs that support 3D representation enable accurate visualization of three dimensional spaces. "This has a subtle impact on students as they become more attuned to thinking in three dimensions since such programs also offer fast generation of realistic 3d views

Databases

In the next phase of the course, the 3D models were made more complete by introducing and utilizing the concepts of databases. The database project required students to define, represent, and associate a number of parameters and program requirements that could integrate graphic and non-graphic representations. This information was then inputted into a database. The instructors noted that the earlier notion of RDM and state space search remained the same in this assignment.

The authors believed that parallels existed between database concepts and design experience, both could be considered large collections of rules that when combined could lead to new design processes and descriptions. "A database is a collection of structured information, and such information can be collated in various ways to generate new information relative to design goals. Similarly, design expertise can be viewed as a large collection of design rules that are applied in varying contexts, and their combined processing brings forth new design descriptions."

Parametric Variations

According to the RDM, each stage of design development adds to and modifies information from the previous stage. During this process, concepts are made more concrete utilizing different forms of representation. This is done by emphasizing the more relevant points of data from previous stages.

The students were required to develop an ordering system to select and transform data, which would be utilized to calculate illumination levels in an interior space. The authors asserted that this exercise served to bring together several issues that related to architectural modeling and computation. It also provided an opportunity for the students to "define a state space, and search for feasible states for a given task." By using spreadsheet programs, the ideas of computation as representation of data, relations between them, and procedures by which possibilities inherent in a model can be explored, are made obvious. This in turn leads to the discussion of parallels between architectural design process and computation, and how the experience accumulated by designers over a number of years might be represented and used in a computer.

Course Summary

The authors claimed that the concepts the course introduced were hierarchical in that each project was an enhanced and more rigorous version of the one that preceded it. The assignments presented the students a hierarchy of examples of following categories:

1. Automated evaluation of designs generated by (what were at the time) traditional means
2. Stepwise interactive generation

3. Non-exhaustive generation of feasible solutions
4. Generation of (sub) optimal designs

They hoped that by taking a structured approach to the introduction of ideas that students gained a conceptual understanding of the role of models and their representations. “ *By emphasizing a conceptual over a procedural approach, we also hope that students articulate the knowledge they gain in this course in a fashion that is independent of particular tasks, domains, and software or hardware considerations.* “

Reflections and Methods

They utilized informal evaluative techniques, which included written and oral feedback, as well as course assignments. The authors stated they were “quite pleased with their choice to use representation as the common thread” of the course. They explained that this thread was able to best explain the remaining four models within said context. They believed at the time that this format provided a concrete foundation upon which they could build. They claimed the course sparked interest in the students, several of them “spontaneously used their experience in other courses. “

They also cited several areas where the course could have been improved. For example, they could have provided more structured links to the other five models they discussed. They also believed that the introductory nature of the floor plan exercise was not stimulating to the students, and did not feel that the database projects motivated the students to further investigation.

The most important shortcoming they discussed was that they needed to better integrate the course into the sequence of courses in the department’s curriculum, yet still maintain “its emphasis on concepts independent of particular applications and tasks. A stronger treatment of procedural ideas would assist our introductory and advanced programming courses. More rigorous consideration of geometry could motivate our course on geometry and computation. If search were treated more seriously, students could be better prepared for the material in our advanced course on rules and representations."

Important points to consider throughout the thesis:

1. The concept of rational decision making (RDM) was central to their course. The notion of RDM is a cyclical and iterative process. Parallels between the cyclical or circular design process and RDM will be mentioned later.
2. Course content: the course was structured around five models, or concepts.
    a. Graphic Pictures: Raster vs. vector, digital imaging
    b. Graphic 2-dimensional: Plans, sections
    c. Graphic 3-dimensional: 3D modeling
    d. Databases: early contribution of data that could be used for information storage, parametric inputs as well as for technology that has not yet been invented.
    e. Parametric Models: in some senses, parametric by today's standards, in other senses parametric in terms of design process and development. It could also be considered utilizing computation during the design process.
3. Methods: The methods they used to measure success were largely qualitative, written and oral feedback, and the student assignments.
4. Self-criticism, the authors stated that the course had the following weaknesses:
    a. Links between the five models could have been more structured.
    b. Introductory nature of some projects was not stimulating to the students.

c. The database projects did not motivate students towards further investigation.

d. It was essential that the course be better integrated into the sequence of courses in the department's curriculum yet still maintains its emphasis on concepts independent of particular applications and tasks.

These four criticisms were used as parameters that assisted in the creation of the Y model curriculum/case study developed and described later in this document.

Chapter 4.
Introduction to Design Computing

This chapter will briefly outline introductory design computing curriculum used by the some of the top programs in the United States.

"America's Best Architecture & Design Schools" is conducted annually by *Design Intelligence* on behalf of the Design Futures Council. The research ranks undergraduate and graduate programs from the perspective of leading practitioners. This 14th annual survey was conducted in mid-2013. (Design Intelligence, 2013, p. 18).

"In your firm's hiring experience in the past five years, which schools are best preparing students for success in the profession?"

The collegiate programs that hiring firms deem strongest in educating computer application are:

1. Massachusetts Institute of Technology
2. Southern California Institute of Architecture
3. Columbia University
4. Calif. Polytechnic State Univ., San Luis Obispo
5. Harvard University

Harvard does not offer an undergraduate architecture degree. As the focus of this thesis is undergraduate design computing, Kansas State University (#6) will be examined instead.

Massachusetts Institute of Technology

1. Computer Modeling- Representation of shapes; represent design ideas in 2 and 3 dimensions in the form of computer solids. (Windows based software, AutoCAD, 3D visualization, Adobe Photoshop)

2. Visualization- Visualize models through well rendered images to be used for design studies and presentations.
3. Fabrication-Fabrication of design ideas utilizing rapid prototyping tools and a process of fabrication. (3D printing)

(Sass, MIT Introduction to Computers in Architecture, 2013)

The goal of this is one semester course is to teach computing by teaching architecture. The introductory course is based on a Constructivist Learning Theory. It provides a framework for approaching fabrication. Constructivist learning theory is focused on self-reflection and experiential learning. The learning is scaffold for the student, which is provided by the instructor. The theoretical framework for Constructivist Learning Theory comes from a combination of ideas from Dewey, Bruner and Vygotsky.

MIT's scaffold for teaching computation and fabrication supports the production of designed products in four stages: Discovery, Design, Development and Delivery. Work steps for students employ methods found in architecture and mechanical design.

First, the student analyzes and existing product. After the students generates a new model as a collection of ideas mostly inclusive of new Discoveries. Third, formal steps in assembly design, design of product architecture and physical prototyping lead to well-designed components and connections. The final development is focused on manufacturing and finishing.

This process is absent a specific product. This process can be assigned to fabrication of anything from a cell phone to a skyscraper (Sass, 2013).

Southern California Institute of Architecture

1. 2D Drawing Fundamentals-Principles of digital drawing tools essential to 2D architectural representation. First semester.
2. 3D Modeling- Work is centered on advanced digital 3D drawing and modeling techniques. Second semester.
3. Digital Fabrication-Introduction to advanced techniques in digital modeling and processes of fabrication. Third semester (SCI-ARC, 2013).

SCI-ARC follows a rigid, three semester sequence. This first course introduces the principles of 2D architectural representation. Students learn the projective techniques for architecture, the conventions, and interface of the 2D modeling programs. "Of central importance is instilling in students a critical sensitivity for the inherent bias and nature of each deployed medium."

The second course expands upon the analytical techniques and strategies for the study of architecture. Digital 3D drawing and modeling techniques for the construction and evaluation of spatial conditions is emphasized. Students cover, texture mapping, lighting and rendering.

The last course in the sequence is an introduction to digital fabrication. Projects include production of digital models and physical output using computer numerical control (CNC) devices. (SCI-ARC, 2013)

Columbia University

Introduction to Computer Graphics

1. Geometry 1 and 2: polygon mesh and subdivision modeling, open GL, parametric curves and surface.
2. Ray Tracing: Illumination and shading, raster-based renders, textures and materials
3. Animation: Animation and simulation.

This one semester course is nearly identical to Architecture 481, 3D Modeling and Rendering, at the University of Washington. Its focus is the generation and manipulation of the virtual visual; it is designed to provide technological fundamentals to a variety of media, with an emphasis on "photorealistic rendering". This course also spends time analyzing other applications, including interactive rendering game engines (Columbia U. , 2013).

California Polytechnic State University, San Luis Obispo

1. Photoshop-Scan and adjust, enhance physical drawings, add entourage to architectural presentations, architectural collage
2. Form Z-3D modeling, 3D subtraction, massing models, organic shapes, terrain models,
3. InDesign- Adding text to layouts

   This is a one quarter course.

Kansas State University

Digital Designs and Applications

1. Website
2. Sketch up
3. Rhino
4. AutoCAD
5. Revit
6. Rendering

This course surveys a wide variety of contemporary design and visualization software. The intention of this course is not mastery of a single piece of software, but instead an introduction to the tools with a goal of understanding when the specific tools are appropriate.

In this one semester course, fabrication is taught in parallel with digital design. “Laser cutting and 3D printing are always a part of the course and cnc milling is engaged by some at their interest. Rhinoscript and grasshopper are also always present in some form, either geometry generation or analysis.” (Headley, 2013) (University, 2013)

Chapter 5.

The history of Architecture 380, an introduction to Design Computing

University of Washington

Architecture 380, Computers in Architecture is a required course in The University of Washington's Bachelor of Arts in Architectural Studies program. Students typically take this course in either the second or third quarter of their junior year. This is the student's first year after being officially admitted to the program. By this time they would have taken the introductory graphic communication courses, and at least one studio. The description of this course reads as follows:

"Laboratories, lecture, and demonstrations to introduce computing in environmental design and planning." (Washington, 2013)

The course is typically taught by senior faculty, graduate students or recent M Arch graduates. The exact curriculum varies from quarter to quarter depending upon instructor preference, industry trends (technological developments), etc…

Another factor that has influenced the curriculum is the amount of "computing" the students are exposed to in preceding courses. Until 2007, the introductory graphic communications courses (Architecture 210, Architecture 211) were taught using strictly analog methods of representation. Since 2008, these courses have utilized an integrated approach, whereby hand drawing skills are taught more or less simultaneously with digital representation tools. Architecture 210 and 211, Design Drawing I and II, are described as follows:

"Projects, lectures, demonstrations, and exercises to develop skill in freehand drawing and an understanding of drawing as a vital means to see, analyze, and represent essential aspects of the visual environment." (Washington, 2013)

These are introductory course in architectural representation. Students are required to analyze existent objects and architectural spaces utilizing introductory freehand drawing, axonometric and orthographic techniques. A 50 minute lecture, once a week, introduces the students to the concepts and content which will be the focus of the two, three hour studio sections for the week. The goal of Architecture 210 is that the students will acquire a comprehensive skill set in hand drawing and both raster and vector based digital media, specifically, Adobe Photoshop, and Illustrator.

Architecture 211 marks the first time the students are given a site specific architectural design project. This studio continues to build and integrate representational skills in hand drawing, Adobe Photoshop and Illustrator, and introduces the students to 3D modeling software, in this case, Sketch Up.

"The simultaneous introduction, examination and discourse of architectural concepts and the building of strong representational skill are the main goals of this course." (Proksch, 2013)

In 2011, the "stick studio", the student's first studio, which utilized physical models to expose students to the wood shop, wood frame construction, and design, was replaced with a studio that was paired with a digital graphics course, Architecture 315. From 2004 -2011, the "stick studio" also included a 3d modeling component. The digital graphics course had been taught in the 300 level studio for several years before. This course dove deeper into InDesign, Photoshop, and Illustator, as well as Google Sketch Up. In the fall of 2012, the students also received a single lecture on Rhino. Although the design requirements remained more or less the same, the emphasis on analog (woodshop) tools, physical model building, and experiential learning of wood frame building components and processes was reduced, and the use of digital tools and their respective processes was increased. This emphasis, in terms of representation, was on digital 3D modeling, and post production using Photoshop. The students were free to utilize whatever 3D modeling software they wished, but according to student surveys, most continued to utilize Sketch Up. Digital rendering and texture mapping techniques, etc.

were not taught in this course.

The Traditional Approach to Arch 380

After reviewing available syllabi, assignments, and projects, from 2006 -2013, what will henceforth be referred to as "the traditional approach" describes a curriculum that exposes the students to multiple computing concepts and their correlating software applications in short bursts.

Sample Curriculum, Traditional Approach to Architecture 380

2010 Winter Quarter

1. Sketch Up
2. Photoshop
3. Ecotect
4. Illustrator
5. InDesign
6. Rhino
7. Grasshopper

2013 Spring Quarter

1. Blog
2. Sketch Up and Kerkythea
3. Illustrator
4. AutoCAD
5. Rhino
6. BIM Lecture

7. Simulation Based Design Lecture
8. Vray for Rhino
9. InDesign
10. Photoshop

Concepts and software previously covered/discussed in Architecture 380:

Thus far the traditional approach has exposed the students to multiple software applications in short bursts, anywhere from 6 to 10 different pieces of software have been introduced in the course of a quarter. The logic being this is a "survey" course of design computing. Many of the students that have taken this course since 2009 that have been interviewed or surveyed don't feel as if they are getting as much as they could out of this approach. Although students do appreciate being exposed to what is out there, there are some criticisms by students of the multi-software approach. They tend to fall into one of two categories:

Criticism 1.

Too much info is presented too quickly; they end up feeling as if they have learned nothing.

"Three years after the fact, and I am still struggling with that software because they never bothered to actually teach me how to use it." 2010 undergraduate student, graduate student in 2013

"I THINK IS NECESSARY TO SPEND MORE TIME WORKING IN A (sic) SPECIFIC SOFTWARE, EXPLORING MORE ITS TOOLS AND THE CAPACITY TO USE THAT IN THE DESIGN PROCESS." 2013 student

"I gained a broader awareness of different programs that can be used in design, but still not sufficient knowledge of how to actually use those programs." 2013 student

Sub-Criticism 1.

In addition to feeling a bit overwhelmed by the sheer volume of software packages presented, many students also claim that a lot of information was repeated from 210/211, specifically the Adobe suite.

> "I found the quick and dirty approach to multiple software to be frustrating. I didn't have the availability to ask fellow students or sufficient access to the instructor. I felt as if the TA believed I should have already had that knowledge. If I had my druthers the class would have been focused on rhino and if we had focused solely on that one application I would have increased my design capabilities. After my senior year I finally understood how powerful that program is, however I was not versed in its diversity and I was frustrated in my inability to use it." 2011 student, 2012 program graduate

"I've struggled with finding the time to teach myself how to properly and most efficiently utilize this program and I thought that this quarter much like last quarter would help me to achieve that. Instead we've touched on the Adobe suite, Sketch-up and Rhino and I really know no more than I did before."

2013 Student

Criticism 2. Expectations

They didn't learn what (software) they wanted to learn. In 2010, a common complaint was that they didn't learn AutoCAD. A year later, individuals that took subsequent fabrication courses complained that they were expected to "know" rhino after only working with it for 4 weeks in 380, followed by an extended lapse in usage, 3 moths to a year. The current academic year, 2012/13 a common complaint in the standard course, as well as the revised course is that they did not learn Revit. Of the students that complained about a lack of Revit in the curriculum, none of them referred to it as Building Information Modeling.

"I graduate next week and I don't know how to do anything that will get me a job"

2012 student quoted in May 2013

Student perceptions of value in the traditional approach

This is not to say that students do not see a value in the traditional approach. Many appreciate the exposure and believe the information was worthwhile. When questioned as to what they believe they learned /of what benefit was the traditional course, some replied,

"It was good, I appreciated learning what was out there, but they tried to cover was way too much way too fast."

2010 undergraduate student, currently a graduate student in 2013

"A broader awareness of different programs that can be used in design, but still not sufficient knowledge of how to actually use those programs."

2013 student

"It challenged me personally to understand the software on my own with what little knowledge I had prior to entering the class. I can however I can say that I am now "familiar" with multiple programs that prior to the class, I wasn't. Although I'm not fluent in them I understand what can and cannot be done. "

2011 undergraduate student, a 2012 graduate

"While we may not have gone as in-depth on any one particular program, we got a good overview of what is out there for us to use and how we can begin familiarizing ourselves with those types of programs."

2013 student

"Studio never teaches us to learn software but other courses often require is to already know how to use it. This course is EXTREMELY essential, but may come too late in the curriculum."

2013 Student

Flipping the Classroom

Lectures/pedagogy:

Several versions of 380 have utilized online tutorials in order to teach "button pushing" outside of class so that the lectures could focus on teaching underlying concepts and content.

Student Criticisms of classroom flipping:

"They obviously knew how to use the programs, why did they make us learn stuff using video tutorials? I remember I was really frustrated when we were told to learn Eco Tec online, and we were sent to links that didn't even work."

Interview with a 2010 undergraduate student, currently a graduate student in 2013

"When I don't know how to do something, and there is nobody else in the room, I go to the internet, so it is a pretty good resource."

2011 380 student, 2012 graduate

"We watched you tube tutorials during class as part of the lecture instead of being taught directly by the teacher, who was in the room in the time, as well as the TA. I am ok with that, but I did hear some people complaining about paying a lot of money to watch free you tube videos. I would have appreciated it if my tuition money had been spent more responsibly by using instructors that A. had a complete understanding of the program, and B. actually knew how to instruct students. I felt like the grad students teaching the course were just phoning it in. I needed someone that could reel me in and teach me how to move forward with an idea, not just present some information and move on."

2011 undergraduate student, a 2012 graduate

"I think that those are very important things to learn and that they are extremely relevant, but we were expected to learn them by a "teach yourself method." If we are paying thousands of dollars to take this course we should not be told to teach ourself (sic) the material through free youtube (sic) videos."

Student 2013

Preceding Courses

As mentioned earlier, at the University of Washington there are three required courses that students must take prior to Architecture 380. Two of them, Architecture 210, and Architecture 211, are prerequisites to being accepted into the major. In those courses, students are exposed to Adobe Photoshop, InDesign, and Illustrator, as well as Sketch up. Architecture 315 is taken simultaneously with the first studio. It focuses on graphic techniques and representation, and further exposes the students to Adobe Photoshop and Illustrator, as well as Sketch Up. Students are introduced to the Autodesk suite of AutoCAD and Revit. One of the lectures was dedicated to Rhino.

Subsequent Courses

Although Arch 380 is the only required design computing course, undergraduates do have the options of taking more advanced courses in Digital Fabrication, computational geometry, lighting analysis and simulation. Furthermore, there are two "software specific classes" Revit, as well as CAD and working drawings. Arch 478, CAD and working drawings is not a software class per se, rather it utilizes AutoCAD as a vehicle for teaching construction documentation.

Rhino at the UW

"Rhinoceros (Rhino) is a stand-alone, commercial NURBS-based 3-D modeling software, developed by Robert McNeel & Associates. The software is commonly used for industrial design, architecture, marine design, jewelry design, automotive design, CAD / CAM, rapid prototyping, reverse engineering, product design as well as the multimedia and graphic design industries.

Rhino specializes in free-form non-uniform rational B-spline (NURBS) modeling. Plug-ins developed by McNeel include Flamingo (raytrace rendering), Penguin (non-photorealistic rendering), Bongo, and Brazil (advanced rendering). Over 100 third-party plugins are also available. There are also rendering plug-ins for Maxwell Render, V-ray, Thea and many other engines. Additional plugins for CAM and CNC milling are available as well, allowing for toolpath generation directly in Rhino.

Like many modeling applications, Rhino also features a scripting language, based on the Visual Basic language, and an SDK that allows reading and writing Rhino files directly. Rhinoceros 3d gained its popularity in architectural design in part because of the Grasshopper plug-in for computational design. Many new avant-garde architects are using parametric modeling tools, like Grasshopper.

Rhino's increasing popularity is based on its diversity, multi-disciplinary functions, low learning-curve, relatively low cost, and its ability to import and export over 30 file formats, which allows Rhino to act as a 'converter' tool between programs in a design workflow."

(Robert Mcneel, 2013)

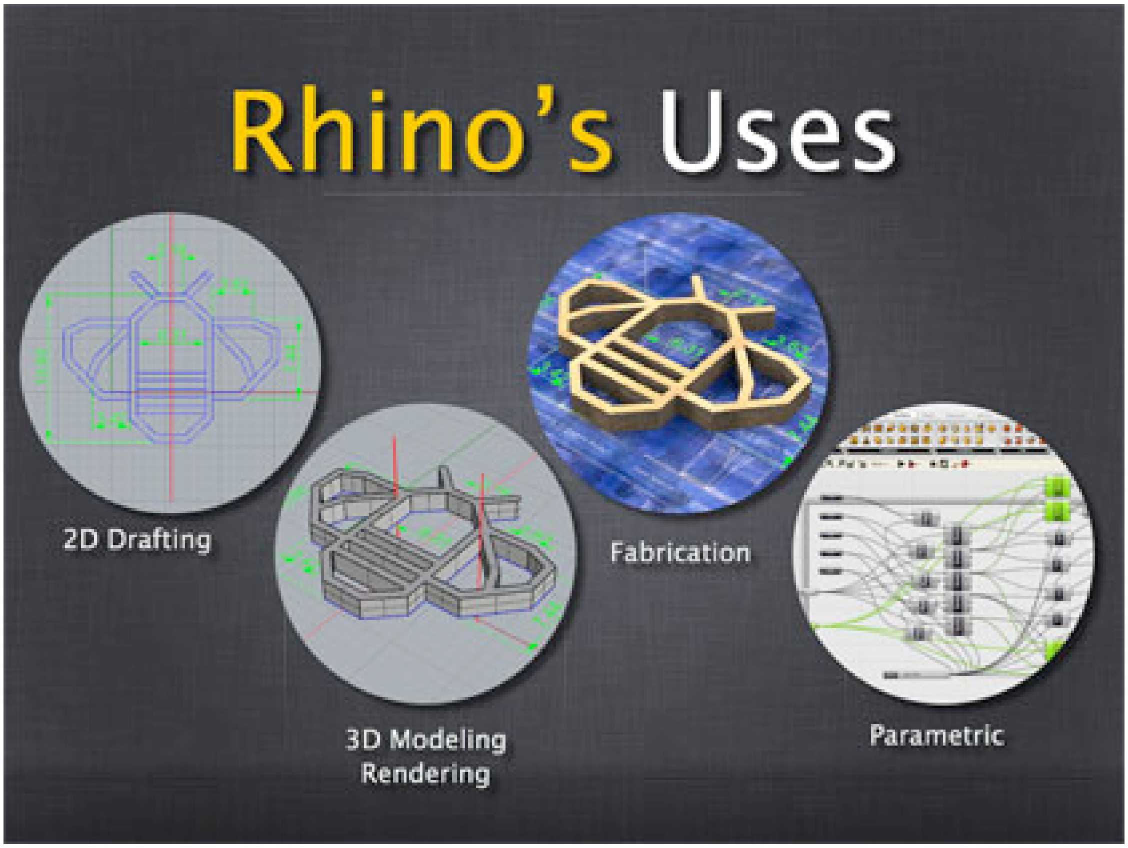

Figure 5.1

Because of the abovementioned diversity, Rhino and its sundry plugins are utilized in several upper level design computing courses at the UW. Courses that utilize Rhino include the digital fabrication series, modeling and rendering, and computational geometry. In the past, it has always been unclear to the instructor of these courses as to the students' understanding Rhinoceros, one of the primary tools. There does not seem to be a single course where students are introduced to, and properly trained in, Rhino. For example, Instructors in 300 level courses and studios and studios are aware of their students' capabilities in, and understanding of graphic applications such as Adobe Photoshop and Illustrator. Students with no experience with Rhino often find themselves trying to quickly learn an entirely new application, whereas others do not. This results in a class split, students inexperienced with Rhino are forced to dedicate additional time to learning the software. Arguably, this time could be better spent focusing on other aspects of the respective courses. In some cases, the students' inability to either learn the technology on their own, or learn as they go, is a contributing factor to their dropping or doing poorly in the course. In 2012/13 I had the opportunity to assist the introduction to Digital Fabrication courses and I found this to be true. That being said, it was my facility with that tool, Rhino, which was partially responsible for my ability to do so well in that course when I took it.

Many courses at the UW take advantage of how one piece of software relates to another. Students can often be seen moving digital data from one program to another, such as editing an exported Sketch Up image with Photoshop, and moving that into InDesign, but thus far, no courses at the UW have explored in depth the potential for a single piece of software to be used for multiple outcomes, in this case fabrication and representation. Rhino can be used to draft, model, render, fabricate, and has the potential to be used parametrically as well. It was my hypothesis that in giving the students a solid understanding of a single piece of software it would lead towards facility with the tool, thereby making it easier for the students to focus on things like design, structure, construction, etc… Furthermore, I propose that a solid, conceptual understanding of the methods, concepts, and limitations of this software will make it easier for them to learn similar software later on. For example, Rhino utilizes a similar interface and numerous legacy commands from AutoCAD, thereby making the transition from one to the next much smoother than the students' original introductory experience to either AutoCAD or Rhino.

Chapter 6.
The Y Model

The Y model proposes the acquisition or buildup of a logical progression of skills and or knowledge as a foundation for students to pursue further, similar, yet possibly divergent outcomes. The concept of a Y model is not unique to education; similar approaches and models can be found in business, leadership training, logistics, and software development (see appendix). In this case, the Y model was adapted from the American Association of Snowboard Instructors (AASI).

The Y Model of Snowboard Instruction

In the late 1980s and early 1990s, as with computers in architecture firms at the time, snowboarders began to appear at ski resorts across North America. Gradually, ski schools began to see an influx of students showing up with snowboards and expecting lessons from alpine instructors who had no idea how to ride a snowboard. Although skis and snowboards both were used to go down the hill, the manner in which these tools were utilized was completely different. It quickly became clear that this new tool, the snowboard (not unlike the computer) and it's new demographic of users, would require an equally fresh pedagogy. Eventually, small, independent groups of the braver (and younger) ski instructors began to dedicate their time to understanding this new tool, its nuances, and most importantly, its users. I was among this group.

I have been a professional ski and snowboard instructor since 1992. I am fully certified in both alpine skiing and snowboarding. I have been a consultant to industry since 1999. From 2008-2013 I was the Snowboard Education Chair for the Northwest Division of AASI. I was responsible for the training and certification of every snowboard instructor in Washington, Oregon, and parts of Idaho and Montana. The Y model of snowboard instruction is one that I am extremely familiar with.

The Y model began to be utilized in the early 1990s by the American Association of Snowboard Instructors. It is essentially a pedagogical approach that considered, from the beginning, what it was that the student needed to learn, in order to meet their goal. The Y model consists of 4 parts and is often compared to a martini glass. According to AASI, the four parts are the base, the foundational (stem), the developmental (bowl), and the applications (4.5 fluid ounces of synergy and olives). The first two parts of the model, the base and the foundation, specifically address fundamental skills required of all snowboarders, regardless of what type of snowboarding they wish to aspire to. Once the students have some fundamental skills, they can begin to focus on, and learn specific techniques that will help them to achieve their end goals. Maybe they want to ride a half pipe, maybe they want to race, maybe they want to ride fresh powder. Regardless of their goals, transparency of their tool is essential in order to do any of those things at a high level.

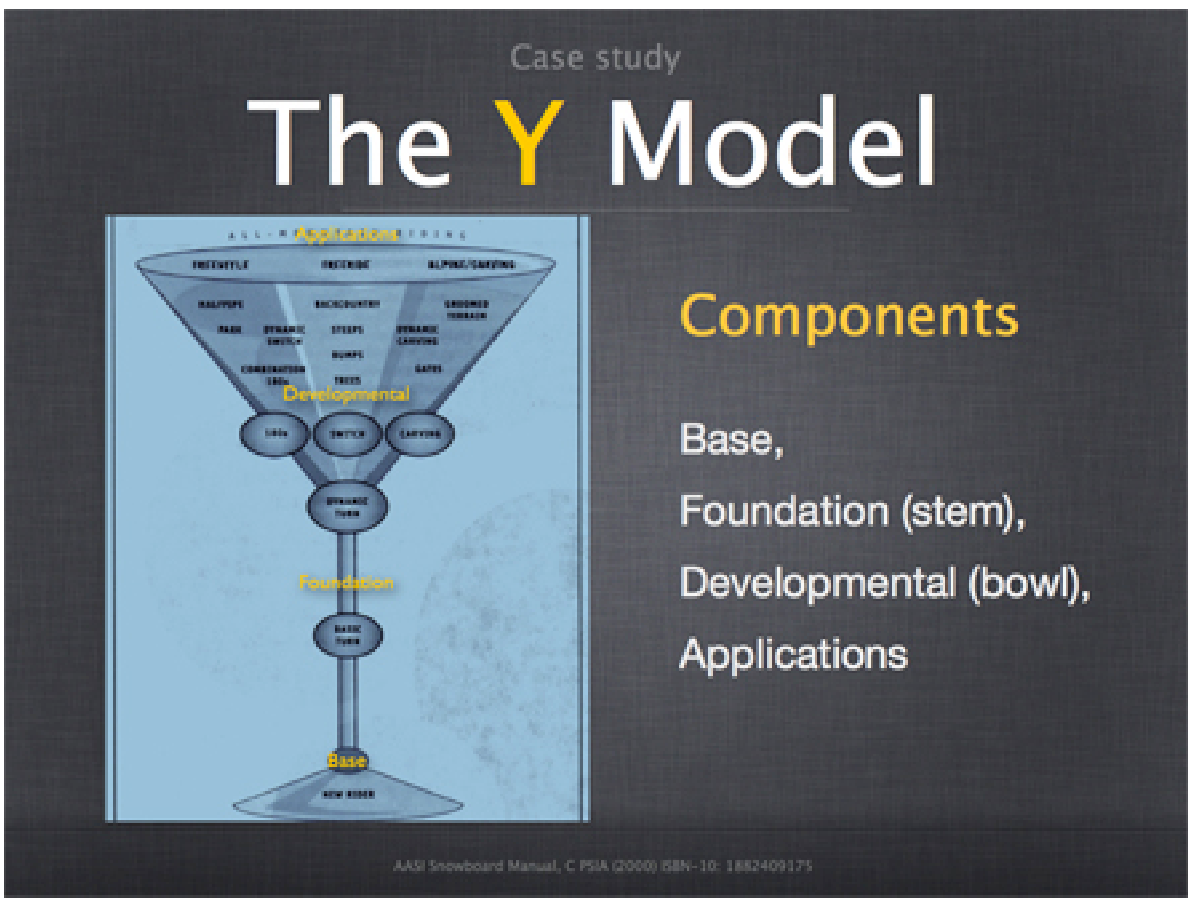

Figure 6.1

Base

The bottom of the model (the base of the challis) is where snowboarding evolves—the new rider. It is never particularly pleasant to be in this phase. During this phase, the new rider falls constantly, and often times wants to quit out of sheer frustration. It may take hours to travel 50 feet. Expert skiers who try to learn snowboarding lament this phase. This is the phase where having a good instructor can make all the difference. A good instructor can teach good habits while keeping the student from developing bad ones.

The digital is similar. Learning a new workspace and navigation is always a little frustrating. Simple operations are not simple if you don't know how to use them. Experienced 3D modelers are always tempted to fall back on a more familiar piece of software, etc…

Foundation

The foundation, or foundational as it is also referred to, is the stem of the glass. It represents a period in learning where users gain understanding of the movements they need to make to in order to achieve the desired result of the tool (snowboard). All of the common activities of a beginner lesson are contained within the stem of the glass. Once riders have successfully performed the isolated, individual, parts of a turn, they are able to move on to completing a turn. Tasks learned up to that point are directed to that one goal, turning. This is also the time in which students increase their understanding of how certain movements, when used appropriately, can create a variety of tool performances that can result in a multitude of outcomes. Outcomes can be either positive or negative, and can include movements such as turning, stopping, or falling. A rider's skill and versatility within the sport consists of his or her ability to subconsciously or consciously understand and apply when, where, and how to add or subtract specific movements or sequences of movements to create and/or diminish board performances that then result in a variety of outcomes. There are many similarities here between this sport and design. Snowboarders describes their path as a line, and skis and snowboards can both carve into the snow. Just like drawing a line or carving marble, there is going to be an interface between the user, the tool, and the medium. In this case it is the snowboard and the snow, but it could just as easily be the pencil and the paper or the chisel and the marble. In these cases, the tools affect on the medium is going to be a direct result of the user's combination of flexion, extension or rotational movements combined with the amount of pressure they exert on the tool. This is true of skiing, snowboarding, sculpting, or drawing.

Developmental

Beyond making turns on a groomed hill, the Y model enters the world of all-mountain riding, represented by the liquid-containing portion of the glass. The first segments are developmental in nature. They set the user for greater success in all of the above application sections. For example, being able to utilize movements that are applicable to one style of riding can be extremely helpful as a recovery move. Several Half-Pipe Olympians train on race courses in order to improve their ability to hold an edge in icy conditions. This ability to ride faster is applicable anywhere, but they can use it to increase the speed of their approaches, thereby increasing their amplitude in the pipe (they can jump higher).

Applications

There are three general categories of riding; freestyle, free-ride and race. Racers tend to ride on groomed terrain and keep their boards on edge as they ride. (carving). Free-riding consists of playing with the natural terrain of the mountain to take advantage of bumps, steeps, off-piste, and trees. Freestyle is mostly performing tricks using manmade or natural features. Freestyle riders ride the half pipe, ride rails or boxes, and hit jumps.

Once students reach the application phase, or the rim of the martini glass, you can become a specialist. It is at this point where the efficient techniques or movements required for one side of the martini glass (the applications) run the risk of being inefficient if applied to a different application. That being said, some of the unique blends of riding, for example, riding switch and carving on ice, have the potential to assist riders regardless of their desired application (AASI, 2000).

The generalizable nature of the Y model made it a logical choice as a pedagogical approach to yet another set of new tools.

Chapter 7.

The Y Model Applied to Architecture 380

I saw an opportunity to apply this teaching methodology to the Architecture 380 course. In this study, the rider was replaced by the user, and the snowboard was replaced by the software, Rhino. As mentioned earlier, snow sports can be seen as similar to computing, in that familiarity with one tool allows one to more easily learn the next. Just as an AutoCAD user can utilize many legacy commands, existent concepts, skills, and commands in Rhino, a skier or snowboarder's understanding of snow conditions and the concepts of sliding transfers directly to the other tool, thus establishing a solid foundation and making the second tool easier to apply to the environment.

Base and Foundation

In this case the base component of the Y model consists of understanding the navigation of the rhino workspace. Basic commands are covered, as well as basic 2-d drafting. Introductory modeling techniques such as creating primitives, manipulating 3d structures, and basic transformations are also covered. Representational concepts such as polygon mesh models and wireframe representation are also discussed. Covering the base was only touched on briefly because the entire class had already worked in digital 3d space for some time due to their utilization of Sketch Up and had received a short Rhino tutorial the preceding quarter so these concepts were fairly easily disseminated. An important aspect of this section of the instruction process was to explain the logic behind the categorization, location, and functions of the tools, not just what buttons to push. This provided the students with an immediate ability to learn and explore on their own. The intent was to provide them with an inherent knowledge of this and similar processes/software/tools that went beyond asking a neighbor for help, or an internet search.

Developmental

The developmental component of the Y model consisted of experimenting with, and understanding of, more complex modeling techniques, such as Boolean operations, complex curvature, splines, patches, and nodes.

Application

The application phase in this course referred to three general categories- rendering, 3D modeling, and fabrication. As in snowboarding, there is much overlap. Without a proper understanding of modeling techniques, concepts, and processes, it is difficult to produce a successfully fabricated or rendered project. All three of these outputs require similar skills and contain similar elements, and all have elements of the others embedded in them. As in snowboarding, techniques and approaches that can be used to create a successful rendering may not be the correct choices when it comes to fabrication. 3D modelling skills are essential in order to fabricate, or render.

In order to apply the Y model to this design computing course, the curriculum needed to be reworked.

First, tools that were covered extensively in previous courses were eliminated, in this case, Sketch Up, and the Adobe suite. Second I opted against glancing over tools that would have a specific course dedicated to them in the students' future. In this case, AutoCAD, Revit, Web Design, and Grasshopper were all eliminated.

Goals of the Y model approach:

The goal of the Y model course was to develop a course that would:

1. Address the Process or steps required to perform specific results. This first goal teaches button pushing, it solves simple problems.

2. The second and ultimate goal of this course was to allow students to understand the theories, concepts and principles that drive a specific software's interface and toolset. This second goal provides a foundation or insight needed for the students to gain transparency with a tool and solve new and complex problems.

Transparency with Rhino

After examining what would be successive courses in design computing, I saw the prominent role that Rhino plays in the department. It is specifically used in seven courses that follow Arch 380; three digital fabrication courses, two modeling and rendering courses, one computational geometry course (grasshopper), as well as the annual summer fabrication studio. Finally, it is utilized as a default tool in many undergraduate and graduate studios.

Although Rhino is used in these courses, it is never specifically taught in any preceding courses. When students take the upper level courses, they are already expected to know the software. Often times they spend their time trying to learn Rhino instead of focusing on the content of the course.

Although Rhino has the ability to perform many functions, 2D drafting, 3D modeling and rendering, is useful in the digital fabrication process, and has a parametric plugin, each course that uses it tends to focus only on how it can be used for a specific outcome. The other potentials of Rhino are rarely discussed. In fact, I was not able to discover a single course anywhere that specifically used a single piece of software to teach drafting, 3D modeling, fabrication, and rendering. This seemed odd, because, as mentioned in the literature review, integrating fabrication with digital design tools has several advantages.

The Y Model course attempted to take advantage of Rhino's potential to be used for multiple outcomes, in this case, fabrication and representation. It attempted to teach Rhino properly and efficiently, from the ground up, utilizing a long term project that taught fabrication and representation simultaneously. The goal of this approach was to allow students to achieve transparency with a single tool. Finally, it would address the relevancy of the tool in both studio and real world applications. Working in parallel mediums would determine how the students approached tool use.

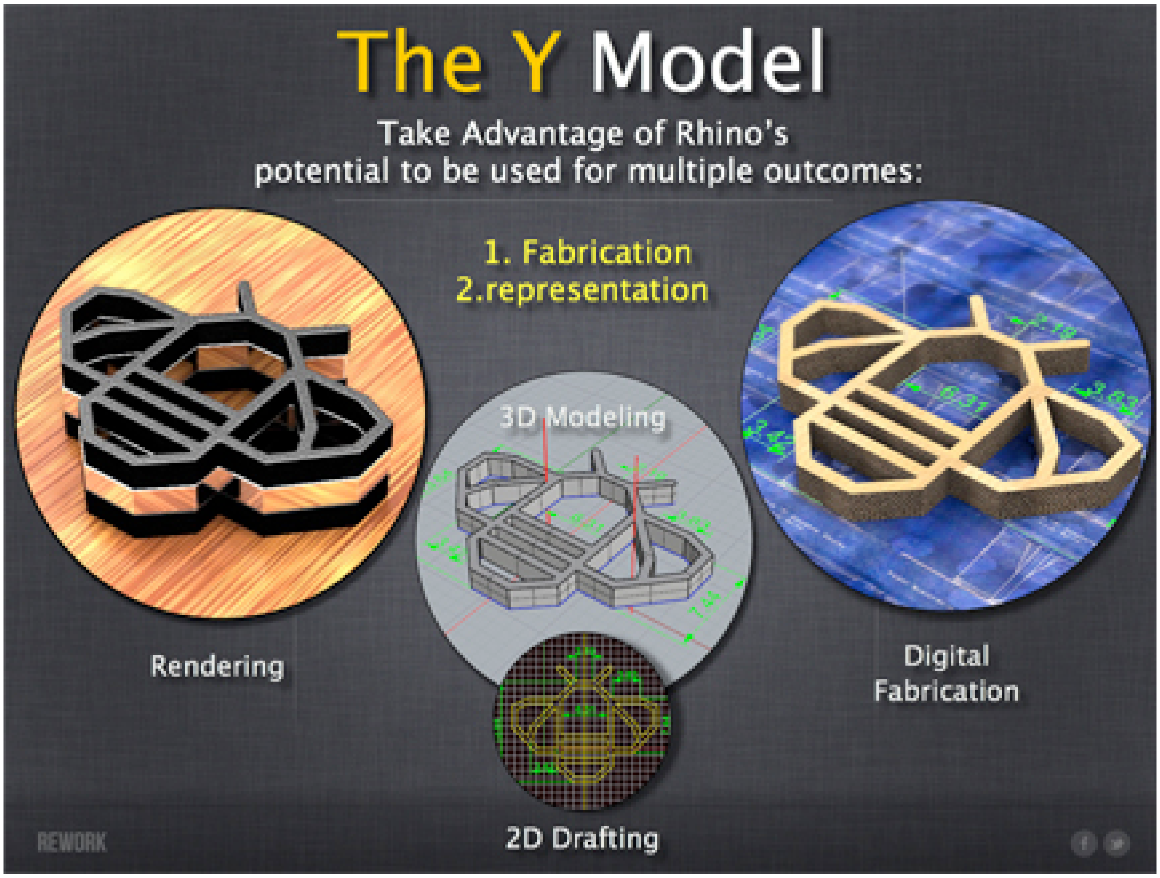

Figure 6.2

In nearly every class meeting it was emphasized that the students needed to leave the course understanding 3 things:

1. Polygons are expensive
2. Fabrication is more than pushing a button
3. The approach to the software or tool is dependent upon the desired outcome of the project

(fabrication vs. visualization).

During the earliest phases of the course, the students did not necessarily understand what these statements meant, but as the course progressed they began to…

Assignments:

Although this was not a design studio, it did contain some design requirements. The students were given a term long project, to design a playground. A playground was chosen due to its whimsical nature and Rhino's strength as a free form modeler. The program requirements allowed the students to move from creating simple to complex geometries as their familiarity with the software increased. (see appendix for full assignment descriptions and results)

Project one, simple fabrication

The first fabrication project was assigned within the first three weeks of the quarter. One of the class sessions consisted of hands on laser cutter training. For most of the students, this was their first opportunity to make concrete something that came directly from the digital world. The assignment was to create, from a rhino file, a simple holder out of chip board or a similar material. The holder had to be held together without glue or tape. This is similar to what is typically the first assignment in the digital fabrication courses. Since the elimination of the stick studio, model making is not taught specifically in the BA in Architectural Studies program; as a result, students may not be as familiar with material concerns as they have been in the past. I made a conscious choice not to mention material thickness or other concerns. The logic being that this was an early project, and through the process of guided discovery, they would come to this realization on their own. This is not to say that I did not make the information available to them prior to their beginning the assignment. I provided the class with a pdf of chapter 4 of my book, which discusses planning a model and covers those concerns in depth. Furthermore, on the actual assignment sheet, several commands were suggested, specifically the command, flow along curve, which would have solved the issues they were having with aligning the tabs (Congdon, 2010). Projects were turned in and a short critique which primarily addressed design and construction issues took place.

Long term project, The Playground, and its deliverables:

The remainder of the course consisted of two long term projects, equal parts fabrication and visualization (modeling, rendering).

1. A midterm fabrication project, known as the cool box, was assigned.

2. A final project, which integrated the cool box project with pin ups/renderings as well as a physical model of some part of the playground.

The Cool Box

The cool box project was inspired by a story told to me by Alec Vassiliadis, the model maker for NBBJ.

> "The 4" tall model and the box which contains it were planned and built to be a cohesive whole. When the architect arrived at the client's office, he said nothing about the exquisitely crafted box that he placed in the center of the long, empty meeting table, itself made of a beautiful hardwood. As he began to speak, he would casually slide the box partially open, only to shut it again. Each time he did this, it served to heighten the sense of excitement, mystery, and anticipation as to what was in the box. Before he finished the talk, he excused himself, and went to the restroom, leaving the small, mysterious box sitting on the table. When he returned, he found that the clients, like children on Christmas Eve, were unable to contain themselves. They had opened the box, and removed the model, around which they huddled like a campfire. This small model managed to dominate the

immense boardroom, and captivate its viewers." (Congdon, 2010)

COOL BOX ASSIGNMENT REQUIREMENTS:

Bearing some of the abovementioned things in mind, and utilizing your digital fabrication skills, create a 12" x 12" x 6" box that will contain, display, and safely transport your model, a cd, and 11 x 17 pdfs.

Long term project, The Playground

Students were required to create a park and a piece of playground equipment.

This project echoed two of the course's main goals:

1. To develop a "critical eye" with regard to computer graphic (CG) images by developing understanding of, and experience with 3D modeling and rendering.
2. Introduce some fabrication techniques and concepts. By the completion of this project, students would understand that CAD/CAM activities are not something that is executed with the simple push of a button.

Playground/park Program Requirements:

1. Seating
2. grass and trees or
3. Concrete and/ or brick paving
4. Soft groundcover below the play area
5. Fence or some sense of enclosure
6. Trash receptacle
7. Grill

8. Bike rack
9. A 25'x 25' (approx.) modular play structure which contains: a slide, a ladder and/or steps, monkey bars, "tubes" to crawl through, and roof portions. Materials, steel, wood, plastic.

The programmatic requirements were designed such that students could progress from simple to complex 3D forms as they gained comfort with the software.

The Physical Model:

They were required to digitally fabricate a model of either the entire park at a small scale, a piece of playground equipment at a larger scale, or both.

Final Deliverables:

The students were required to present a project which integrated the cool box project, the maquette of their park, two 11 x 17 pin ups, and anything else they would need in a presentation. The cool box project needed to be disassembled and assembled in 30 to 45 seconds in the event the student received a scathing review.

Course Summary

I believe that teaching skills that were immediately relevant to the design studio increased motivation, retention and understanding of the concepts relevant to the course. Requiring and critiquing several cool box prototypes at different scales over the course of the quarter encouraged the *Rational Decision Making* process to occur. While the fabrication prototypes were in process, the students were concurrently learning more complex modeling and rendering techniques, basic texture mapping, and lighting. I believe this overlap provided the students with new insights as to how working in multiple media has the potential to enrich the design process. I observed both of the studio final critiques that quarter. The students that took the Y model Architecture 380 concurrent with said studio were, for the most part, producing higher quality renderings than their peers. This should not come as a surprise, because, for the most part, the other students were not exposed to these processes yet, so it stands to reason that the students exposed to the information would be able to demonstrate that fact. At the time of this writing, this same curriculum is being utilized by another instructor. Observations of that particular group of students should provide an opportunity for a less biased observation.

After discussing studio demands and deadlines with the students, we opted to have the course final review during finals week, two days after their final studio review. It is my hypothesis that the students spent the preceding weeks immediately applying the modeling, rendering, and physical model building skills they acquired in Architecture 380 to their studio finals. By moving the due date back a week, they effectively gained more experience in the processes, and delivered higher quality projects than would have been possible had they had less time to harness their skills and complete the project. Several researchers, including Chiu, Goldman and Zdepski, Richardson, Sapene, Miranda and Gribou ,Akin, Ataman and Carraher have discussed the benefits of an approach to digital media courses that ties introductory digital skill building exercises and tasks in with the studio projects. Many of the abovementioned authors have proven this approach to be effective in their own and other case studies.

Final Review

Three UW faculty attended the Arch 380 final review, two faculty were from the Architecture department, one was from the Industrial Design Department. When asked via email to comment on what they had seen, this was the reply:

"The coursework provided students with a strong foundation of digital skills that are applicable to all facets of their design education and career."

"The ability for students to convey their design intent significantly improved as a result of this class."

"The final project presentations indicated a high level of understanding in the digital and physical design space and their interrelationship."

Follow Up Studio Assessment

After the subsequent term ended, several instructors were surveyed regarding what they had observed, in terms of the skill development of the Y model control group. See appendix for full transcripts.

Chapter 8.

Methods

Arch 380 was taught at the University of Washington twice during the winter and spring quarters of 2013. The winter quarter the students were taught using the Y model. The spring quarter students were taught, by a different instructor, using the traditional approach. In the fall of 2013, the course was taught by an instructor other than myself, using the Y model approach. During the first semester of 2013, Kansas State University taught their Digital Design and Applications course, which was mentioned earlier in this document. Each section was given the same survey at the same point during the quarter. Students were informed it would be voluntary and anonymous. They were also informed the surveys would be used to gather data for a graduate thesis focused on design computing education.

The winter and spring sections had between twenty and twenty six respondents each. The second Y model course and the K.S.U. sections each had eight respondents. Although not a particularly generous number, it provides a fairly accurate account of a single class at a particular moment in their education. A more accurate set of data could have been complied if both sections had been taking the course simultaneously. Furthermore, it was neither possible nor ethical to create a control group that had zero access to the information being presented to the other. The collaborative nature of the studio is such that information is disseminated through the group, often times without formal instruction by an instructor. In order for these data to be truly representative, this experiment would need to be conducted several years in a row. As this writing is for a relatively short termed MS Thesis, this was not possible.

These surveys were administered to assist in discovering student motivations, processes, expectations, and understanding of the underlying principles of the course. There were questions about whether the course content changed the way they would approach design. I specifically spoke with the pilot Y model students about how they might want to approach technology in terms of design, so the overwhelmingly amount of "yes's" to that question should not be a huge surprise. Students were given the opportunity to elaborate and explain their responses, so in many cases, the individual responses may be slightly more telling than the graphs. A complete transcript of those comments can be found in the appendix.

Another section of questions concerning laser cutting, fabrication, rendering, and modeling, that were Rhino specific were given on the first and last days of the Y model course. They were also given to the traditional course at the end. This particular set of questions was given in order for me to assess understanding of my section, but it did present some interesting data that could lead one to hypothesize about dissemination of knowledge in the studio culture. Of particular interest might be the software or process specific questions that were covered in both courses; in depth in the Y model, and a more cursory exploration in the traditional approach.

After gathering and compiling this data, it became obvious that many of these questions were addressing or assessing student expectations and self-assessments of their skills relative to each other rather than actual comprehension. Many of the student responses were either positive or negative based upon what they felt they needed to learn in order to either get a job or do better in their studio.

In many ways these surveys can be used to assess the following:

1. What the students believe they learned.

2. What the students felt they needed to learn (student expectations, NOT faculty expectations.)

3. Student impressions of the appropriateness of the subject matter in a specific educational arc, at a specific moment in time (2013), in a specific curriculum (UW Architecture).

These surveys do not give pertinent data as to:

1. What the students will actually need in the next 10 years.

2. What they really need to learn, in both understanding of technology or design.

3. What they will learn (technology and design wise) both in the university and during the internship.

The complete list of questions, their corresponding graphs, and each written response, is included in the appendix.

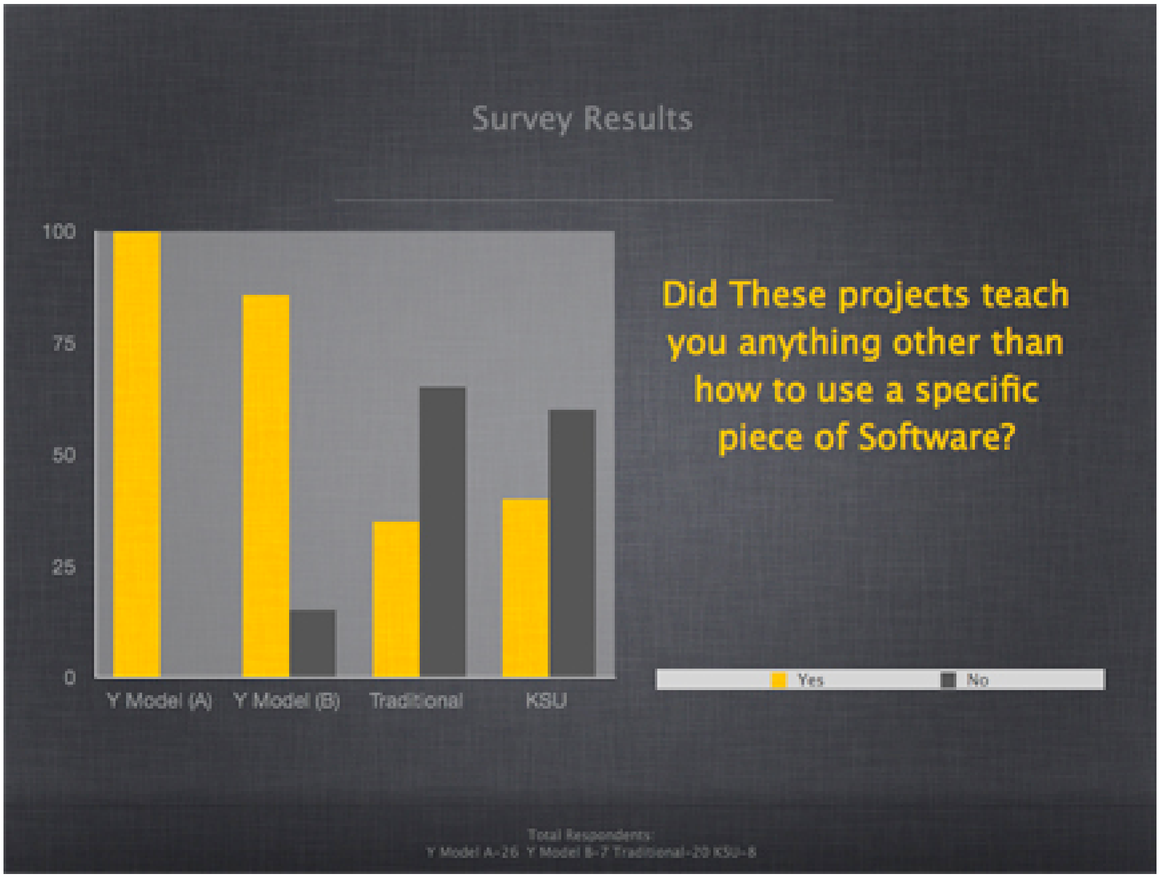
Survey Results
Did These projects teach you anything other than how to use a specific piece of Software?
100
75
50
25
0
Y Model (A)
Y Model (B)
Traditional
KSU
Yes
No
Total Respondents:
Y Model A-26 Y Model B-7 Traditional-20 KSU-8

Figure 8.1

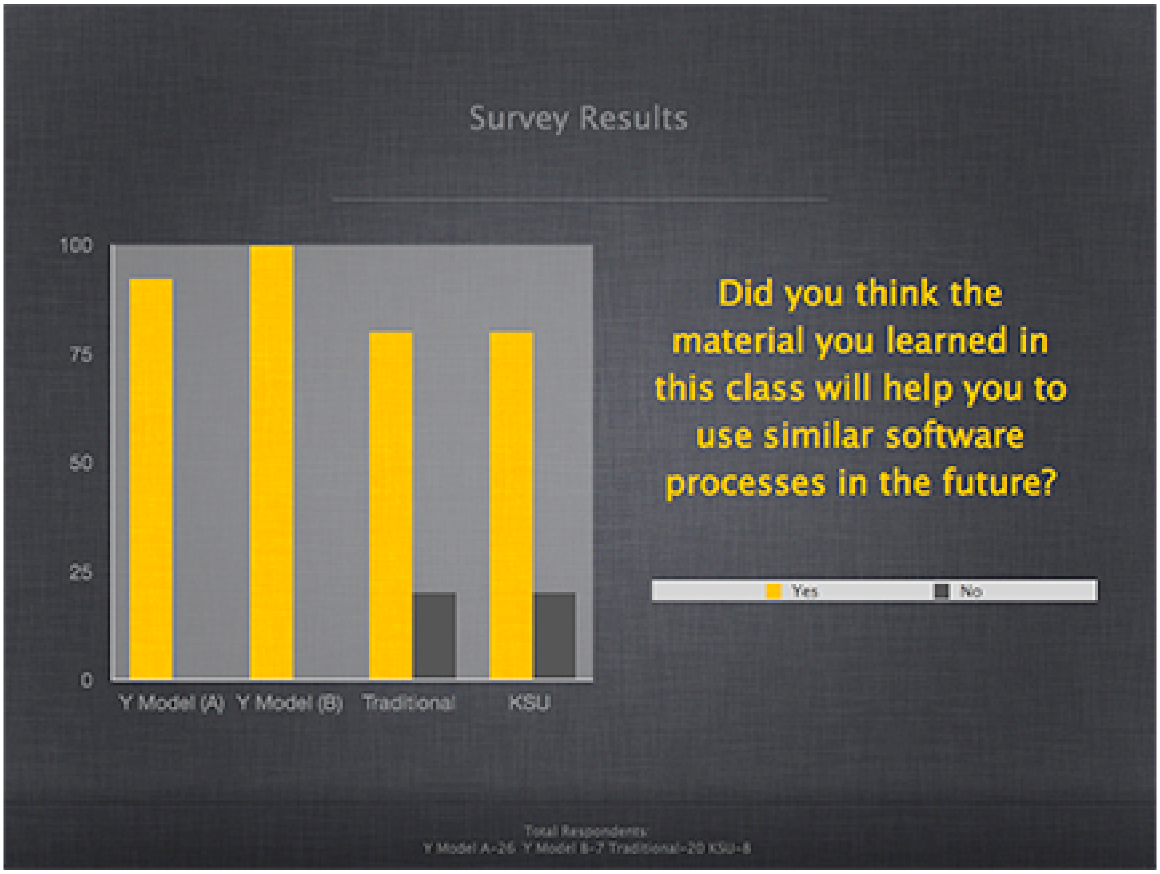
Survey Results
100
75
50
25
0
Y Model (A)
Y Model (B)
Traditional
KSU
Did you think the material you learned in this class will help you to use similar software processes in the future?
Yes
No

Figure 8.2

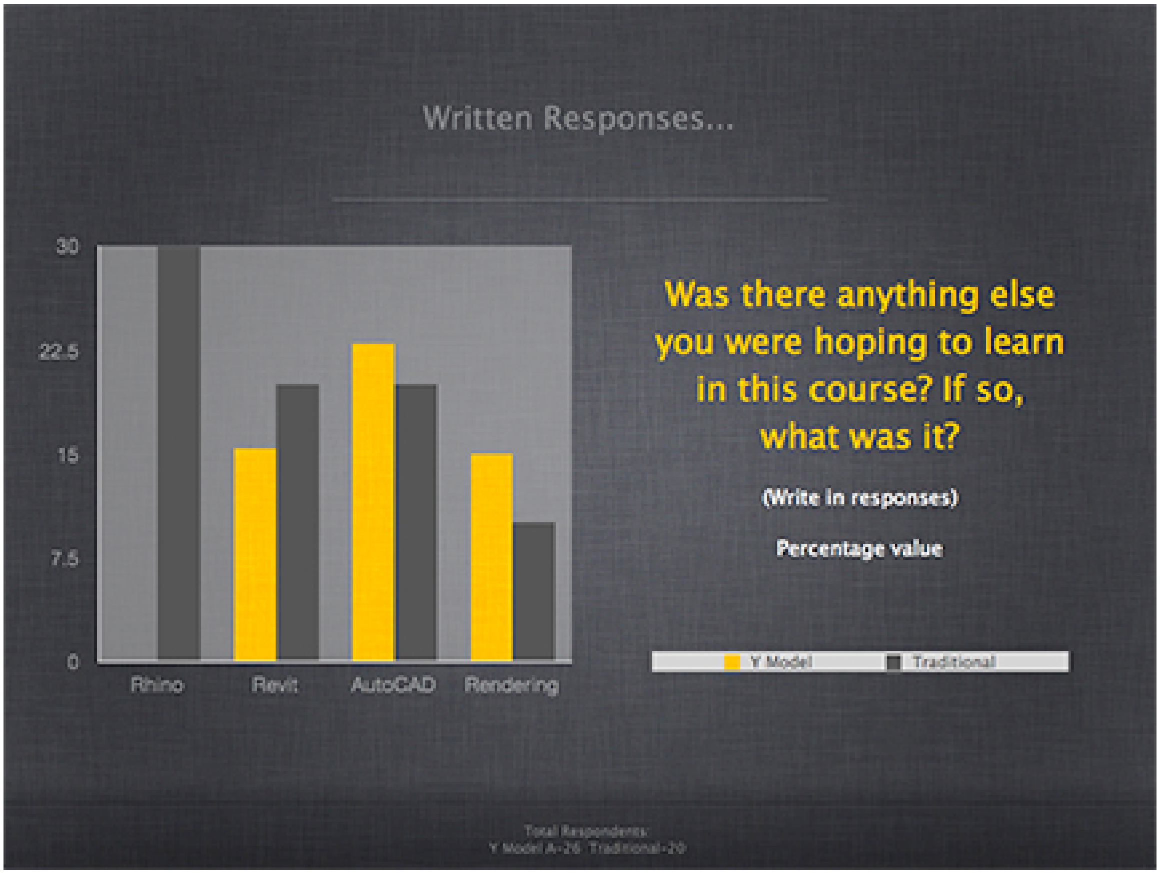
Written Responses...
30
22.5
15
7.5
0
Rhino
Revit
AutoCAD
Rendering
Was there anything else you were hoping to learn in this course? If so, what was it?
(Write in responses)
Percentage value
Y Model
Traditional

Figure 8.3

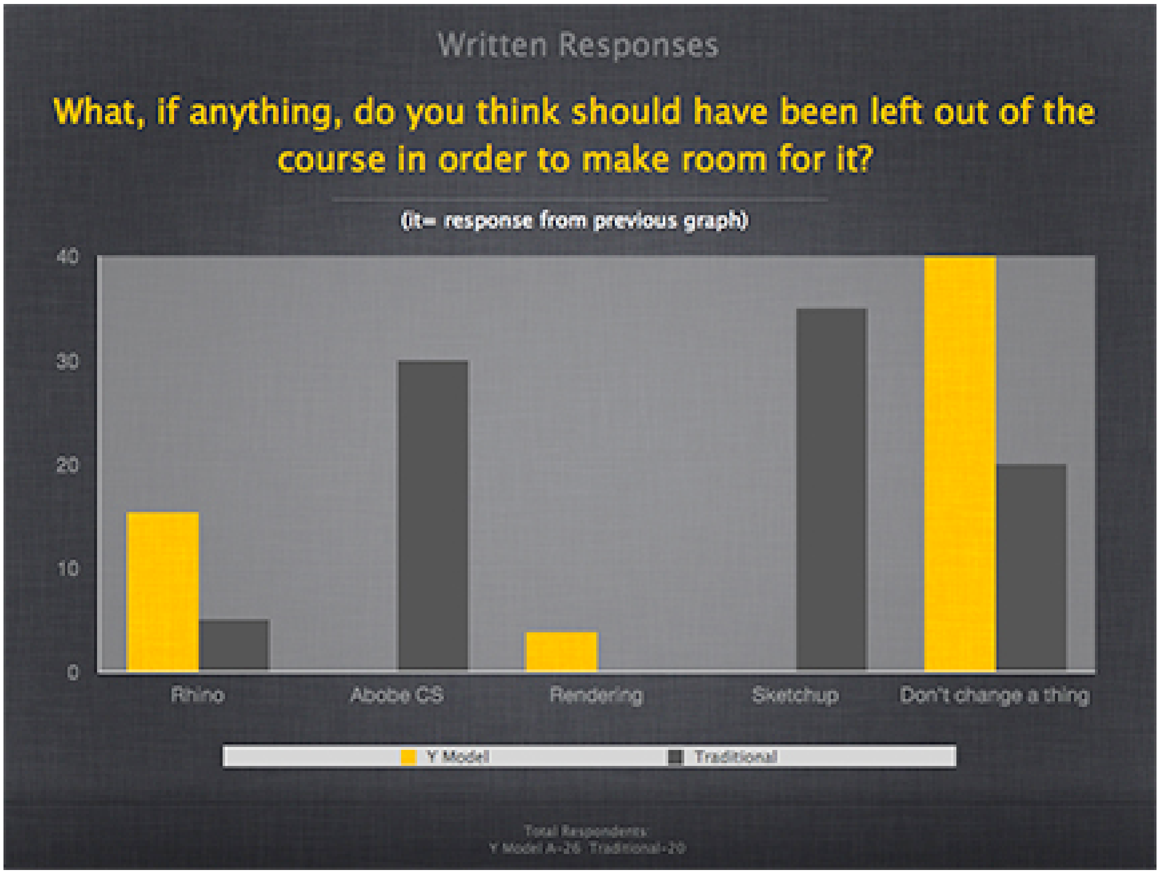

Figure 8.4

The data indicate that the Y model students were mostly satisfied with the course and saw value in what they were learning. However, there was some dissatisfaction expressed. One interesting statistic was the similar percentage of students who mentioned that they specifically hoped to learn AutoCAD and Revit. The traditional course did cover those two programs, whereas the Y model section did not. The Y model spent more time introducing rendering processes and concepts, yet more Y model students felt they wanted to learn more rendering.

Based upon student feedback, some changes were made to the Y model curriculum before it was taught second time, specific changes include:

1. Begin with 2 weeks of AutoCAD for 2D work, stressing the legacy commands…

Teach legacy commands and skills that will cross over immediately to Rhino.

2. The term long project can be begun in AutoCAD and the data can be imported into Rhino, or the students can choose to present portions of the project in an AutoCAD.
3. Flamingo was not originally taught in the Y model course; rather it was introduced at the request of the students. Flamingo was taught in the revised curriculum.

AutoCAD follow up

Because there was a desire expressed by a few students in both sections to learn AutoCAD, two surveys were given to the Arch 380 alumni who took Arch 478, CAD and Working Drawings. The purpose of these surveys was to see what effect, if any, their short exposure to, or lack thereof, had on their learning AutoCAD nearly nine months later. These data can be found in the appendix.

Chapter 9.

Conclusion

This study investigated and used pedagogical approaches to an introductory design computing course that could teach students to face and adapt to changing technology. It searched for ways to expose students to fundamental concepts that will be useful now and into the future by addressing fundamental principles that we hypothesize will persist despite rapid technological changes. It suggested an approach that could provide students with the ability to generate and communicate ideas utilizing multiple processes (approaches) and media.

Many college and university programs attempt to accomplish these goals utilizing a traditional "survey" approach, introducing a wide berth of software and concepts to students in a short amount of time. Although this is helpful in terms of their understanding exactly what is out there, there is s a strong possibility that they will not get much more than that out of such a course.

This study asked how could we improve or build upon the traditional (survey) introduction to design computing course model. Evidence suggests that it is important for the intro DC instructor to know where the course fits in the curriculum, and attempt to make the information presented in the class relevant to the students at that point in their academic career. In the case of the UW, since students are scheduled to take Arch 380 in different, successive, quarters, this complicates matters. One approach would be to offer the course to the entire academic class at once, immediately following Architecture 315. If logistics dictate that the course needs to be offered twice, during successive quarters, having the same curriculum in both sections would insure consistency in terms of the material taught. Another method of keeping the course relevant is to be aware of how its content can be used in conjunction with the design studio. This sentiment was echoed by numerous students in the university

end of class survey; it was noted that they appreciated attempts to introduce material which was immediately applicable and relevant to their current studio course. Finally, in order to truly be effective, instructors should be aware of what other technologies and content have already been, and are about to be, taught. Students do not appreciate learning the same thing over and over.
Another option is a survey course in DC that requires a logical progression of follow up courses that go more in-depth into certain software types and concepts. If the students are made aware that these (marketable) skills will be taught to them during the course of their education, that would change the student perception of what the intro course would be, which would most likely lead to more satisfied students.

Perhaps the answer is not a course, but courses? Southern California Institute of Architecture utilizes a highly successful three semester sequence. Although it was specific to the University of Washington, one student suggested it be a two quarter sequence; Intro to DC one and two. They suggested the first course be the Y model curriculum, and the other course being 50% CAD, and 50% BIM. This would give savvy students a solid foundation upon which to build, and less savvy students a helping hand when they took a later course that focused on one of those four concepts. The weakness of this approach is that it still fails to introduce or address either simulation, or what we think of today as parametric, or databases. However, there are introductory courses in Digital Fabrication using Rhino, BIM using REVIT, working drawings using AutoCAD, simulation courses using Ecotect, computational geometry using Grasshopper, and modeling and rendering, which allows the use of any software, but demonstration of concepts are achieved using Rhino.

Further Research

Should this curriculum be utilized in the future, its outcomes can be measured and compared to the pilot courses. Student progress and success would ideally be tracked over several years via the utilization of interviews and surveys of faculty, professionals, and students.

Conclusion

This study has revealed a potential approach to an introductory design computing course that utilized a single tool for multiple outputs. This thesis's literature review, data, and student output, both during and after the course, suggests that the Y model exhibits potential as a pedagogical approach. Working in parallel mediums reveals advantages and disadvantages of the processes to the students. It provides them with new insight into the relationship between process and content. Finally, working in parallel media can reinforce both the contrasts and shared principles, thus contributing to a greater understanding of approaches and organizational strategies of the programs.

Finally, in order to best utilize the Rational Decision Making Process, students need to gain transparency with their tools. It is not until they are unencumbered by a tool that they can use it freely. In the digital, this mastery must be arrived at with a thorough understanding of the principles that inform the software, and not just memorizing which buttons to push.

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Appendix A. Introductory Survey

After the 300 level studio, how familiar are you with Rhino?

1. What is Rhino?
    - a. I opened it, but I went back to sketchup
    - b. I have messed with it, got frustrated, and went back to SketchUp
    - c. I feel confident; I can make straight and square buildings
    - d. I could make some curved and complex shapes
    - e. I could make a rubber duck using rhino
    - f. Frank Gehry calls me when he gets stumped
    - g. Other:

2. How familiar are you with the laser cutter?
    - a. What is a laser cutter?
    - b. I went to training, but I never used it.
    - c. I have used it, but I forgot how.
    - d. I have used it, and I could do it again.
    - e. I can use the laser cutter

3. How familiar are you creating renderings in Rhino?
    - a. Not at all
    - b. I have done it before
    - c. Comfortable, but I could use a few pointers
    - d. I know what I am doing

4. In terms of rendering, how familiar are you with the concept of texture mapping and lighting?
    - a. What is a texture map?
    - b. I understand the concepts, but can’t really do it.
    - c. I do some texturing mapping, but usually do post production stuff in Photoshop.
    - d. I am confident and comfortable.

Appendix B. Progress Survey

1.What I'm learning in this class will:
- a. Prepare me for professional practice
- b. Give me skills that other students may not have
- c. Help me to do better in my studio classes
- d. Helps me understand how technology can be used in design

2. Now that I know a little bit more I will:
- a. Use technology differently than I did before when I design
- b. Think about the construction as well as the design
- c. Do more testing before assuming a design is complete
- d. Do everything exactly the same

3. I still hope to learn
- a. Ways to use the technology to improve/refine my design
- b. Ways to improve my design during fabrication
- c. How to get better at using the technology
- d. Not much, I know enough now

4. Using technology
- a. Is essential to a creating a good design
- b. Allows me to visualize a design in ways that sketches don't
- c. Is easier than sketching
- d. Is harder than sketching

5. Fabricating a design
- a. Is harder than I anticipated
- b. Is easier than I anticipated
- c. Shows where the digital model has shortcomings
- d. Helps me to see where I can improve the digital model

6. It would be great if
- a. What I learned in this class supported lessons in the studio class
- b. Studio demonstrated how to incorporate using the software from this class
- c. Studio work requirements used what I learned in this class
- d. I could demonstrate what I learned in this class in studio work

Appendix C. Last Day Survey

1. How often did you utilize analog processes when designing your projects for this class? Sketching, study models, etc.…If you do use these processes, at what point in the project do you do so? Please answer in the short answer portion.
   a. Always
   b. Sometimes
   c. Never
   d. Other

2. Why is the class suddenly interested in using flamingo? If you personally are not, please answer so.
   a. See below
   b. I am not interested
   c. Other

3. When designing (for this and other classes) do you:
   a. have concrete ideas in mind and then attempt to build them in the computer.
   b. It depends, see explanation below.
   c. Other.

4. Did these projects teach you anything other than how to use a specific piece of software? If so, what?
   a. Yes
   b. No
   c. Other

5. Will you approach (thinking about) future projects differently as a result of anything you learned in this class? Please explain.
   a. Yes
   b. No
   c. Other

6. Did you see any value in failures? Why or why not?
   a. Yes
   b. No
   c. Other

7. Did you feel encouraged to experiment in this class? Please explain.
   a. Yes
   b. No
   c. Other

8. Was there a point in the quarter where you felt the need to play it safe on your projects? If so,

when was it?

a. Yes
b. No
c. Other

9. Do you think the material you learned in this class will help you to use similar software or processes in the future? Why or why not?
   a. Yes
   b. No
   c. Why or why not?

10. Did the form of your cool box project effect your final presentation strategy, or vice versa?
   a. Cool box effected final presentation strategy
   b. Final presentation idea influenced cool box
   c. Each influenced the Other
   d. Please explain

11. What is the relationship between what is being taught in this class vs. what is being taught in other classes? I.e., is there an overlap?
   a. Some overlap
   b. No overlap
   c. All overlap
   d. Please explain

12. Will you use rhino or other software to visualize an idea? Please explain.

13. Was there anything else you were hoping to learn in this course? If so, what was it? Recognizing the fact that there is a finite amount of time to present information, what, if anything, do you think should have been left out of the course in order to make room for something else?

14. What is Rhino?
      a. I opened it, but I went back to SketchUp
      b. I have messed with it, got frustrated, and went back to SketchUp
      c. I feel confident, I can make straight and square buildings
      d. I could make some curved and complex shapes
      e. I could make a rubber duck using rhino
      f. Frank Gehry calls me when he gets stumped
      g. Other:

15. How familiar are you with the laser cutter?
      h. What is a laser cutter?
      i. b. I went to training, but I never used it.
      j. I have used it, but I forgot how.
      k. I have used it, and I could do it again.

l. I can use the laser cutter

16. How familiar are you creating renderings in Rhino?
    m. Not at all
    n. I have done it before
    o. Comfortable, but I could use a few pointers
    p. I know what I am doing

17. In terms of rendering, how familiar are you with the concept of texture mapping and lighting?
    q. What is a texture map?
    r. I understand the concepts, but can’t really do it.
    s. I do some texturing mapping, but usually do post production stuff in Photoshop.
    t. I am confident and comfortable.

18. Do you have any final comments?

Appendix D. First and Last Day Survey Results

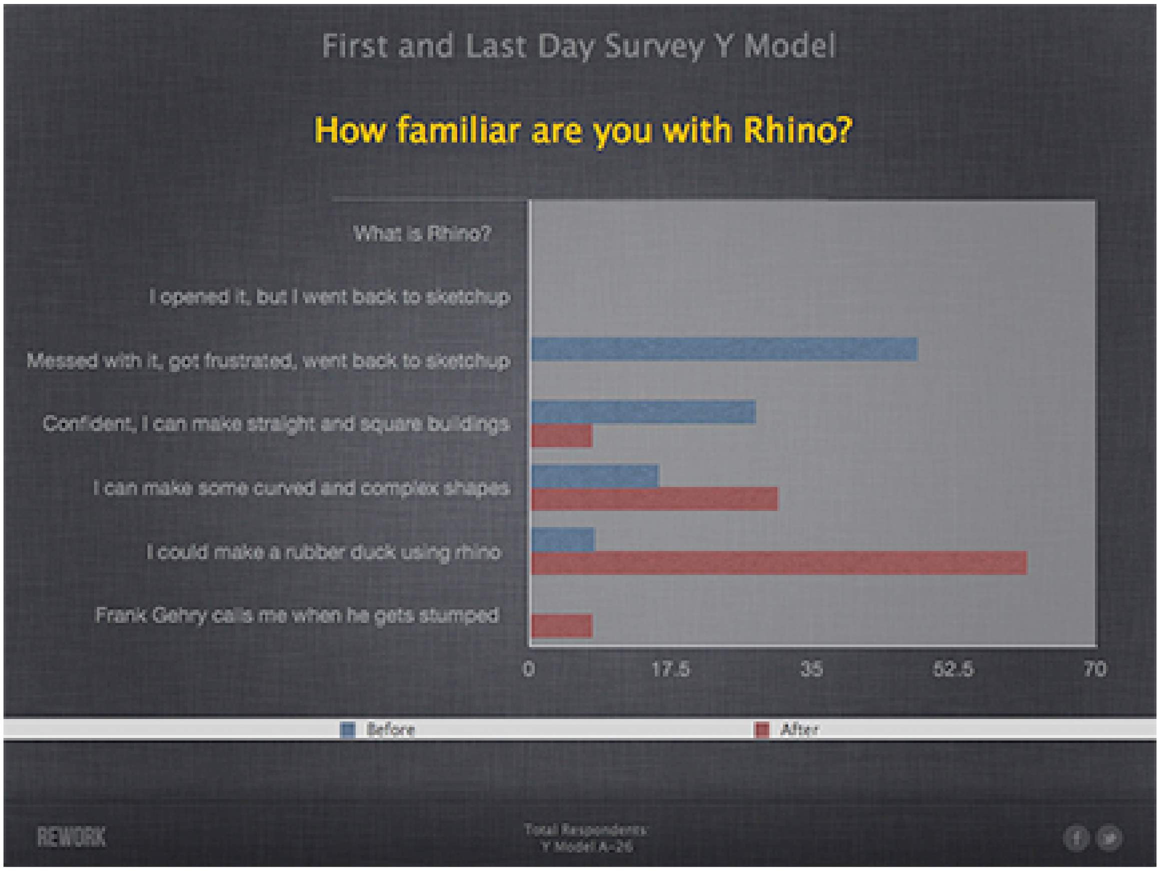


Figure D.1

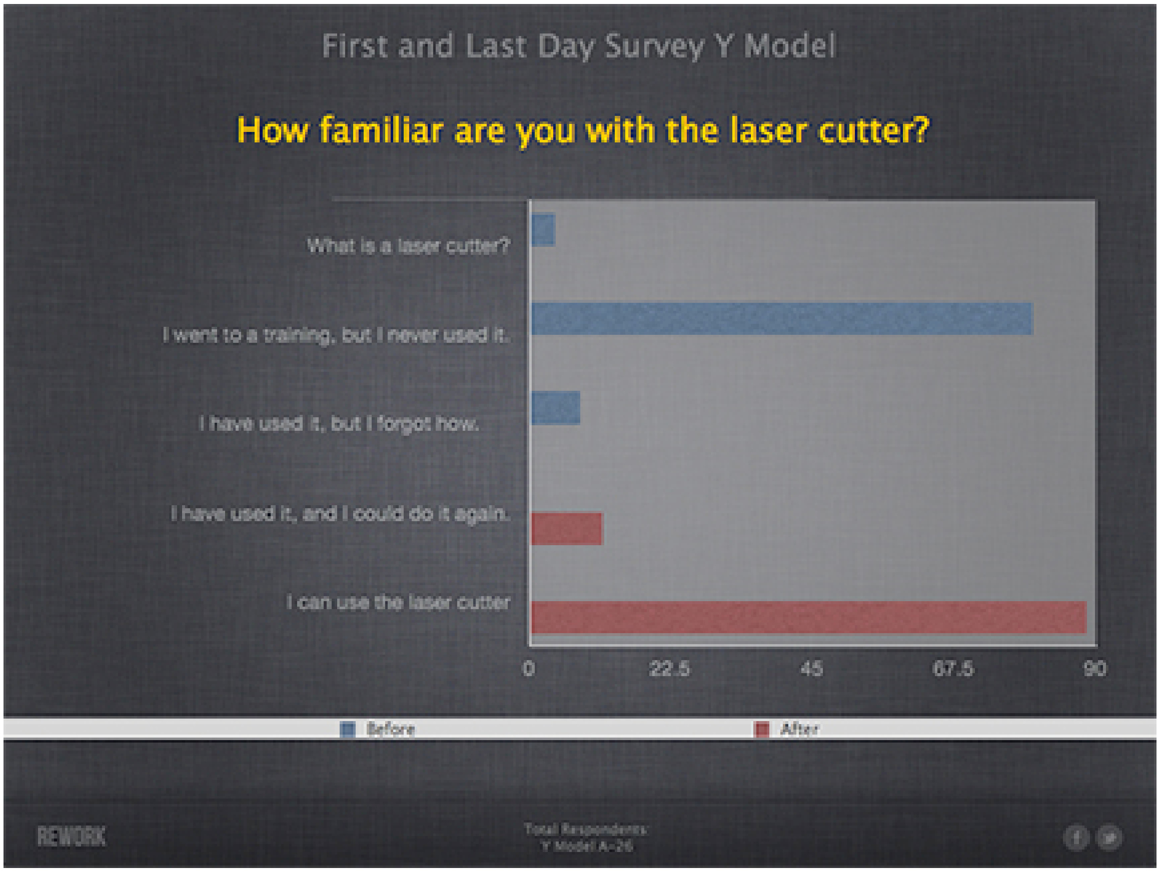

First and Last Day Survey Y Model
How familiar are you with the laser cutter?
What is a laser cutter?
I went to a training, but I never used it.
I have used it, but I forgot how.
I have used it, and I could do it again.
I can use the laser cutter
0
22.5
45
67.5
90
Before
After
REWORK
Total Respondents:
Y Model A-26

Figure D. 2

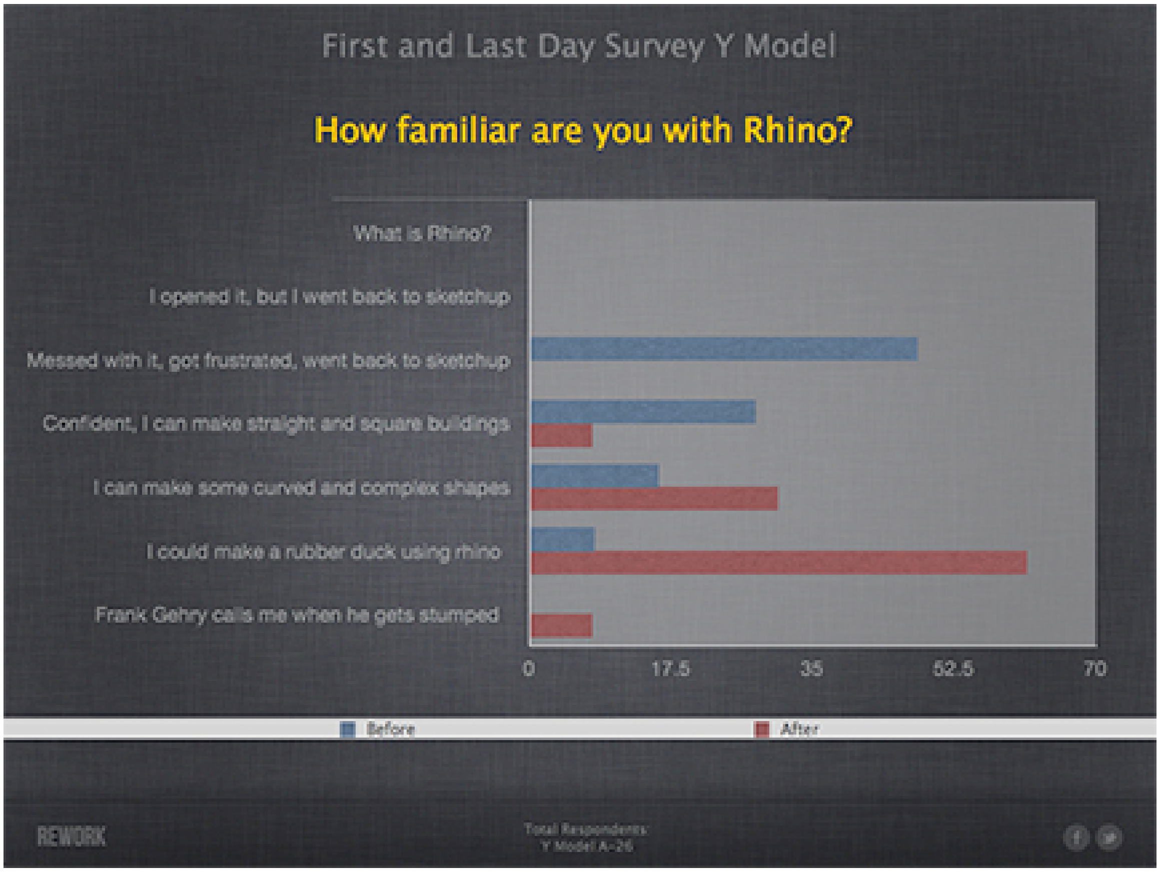

First and Last Day Survey Y Model
How familiar are you with Rhino?
What is Rhino?
I opened it, but I went back to sketchup
Messed with it, got frustrated, went back to sketchup
Confident, I can make straight and square buildings
I can make some curved and complex shapes
I could make a rubber duck using rhino
Frank Gehry calls me when he gets stumped
0
17.5
35
52.5
70
Before
After
REWORK
Total Respondents:
Y Model A-26

Figure D.3

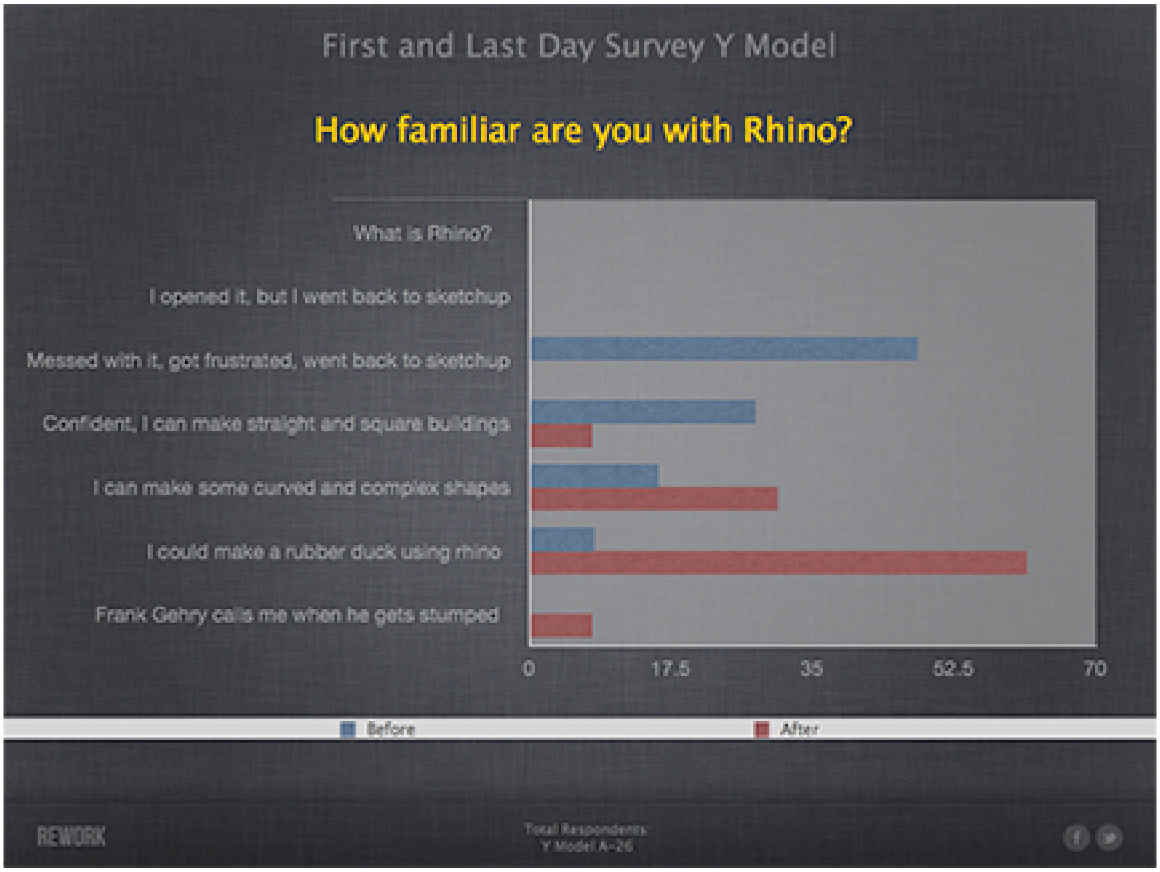

First and Last Day Survey Y Model
How familiar are you with Rhino?
What is Rhino?
I opened it, but I went back to sketchup
Messed with it, got frustrated, went back to sketchup
Confident, I can make straight and square buildings
I can make some curved and complex shapes
I could make a rubber duck using rhino
Frank Gehry calls me when he gets stumped
0
17.5
35
52.5
70
Before
After
REWORK
Total Respondents:
Y Model A-26

Fig D.4

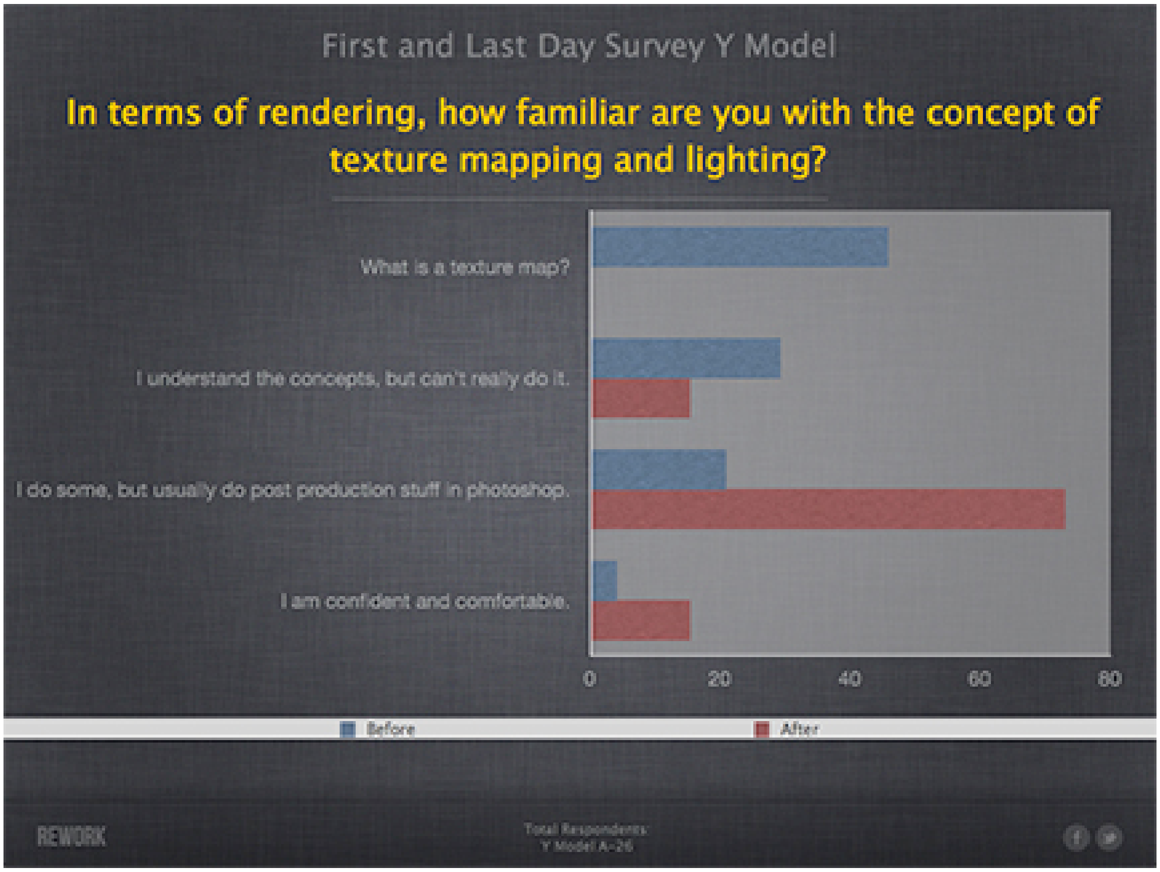

First and Last Day Survey Y Model
In terms of rendering, how familiar are you with the concept of texture mapping and lighting?
What is a texture map?
I understand the concepts, but can't really do it.
I do some, but usually do post production stuff in photoshop.
I am confident and comfortable.
0
20
40
60
80
Before
After
REWORK
Total Respondents:
Y Model A-26

Figure D.5

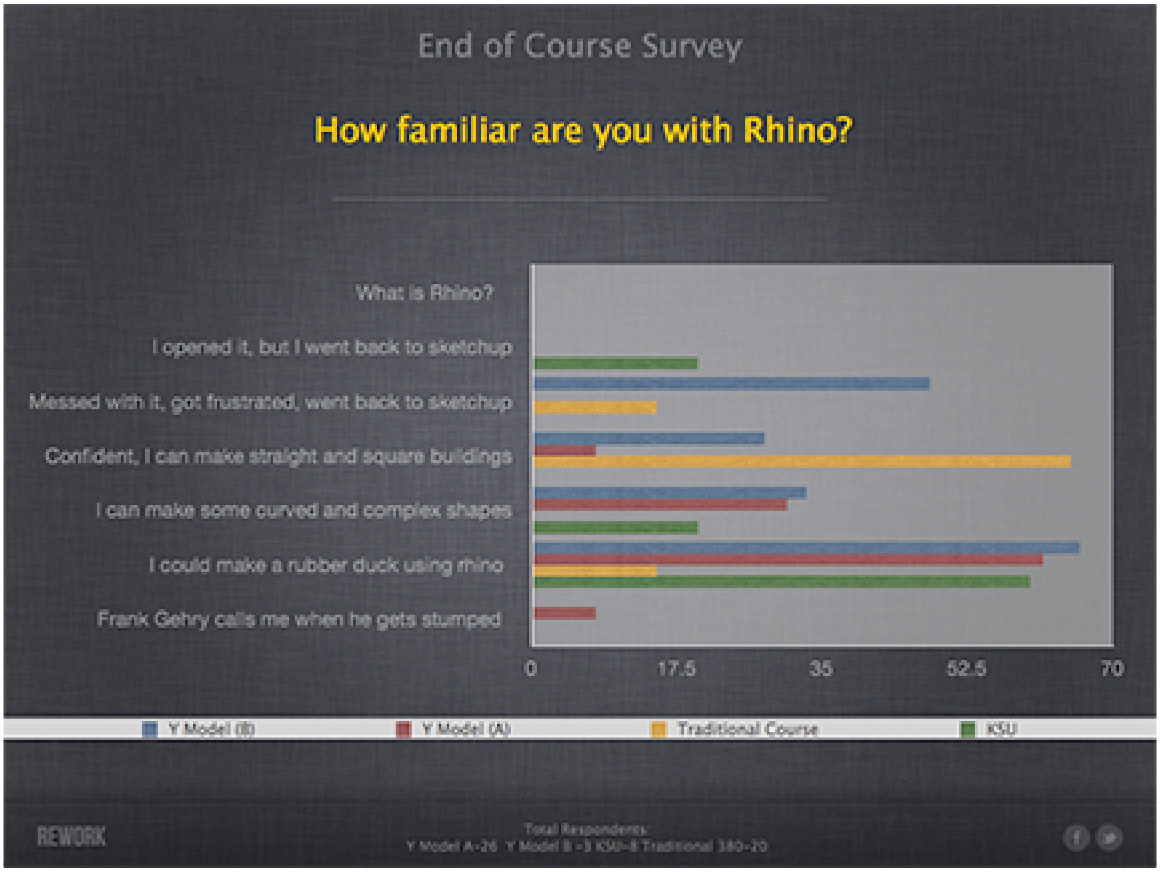

End of Course Survey
How familiar are you with Rhino?
What is Rhino?
I opened it, but I went back to sketchup
Messed with it, got frustrated, went back to sketchup
Confident, I can make straight and square buildings
I can make some curved and complex shapes
I could make a rubber duck using rhino
Frank Gehry calls me when he gets stumped
0
17.5
35
52.5
70
Y Model (B)
Y Model (A)
Traditional Course
KSU
REWORK
Total Respondents:

Figure D.6

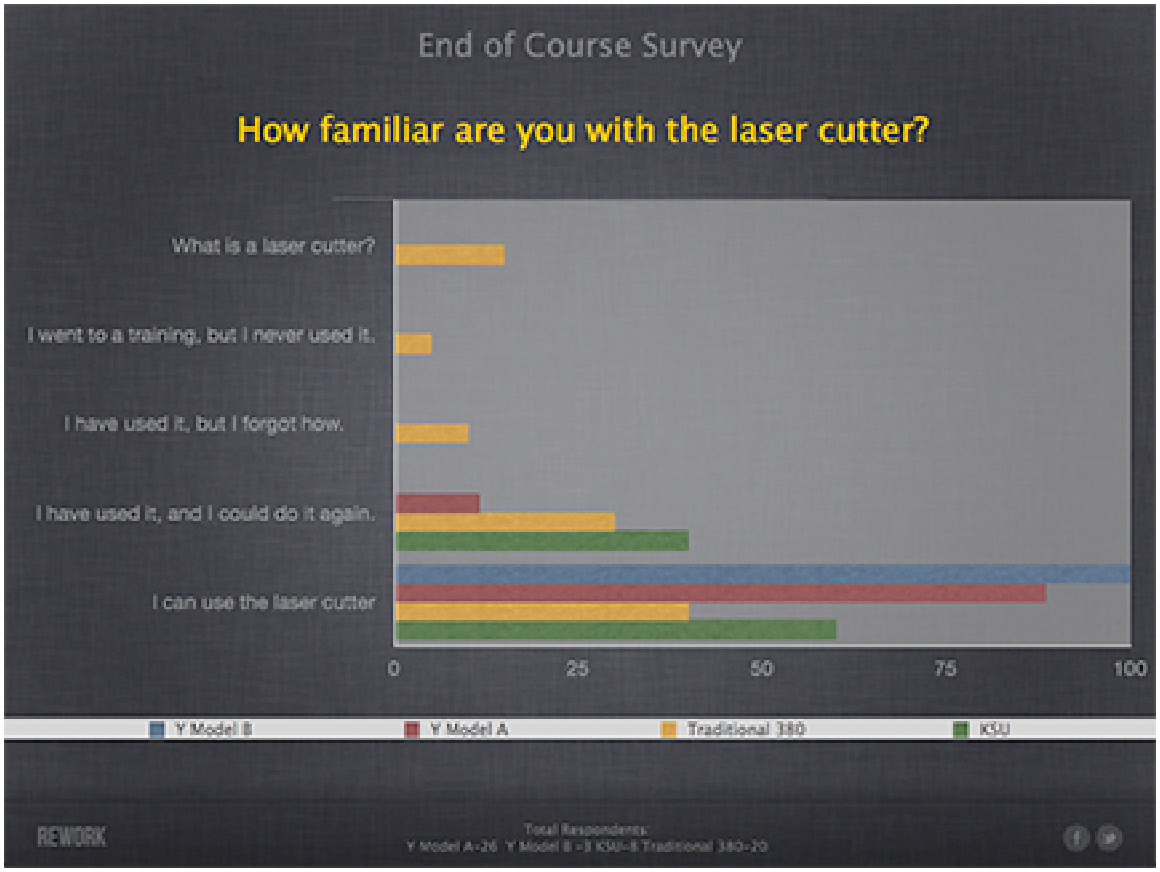

End of Course Survey
How familiar are you with the laser cutter?
What is a laser cutter?
I went to a training, but I never used it.
I have used it, but I forgot how.
I have used it, and I could do it again.
I can use the laser cutter
0
25
50
75
100
Y Model B
Y Model A
Traditional 380
KSU
REWORK
Total Respondents:
Y Model A-26 Y Model B -3 KSU-8 Traditional 380-20

Figure D.7

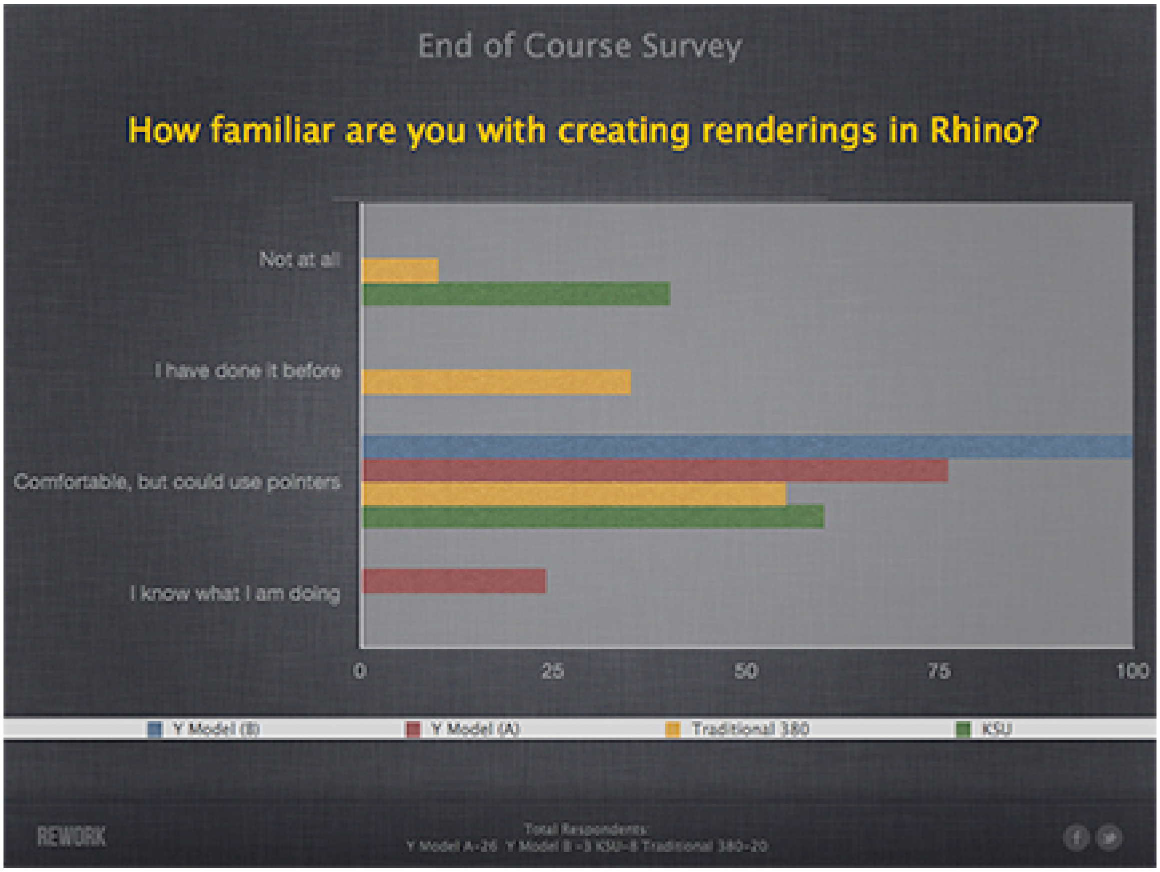

End of Course Survey
How familiar are you with creating renderings in Rhino?
Not at all
I have done it before
Comfortable, but could use pointers
I know what I am doing
0
25
50
75
100
Y Model (B)
Y Model (A)
Traditional 380
KSU
REWORK
Total Respondents:
Y Model A-26 Y Model B -3 KSU-8 Traditional 380-20

Figure D.8

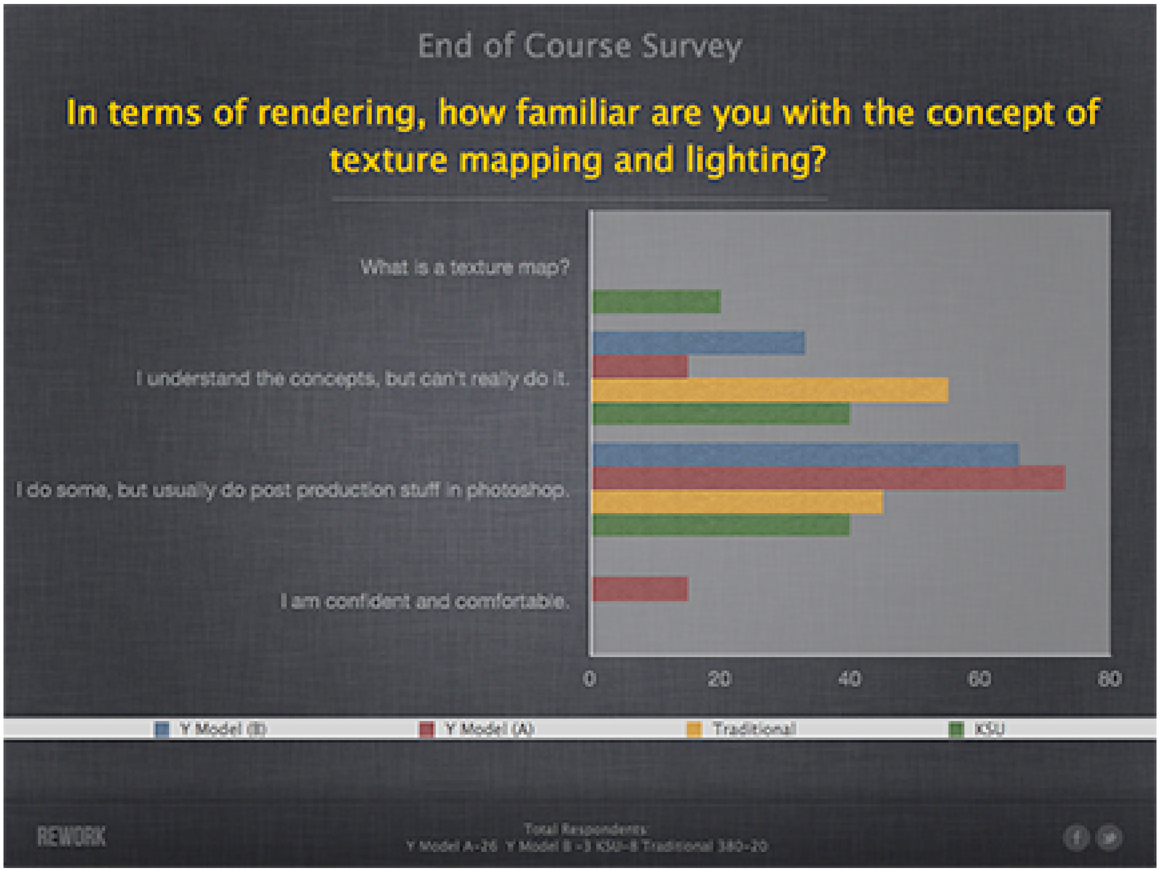

End of Course Survey
In terms of rendering, how familiar are you with the concept of texture mapping and lighting?
What is a texture map?
I understand the concepts, but can't really do it.
I do some, but usually do post production stuff in photoshop.
I am confident and comfortable.
0
20
40
60
80
Y Model (B)
Y Model (A)
Traditional
KSU
REWORK
Total Respondents:

Figure D.9

Appendix E. AutoCAD Survey Results

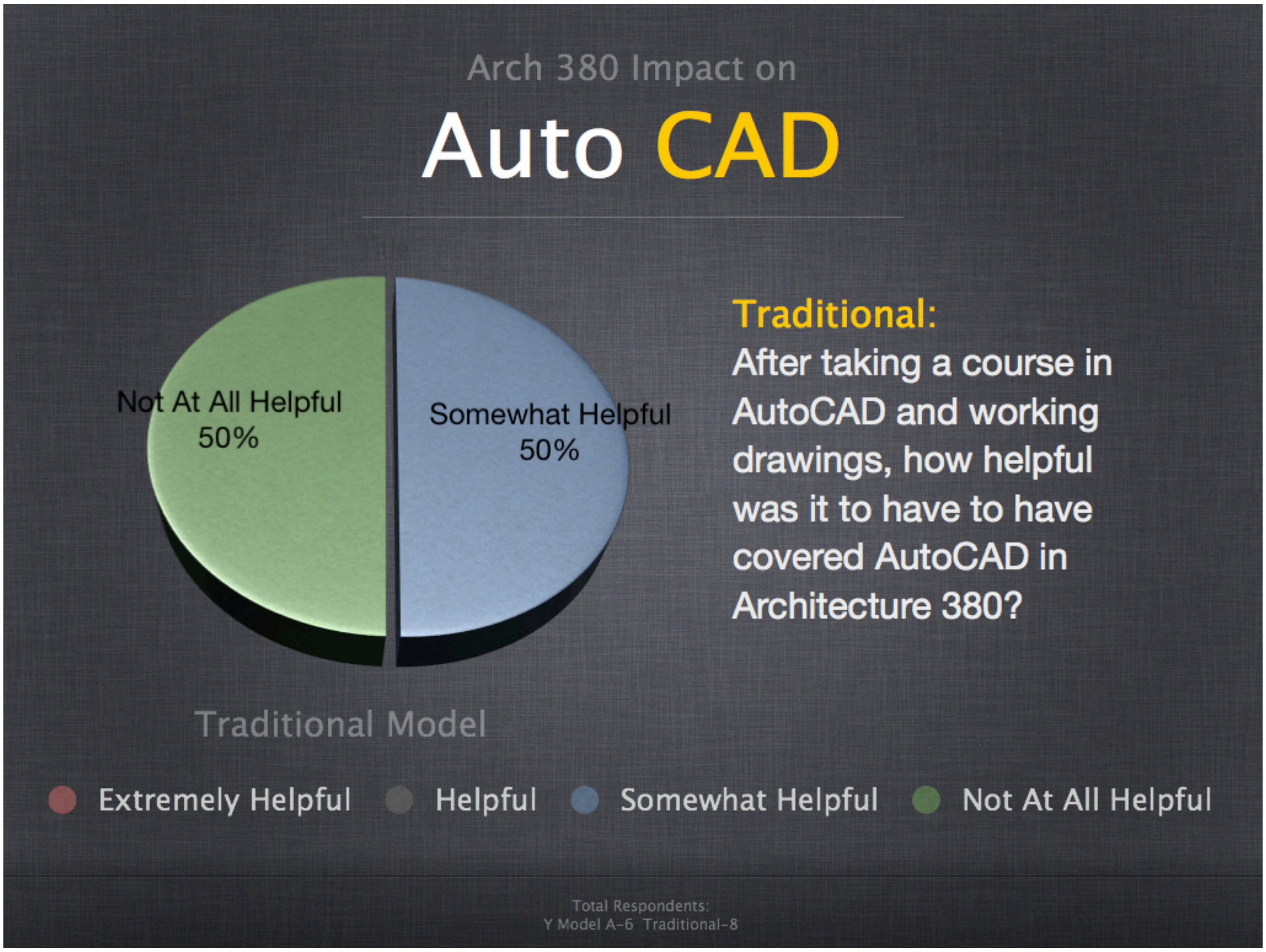
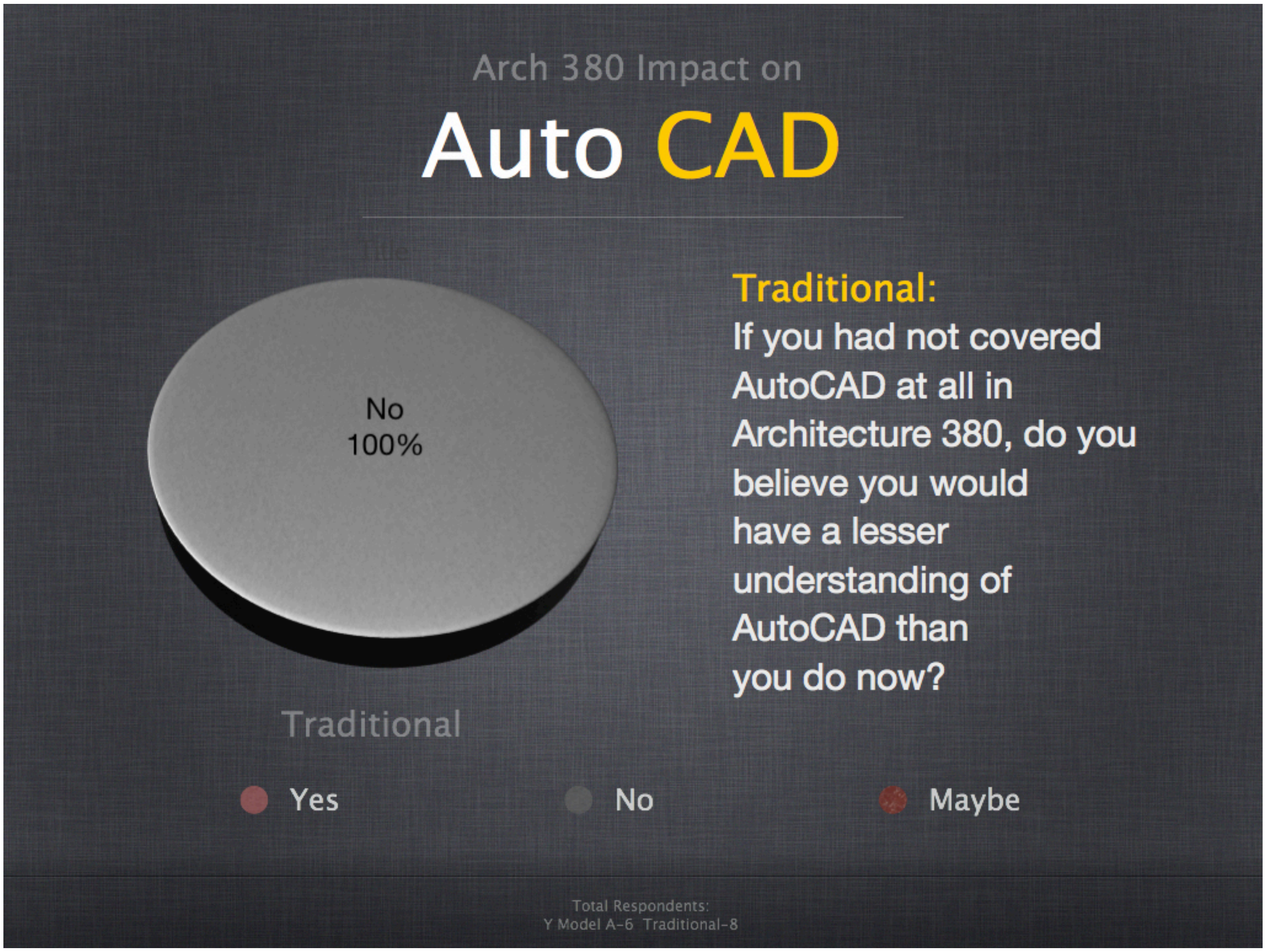


Figure E.1



Arch 380 Impact on
Auto CAD
Traditional:
If you had not covered AutoCAD at all in Architecture 380, do you believe you would have a lesser understanding of AutoCAD than you do now?
No
100%
Traditional
Yes
No
Maybe
Total Respondents:
Y Model A-6 Traditional-8

Figure E.2

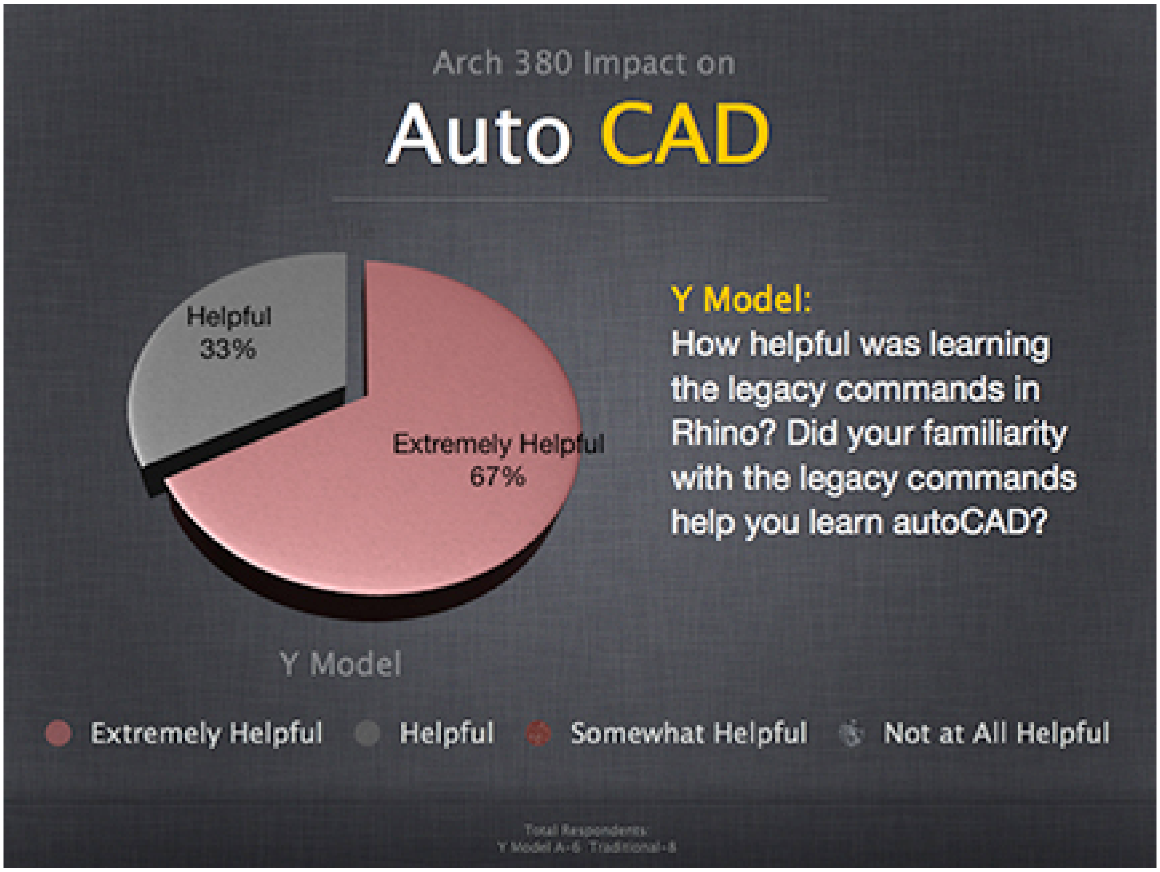

Arch 380 Impact on
Auto CAD
Helpful
33%
Extremely Helpful
67%
Y Model:
How helpful was learning the legacy commands in Rhino? Did your familiarity with the legacy commands help you learn autoCAD?
Y Model
Extremely Helpful
Helpful
Somewhat Helpful
Not at All Helpful

Figure E.4

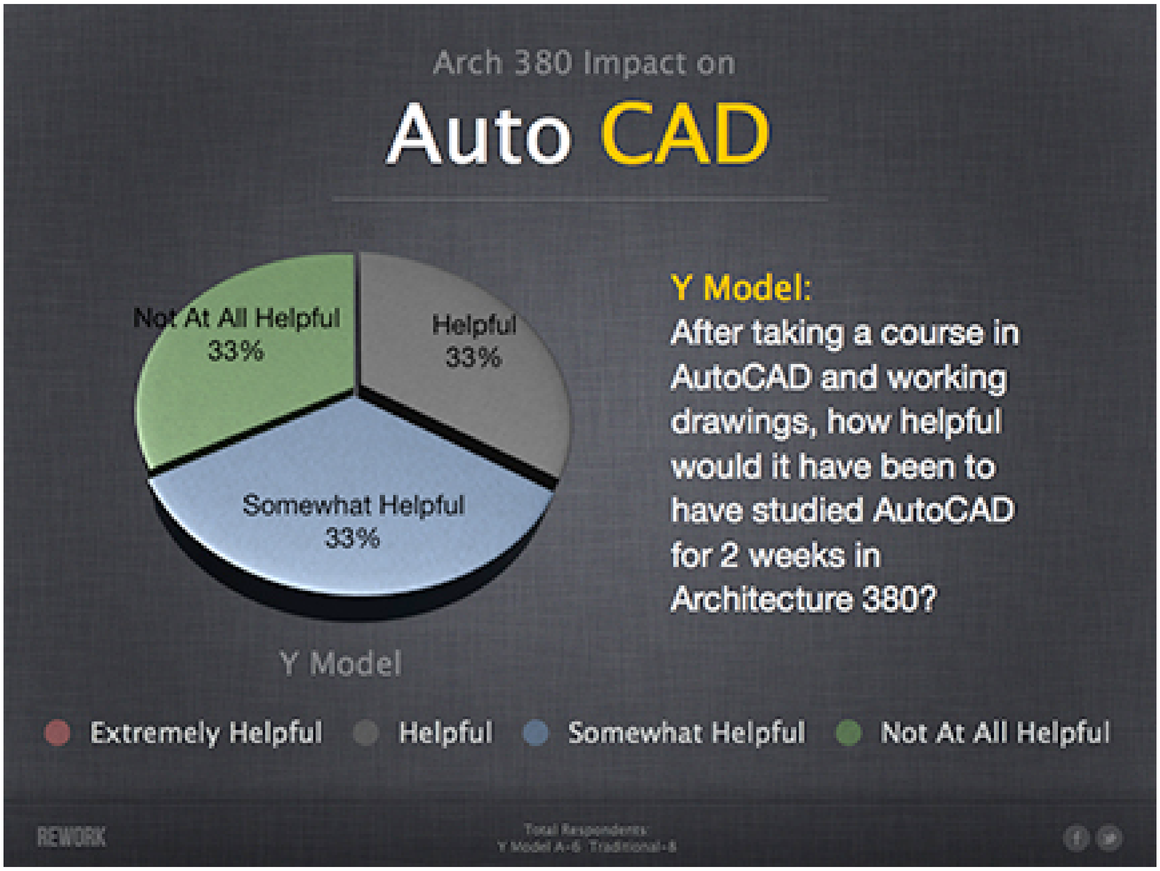

Arch 380 Impact on
Auto CAD
Not At All Helpful
33%
Helpful
33%
Somewhat Helpful
33%
Y Model
Y Model:
After taking a course in AutoCAD and working drawings, how helpful would it have been to have studied AutoCAD for 2 weeks in Architecture 380?
Extremely Helpful
Helpful
Somewhat Helpful
Not At All Helpful
REWORK
Total Respondents:
Y Model A-6 Traditional-8

Figure E.5

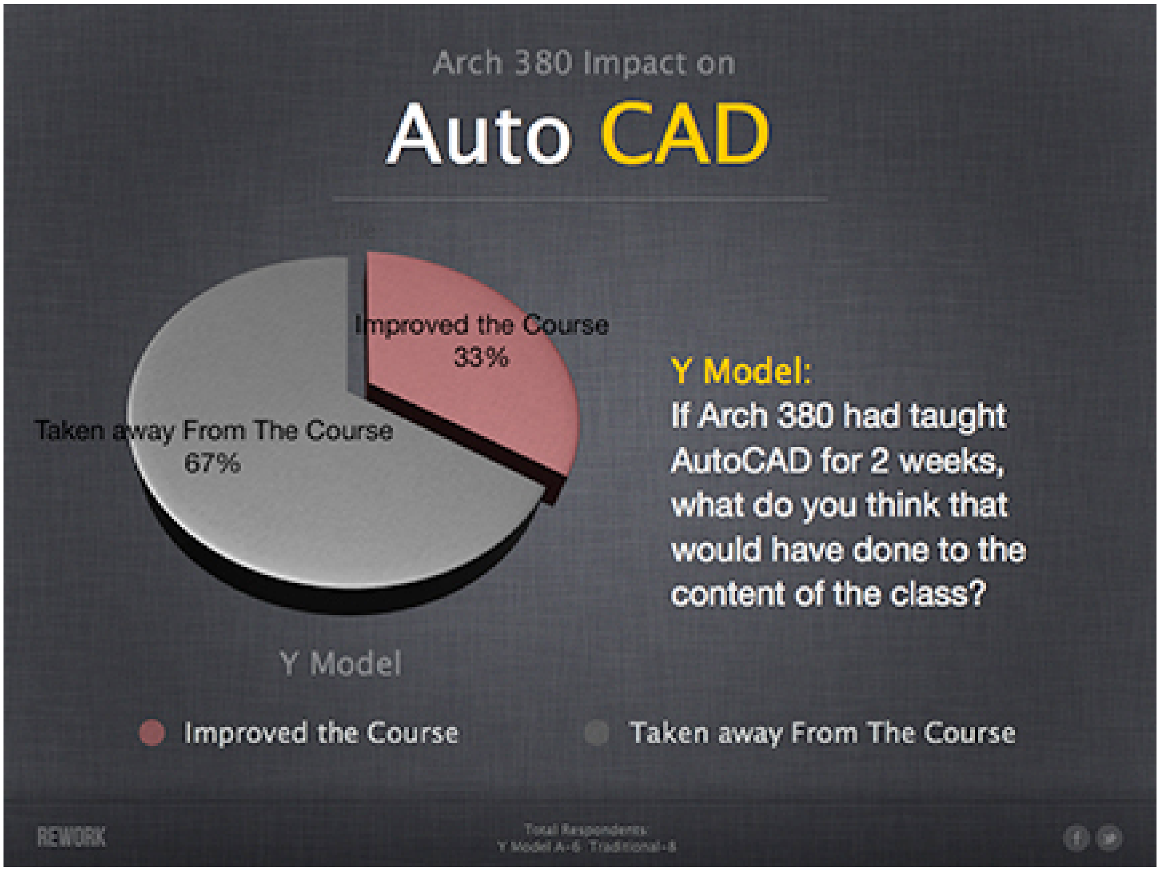

Arch 380 Impact on
Auto CAD
Improved the Course
33%
Taken away From The Course
67%
Y Model:
If Arch 380 had taught AutoCAD for 2 weeks, what do you think that would have done to the content of the class?
Y Model
Improved the Course
Taken away From The Course
REWORK
Total Respondents:
Y Model A-6 Traditional-8

Figure E.6

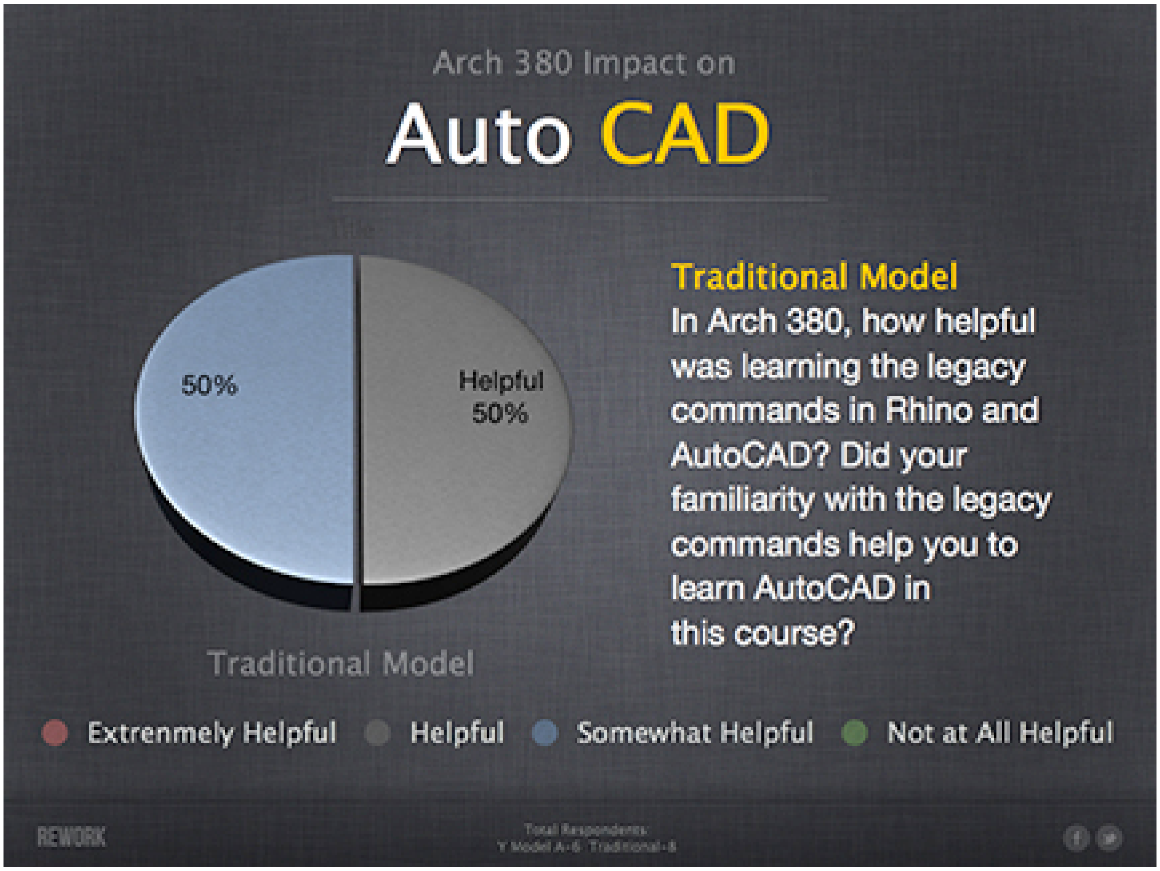

Arch 380 Impact on
Auto CAD
Traditional Model
In Arch 380, how helpful was learning the legacy commands in Rhino and AutoCAD? Did your familiarity with the legacy commands help you to learn AutoCAD in this course?
50%
Helpful
50%
Traditional Model
Extrenmely Helpful
Helpful
Somewhat Helpful
Not at All Helpful
REWORK
Total Respondents:
Y Model A-6 Traditional-8

Figure E.7

Appendix F. Rendering Survey Results

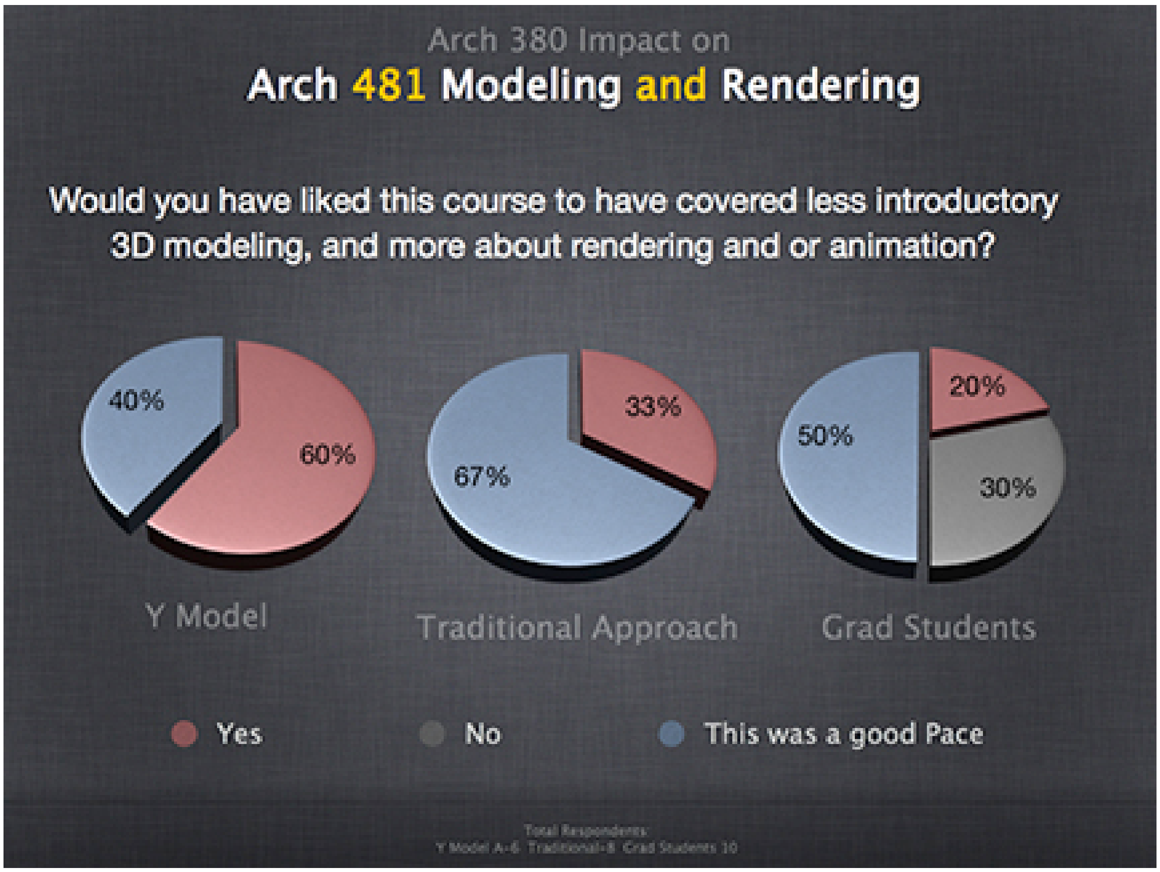


Figure F.1

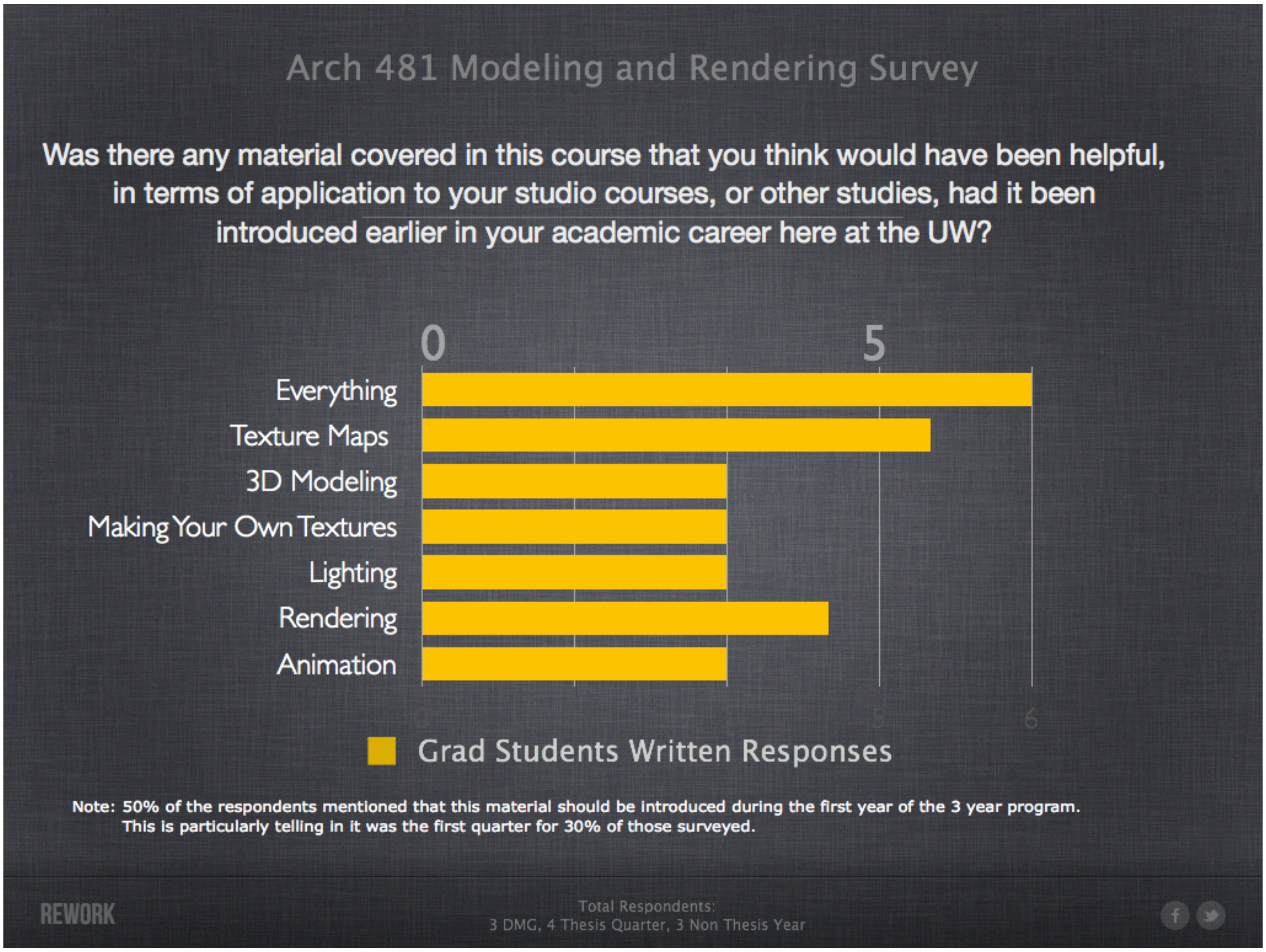

Arch 481 Modeling and Rendering Survey
Was there any material covered in this course that you think would have been helpful, in terms of application to your studio courses, or other studies, had it been introduced earlier in your academic career here at the UW?
0
5
Everything
Texture Maps
3D Modeling
Making Your Own Textures
Lighting
Rendering
Animation
Grad Students Written Responses
Note: 50% of the respondents mentioned that this material should be introduced during the first year of the 3 year program.
This is particularly telling in it was the first quarter for 30% of those surveyed.
REWORK
Total Respondents:
3 DMG, 4 Thesis Quarter, 3 Non Thesis Year

Figure F.2

Supplemental Materials

Arch 380 Syllabus

Week 1: Jan 9

Review of 2D and 3D basics; Quarter overview and project outline.

Introduction of quarter long project

Week 2: Jan 16

Deliverables due project 1:

Rhino model and 1 or 2 digital 11 x 17 pdf

Basic Modeling review, Complex modeling, Boolean operations, Complex curvature

NURBS, Splines, etc.

Principles and introduction to modeling of curved objects

Beyond surfaces of revolution and sweeps. (NURBS, patches, handles, nodes)

Homework:

Refine park design; begin to create digital models of objects in the park

Week 3: Jan 23

Deliverables due project 2:

Rhino model of park, one or two 11 x 17 digital pdf support materials/presentation for park

LECTURE

Introduction to Rhino render, v5, and flamingo NXT,

Concepts: Faux geometry: Smoothing (Gouraud/Phong), Texture

maps (surface, solid & procedural textures, color,

transparency & bump maps);

environment maps.nes/surfaces; 'back-siding' 'culling' and depth sorting.

Homework: Begin experimenting with texture maps and material simulation, turn in two 11x 17 virtual pdfs to the catalyst site of your rendered objects and park design

Week 4 Jan 30:

Deliverables due project 3:

Two 11x 17 virtual pdfs to the catalyst site of your rendered objects and park design.

Lecture

Introduce fabrication project 1; developable surfaces, introduce fabrication project 2, 3d printing, closed poly models, introduction to digitizer

Homework:

Fabrication project 1, (project 4)

Week 5 Feb 6:

Deliverables Due fabrication project 1 (project 4) :

Fabrication project 1, 1 physical model, jpegs of the model, 1 rhino model

Lecture

Editing, Visibility & Lights, ADDING LIGHT: SHADE & SHADOW

#1 Lights (point, spot, sun, area, real), Shade & Shadow

#2 Hidden-surface removal by z-buffering. Creation and management of geometric detail. Symbols: instances v. copies.

Homework:

Project 5, Begin refining design for "model of park" turn in one 11 x 17 digital pdf of model (schematics ok)

Turn in one 11 x 17 pdf of rendered park design, with a special emphasis on natural lighting

1 rhino model (rendering), 1 rhino model (of physical model)

Week 6 Feb 13:

Deliverables project 5, fabrication project 2:

Review fabrication project 2, which is due today, closed polygon mesh model only no physical artifact due, one 11 x 17” pdf describing project, with proof that mesh model is closed.

Homework:

Fabrication project 3, Model box

Lecture

TBA

Week 7 Feb 20:

Study/process model due/ Review/ desk critiques

Week 8 Feb 27:

Deliverables, fabrication project 3, Model Box Model case due

/ Review/Work Session

Week 9 March 6

Work Session

Week 10 March 13:

Final Review, all Projects due

Deliverables:

4 fully rendered pdfs describing project, which is really 2 models, the park, and the model of the park, turn it all in inside the cool box you made.

A cd with each weeks assignment in it, your final digital models, 1 for rendering, 1 for fabrication, and photos of your final model.

DESCRIPTION OF PROJECTS

Playground project:

Arch 380

UW Winter 2013

Utilizing the rhino model as a point of departure, you will create a park and a piece of playground equipment. This project has two main goals:

• To develop a "critical eye" with regard to computer graphic (CG) images by developing your understanding of and experience with 3D modeling & rendering. Images are communicative tools, linked together and used to "tell a story" to someone else.

• Introduce you to some fabrication techniques and concepts. You will also employ Rhino and utilize some of the fabrication tools. By the completion of this project, everyone should understand that CAD/CAM activities are not something that is executed with the simple push of a button, despite what various glossy architecture blogs would have us believe.

Models, both physical and digital, are not "objective reality" from which rendering programs simply produce precise "snapshots". They are "authored"–created and manipulated to accomplish a particular communication goal. There are overlaps between digital techniques in model making and rendering using traditional media–different visual results, but similar authorship goals, responsibility and opportunity. THINK about what story you are telling with each image, model, and object.

You cannot approach a physical model the same way you approach a digital model. Although the departure point is the same, the endpoints are very different. This project will require you to use the computer as both a tool, and a medium. Everyone in this course should have taken the 300 level studios, and should be familiar with rhino 4.0. Please let me know if this is not the case.

Playground/park Program Requirements: (feel free to add extra elements if you feel it will enhance the design)

1. Seating
2. Grass and trees or other growies
3. Concrete and/ or brick paving
4. Soft groundcover below the play area
5. Fence or some sense of enclosure
6. Trash receptacle

7. Grill

8. Bike rack

9. A 25'x 25' (approx.) modular play structure which contains: a slide, a ladder and/or steps, monkey bars, " tubes" to crawl through, and roof portions. Materials, steel, wood, plastic

The modular play structure will be the bulk of this project. Begin by creating an overall design of your play structure. Refine your structure into modular components; consider how they will fit together, both in reality, and in your model. Create blocks or instances of the individual modules; you will need to do this for both the rendering model, and the fabrication model. Think carefully about blocks and instances when creating your modules.

Nearly every week, you will be required to create digital models and renderings of your park and your modular structure. You will also be required, from time to time, to fabricate, using the laser cutter or 3d printer, physical studies and/or components of said model.

The Rendering model:

It is my belief that each week you will learn a little more about modeling and rendering, and therefore your digital models will improve a bit each week. One of the things you will realize, if you don't already know it is that when it comes to rendering, polygons, textures, and lights are expensive. You may very well find the perfect view, and turn that same view in every week. Same view, only better, every week.

The physical model:

You will be required to digitally fabricate (please aim for a 90% digitally fabricated) model of either your entire park at a small scale, your piece of playground equipment at a larger scale, or both. It is really up to you, what type of model you choose to create, and at what scale you choose to create it. The material choices are up to you as well, the laser cutter will cut most anything, wood, paper, board, acrylic, MDF, leather, etc… You are also welcome to 3d print some parts as well. Be sure to read the handouts on planning a model.

The Cool Box:

Be sure to read about and understand the "cool box" project before making any drastic model making decisions.

FINAL PROJECT DELIVERABLES

4 fully rendered 11 x 17 physical pdfs describing project.

The project, which is really 2 models, the park, and the model of the park, and the cool box it goes in.

A cd which contains:

each week's assignment in it, your final digital models, 1 for rendering, 1 for fabrication, digital files of the abovementioned pdfs, and photos of your final model, and model box combo.

Turn it all in inside the cool box you made.

Arch 380

Winter 2013

Fabrication Project 3,

The Cool Box

All too often students and professionals alike, in a creative zeal, begin their model without regard to where it will rest or how it will be presented. Before beginning a model, ask: How will it fit in with the other presentation materials? Will it be complementary to the design drawings, or will it stand alone? More often than not, a poor presentation is the result of poor planning as opposed to poor technique.

Think about the base during the early phases of the project, and do not skimp in terms of time or materials. A presentation quality base can be used throughout the design development process. If made well, and constructed on wheels or casters, a single base or pedestal can be used, and re-used for several models and purposes.

Regardless of whether a base will feature contours or not, most professionals prefer to construct a "foundation" board for bases of a solid, rigid material such as MDF, melamine board, or, occasionally, ¼-inch or thicker acrylic. Acrylic bases are especially useful should you wish to illuminate your model from below. Bases for study models, or smaller models (11″ × 17″ or smaller) made from lightweight, paper-based materials can be constructed from ¼-inch or thicker foam core. Be aware, the larger the foam core base, the greater the chance it will warp or deform over time. It is absolutely impossible to construct a quality model on a warped base.

Hint: Our Laser cutter can cut ¼" MDF

Hint, Hint: the thicker the material, the longer it takes to cut on our laser cutter. The laser cutter etches as well as cuts.

Hint, Hint, Hint: sometimes people get so excited about digital technology, they forget about analog methods which may actually be faster.

Hint, Hint, hint, hint… It may be faster to rip a thicker material on a table saw than it is to setup a file, and wait in line for a tool. Try and make this project about 80% digitally fabricated…

Alec Vassiliadis, the model maker for NBBJ, once told me a story.

The 4” tall model and the box which contains it (Figure 4.1 and 4.2) were planned and built to be a cohesive whole. When the architect arrived at the clients office, he said nothing about the exquisitely crafted box that he placed in the center of the long, empty meeting table, itself made of a beautiful hardwood. As he began to speak, he would casually slide the box partially open, only to shut it again. Each time he did this, it served to heighten the sense of excitement, mystery, and anticipation as to what was in the box. Before he finished the talk, he excused himself, and went to the restroom, leaving the small, mysterious box sitting on the table. When he returned, he found that the clients, like children on Christmas Eve, were unable to contain themselves. They had opened the box, and removed the model, around which they huddled like a campfire. This small model managed to dominate the immense boardroom, and captivate its viewers. When it comes to scale, bigger is not always better, remember, there are always a multitude of factors that one should consider.

How will you transport it?

Will it fit through the door of your studio? Will it fit through the door of your house? Will it fit through your client’s door? Can you fit it into your car? Can it be carried on to an airplane? If so, will it fit under the seat in front of you? How many times will you need to transport it?

ASSIGNMENT REQUIREMENTS:

Bearing some of the abovementioned things in mind, and utilizing your digital fabrication skills, create a 12” x 12” x 6” box that will contain, display, and safely transport your model, a cd, and 11 x 17 pdfs.

Feel free to use glue, hinges, or any type of mechanical fastener you wish. If you are interested in creating something that you think is beyond the scope of your current digital skillset, see me individually, I can probably be of assistance.

This can be made of any material you wish. You can even mix and match materials. Remember, the laser cutter can etch as well as cut.

Make sure your box is cool.

Make sure your name is on the box.

Make sure the box can open and close.

Make sure the box holds everything, cd, model, 11 x17 pin ups, pins? usb?.

Make sure the box can have at least 4 other students boxes stacked on it.

What is your box doing when everyone is looking at your other presentation materials?

The box is worth 10% of your grade.

Student Images