Balancing Manual and Digital Design Methods

A Study of Studio Furniture Manufacturers

By

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ABSTRACT

The purpose of this study was to determine appropriate uses for digital design tools and the benefit of a close relationship with both materials and manufacturing processes. The study was conducted with studio furniture manufacturers, a group of interdisciplinary individuals who possess both woodworking and design skills. Semi-structured interviews were conducted and analyzed for opinions related to division of labour, innovation and processes, and education and culture. Results showed that digital design tools are appropriate when they do not significantly alter the design process as a whole, and offer real value to the user. Their connection to materials and manufacturing informed their designs, and provided inspiration for future work.

Keywords: Industrial Design, Digital Tools, Manufacturing, Craftsmanship, Studio Furniture.

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DEDICATION

for Jenna

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CHAPTER

1. INTRODUCTION

Balancing Manual and Digital Design Methods

A Study of Studio Furniture Manufacturers

> *It may be prophecy that the ideal of design for the machine will be realized by the designer-craftsman, who knows by contact the processes which give his conceptions form, or else by the craftsman-designer, who fully realizes that quantity-producing machinery extends the field of his craft.*
>
> (Bach, 1937, p.83)

The purpose of this research is to investigate how a study of craft and craftsmen* can help influence a balance between the physical and digital tools used by industrial designers in their design activities. Digital tools increasingly dominate the nature of the work done by designers to the point that an understanding of the benefits of traditional tools and methods of working is vital. Designers are now afforded the ability to replace the creation of a physical model or prototype with the creation of a digital model, through Computer Aided Design (CAD). While this change offers benefits in terms of facilitating downstream movement, through Computer Aided Manufacturing (CAM), it diminishes

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* While the term craftsmen is used throughout this thesis, no particular gender is implied. The use of craftsman as opposed to craftswoman or craftsperson is due to a discussion of craftsmanship, which does not have feminine or gender neutral equivalents.

the design work that was accomplished through physical modelling (e.g. scale, ergonomics and tactility). Whereas digital tools will continue to evolve, the designer's alienation from materials and process continues to grow due to the division of labour.

1.1. Background

Moore's law has been called the "emblem for the whole of technological change" (Brock, 2006, p.ix). It describes the doubling of transistors on an integrated circuit approximately every two years and has held fast since 1965 (Moore, 2003). The quantity of transistors shipped has grown and the price per transistor has shrunk accordingly. This pattern has brought about one inescapable fact, that we are now surrounded by technology in many facets of our lives.

Technologies have created a measurable effect upon most areas of work. While many jobs are a direct result, and act in support of new technology, there are also many jobs that predate computer technology. Word processors and spreadsheets provide powerful tools to occupations that previously involved significant manual work. Writers are able to edit their works with ease and accountants can now do computationally intensive tasks with the click of a button. Their objects, ideas and numbers, are intangible and remain unchanged in these new formats.

Other professions work with much more tangible materials; a machinist works with metal, a chef with food, a cabinetmaker with wood; and each with his or her respective tools. For some, it is now common to work with a digital representation of an object rather than with the object itself. The change in object also requires a change in tool.

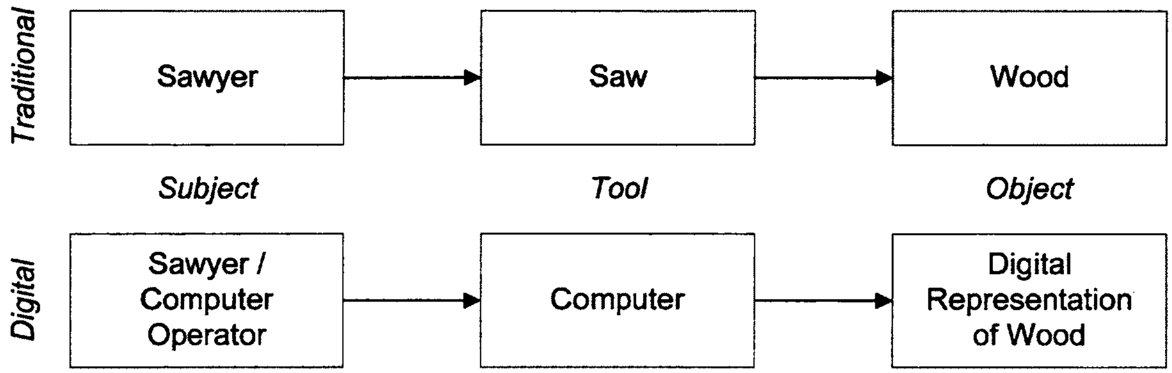


Figure 1 - Subject - Tool - Object Relationship

With a change in both the object and tool, the nature of the work itself also changes. Previously, certain job titles were related to the tool that was used to perform a given task e.g., Sawyer (See Figure 1). Even when the movement was made from hand tools to power tools, the nature of the work and the sawyer's title remained the same. However, many such tasks can now be accomplished by operating a computer.

According to Nigel Cross (Cross, 2007, p.33) the aim of the designer is "the communication of a specific design proposal." In the specific area of industrial design this design proposal describes a (potentially) very real and tangible object. While the proposal is nothing more than a highly detailed idea, we must be careful not to confuse the communication of the design with the process of developing a new idea. A digital model created with computer aided design (CAD) software is an excellent method for communicating an idea but should be preceded by many other artefacts, including handmade sketches, low fidelity prototypes and models as well as a host of other product design methods (IDEO, 2003).

The choice of tool is therefore also a choice about process. There are three thematic areas revealed by the literature that have been examined in this thesis that are relevant to the issue of digital versus analog tool selections: division of labour, innovation and process, and educational and cultural factors.

1.1.1. Division of Labour

It has been the industrial designer's traditional responsibility to ensure that products can be manufactured in an industrial setting. This means that they are required to have a working knowledge of the particular manufacturing processes being used. Designer and educator Wim Gilles recommends going as far as studying shop floor realities (Gilles, 1999). However, this traditional relationship is slipping. A 1996 survey of different firms shows that even 15 years ago, design activities were not always associated with departments responsible for production (Walsh, 1996).

A disparity in proximity between the designer themselves and the manufacturing facility can lead down a slippery slope to job compartmentalization. In the extreme case, an industrial designer becomes relegated to that of the stylist, called upon last to "put the lipstick on the pig" (Hong, 2011, p.10). This disconnection and reordering of the design work can lead to poorer products and can have consequences during manufacturing processes. Digital material and process libraries also need to be complemented with direct experience and experimentation involving materials, especially in the case of students (Hallgrimsson, 2012). When designers come in contact with actual materials, it spurs creativity and innovation (Alesina & Lupton, 2010). This phenomenon has also been observed in craftsmen, who create and envision new opportunities and processes in a hands-on way. Sam Maloof, a highly respected Californian furniture maker who has designed more than 500 pieces claimed in an interview:

> *I draw with my bandsaw-with no lines or anything. A very well-known blacksmith said, 'I use my hammer as my pencil; I use my anvil as my table.' I use my bandsaw as my pencil.*
>
> (Christiana, 2005, p.78)

1.1.2. Innovation and Process

A global marketplace means that firms no longer just compete on price and quality; they must also fight to be first across the finish line (Zirger & Hartley, 1994). Being first to market with a new product offers several advantages such as a longer sales period, and the ability to charge higher prices. One method of being first to market, other than starting earlier, is to have a shorter development time. Achieving shorter development times for new products has been directly identified multiple times as being one of the keys to profitability (Gupta & Souder, 1998). This push to reduce development times is felt by all parties in the development cycle, including industrial designers. The use of computer aided design (CAD), computer aided manufacturing (CAM), and rapid prototyping (RP) technologies are aimed at reducing the critical path timeline to a finished product.

At the same time, being first also implies innovation. As will be expanded upon in the literature review, research has shown that making exclusive use of CAD is not effective from the standpoint of innovation. While use of these tools does offer an increase in throughput from the design function, using them exclusively can lead not only to a sacrifice in the quality of the design, but also to a lack of efficiency and innovation.

1.1.3. Education and Culture

Industrial design education does attempt to follow changes in design practice, as one would expect. But due to a highly generalized set of skills, the breadth of design education can come under the knife by those who want to better prepare students for the work place. One study, seeing that 55.1% of job openings require skills with CAD software, recommends actively decreasing student instruction in areas of drawing and model making (Yang, You, & F. Chen, 2005, p.174). This raises not only a concern for balancing the use of digital tools in education but in practice as well, as the two are inextricably linked. While there is no denying that digital tools have their benefits, the research clearly shows the underlying importance of foundational skills in drawing and modelling.

The balance between a physical and digital process for industrial designers faces attacks from three different areas. In some quarters, the increased specialization of industrial design has led to a departure of the generalized, craft based approach from which design originated. Economic conditions accelerate the drive toward an ever shortening development cycle and the use of computer driven tools to that end. Finally, the education of designers is under the pressure of a perceived market demand for strictly computer-based skills.

1.2. Scope and Rationale

Industrial designers are facing pressures in a tight economy to speed up their process and enable a quicker time to market for new products (Ye et al., 2008). Any new tools must support ideation while facilitating downstream movement for a given design. They must be careful, however, to temper new tools and processes with established practices. Speed should not be gained at the expense of proper design thinking; faster does not equal better when important steps in the design process are omitted.

Similarly, craftsmen are facing ethical dilemmas about the nature of their work. Their survival depends on their ability to produce tangible artefacts made by their hands in real materials. One such group of craftsmen are studio furniture manufacturers, who rely on design and woodworking skills to produce custom made furniture. The competition from furniture that has been mass produced cheaply overseas and sold in warehouses has driven this group into smaller and smaller niches.

In spite of a long history, the market for higher end furniture made by hand is shrinking and losing ground to cheaper imports and cheaper mass produced furniture. Industry Canada has reported that due to inexpensive imports, and a change in buying habits, custom furniture production in Canada is in trouble (Industry Canada, 2010). However, by adopting technology and working with it, small firms can utilize new process innovations and remain competitive with large producers (Nye, 2006, p.125).

In order to avoid the division of labour, these craftsmen are actively being trained to use new technological tools. Many college level cabinetry programs now include courses on CAD to meet this demand. However, although recommendations exist, there are no government requirements for education or certification in Canada for the trade. In the International Labour Organization's 1991 report on technological changes in the wood industries, the problem was already made clear:

> *Knowledge and skills which are specific to woodworking are becoming less important. In fact, metalworkers accustomed to operating CNC machines are now finding ready employment in some woodworking sectors since old-style woodworkers sometimes lack the education and training to adapt to the new technology.*
>
> (International Labour Organization, 1991, p.21)

Studio furniture manufacturers cannot simply change from using traditional tools to only using digital tools, without it possibly altering their identity as well as the outcome of their work. Despite growth in personal computer usage by cabinetmakers, and a growing number of available software packages, some studio furniture manufacturers have been slow to adopt computer aided design tools in their work. One prominent Canadian craftsman even speaks out against using computers (Fortune, 2011, p.44). Cultural aspects of craft create the feeling that certain operations and methods of working are forbidden. These include prescriptions from other craftsmen, internal pressures to maintain integrity, and expectations from customers that their product is made in a certain way. While digital tools offer other benefits, the facilitation of mass production that they provide may be at odds with the bespoke nature of studio furniture manufacturing. If the customer's perception of what constitutes appropriate use of technology is to change, it must come from the craftsman.

As this study will show, there are also craftsmen who have found a way to embrace new technology, while respecting traditional practices. These craftsmen are neither just computer operators nor are they married to their traditional tools in such a way as to impede the speed of their work. In his 1968 treatise on craft and workmanship, David Pye points out that there is significant workmanship done outside the realm of mass production that is "appallingly bad" (Pye, 1968, p.6). He also mentions that there are excellent examples of mass production in terms of quality. Child explains that the culture of banking has grown with the practice, as characterized by an "appearance of soundness, respectability, and orderly administration" (Child, 1985, p.31). The saturation of banking practice by computer technology has done little to alter these characteristics. In her extensive work 'The Silk Weavers of Kyoto', Hareven shows that even artisans creating traditional items can successfully adopt high technology tools and still maintain their market and integrity (Hareven, 2002).

1.3. Methods

A study of professional studio furniture manufacturers was undertaken to gather information concerning appropriate uses of digital design tools and the benefits of craft production. Seven candidates were interviewed regarding their design activities. These interviews were analyzed qualitatively to obtain data concerning their beliefs and actions in regards to the three thematic areas mentioned above. In addition, a direct comparison was made between the design methods of two of the participants, one who had embraced digital design tools, and one who had not.

1.4. Significance to the Field of Design

Innovation is one of the cornerstones of design. Technology can negatively affect the design outcome when it short circuits certain critical aspects of the design process. Similarly technology can greatly improve the speed and accuracy of the process and should not be ignored. There is a traditional relationship between the craftsman and the designer. In certain industries, the roles of the designer and craftsmen have been intertwined as they work together realizing new designs and possibilities through experimentation (Pallasmaa & Aalto, 1985). This study of studio furniture manufacturers aims to better understand the shifting role between craftsmen and designers, as some studio furniture manufacturers are embracing digital tools that allow the effective reproduce their own designs in multiples, thus enabling a form of mass production. The study of the division of labour in this context is particularly important as the craftsmen only retain their identity as long as they retain their connection with the materials. At the same time, the traditional bonds between the designer and the maker are increasingly being broken, due to the globalization of production in a digital world. This has implications for designers in terms of how they learn and experiment with materials. It also underlines the importance of modelling and prototyping.

CHAPTER

2. LITERATURE REVIEW

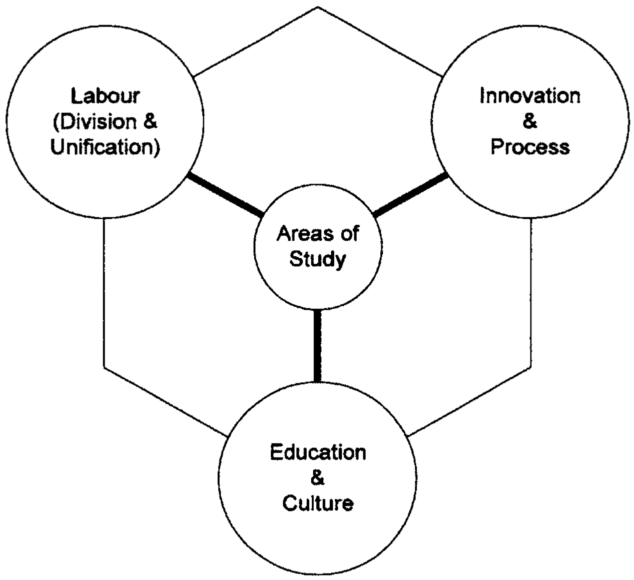


Figure 2 - Areas of Study

This literature review is broken into three main sections, preceded by a short preamble that discusses terminology related to models and modelling. The three main sections relate to the three problem areas established in the introduction: Labour, Innovation and Process, and Education & Culture.

2.1. Definitions

2.1.1. Models and Modelling

The term 'model' has a no less than a dozen definitions (Merriam-Webster, 2011a) but for the purpose of this thesis a model refers to a representation of a product concept or idea. Building on that definition, modelling is the creation of these representations.

The importance of modelling to the nature of design is explained by Cross:

> *At its core is the 'language' of 'modelling'; it is possible to develop students' aptitudes in this 'language', equivalent to aptitudes in the 'language' of science (numeracy) and the 'language' of humanities (literacy).*
>
> (Cross, 2007, p.17)

While designers will typically make use of several types of models in their process, their goal is the communication of a mature design proposal which will also manifest itself as one of the following models.

2.1.1.1. Descriptive Model

Descriptive models typically take the form of a verbal specification that represents a product concept during the early stages of development.

2.1.1.2. Mental Model

According to Ferguson, these internal representations of product concepts typically appear in the mind's eye of the designer (as cited in Cross, 2007, p.29).

2.1.1.3. Visual Model

For the purpose of this thesis, a visual model refers to a graphic or visual representation of a product concept. This type of model is typically created or represented with traditional media such as pencil and paper or more currently with pixels.

2.1.1.4. Physical Model

While many different sources use the terms prototype and model indiscriminately, for the purpose of this thesis, a prototype will refer to a physical model, which embodies one or many attributes of a product concept.

2.1.1.5. Digital Model

Digital models are mathematical representations of the physical properties of a product concept. These are more typically referred to as CAD models, and can take the form of surface geometry, solid parametric models, or simple two-dimensional plans.

The models mentioned above are listed in Figure 3 below.

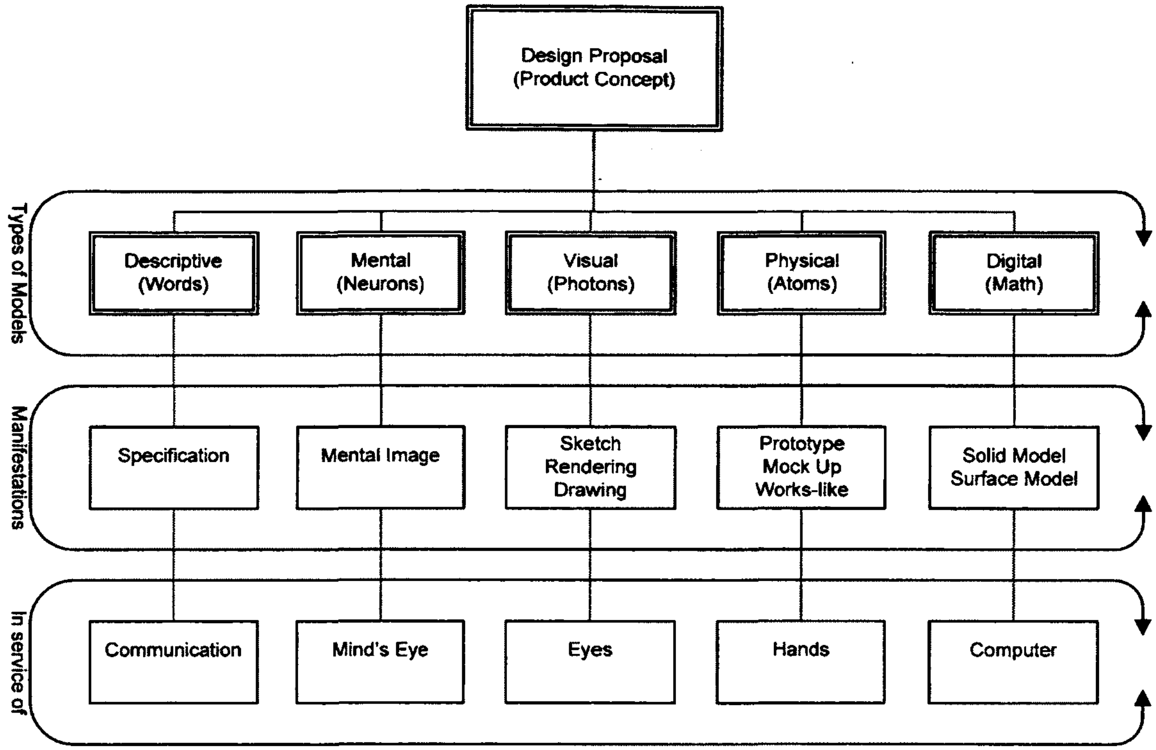


Figure 3 - Models Used by Designers

2.2. Labour

This section discusses the labour of industrial designers and studio furniture manufacturers, along with a discussion of craftsmanship. It explores the historical division between designing and making, gives examples of tools and techniques that are used by each, and finally surveys areas in which designing and making are merging.

2.2.1. The Nature of Craft Production, Craftsmanship, and the Craftsman

While occupational definitions for Industrial Designer and Cabinetmaker are readily available from government sources, the exact nature of what constitutes a craftsman is more elusive.

2.2.1.1. Craft Production

The term Craft Production was elucidated in terms of automobile production in The Machine that Changed the World (Womack, Jones, & Roos, 1990). An augmented definition for the characteristics of craft production as it pertains to studio furniture manufacturing is as follows:

- A work force that is highly skilled in design, machine operations, and assembly
- The use of general-purpose machine tools and / or hand tools to perform sawing, planing, drilling and other operations on wood
- A very low production volume – 1000 or fewer pieces of furniture a year, only a few of which are built to the same design

The first point illustrates the absence of a division of labour in craft production; workers are responsible for design, as well as manufacture and integration of a specific good. The second point allows the worker to use both hand tools and machine tools to complete operations on an object. These operations will be specific to the nature of the goods being manufactured. Specific operations and products in this definition can be altered to form a generic definition for craft production.

2.2.1.2. Craftsmanship

Craftsmanship is notoriously hard to define. Merriam-Webster merely adds craftsmanship as related to the term craftsman for which the definitions mention practicing a trade or handicraft as well as performing with skill and dexterity (Merriam-Webster, 2011b).

Craftsmanship has been defined as a set of standards (Crawford, 2009, p.6). The content of these standards requires further definition, but Crawford adds: "Craftsmanship means dwelling on a task for a long time and going deeply into it, because you want to get it right" (Crawford, 2009, p.20). More important than the implication that craftsmanship is the pursuit of correctness, is that it is "you", the craftsman who is in pursuit of it. In 'The Craftsman', Sennett defines a craftsman as someone who does good work for its own sake (Sennett, 2008, p.20). In that regard, craftsmanship is intrinsically motivated. While the drive toward craftsmanship is personal, the end result is not. Sennett recounts how ancient craftsman were addressed not by name but by their profession and that "a neurotic relation to your father" is no excuse for poor work (Sennett, 2008, p.27).

Pirsig offers "That is what caring really is, a feeling of identification with what one's doing. When one has this feeling then he also sees the inverse side of caring, Quality itself" (Pirsig, 2006, p. 381). Sennett proposes that "The craftsman represents the special human condition of being engaged" (Sennett, 2008, p.20). So, if craftsmanship is a standard to which one must adhere, the craftsman must be interested in his work.

Kritzer's "Toward a Theorization of Craft" puts forth three elements that are internal to the process of craft: craft has an aesthetic of skill, it involves a specific set of tools and techniques, and involves significant problem solving (Kritzer, 2007). In regards to craftsmanship, the requirement for skill is addressed. This skill is in the use of tools and techniques as well as problem solving, both of which are reflected in the work itself.

David Pye would prefer to dispense with the term 'Craftsman' and replace it with the term 'Workman', which "should imply the highest respect" (Pye, 1968, p.23). For Pye, workmanship is "the application of technique to making, by the exercise of care, judgment, and dexterity" (Pye, 1968, p. 21). His definition falls in alongside the others and reiterates dexterity, imbuing the activities with a sense of physicality.

From these passages, the following definition can be synthesized: Craftsmanship is a hallmark of the physical and mental skill, care, and attention that goes into the production of an object.

2.2.1.3. Craftsman

A craftsman will be defined in this thesis as someone who is engaged in craft production and whose work exhibits the values of craftsmanship.

2.2.2. The Division of Labour

Soule claims that it was the division of labour, not new machines that were symptomatic of the industrial revolution (Soule, 1956, p.33). Walsh states that design has been continuously growing apart from the production environment since before the widespread adoption of mass production (Walsh, 1996). Previous to mass production, material goods were the result of craft production in which the craftsman handled design activities as well as manufacturing and eventually sale of a particular good. Walsh offers that Wedgwood made use of the first separation between design and manufacturing by employing a master potter to create prototypes, which were in turn copied by other potters.

Notice that this 'industrial designer' was a master potter. His knowledge of the remainder of the process would have been unparalleled. By comparison, few of today's industrial designers would have useful experience in a particular manufacturing trade. Even fewer would hold the title of master. In a four year bachelor's degree, an industrial design student may only be exposed to a survey of the methods of manufacture. In their working careers, some designers may never be exposed to manufacturing because of a remoteness from the location of the design work. This ultimate division of labour removes the designer from many of the traditional activities in which such an individual would have would have participated previously. Berends, Reymen, Stultiëns & Peutz have determined through literature review that the number of design consultancies in the UK are rising (Berends, Reymen, Stultiëns, & Peutz, 2011). Industrial design consultancies offer design services for hire and in some cases, junior designers are tasked with envisioning new ideas with a focus on end user requirements, but not necessarily manufacturability. Industrial designers, while owing their profession to the division of labour, should be cognizant of their roots and purpose.

2.2.2.1. Prototyping vs. Production

One difference between studio furniture manufacturers and industrial designers is that production of the actual product lies with the studio furniture manufacturer whereas industrial designers may produce several prototypes that approximate the final product with high accuracy while leaving the production of the final product to someone else. New advances in technology that allow a designer to handle manufacturing duties are addressed below in a subsection titled Rapid Manufacture.

2.2.3. What Designers Do

The job of the industrial designer is the communication of a design proposal to another party, for which they have many different methods at their disposal. Pei et al. list twelve different types of visual model and five different varieties of physical model (Pei, Campbell, & Evans, 2011). The materials that allow for fast, easy and economical physical modelling are typically not the same materials used to manufacture a consumer product. While the designer may come infinitely close, the final products are created using mass production techniques. Instead of a final product, the drawings and prototypes of industrial designers are their final output. Those items are in turn used to commit to and create tooling (Pei et al., 2011), which can often be costly both in time and money (De Leeuw, 2002). It is this tooling, together with various assembly processes that will produce the final product.

2.2.3.1. Sketching and Drawing

The title of Mark Gross's paper 'The electronic cocktail napkin' describes how we normally think about sketching: informal drawings, thrown down hastily and often messily on what ever was handy during a moment of inspiration, e.g., a cocktail napkin. While slightly more formalized in nature, this is what lies at the heart of a designer's sketching activities. As expected, sketches have been recognized as the first visual models created by designers (Israel, Wiese, Mateescu, Zöllner, & Stark, 2009). Sketches have been described as the characteristic medium of design (Menezes & Lawson, 2006) and have been tied to creativity itself (Verstijnen, Vanleeuwen, Goldschmidt, Hamel, & Hennessey, 1998, p.520).

The creation of sketches is typically what happens during the conceptual design phase. This phase has also been called the 'generative phase' where the designer is "thinking with a pencil" (Cross, 2007). These sketches have been described as conversational, between the designer and the drawing according to Schön (as cited in Stones & Cassidy, 2010), or between the designer and herself according to Laseau (as cited in Stones & Cassidy, 2010). Jonson goes as far as saying that real ideation is a combination of visualization and verbalization (Jonson, 2005, p.621). The interaction between a designer and their drawing is arguably more important than the drawing itself (Menezes & Lawson, 2006).

Attempts to develop strict classifications for different sketches are becoming more mature (Company, Contero, Varley, Aleixos, & Naya, 2009; Pei et al., 2011). Company et al., have classified three different types of sketches: thinking sketches, talking sketches, and prescriptive sketches while Pei et al., have identified four distinct categories: personal sketches, shared sketches, persuasive sketches, and handover sketches.

Historically, sketching has belonged to the pen or pencil and paper. It is only recently with the interest in CAD integration that digital, or computer aided sketching (CAS) has been pursued (Fish & Scrivener, 1990). The integration of sketching and computers will be addressed below in Integration of Digital and Physical.

Three main attributes of sketching were elucidated by Fish and Scrivener: Sketches use a two dimensional system of signs to depict a three dimensional scene; sketches don't provide the whole picture; and finally, sketches are ambiguous (Fish & Scrivener, 1990). It is precisely this ambiguity that makes sketching a valuable tool and beneficial to creativity (Huang, 2008; Ibrahim & Rahimian, 2010; Israel et al., 2009; Pei et al., 2011).

To quote Buxton: "If you want to get the most out of a sketch, you need to leave big enough holes" (Buxton, 2007, p.115). One empirical study found that as sketching was added to design activities, design solutions improved in quality over design activities where no sketching was done (Schtüze, Sachse, & Römer, 2003). However, one study found that there was no difference between sketching and not sketching during the conceptual phase of design by three architects (Bilda, Gero, & Purcell, 2006). The researchers were quick to point out that these results do not transfer across all design disciplines or design phases.

Drawings are more formal than sketches and generally conform to a set of guidelines or rules (Pei et al., 2011). The work done by Pei et al. has identified scenario and storyboard, layout rendering, presentation rendering, and perspective drawing as belonging to the set of industrial design drawings. Typically, drawings are prepared with the purpose of communicating one or more aspects of a design to another party. They can include highly detailed technical blueprints or show the product in the context of its use.

Although typically created with traditional drawing media, sketches may be created in many other ways. Beside a host of pens, pencils, pastels and paints, this type of visual model may also be created as a software illustration or a series of photographs. Certain types of drawings lend themselves to a combination of media. A series of photographs may be taken of a user interacting with a dummy product. These photographs can then be traced or simplified and have the new product concept drawn in over top. This may be done with traditional media, digital media, or a combination of both.

2.2.3.2. Prototypes

Prototypes can take as many forms and serve as many different uses as visual models. In fact, some physical models are created solely for visual evaluation. Ullman identifies four major prototype categories in the product development cycle: 'Proof of concept', 'Proof of product', 'Proof of process' and 'Proof of production' (Ullman, 2002). Industrial designers are typically responsible for producing the first two, while the second two would be produced by methods of mass production.

A triangular model for the function of a prototype was developed by Houde and Hill at Apple Computer. At the vertices of the triangle are 'Implementation', 'Role', and finally 'Look and Feel' (Houde & Hill, 1997). Like other triangle models, a particular example is located in the triangle as a way to describe which attributes it takes on. A prototype can trend toward a vertex if it is for one use; or a side if it illustrates two facets of the design. Prototypes that approach the finished product typically move toward the centre of the diagram as they equally represent all aspects of the product.

Pei et al. describe a series of sixteen prototypes that serve various purposes for both industrial designers and design engineers. The list begins with "Sketch Models" which are described as low definition and ends with "Pre-Production Prototype" which are made with off-tool parts to test the actual product before volume production begins (Pei et al., 2011).

The important conclusion from these surveys is not the rigid categorization of a designer's prototyping activities, but the acknowledgement that there is an iterative process that begins in the conceptual phase of new product development; which has been called "The Fuzzy Front End" (Cagan & Vogel, 2002, p.110). These prototypes can start off as nothing more than a folded piece of paper or found objects held together with tape (Brown, 2009, p.90). From that point, prototypes become more refined and more specialized in order to address the myriad concerns of the industrial designer.

The reason prototypes are designed is to "answer questions" (Schrage, 1993, p.5). In regards to prototypes made for computer software, Alan Cooper states: "The value of a prototype is in the education it gives you…" (Cooper, 2004, §The Cost of Prototyping). Charles and Ray Eames created exploratory prototypes to refine their ideas which eventually took the furniture world by storm (Brown, 2009, p.88).

In spite of the current possibility of creating digital models at the expense of physical models, there appear to be no dissenting voices when discussing the value of traditional prototypes. Lemons et al. claim that model building can aid the evaluation of ideas and reveal flaws in early sketches (Lemons, Carberry, Swan, Jarvin, & Rogers, 2010), while Sener claims that physical modelling provides the only true way to resolve and evaluate the form of an object (Sener, 2007).

2.2.3.3. *Computer Aided Design*

While computer-aided designer (CAD) software has been around largely since the inception of the computer itself, it was not until the PC revolution that CAD software came into widespread use.

At its most fundamental level, CAD software allows a user to create a digital model of a product concept. This model can be created by drawing lines and surfaces with a mouse, or by entering parameters with a keyboard. As mentioned above, there are several types of digital models, each of which have creation methods more suited to specific natures. Two dimensional drawings can be easily entered with a mouse by drawing lines, just as one would with a pencil and ruler. Solid models typically require a more interactive process where two dimensional profile drawings are extruded or revolved into solid bodies. The software allows for secondary operations to be performed on these bodies in a way which mimics real world machining operations such as drilling and chamfering. These operations are organized in a feature tree, which details the build history of the particular solid. Surface models can be augmented with a mouse in a process similar to working with clay.

The input tools for CAD software have traditionally been the mouse and keyboard but new technologies are being created which allow a much more natural interaction with the software. These will be addressed below in the section titled Integration of Digital and Physical. The limitations of the mouse and keyboard are apparent in the face of the complexity of most CAD software. As more features are added to improve functionality, the basic operations of the software become difficult to use. Verstijnen et al.'s recommendations for CAD tools were that they be both "intuitive" and "helpful" (Verstijnen et al., 1998). Unfortunately, this is not always the case.

Richard Sennett's attack on CAD centers largely around what the software allows the user to skip; tasks essential to the design process can be easily or unknowingly circumvented. The drawing and re-drawing of architectural site plans that formerly helped to familiarize the architect with the site are automated in CAD. Likewise, the ability to change a drawing with ease causes the architect to consider each action less than they would on a traditional drawing done in pencil (Sennett, 2008, p.39-44). McCullough on the other hand believes that although CAD is another entry to the list of "workplace mechanizations", it is the perfect intersection of manufacturing three dimensional objects and computers (McCullough, 1998, p.198).

Nass and Moon have catalogued a series of four groups of studies that show that users frequently treat computers as humans and assign attribution to their behaviour (Nass & Moon, 2000). While we cannot assign blame to our tools, we must make sure that we are using them appropriately. Barry Jones states that technology "has an equal capacity for the enhancement or degradation of life, depending on how it is used" (as cited in Murphie & Potts, 2003, p.22). Buxton's corollary to the idea of technological neutrality is "Without informed design, technology is more likely to be bad than good"

(Buxton, 2007, §Moving to a Solution). The use of computers can become a very divisive topic.

As described above, the job of the industrial designer is both the creation and communication of a design proposal. They have several tools at their disposal for the creation and development of their ideas including sketching, drawing and the creation of prototypes. The methods used to communicate these ideas can be drawings, prototypes and digital models (CAD models).

2.2.4. What Studio Furniture Manufacturers Do

A studio furniture manufacturer's job is the design and creation of furniture and cabinetry in non-industrial settings. While each studio furniture manufacturer may have a particular specialty (chairs, tables, case goods, etc) their methods and tools are generally the same.

A discussion of handmade objects is not complete without mentioning Pye's position that possibly the only things that are truly hand made are pottery and woven baskets (Pye, 1968, p.10). As soon as a tool is being used, it becomes a very slippery slope to designate which tools are considered 'appropriate'. It is far easier to list the available tools than to pass judgment on which ones are considered proper.

2.2.4.1. Design Activities

Studio furniture manufacturers typically uses fewer prototypes (Rogowski, 2007) and drawings (Lowe, 2003) than an industrial designer. They typically avoid full scale prototypes made with accurate materials, akin to 'appearance models' made by designers, in favour of scale versions in authentic materials (Rogowski, 2007) and full scale prototypes in inexpensive materials (Allen, 1999). Allen suggests that accurate prototypes can be used as templates for production items. In much the same way that an accurate digital model can be use to generate tooling, and subsequently, production parts, a studio furniture manufacturer's physical prototype may be used to guide machinery performing operations on production materials.

However, the studio furniture manufacturer's creative process need not necessarily end with the preparation of a working drawing or a prototype; some are more creative with their tools in-hand (Christiana, 2005). This separates the design activities between the studio furniture manufacturer and the industrial designer; the drawings and prototypes of a studio furniture manufacturer act as guides; not as a concrete definition. In 'Zen and the Art of Motorcycle Maintenance', Pirsig states, "The craftsman isn't ever following a single line of instruction. He's making decisions as he goes along" (Pirsig, 2006, p209). One craftsman even recommends eschewing traditional full scale drawings (Stevens, 2000).

2.2.4.2. Production Activities

> *An expert carpenter or cabinet-maker will save much time that can be used to better advantage, and will lose nothing of artistic quality in his work, if he makes use of all the modern machines, for sawing, planing, boring, mortising, scraping, sandpapering, and otherwise preparing his material for use, instead of insisting that all these things be done by hand.*
> Gustav Stickley as cited in (McCullough, p.66, 1998)

In the studio furniture manufacturer's quest to turn rough sawn lumber or sheet material into furniture or cabinets, they have several basic operations at their disposal which are embodied by a multitude of different tools. Some of the most easily overlooked are those that aren't used to work the wood in any way; only to describe what should be done and where. Layout tools (see Figure 4 below) include but are not limited to marking gauges, rulers, combination squares, marking knives, sliding bevels and pencils.

Figure 4 - Layout Tools for Woodworking

As a general order of operations, a piece of rough lumber is cut to an approximate length using a saw. Traditionally this has been the work of a crosscut hand saw but is now more likely to be done by powered radial arm saw, or a mitre saw. The next operation is to flatten one face of the board. A series of hand planes of various lengths can be used for this operation (See Figure 5 below); a powered machine called a jointer is now the easiest way. After one long edge has been squared to the flat face (either by jointer or by hand plane), the board can be brought to the correct thickness either by hand planing the surface or with a machine called a thickness planer.

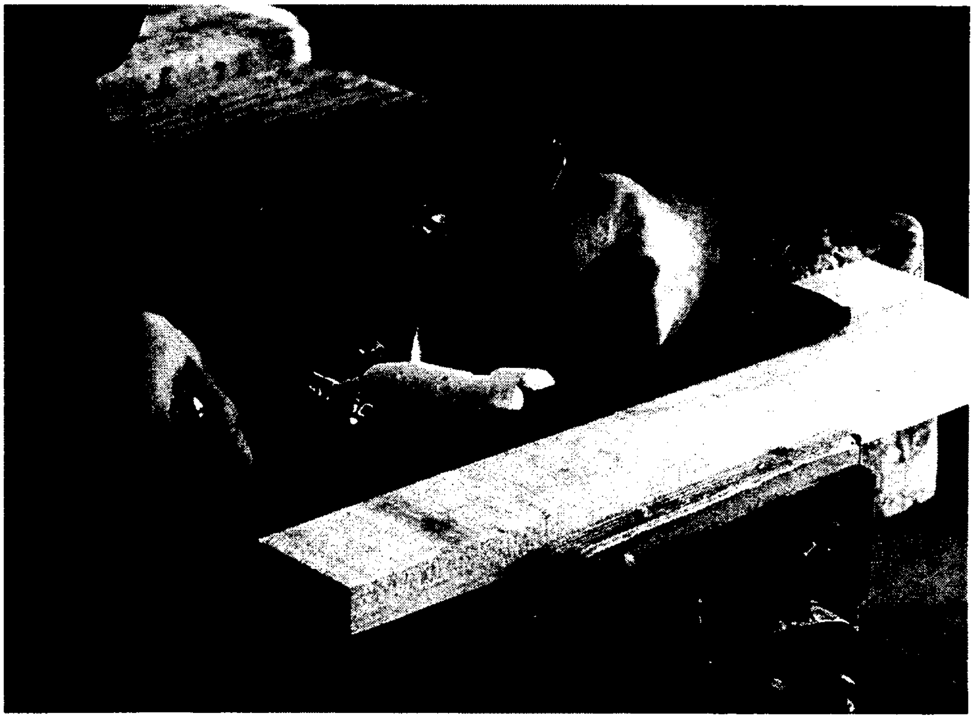


Figure 5 - Flattening a board with a metal fore plane

At this point, the operations on a single board can be quite divergent. A series of boards may be glued edge to edge to form a wider panel to serve as a door or a table top. The boards may also be glued face to face to create a turning blank that is then worked on a lathe. Hand tightened clamps typically hold boards together while glue is setting.

Subsequent changes to the width or length of a board can be made with hand saws or a table saw (machine). Curvilinear cuts can be made by hand with a jig saw or by machine with a band saw. Profiles can be added to board edges with a series of specialized hand planes or with a hand held powered router. Holes can be cut either with a powered drill or by using a hand powered bit brace. Joinery is typically tool dependent; the best way to cut dovetails is with a dovetail saw. Chisels take many shapes and sizes and serve dozens of uses. Due to their specialized nature and detail oriented domain, chisels generally do not have machine counterparts. Specialized chisels as well as rasps and files are used for sculptural or decorative elements (See Figure 6 below). In the finishing stages, sandpaper can be used directly in hand, attached to powered hand sanders, or found in large stand alone machines.

Figure 6 - Chisels and Rasps

This list is surely not exhaustive but provides a general overview of what is available. The reader should consult a book such as Collins Complete Woodworker's Manual (Jackson, 2005) for complete descriptions of all of the tools mentioned. Worth mentioning is that most woodworking machinery is simply a powered version of an operation done by hand.

2.2.5. The Unification of Labour

> *To design in a vacuum with the emphasis on expression would result in ill-thought-out products. For the most part, the stories in this book accentuate the collaborative way in which designers work with manufacturers and, above all, technicians and crafts people.*
>
> (Hudson, 2011, p.7)

One paper suggests that when a designer produces a one-off design, they become a 'craft-designer' (R. I. Campbell, Hague, Sener, & Wormald, 2003). Although the definition mentions that the input of 'handi-craft' is applied to the design and manufacture, it does not specify that the designer also has to be the maker. The writers go on to identify the 'artisan-designer' who uses advanced new technologies to create bespoke items for customers. Craftsman-Designer Mark Weinstock's leather bowls for example were the result of his familiarity with the material and days of experimentation (Isaac, 1998).

Pye's description of designers opens the floor to an entire spectrum of possible duties. He describes the designer as a decision maker who sets the content of drawings and specifications. In parentheses he notes that "The designer may of course also be the maker" (Pye, 1968, p.20). This implies that the individual's title is merely one of choice. The designer may finish their design work and don their maker hat, or the maker may have a specific hat that they wear during their design activities.

The concept of lean production is introduced in 'The Machine that Changed the World' (Womack et al., 1990). In simple terms, the authors describe lean production as a combination of the best aspects of both craft and mass production. This is not to say that in lean production the roles of the craftsman and the industrial designer have merged; only that their domains are starting to overlap.

2.2.5.1. *Studio Furniture Manufacturer*

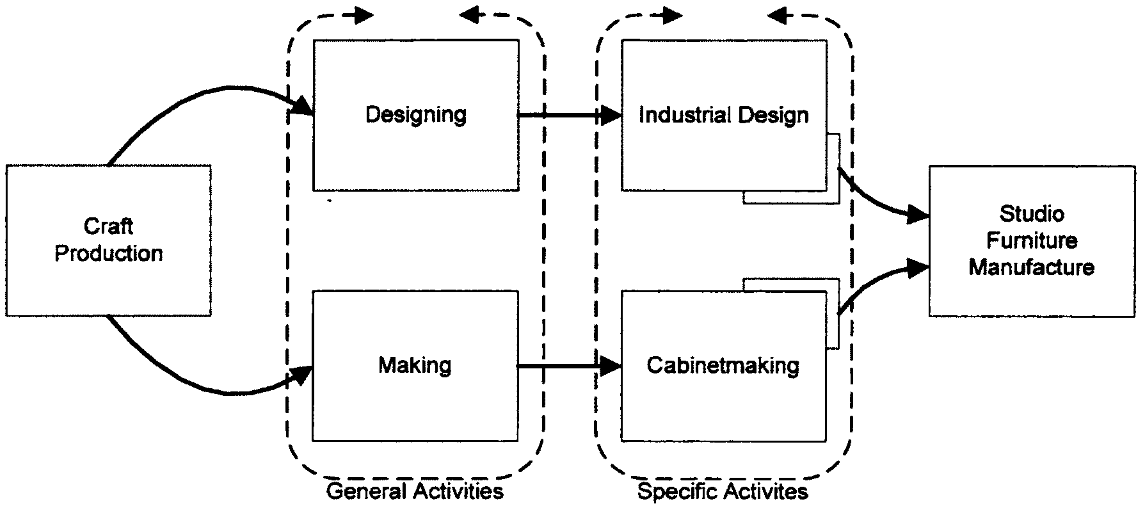


Figure 7 - Derivation of Studio Furniture Manufacturing

Self titled "Designer/maker" Michael Fortune has successfully bridged the gap between craftsmanship and design for industry. After completing a commission of 8 chairs for $3400 a piece, he revisited the design (Binzen, 2009; Kapsales, 2009). Fortune, whose style typically eschews right angle joints in favour of more artistic solutions requiring considerable woodworking skill, simplified the design so it could be manufactured with basic machines by semi-skilled labourers. The entire production process was parachuted into a Belizean community where the chair is now produced for $34. Fortune bridges the gap between craft and industry by not only being highly respected furniture designer but a well recognized craftsman as well. This combination of disciplines is what lies at the core of the studio furniture manufacturer. Rather than simply offering manufacturing and design to specification services, Fortune takes a boutique approach, where his design work and personal brand becomes part of the object's appeal.

2.2.5.2. *Do-It-Yourself Movement*

The Do It Yourself (DIY) movement, with publications such as 'Make' and 'Craft', has empowered an entire generation of people to invent and manufacturer their own material goods. While not specifically a political movement (Gschwandtner, 2008) it does take general aesthetic cues from anti-industrial and punk-rock sentiments (Green, 2008). The main difference between DIY culture and both craft and mass production is that its products are generally made for self consumption rather than for sale.

The concept of community also factors heavily into the DIY movement. Much like open source, "Open Design" involves a transparent sharing of plans and tutorials in an online community (Bonanni & Parkes, 2010). Fostering access to specialized machinery is also a goal of the open design community, but various companies have also turned manufacturing as a service into a viable business model. Shapeways offers the ability to "Buy, Make & Sell Your Products" by using rapid prototyping technologies (Shape Ways, 2011). A detailed discussion of the trend toward industrial designers as makers is found below in the section titled Rapid Manufacture.

2.2.6. Summary

Before the industrial revolution, the designer and the maker was the same person. Since then, industrial design has slowly been moving away from its roots in craft production and intimate knowledge of manufacturing. With no connection to a specific manufacturing process, there comes a risk of under-utilization of the latest technology available or the individual particularities of the facility (Kalay, 2006). The designer becomes disconnected from the downstream functions, and the craft origins of his or her job. However, new technologies and cultures have facilitated a reunification of designing and making.

The design activities of an industrial designer and a studio furniture manufacturer are quite similar in nature and only vary in scope. Studio furniture manufacturers like Michael Fortune maintain the design practices of an industrial designer and combine them with the technical knowledge and skill of a cabinetmaker, and the care and attention of a craftsman.

Lastly, a true knowledge of manufacturing and a hands-on design process can benefit the outputs of design. Books such as 'Shop Class as Soulcraft' and 'The Craftsman' attempt to illustrate the value of working with one's hands, not just in the sense of manual labour, but in the sense that through working with one's hands one becomes engaged in the task (Sennett, 2008). The hands are only the gateway to this engagement as soon the eyes, ears, nose and in some cases mouth are all occupied.

2.3. Innovation and Process

This section discusses innovation on several levels. The innovation of business production methods are explored first, followed by the innovations employed by industrial designers and studio furniture manufacturers in their design work. These innovative new methods have led to further innovations in how goods are actually produced and by whom. Lastly, a short section describes how these new methods hurt or help the act of producing innovative designs.

2.3.1. Business Requirements

Bower & Hout's 1988 article on fast-cycle capability illustrated the need for organizational speed to become successful. Following quickly after was the seminal 'The Machine that Changed the World' by Womack, Jones & Roos which detailed the concept of lean production. Since then, shorter development times for new products have been identified multiple times as one of the keys to profitability (Langerak, Griffin, & Hultink, 2010; Ali, Krapfel, & LaBahn, 1995).

One way to speed up product development times is to get multiple parties speaking the same language in regards to a particular design concept. Mathematics has been described as the universal language; apropos the lingua franca for design is the digital model.

Powerful CAD models utilizing solid modeling techniques can be used by designers, engineers, toolmakers, sales, and marketing divisions as they can be very true to the final object including parameters of weight, material density and exact visual representation (See Figure 8 below). Most importantly, they facilitate the movement of a design concept downstream (Monica Bordegoni & Cugini, 2005; Reed, Scanlan, Wills, & Halliday, 2011; Stark, Israel, & Wöhler, 2010; Ye et al., 2008).

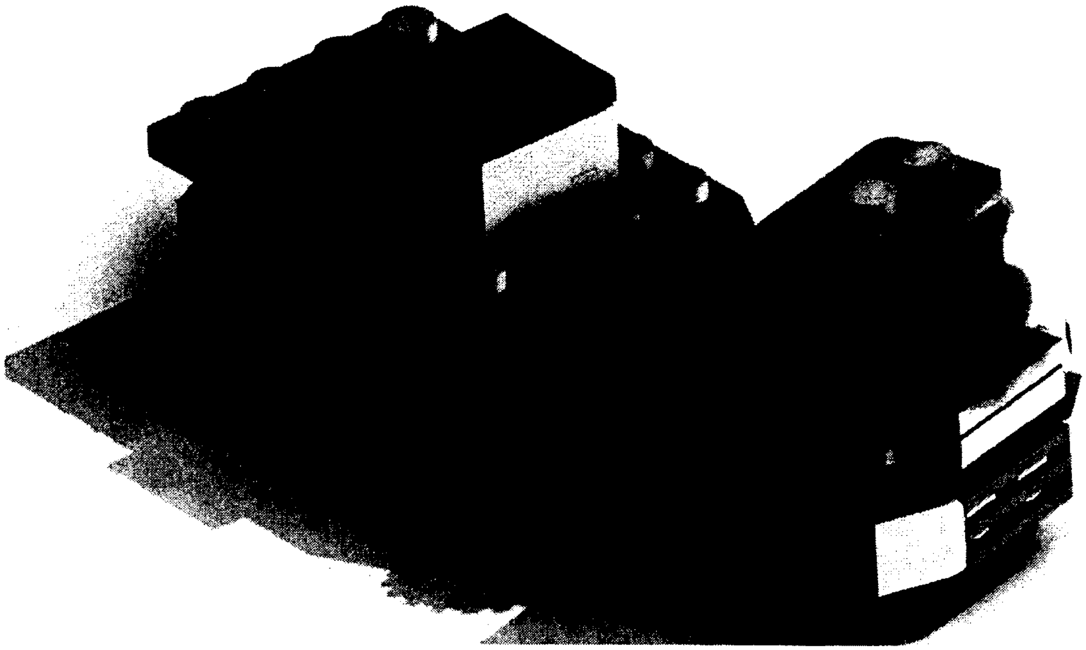


Figure 8 - CAD rendering from a solid model of a building toy

2.3.1.1. Looking Downstream

Evans reported that UK vacuum cleaner manufacturer Dyson, moved to master CAD model approach in 1996 (M. Evans, 2002). This allowed them to use a single CAD model to drive downstream processes such as manufacturing and the creation of documentation. In a display of its importance, two studies on the suitability of particular digital design tools mentioned specific short comings in their ability to facilitate downstream movement (R. I. Campbell et al., 2003; M Evans, Wallace, Cheshire, & Sener, 2005).

This movement is important to the process of new product development, but the job of the designer is not merely the creation of a CAD model. The designer must first have something of value to communicate. An exploration is found below of how the tools traditionally used by industrial designers to not only communicate, but to develop their ideas are being supplemented and supplanted by digital technology.

2.3.2. Integration of Digital and Physical

On a macro level, physical and digital tools are being integrated in what are referred to as a 'Virtual Guild' (Bonanni & Parkes, 2010). These online communities work to bring together open source software, CAD models, technical tutorials, and access to manufacturing tools to help support craft goods. A list of the ways in which physical and digital tools are being integrated at the practical level is as follows.

2.3.2.1. Sketching

In 1996, Mark Gross proposed the 'Electronic Cocktail Napkin" which was a digital environment specifically geared toward aiding conceptual design. The program allowed the user to create free form diagrams without being required to worry about the details. It was understood that initial stages of drawing must be unencumbered by the details of a regular CAD suite, but it must flow freely into that next stage (Gross, 1996). Since then, little has changed.

Coyne reveals that users of CAD thought that its emphasis was on the editing of drawings, rather than creation. It was that paradigm that prevented "radical rethinking" (Coyne, Park, & Wiszniewski, 2002). "Modifying" as an action was observed more frequently in digital design media than with traditional drawings (Bilda & Demirkan, 2003). However, current CAD systems have also been criticized for lacking "fluid and intuitive interaction" (Prats, Lim, Jowers, Garner, & Chase, 2009; Stark et al., 2010). A recent comparison of CAD and manual sketching tools produced a list of issues with current systems which include limited efficiency when dealing with the activities of conceptual design and requiring an unnecessarily high degree of skill in order to achieve satisfactory results (Ibrahim & Rahimian, 2010). CAD tools still appear to be plagued by a few key problems.

One CAD system has been created that provides a more intuitive sketching interface which is aimed at end users, rather than designers (Y. Igarashi & Igarashi, 2009). While this points in a positive direction for ease of use, the software is geared toward the design of plush toys and is relaxed in its treatment of form and dimensions. Any generic downstream functions would be severely limited.

Industrial designers still suffer problems with the lack of sketch functionality found in CAD software as evidenced by the volume of research that continues to be conducted. Cook and Agah's 2009 survey of sketch based 3D modelling techniques comes to several conclusions. One is that the ambiguity which fuels the design process is at odds with the goal of the computer software to resolve it. Another is that while a sketch-based interface is ultimately supposed to support the designer's current abilities, specific drawing techniques have to be avoided in order to work with the system.

The research done on sketching does appear to be bearing fruit. Prats et al. developed a language of shape transformation rules with the intent of informing sketching functionality in future CAD software (2009). As well, Cook and Agah predict that future systems will allow the user to work in a more natural style, rather than having to conform to the requirements of the software (2009). Tian et al demonstrated software that allows a digital freehand sketch to be interpreted as three-dimensional geometry which can then be subjected to mechanical analysis (Tian, Masry, & Lipson, 2009). In a 2011 study it was shown that a digital sketching environment that emulated a traditional sketching environment facilitated similar results and allowed for distributed collaboration (Tang, Lee, & Gero, 2011).

2.3.2.2. Prototyping

It is important to note that digital models are mere analogues of physical prototypes. Their relationship is similar to the one between an audio recording of a musician playing an instrument (regardless of the digital or analog format) and the actual performance. In both cases, something is lost between the real thing and the reproduction. The fidelity of the digital model to a physical prototype is limited by the features and options in the software used to create the model. A designer may find themself at a loss when attempting to create a digital model that is simply not allowed by their software of choice. In this regard, the need to pair a digital and a physical model becomes apparent.

While pushing forward toward ever greater use of digital design tools right through to digital manufacture, some wonder about the impact of losing the physical model (R. I. Campbell et al., 2003; Charlesworth, 2007; Bahar Sener, 2007). To this end, three ways have been identified in which physical modelling has been integrated with digital modelling. First, haptic technology allows a designer to use a touch sensitive hardware interface to 'feel' a digital model. These interfaces can be used to simply interact with a digital model, or to represent traditional physical prototyping media which provides the ability to shape a model inside of computer software. Second, 3D scanning technology allows traditional physical prototypes to be scanned into digital models automatically by special hardware and software. Third, rapid prototyping technology allows for certain digital models (solid and surface models) to be printed out into physical models by one of several processes. Each of these three methods of integrating physical and digital models is discussed in turn below.

2.3.2.2.1. Haptics

CAD modelling, when used as a replacement for physical modelling, can short-circuit many of the additional reasons for creating physical models. While the form can be defined parametrically for downstream processes, the designer loses a sense of the volume, balance, weight, grip comfort and surface texture. The designer also loses the ability to interact with the final material itself (if that also happens to be the modelling material) and misses the opportunity to gain insights into any particular restrictions or advantages that comes with it.

In a study of haptic modelling, an exercise in creating a perfume bottle revealed that while the process paid no respect to the eventual materials of manufacture, it did allow the designer to get a more realistic sense of the textures involved (R. I. Campbell et al., 2003, p.29). With the haptic interface, the designer was able to feel the difference in texture across the face of the designed bottle. The parametric model was subsequently used to print the model (see the section on Rapid Prototyping below) so that the texture could be evaluated in a more traditional method as well.

Many modelling solutions have been created by way of haptic interfaces. Bordegoni et al. have created two separate digital modelling solutions; one for model creation and another for ergonomic verification (M Bordegoni, Colombo, & Formentini, 2006). While this effort does capture two of the uses for physical models, they do have their limitations. The model creation interface is based around the practice of clay modelling. While this is a popular physical modelling medium, it is limited to only this medium, and the methods associated with it. The ergonomic verification interface is quite involved and requires that a head mounted display, tracking cameras, and force feedback interface be connected to a computer in order to test a model that would have to have been previously generated in CAD software.

More quantifiable benefits to haptic interfaces have been demonstrated recently. Rahimian and Ibrahim's study of architects using a sketch-based haptic environment does show increased collaboration and an increased problem finding ability (Rahimian &

Ibrahim, 2011). The authors acknowledge that this is not an end, but the research should be used to further develop virtual design environments.

2.3.2.2.2. 3D Scanning

One promising area of research is the Reverse Innovative Design (RID) design methodology formalized by Ye et al. (2008). Using 3D scanning techniques, a designer is able to transfer a physical model into the digital domain to facilitate further modification and downstream activities. The system is currently able to interpret physical models and transfer them into several types of digital models depending on which downstream activity is required. While the system does appear to bridge the gap between physical and digital, the authors admit shortcomings in highly stylized objects and soft goods.

2.3.2.2.3. Rapid Prototyping

In 1986 the first rapid prototyping system 'printed' a solid model from CAD geometry. This integration of the physical and the digital has been quite successful as no less than five separate processes currently exist which allow a multitude of materials to be used including many plastics, paper and even metal. One unfortunate caveat to these processes is that they all have CAD software as a gateway. A designer must still spend time putting his or her model into the software before they can extract it from a rapid prototyping process.

One important concern being voiced is the cost of RP models. In comparison to traditional sketch models, the difference in cost and labour and equipment is substantial (Anne Römer, Pache, & Lindemann, 2001). This time intensive task is not ideal for early prototypes which should be "fast, rough & cheap" (Brown, 2009, p.90). Frederick Brooks is quoted by Cooper as saying "Plan to throw one [prototype] away" (Cooper, 2004, §The Cost of Prototyping), which can be difficult. When CAD models are used to prepare physical RP models, that particular form and the effort expended to produce it are often difficult to discard (Anne Römer et al., 2001).

2.3.2.3. Computer Driven Tools

2.3.2.3.1. Rapid Manufacture

The next logical steps as rapid prototyping systems evolve both in range of materials and robustness of prototypes are toward the rapid manufacture (RM) of parts. One study, although concluding that the technology is not currently ready, studied the feasibility of using RP technology for the creation of facial prosthetics.

Several companies are already employing rapid manufacturing as a business opportunity. Paramount Product Development Specialists (www.paramountind.com) offers not only product design services, but rapid tooling and rapid manufacturing services. The company lists several aerospace companies as clients of its rapid manufacturing service, showing that RM parts are receiving major attention. EnvisionTEC (www.envisiontec.de) is a producer of machines which produce shells for hearing aids. These machines use standard rapid prototyping technology to produce parts which go into service themselves, rather than act as prototypes for final parts produced using other methods.

As mentioned above Shape Ways allows users to upload digital models and have their designs created in several types of plastic like nylon or ABS, as well as sterling silver or stainless steel. Users can then sell their designed objects to others with a markup in order to create a profit for themselves. This level of technological and logistical maturity now allows for what Campbell et al. called "The Bespoke Designer" (R. I. Campbell et al., 2003); a report concerning this "Materialization of Digital Information" has even come out of the University of Toronto (Ratto & Ree, 2010).

One of the featured designs in Hudson's compendium of design processes is Lionel Dean's Entropia light. The light is not only manufactured by, but also designed specifically to be manufactured with rapid prototyping machines (Hudson, 2011). Previously, manufactured goods only became profitable if manufactured and sold in large quantities to offset the high cost of tooling and development. With the ability of rapid prototyping to dispense with the need for tooling, and the ability of a single designer to bring a product to fruition, one wonders if the previous overseas exodus of manufacturing might be reversed.

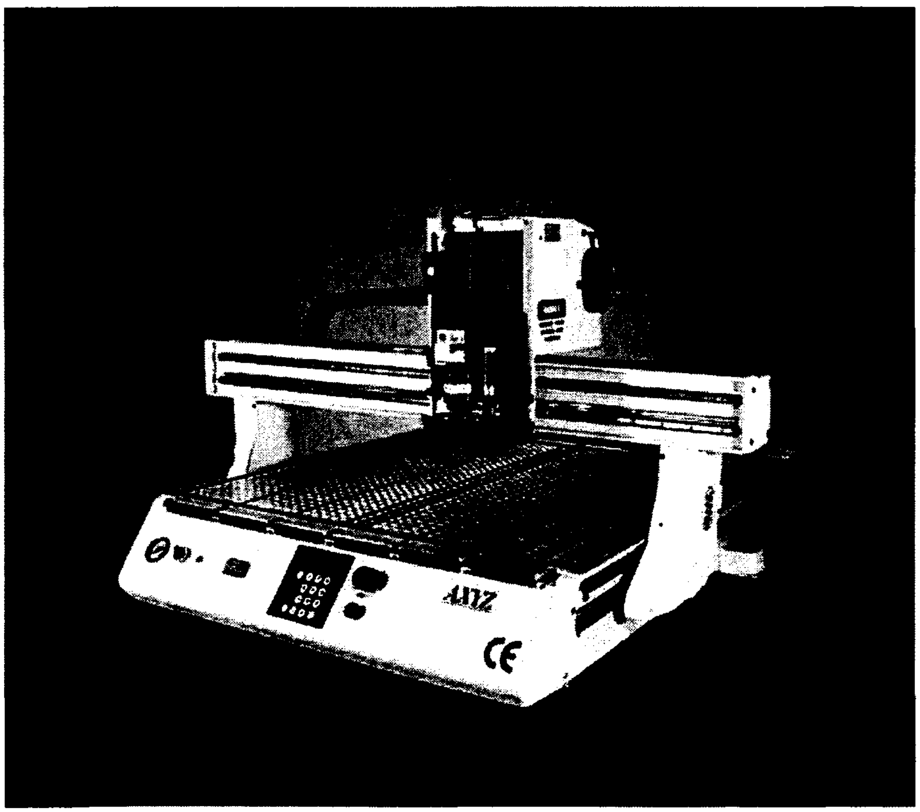
2.3.2.3.2. Computer Numerical Control (CNC)

> *It must be emphasized that the design of the manufacturing application package is closely tied to the nature of the actual manufacturing process envisioned as well as the material nature of the artifact itself. Creation of a good digital manufacturing application model fundamentally requires that the user be completely familiar with the manufacturing process itself. Typical CAM software is not a replacement for knowledge of the process involved and related constraints that surround it.*
>
> (Schodek, D. et al., 2005, p.14)

Before the use of rapid prototyping as a production method, computer numerically controlled (CNC) machinery was the only way to turn a parametric model into a physical model. CAD software together with a CNC machine is typically referred to as Computer Aided Manufacturing (CAM). Initially, CNC machines were created by retrofitting standard machine tools with servo driven controls and linking these to a computer interface. CNC machinery has evolved past that stage to machines that lack any sort of physical interface to control operations, yet when running, can move a tool in relation to the work in 5 axes.

The limiting factor of these machines is that they only work in a subtractive nature, that is, they use a tool to remove material from a blank, in much the same way that a statue is carved from stone. Rapid prototyping processes use an additive process to add material to a blank canvas. This eliminates certain geometrical limitations that are faced in subtractive processes.

The use of CNC machining in the world of woodworking draws opinions from several corners. Two important factors should be considered first. The first is that, unlike most machine tools which are essentially powered versions of traditional hand tools, there is no traditional ancestor for the way in which CNC machines work with wood. In terms of a 3 axis milling machine (See Figure 9 below) a router bit cuts successive profiles of a shape into the work piece, moving incrementally over the entire piece until it is finished. This may be done in several stages consisting of rough passes and fine passes with a tool change in between.



(AXYZ International, 2011)

Figure 9 - 3 Axis CNC Router

Exceptions to this are when a CNC machine is used to cut two dimensional profiles into flat material or when the CNC machine is a lathe. In the first case, this operation is akin to work done on a band saw, typically for generating templates to be used later. In the second case, the lathe has a long history both as a human powered device and as a machine tool. The ability of a woodworker to turn a piece by following a template is easily extended to CNC machinery. These two exceptions are covered by the next point.

The second main factor worth noting is that once the work piece is secured in a CNC machine and the cycle begins, the machine typically runs to completion without human intervention. This point is the one that drives the philosophical debate.

McCullough's definition of a tool is "a moving entity whose use is initiated and actively guided by a human being, for whom it acts as an extension, toward a specific purpose" (McCullough, 1998, p.68). This is quickly backed up with an assertion that it is participation that determines what is and is not craft. Although the creation of the idea, and the parametric model required the participation of a human, the creation of the part almost certainly did not.

David Pye's treatment of this topic is described by two phrases: "The workmanship of risk" and "The workmanship of certainty" (Pye, 1968, p.7). He gives examples of what constitutes both but the true impact of these terms becomes clear as he defines the difference between them:

> *An operative, applying the workmanship of certainty, cannot spoil the job. A workman using the workmanship of risk assisted by no matter what machine-tools and jigs, can do so at almost any minute. That is the essential difference. The risk is real.*
>
> (Pye, 1968, p.9)

CNC machines have the ability to do many tasks with ease, such as the creation of long, graceful curves, or the carving of a perfect ball and claw foot. The creation of parametric models and correct machine setups are by no means an easy short cut. These machines have the ability to create multiple identical copies of an object, and spare the operator the risk of personal injury by avoiding the necessity for close proximity to machine tools. However, for all of their benefits, CNC machines may never find widespread acceptance because of a belief that the workmanship of risk, which it circumvents, was the source of value for the finished piece of work.

2.3.3. Digital Tools and Innovation

One reason for the adoption of digital design tools is the perceived benefit to the generation of innovative ideas. The claim that digital tools somehow foster creativity and innovative thinking needs to be examined closely.

There is no doubt that digital tools themselves are innovative. They present a radically new way of designing objects which confers many benefits upon those who use them. But they may be used to short cut the truly beneficial activities which were the generators of innovation. While making no claims about the nature of prototypes, Schrage claims that it is the "emerging sequence of prototypes [that drives] the innovation process" (Schrage, 1993, p.9). As mentioned above, digital models and physical prototypes can be hard to alter or redefine because of an attachment to the time and money spent on their generation.

One recent study shows that physical prototyping can lead to less fixation during design activities (Youmans, 2011). Yang agrees that while generating a digital model with CAD software can yield significant information, it will be different information than that gained from the preparation of a physical model (M. C. Yang, 2005, p.650). Even for something as complex and costly to develop as a new car, the traditional methods of full scale mockups in clay still stand. The clay models being used by auto manufacturers are being supplemented by technology, but the transition to a completely digital process would produce mixed results (Stein, 2001) and be cost prohibitive (Kisiel, 2002).

The use of digital design technology mirrors Cagan and Vogel's "parachuting" metaphor (Cagan & Vogel, 2002, p.4). Companies often treat a particular technology as an end unto itself and create a product around it, typically ignoring the fuzzy front end of the product development. These products typically fail because the company neglects to determine what the customer was truly after. In much the same way, companies tend to treat digital methods as ends rather than a means to an end.

2.3.4. Summary

In an attempt to capture more market share or command higher profits, businesses are turning toward digital tools. The adoption of CAD allows designers to more easily communicate with team members further along in the product development process. While allowing designers to bypass physical processes, certain digital tools actually facilitate the creation and use of prototypes. Computer driven production tools allow for one continuous stream in the production process. Businesses must be aware that although they are adopting innovative tools, these are not guaranteed to generate innovative or desirable products.

2.4. Education & Culture

> *It is all too easy to believe that the objects of desire with which we surround ourselves are virtually produced overnight: the consumer and aspiring young designer are given little idea of the complexities, trials and tribulations that have gone into their creation.*
>
> (Hudson, 2011, p.7)

2.4.1. Education of Designers

In a 2011 essay, Ragland (citing Fiell & Fiell, 2006, and Julier, 1997) claims that when Walter Gropius founded the Bauhaus school, one of his intentions was to reconcile the values of craft with the profitability of mass production (Ragland, 2011). Since then, many of the values of craft have fallen by the wayside in design education. In the UK, there has been a recommendation to shift students away from fine arts into more applied programs like industrial design (Queensberry, 2009). In these programs, there has been an additional shift in the focus of their education.

Modelling education is currently in a state of flux, with some who would recommend moving toward the use of all digital sketching and modelling tools (Yang, 2005). Charlesworth's analyses of Lawson's 'How Designers Think' paints a sunnier portrait for the fate of physical prototyping (Charlesworth, 2007). He states that upon its second edition, Lawson added a section on computer based tools. The third edition however contained a new section on a sketching with a pencil and paper. The results of Charlesworth's own study of undergraduate designers found that computer tools and digital models were of no value in the early stages of a design project. More recently, Aldoy and Evans' study of graduating industrial designers show that while digital tools are seen as valuable, the majority of students would not like to see them replace current physical sketching and modelling techniques (Aldoy & Evans, 2011). McCullough reminds us that "the mastery of craft involves spatial dexterity, and that form giving is inherently a three-dimensional process" (McCullough, 1998, p.129).

2.4.2. Education of Cabinetmakers

Unlike certain trades (Hair Stylist, Electrician, Plumber), cabinetmaker, and subsequently studio furniture manufacturer, is not an occupation that is regulated by the Federal or Provincial governments (Government of Alberta, 2009; Government of Canada, 2010; Government of Ontario, 2009). Any person is free to begin working as and calling themselves a cabinetmaker. Alternatively, every person working in a licensed trade must have a Certificate of Qualification, or be registered as an apprentice. Trade guilds have historically been protective of their trades and advocates for the apprenticeship system. Oscar Ameringer recalls a meeting between guild masters at his father's cabinetry shop circa 1885: "There ought to be laws to forbid people who had not served their time as apprentices, and journeymen, and made their masterpieces, from plying their particular trades" (Ameringer, 1940, p.38). Apprenticeship involves on-the job-training as well as a classroom component. After trade specific requirements are met at work and in the classroom, apprentices are allowed to challenge the examination to obtain their certification.

Due to this lack of certification, the companies that service the cabinetry trade such as tool manufacturers, material suppliers and others, have no guaranteed inroad into the new generation of cabinetmakers. The licensing of the cabinetry trade would be difficult however as woodworking takes many forms. Commercial cabinetry, studio furniture manufacture, millwork, turning, and many forms of artistic woodworking would need to be considered. Many people treat woodworking as a hobby and have little more training than what they learned in high school. In that regard, magazines that cater to the hobbyist or semi-professional woodworker can provide the education required to get started in the trade.

While it is a good start, education alone will not ensure that digital design and manufacturing becomes commonplace or even visible in Canada. As shown by the International Labour Organization, Canada has given a head start to her competitors. When asked in 1985 what measures had been taken to improve the quality of training of managers and workers the responses came: "From the Federal Republic of Germany, the employers' organization states that the decrees regulating training are renewed every three years so that curricula are regularly updated" (International Labour Organization, 1985, p.106) and "The Government of Canada states that no such measures have been taken" (International Labour Organization, 1985, p.105).

2.4.3. Design as Culture

Adorno and Horkheimer (as cited in Murphie & Potts, p.24, 2003) speculated that culture is manufactured and part of an administered system. Although this view sounds quite cynical, Cross identifies 'material culture' as the world of manufactured objects in which designers can read and write (Cross, 2007). Brian Eno's definition of culture encapsulates "everything we do not have to do" (as cited by Murphie & Potts, 2003, p.9). His examples start with "we have to eat, but we do not have to have 'cuisines'". The works of a furniture designer can fall precisely into this category, not because of any inherent lack of necessity for them, but simply because many of the basic necessities have been worked out long ago.

These products of design can however be reflections of a particular culture. One often refers to Scandinavian Design or Italian Design. Presumably at one point the designs of a nation reflected some particular aspect of its culture until such point that the designs themselves became part of the culture e.g., Italian leather goods or German automobiles. Gotlieb and Golden follow the culture of Canadian studio manufacturers from the 1930s to the present, noting all of the educational, governmental, organizational and cultural influences that have shaped it. While each product may reflect a certain aspect of Canadian culture, either aesthetically or through use, the actual design and manner in which they are produced is also symbolic of Canadian culture. Craft's role as a vehicle for culture is undeniable. Birgitte Jahn says:

> *Craft is one of the oldest ways of expressing the cultural identity of human beings. Craft tells us about the human experience, around the world it is the witness to how life is lived.*
>
> (as cited in Nelson, 2004, p.223)

2.4.4. Work Culture

> *The common practice that a particular technology represents, in addition to leading to an identification with culture and gender, can also lead to the "right" of the practitioners to an exclusive practice of the technology.*
>
> (Franklin, 1990, p.17)

As industrial design comes under the microscope of design research, it begins to experience an identity crisis as scholars attempt to pick it apart and determine its nature. It also faces pressure as demands for more throughput causes a higher degree of specialization and a narrowing of the scope of what a designer actually does. This is exacerbated by new manufacturing technologies in which any person can become their own designer and maker. Designers must be wary of another division of labour which will end in the subsequent de-skilling of their profession. They should remember that there is joy in the doing.

Kritzer's work on theorizing craft (in order to separate it from other activities) reveals a dichotomy in the elements of its composition; there is an internal side and an external side (Kritzer, 2007). The external side of craft consists of three visible elements:

craftwork is done for someone else (client), the products of craft have utility, and there is consistency across multiple copies of an object. The internal side of craft consists of three elements that are imbedded in the process: there is an aesthetic that reflects the skill of the work which is generally invisible to those outside the craft; there are a definable set of skills and techniques that go into the production of a product, the creation of an object involves significant problem solving.

> *One has to keep in mind how much the technology of doing something defines the activity itself and by doing so, precludes the emergence of other ways of doing "it", whatever "it" might be.*
>
> (Franklin, 1990, p.9)

This internal side of craft is specifically what makes the craft culture not only difficult to open up and explore, but to change. The sentiment that machinery can help craft has been around for decades (Bach, 1937; McCullough, 1998, p.65; Nelson, 2004, p.223). Some members of the community, for a multitude of reasons are still apprehensive. Pirsig says that technology suffers from a disconnect between the spirit and heart and unfortunately gets blamed for any accidental wrong doings (Pirsig, 2006, p. 211). As mentioned above, the real issue of guidance and participation in the workings of advanced technology may never be overcome.

2.4.5. Summary

Industrial designers and studio furniture manufacturers both face cultural barriers to the full expression of their respective disciplines. One culture prevents the move forward to embrace new tools, while the other forces new tools onto the participants that should be tempered with traditional methods. While changes to the culture surrounding both disciplines need to be challenged, the educational paths of the industrial designer need to be reviewed carefully to avoid discarding important lessons.

2.5. Literature Review Summary

This section has covered some basic definitions for the subjects of study. The work of both industrial designers and studio furniture manufacturers has been described, including both unique and shared attributes. A framework for discussion of modelling was introduced as well as concepts surrounding craftsmanship. Descriptions of business requirements for digital tools were made as well as counter arguments for their adoption. Finally, educational aspects of both disciplines were surveyed.

While some work has been done, designers still face economic pressures, a separation from manufacturing activities, and lack a clear educational direction on the value of physical modelling. In order to address these concerns, designers must be reacquainted with the craft roots of their profession in order to understand the value of working with their hands and to maintain their importance within the larger scale of product development.

CHAPTER

3. METHODS

In a quest for reduced development times of new products, industrial designers are facing new divisions in their work activities and pressure to use digital tools as a part of their design process. This division and sometimes blind adoption of digital tools is causing industrial designers to lose touch with the craft origins of their job, their connection to manufacturing, and physical prototyping methods. These problems were framed via the following questions:

What can be learned about the appropriate use of digital design methods by studying studio furniture makers?

What does being intimately connected to the manufacturing process do for the design of an object?

This qualitative study explored when digital design tools are appropriate, physical prototyping, and the intimate relationship with the manufacturing process experienced by studio furniture manufacturers. Interviews were conducted with producers of studio furniture in order to collect data on the nature of craftsmanship, workflow, process, design methods and use of digital design technology. These interviews were transcribed, coded and organized into the three thematic areas discussed in the literature review.

3.1. Sample

The sampling procedure used in this study was purposive sampling. The chosen sample for this study was those individuals which fit the description of a studio manufacturer, specifically those whose product is wooden furniture. The reasons behind studying studio manufacturers to inform the field of industrial design are as follows.

According to the definition given in 'Design in Canada' (Gotlieb & Golden, 2005) studio [furniture] manufacturers are typically industrial designers or architects who handle their own small scale production. While there is no particular requirement for the studio manufacturer to be either an industrial designer or an architect, they have a greater interest and focus on design than a cabinetmaker. A studio furniture manufacturer is not merely executing the physical creation of an object, but is also responsible for its design.

Studio manufacturers, for the purpose of this thesis, are seen as an idealized sub-culture of designers. In comparing industrial designers with studio manufacturers several things are apparent. A studio manufacturer's use of digital tools is not for the facilitation of downstream movement in the production cycle. As such, their use of any digital tools will generally be by choice. While they are not focused on communicating downstream, they are intimately concerned with manufacturing and production. They have no ability to "toss it over the wall" and let someone else worry about manufacturing; they must fix their own mistakes. This mimics the pre-industrial revolution relationship of design to craft where the designer was also the maker. A studio furniture manufacturer is not only selling a design, they are selling craftsmanship.

Finally, studio manufacturers are more apt to be purveyors of a cultural identity through their products. The smaller production numbers of their products allows more character to come through in the design rather than having to strip it away for a mass market.

3.2. Participants

The participants in this study consisted of seven people who had the following demographics:

Table 1. Participant Biographical Information

ID	Age	Gender	Education	Training or Experience
Mr. Green	45-55	Male	College – Fine Arts	25 years
Ms. Tan	50-60	Female	University - Engineering	Rosewood Studios Internship with Michael Fortune
Mr. Blue	30-40	Male	University - Science	Rosewood Studios
Mr. Teal	40-50	Male	Some University	25 years
Mr. Orange	40-50	Male	Some University Some College	15 years
Mr. Brown	45-55	Male	None	20 years
Mr. Plum	60-70	Male	R. C. A.	40 years

Participants are identified only by a randomly assigned colour name in order to ensure the anonymity of their responses. One thing common to the participants is that the design and manufacture of studio furniture was their primary source of income. Hobbyists or woodworking students were not consulted for this study. The scope was limited to furniture makers with sufficient experience to immerse them in the field. Participants were also Canadian citizens, although several were born or had studied abroad.

3.3. Materials and Measurement Instruments

3.3.1. Justification

Bryman states "the qualitative researcher embarks on a journey of discovery, rather than one of verification" (as cited in Goulding, 2002, p.16). This quote identifies with the goal of this thesis, to discover what is the appropriate use of digital design tools by industrial designers rather than the testing of a particular hypothesis. The quotation comes from Goulding's treatment of Glasser and Strauss's Grounded Theory.

Glaser and Strauss published The Discovery of Grounded Theory (1967) as a manual for their method of "comparative analysis" (Glaser & Strauss, 1967). Grounded theory allows for theories of social interaction to be arrived at through analysis of data, rather than the testing of an ad hoc hypothesis through gathered data. Goulding's work, Grounded Theory: A Practical Guide for Management, Business and Market Researchers (2002) offers methodological suggestions for this research (Goulding, 2002).

Goulding suggests that the researcher bring a disciplinary background to the research to provide perspective. While not having a career in either, this researcher has diplomas in Furniture Making and Commercial Cabinetry as well as Computer Science, has undergraduate experience in Industrial Design, and has worked in all three fields.

For the actual data gathering methodology, a "face to face semi-structured opened ended ethnographic in-depth conversational interview" is the method of choice for grounded theory (Goulding, 2002, p.59). It was recommended that these interviews be transcribed in full until the recurrent themes presented themselves. The last important aspect is the simultaneous collection and analysis of data. See Interview Questions in Appendix D for a copy of the base line questions used in the interview.

3.3.2. Validity and Reliability

In order to improve the validity of the study, a pilot study was run. Subjects chosen for the pilot study were two woodworkers, working as shop technicians in university wood shops. Both had previous careers as woodworkers outside of academic settings. Initial interviews were conducted in order to test the list of questions for adequate topic coverage and to understand how the questions would be answered. The list of Initial Interview Questions can be found in Appendix E.

Two interviews were conducted and the questions were expanded to include topics that were illuminated during the interview. The final set of interview questions can be found in Appendix D. The interview protocol was refined and formalized.

The pilot study allowed the interview questions to probe deeper by providing time for reflection on initial interviews. Questions such as "what should have been asked" and "what else would be valuable to know" were posed against the results of the interviews. The answers to these questions were then worked into the list of interview questions.

3.4. Data Collection / Procedures

These interviews took place across Canada from Vancouver BC to Ottawa ON between January 2010 and November 2010. Interviews were conducted by phone or in person, at the request of the participant. One interview took place at the studio of the individual, while another took place in a café. One participant preferred to answer the questions through email. Participants were contacted initially to make arrangements, and subsequently, interviews were conducted using the Interview Protocol found in Appendix B. This included being given the Informed Consent form in Appendix A. These interviews were audio recorded for accuracy and field notes were taken with pen and paper. Interviews typically lasted one hour. For the seventh interview, the participant was sent the list of questions, and responded via email. The list of Interview Questions for all participants can be found in Appendix D. Upon completion, participants were provided with a written Debriefing form, found in Appendix C.

Afterward, the recording was transcribed to a written account of the interview. For the initial interviews, these transcriptions were done verbatim, recording every word that was spoken during the conversation. As the count of interviews grew, the verbatim transcription was dropped in favour of a thematic transcription. For the thematic transcriptions, the recording was auditioned and the main points as well as the general feel of the answer were recorded.

3.5. Data Analysis

The sample population, instruments and procedures mentioned above were used to gather qualitative data concerning the opinions and practices of the participants. However, this research began as an inquiry into the use of digital manufacturing processes (CNC) by woodworkers. Initially it was constructed around the hypothesis that woodworkers were stuck in a rut of using traditional methods of manufacturing and not embracing digital tools, particularly, CNC machinery. As such, the data has undergone two separate analyses, the second of which was a result of the first.

3.5.1. Primary Analysis

As a method of analysis, Cultural Historical Activity Theory was used. Activity Theory, as it is more commonly known today, is not a theory, but a lens used to organize and study human behaviour. At its core is the concept of artefact mediation; that we, "the subject", do not operate directly on an object. Instead, the interaction is mediated through the use of tools or "instruments" with the end goal of producing a desirable outcome. These relationships are typically represented graphically, as in Figure 10 below (Kuutti, 1996, p.28).

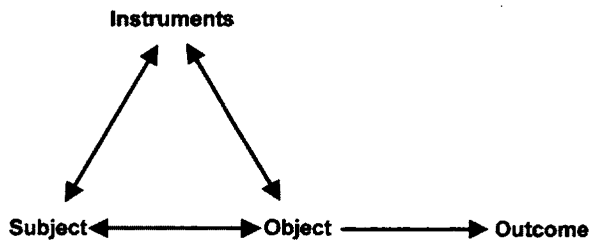


Figure 10 - Basic Activity Theory Framework

Once a particular activity is framed in this manner, the data can be used to expose problems in the activity. These can take different names such as tensions or contradictions. Problems can be found in nodes, between nodes, or between different activities.

While this explanation is cursory, a more detailed description, history and justification for the use of Activity Theory can be found in Appendix G - Activity Theory Description and Justification. The data collection and analysis methods are listed in Appendix H - and resultant data from the analysis can be found in Appendix I - Activity Theory Results.

Following the analysis two major conclusions arose. Firstly, the analysis revealed that the participants had two separate objectives: the manufacture of a physical object, as well as, the design of that object. This additional task separated them from those that, regardless of their skill, were only executing the designs of others. The participants belonged, more appropriately, to a group of designer/makers that are generally referred to as studio furniture manufacturers.

Secondly, in regards to the split between the manufacture and design objectives, a contradiction appeared between the tools used for the design task, and the tools used for the manufacturing task. As mentioned earlier, operation of a CNC machine requires the input of a digital model, generated by CAD software. The participants were not specifically neglecting CNC as a manufacturing tool, they were neglecting (for the most part) CAD as a design tool. At this point, the scope of the research was broadened from studying CNC machinery to the larger context of the digital design process.

3.5.2. Secondary Analysis

Following the retargeting of the research question, new literature research was conducted into craft production, craftsmanship; the division of labour between production and design; design methodology, education and innovation. This research now comprises the literature review found above. From this exploration, the three central themes of Division of Labour, Innovation and Process, and Education and Culture were developed.

Transcribed interviews were reread methodically and passages relating to the three major themes of Division of Labour, Innovation and Process, and Education and Culture were highlighted using separate colours. Once this was complete, the text from each participant was assigned a colour and the passages from the three thematic areas were grouped together into intermediate "chunks".

Each thematic chunk was then read as a whole and sub-themes were identified and organized. Under the division of labour, four sub-themes were identified: connection with manufacturing, communication between disciplines, economic factors, and quality. Four sub-themes were also identified under innovation: physical modelling, innovation in design, sketching, and digital tools. Under education and culture, three themes presented themselves: the role of education, the culture of woodworking, and product culture.

Passages were then organized under these sub-themes and grouped according to similarity. Similar ideas were combined and context was provided by referring to the original interview where necessary. Specific colourings and annotations have been removed to provide a straight forward description of the results.

3.5.3. Tertiary Analysis

Following the secondary analysis, the design processes of two participants, Mr. Blue and Ms. Tan were directly compared. Both participants had similar levels of education and training, as well as similar backgrounds. The major differentiating factor between them was their use of digital design tools during their design activities.

A narrative for the design process of each participant was created from the interview data. These two narratives were compared and contrasted in regards to the specific design tools used and the overall process and methodology employed.

CHAPTER

4. RESULTS & DISCUSSION

The following section provides the results of the participant interviews as well as the narrative description of the design processes and tools used by the selected participants. Both specific and general discussions follow.

4.1. Interview Results

The results of the interviews are organized into three thematic areas: Division of Labour, Innovation and Process, and Education and Culture. Key descriptive passages from interview transcripts have been used to provide context for the ideas presented here.

4.1.1. Division of Labour

Studio furniture manufacturers represent two disciplines, design and manufacture, that are typically divided. This division can be either logical or physical. Four distinct sub-themes emerged under this topic: connection with manufacturing, communication between disciplines, economic factors, and quality.

4.1.1.1. Connection with Manufacturing

As studio furniture manufacturers' duties include the actual manufacture of their designs, there exists a strong connection to hands on activities and repertoire of technical skills. Mr. Green states that his love of woodworking started in high school and Mr. Teal tells of being an amateur machinist previous to his current career. Mr. Orange recounts his education with Michael Fortune, a famous Canadian studio furniture manufacturer (Gotlieb & Golden, 2005), as being "a mix between design and the technical ways to get there". In order ensure that the manufacture of his designs is completed by him, Mr. Plum's design tool kit consists of things that he knows he himself can make.

Mr. Green emphasizes that new technology is not a replacement for knowledge of the materials: "...you can't give a techno geek a CNC machine and expect him to build a thing out of it. He has to have the understanding of woodworking as well". He cites one of his employees as an example; an industrial design student who handles digital modelling and CNC work, who was previously and remains interested in building objects by hand.

4.1.1.2. Communication between Disciplines

When the designer is not specifically the maker, participants identified the need for a strong bond between the two functions. Referring specifically to the use of digital tools for manufacturing, Mr. Green says: "it's really the programmer and the artist or the designer and the programmer [that] have got to work together." Ms. Tan also cites a need to communicate with the manufacturers of parts, and how digital models are making the communication invisible: "you know often when you're speaking to a machinist, you've got to, you've got to convey to them what you want them to do. And in this case, you can simply draw it". Even when designer and maker are in the same shop, Mr. Brown sees the value in proper technical drawings to ensure that the job is done correctly.

4.1.1.3. Economic Factors

One aspect separating amateur woodworkers from professional studio furniture manufacturers is their concern with money. When asked about their most expensive tool, Ms. Tan, Mr. Teal and Mr. Orange confirm themselves. They suggest that wages are expensive, especially for highly trained people such as themselves. Mr. Blue provides two examples of this relating to both the division of labour and digital tools. He has shunned outsourcing the manufacturing of a secondary part by CNC because of the time invested in logistics. "Well the answer is because I'm not going to drive out to [...] just to get one thing." In another example he does use outsourcing to a CNC manufacturer to save his time:

> *So instead I drew, I had the design on the computer anyways, it was easy to exact the bending form from the actual part that I need and lay them out. If I know I needed a 3" thick form, I can, I'd know I needed 6 layers of ½" MDF, it was easy just to lay those out and email a file off to someone to cut them all out.*

Clearly, the idea of trying to save time and money is a concern. Volume and quality are two factors in his decision to do this. The parts that Mr. Blue did have CNC manufactured were essentially secondary tooling, not production parts. Mr. Plum also confirms that he has outsourced the production of CNC parts, presumably at a time savings for himself.

For one line of furniture, Mr. Green received royaltie,s as the licensee was after quantities that only factory production could offer. Unfortunately, in a cost saving measure, the local factory was closed, and the manufacturing was sent to China.

4.1.1.4. Quality

Quality of work plays a part in the division of labour. Because the end product is made by them under their name directly, studio furniture makers are likely to take a craftsman's approach to making their pieces. Mr. Blue claims to be a control freak in that regard and would not outsource the manufacture of final parts. Mr. Plum's solution is to design within his skill set (of making) so that he is not required to seek help in the realization of his products.

With quality as the end goal, Ms. Tan sees the digital model as a useful tool to ensure the work is properly done. "I simply do a drawing on my computer, pass it to someone who plugs it into their computer and there is no need to translate to the operator what it is I want them to do."

4.1.2. Innovation and Process

The design process of studio furniture manufacturers is explored in the following section. The sub-topics presented are physical modelling, innovation in design, sketching, and digital tools.

4.1.2.1. Physical Modelling

Sometimes the design process is handled purely in the physical world. Maloof's sentiments about using his band saw as his pencil are echoed here as well. Mr. Green remarks:

> *I'm quite happy being in the studio on a Saturday morning with a cup of coffee and the table saw and some crazy ideas to try and figure out.*

Sometimes you can only draw so much and then you have to start, I'll literally just go over to the band saw and just start cutting out shapes and just looking at them, and playing with them.

Mr. Brown will move from quick sketches right to the finished materials so that the materials can help dictate the design. Ms. Tan has a more formal design process that involves the creation of scale models to explore form.

Even the raw physicality and tactility of designing with the hands is important. Mr. Green suggests that there is something more to using your hands than can be described:

So, I think, pretty pictures are great, but I'm more... I like saw dust and noise and dirt and a few cuts and bumps to get something built. And even model making I think it's important to do that too. [...] But I think you've gotta get your hand next to the wood, and you're sanding the corner and your hand picks up bumps and little...you know

As a business policy, Mr. Orange purposefully works toward non-digital designing and manufacture in order to capture a niche market for items that are not possibly made by machine.

Even those studio furniture manufacturers who have adopted digital tools recognize the necessity of physical models. Mr. Green says "I still draw my stuff full size, because you cannot get the proportions or the visual of what you're trying to build this big on the computer screen and expect it to stand five feet tall." But he doesn't shun the digital side of the process either.

So what I did, what I still do, is go sketch pad to full size. And I'll draw the whole thing out, exactly the way I want it. So I can stand it up and look at it. Then we'll take a picture of it, and [...] will scan the picture or my drawing, then I let him go. Because I know it's the height I want, it's the width; everything about it is what I want. Then he cleans it up and tweaks it.

Mr. Green, who typically makes one piece and then additional copies to order, illustrates that a combination of both physical and digital is possible and quite necessary for certain types of production. Even in a strict one-off production model, Mr. Blue illustrates his digital and physical design methodology: "I'll maybe develop some ideas in [the] computer and then make some simple mock ups out of cardboard or something like that just to validate, does that even make sense when you see it in the real world, and then go back and forth a little bit."

4.1.2.2. Innovation in Design

According to several participants, an excellent design stands on its own, regardless of what tool was used to develop or produce it. Mr. Green sets up the argument as follows:

If it's well designed and well built and well researched I don't care if it's made by a computer or a blind person. That doesn't matter to me as long.... The proof is in the pudding. If it looks good and it's sellable and people like it and it's enjoyable and it's clever and it's unique, who cares? But I don't think, and we have to be honest here, I don't think computers are going to make us any better designers.

Mr. Blue confirms the sentiment by stating that all of the technology and machinery that goes into mass producing an object would be for naught, if the design was not good.

Ms. Tan confesses the following: "My design skills are not good enough to keep me out of trouble yet. So it's very easy for me to design something that's complex to build. And so, this bed has, I like to tilt my headboards at a slight angle, at about 10 degrees back just to give them some interest and give them...to make it more comfortable to sit up in bed."

Mr. Green articulates the requirement for ambiguity in designing which can be aborted by improper use of digital tools:

> *People can draw images of my furniture before I built it, and I always kinda didn't like that. What's the point of building it if I can already see what it's going to look like? That's half the fun of being creative is you don't know what it's going to look like. You have no idea until it's actually completely finished and then you go, see, that wasn't very good. Or that was great! It's the surprise.*

Mr. Teal uses CAD but for the purposes of customer presentation, rather than as a design tool in and of itself. His design work still gets done by head and by hand. Again, Mr. Orange's choice of shunning technology is to not innovate per se, but to keep to an area specifically that new technologies (CAD/CAM/CNC) cannot go.

4.1.2.3. Sketching

The importance of the sketch is not lost on the interview participants. Mr. Green cites the emergent nature of multiple sketches as the engine for his ideas: "sometimes you'll look at my sketchbook and there will be just clutters of stuff all over it and then they'll all go into one. And that's when the crazy piece comes out."

While Mr. Brown moves from sketches to a physical prototype, Mr. Teal works directly from sketches on the finished piece, and claims to only make a detailed drawing if the piece is sufficiently complex. Mr. Blue moves from sketches to a CAD model but understands his process is not for everybody. "CAD programs are not that easy to use. I use Sketch Up a lot and it's probably as easy as it gets. But still it's a bit intimidating."

4.1.2.4. Digital Tools

Aside from the actual benefits of a digital ecosystem, a set of perceived benefits also exists. Mr. Blue's definition of the benefit of CNC technology is that it allows someone to forgo expensive tooling to realize a design. In a romanticized version of the specific capabilities he remarks: "I enjoy the design more than the making. There have been lots of times where I've, I have a design and if I could just click a button on the screen that says Make and have it pop out of a box, then that would be great."

Mr. Green reports comments from others that in regards to the production process, digital technology is going to 'make it easier'. His personal belief is that while it does not necessarily make life any easier, the benefit of the digital ecosystem is the facility to produce multiple copies of an object.

Some participants also report engaging in activities which could specifically be aided by a digital tool. Mr. Orange reports creating curved contours through the use of a trammel; essentially a beam compass, with one point anchored at the center point of a circle, and a second point defining the circumference. At small radii this method is standard procedure; however Mr. Orange states that he had recently hit a personal record with a twenty-two foot (6.7m) trammel. The effort required to create this arc in the digital realm is arguably an investment against the dangerous and cumbersome nature of his "router stuck to a board."

Ms. Tan admits apprehensions about saving jigs and templates used in her work due to a small shop footprint. While certain jigs are required for machine operation, templates can be stored digitally at no cost to physical space.

The use of digital methods to beneficial ends by the participants has been slightly more selective. Due to the sculptural and whimsical nature of his work, not all of Mr. Green's pieces see more than one-off production levels. However, when a piece does become popular, the investment in digital models allows his studio to produce subsequent copies more quickly through the outsourcing of CNC produced component parts.

Mr. Teal and Mr. Brown both use CAD as a method for preparing drawings for clients but are careful to point out that they would not otherwise go out of their way to create drawings in a CAD environment. Mr. Blue on the other hand has used CAD to prepare photo-realistic renderings for clients and regularly features CAD in his design process. He makes use of the print functionality of CAD to create paper templates which he adheres directly to work pieces. Digital tools do not make up the totality of his design process as he is quick to point out: "I don't want to spend a lot of time doing drawings, because they aren't to the proper scale. And I find for me to just get into working in the real scale quickly, soon, it helps me out. But I go back and forth." His process involves sketches and physical prototypes in cardboard as well as CAD.

Mr. Blue's use of digital tools has not been an entirely trouble free process. He cites some initial misgivings about the abilities of his software of choice. Mr. Brown is also critical of the high costs associated with not only digital tools themselves, but the costs associated with training yourself to use them. Ms. Tan admits to being totally lost when it comes to CAD software and Mr. Green calls into question the reliability of digital tools. He states: "I don't have any more respect for a computer than a table saw. If it works it works, if it doesn't I don't want to have anything to do with it."

4.1.3. Education and Culture

Interview data concerning the education and culture of studio furniture makers is reported in the following section. Data is split into three themes: the role of education, woodworking culture, and product culture.

4.1.3.1. The Role of Education

Mr. Green passionately articulates his requirement for hands on skills by saying "But I think you've gotta [sic] pay your dues in the trenches. You've gotta [sic] understand woodworking. You cannot build on a computer without knowing tolerances." His view is that hands on skills are not being coupled with computer skills and adds "that's what we've got to work on." He attributes this to a perceived decline in high school wood shop classes.

As mentioned previously, Mr. Orange recounts his education with Michael Fortune as being a mixture of both design skills, as well as woodworking skills. Mr. Blue cites a similar experience at Rosewood Studio. Ms. Tan cites an internship, a history of being a hands-on person and even an apprenticeship as a mechanic.

The use of digital tools as part of a design methodology is attributed by Mr. Blue to educational introductions. Mr. Blue suspects that students of fine arts or industrial design have a decided advantage over straight craftsmen. Mr. Plum, when asked about educational methods, provides some insight into the nature of the problem. As the least effective educational method he states: "Manuals. I am prone to making things up and poor at following instructions."

Mr. Teal argues that every tool has a learning curve which must be overcome in order to use it to its full potential: "If you learn how to program a CNC machine, you can do some phenomenal things with it. If you never learn how to sharpen a hand plane, they're phenomenal paper weights."

4.1.3.2. Woodworking Culture

The culture and the passion of woodworking is explained by Mr. Green:

> *Because there's a whole bunch of guys out there and girls that just want to build. I mean, [...] besides the noise and the dust and the dirt and all of it, there is something wonderful about taking an idea out of your head and building it three dimensionally and then standing back and looking at it.*

One large encompassing theme emerges on the subject of woodworking culture: woodworkers are in it for the woodworking. Mr. Blue explains: "I think a lot of woodworkers are not trying to make any money, and the whole point is to work with wood. So then, to deliberately divorce themselves from that by sending something out to be made is kind of running counter to that."

Mr. Teal confirms the cultural importance of doing the work for oneself: "There is a lot of woodworkers out there that, that is their attitude, that, if you're using the CNC machine to shape a part, you're actually taking part of the process out of the hands of the woodworker." Ms. Tan concurs:

> *I would never, ever have a CNC machine cut, do letter carving for me, because it would be so perfect it wouldn't look, it would lose the character that my letter carving gets. Even though my letter carving is very high quality, it's not perfect, it's not consistent. It's that, workmanship of risk type of stuff that [lets] people know it's handmade.*

The irony of the statement concerning the hands of the woodworker is not lost on Mr. Teal. He continues: "But I also realize that there is a certain segment of the woodworking society, woodworking field that would just as soon entirely use hand tools." Mr. Brown agrees that the valley between hand tools and machine tools still must be crossed before one can start worrying about computers.

The bridge toward digital tools does appear to be getting built however. Mr. Green states his bias upfront: "You're not going to see me clicking a mouse to make a curve. I'm going to take a pencil and draw a curve. That's what I'd do." For him, the technology has come too late. He predicts a different picture for the future however: "If you're a techno guy, you're probably not a woodworker. If you're a woodworker, you're probably not a techno guy. So maybe in ten years, this evolution, we'll be comfortable with all that."

While Mr. Green's personal design activities do not include digital tools, his shop as a whole does. This allowance for new tools and techniques comes from his personal aspirations and willingness to blur the disciplinary lines. He remembers his response to a sculpture professor who admonished him for creating furniture: "It's a sculpture! Why can't sculptures be functional, why can't furniture be art and art be furniture." This interaction became quite influential and he recalls picking a direction early: "my plan from the age of 25 on, I said I wanted to be an artist, I wanted to be a designer, I wanted to build."

Another example of blurring the lines comes from Mr. Blue as he recalls a recent craft show that he attended. While there he encountered a jeweller that had prepared necklaces exclusively with a rapid prototyping machine and had added clasps to the finished product. "And I thought that was really interesting because this was still accepted as fine craft because there was zero manual involvement."

4.1.3.3. Product Culture

The products of studio manufacturing are imbued with a particular mystique. Mr. Blue explains: "Like anything hand made is going to have a huge price tag and part of the rationale, or what gets people over that who are buying it is it was made by hand." Mr. Plum offers the following sentiment on the validity of work done by digital tools: "Woodworking as I do it is about my humanity rather than technology."

Mr. Plum immediately points out the contradiction in his words as he cites his own use of machine technology. As mentioned above, on one occasion he has also made use of CNC technology. He clarifies: "If a specific technique becomes relevant within the framework of the commission then it has validity."

Mr. Blue summarizes: "I'm more concerned about what it looks like. I really couldn't care less how you cut that mortise and I don't think anybody else does in the long run."

4.2. Process Narrative (Case Studies)

The following two narratives have been derived from the information provided by the two respective participants as well as observing their work and process.

4.2.1. Mr. Blue

As a philosophy, Mr. Blue values the quality of the design over the particular method of execution. His design process starts in a sketchbook with rough, informal drawings and ideas. He then moves to CAD software for the creation of a digital model. This allows him to quickly judge the proportions of his piece. The digital model is also used to view the piece in perspective, as well as inspect it for visual patterns. At this point, Mr. Blue creates a low-fidelity prototype in cardboard to evaluate the size and presence in a room. An example of a similar full scale prototype in cardboard is seen in Figure 11 below (Prototype: Patrick Bickerton, Photograph: Author).

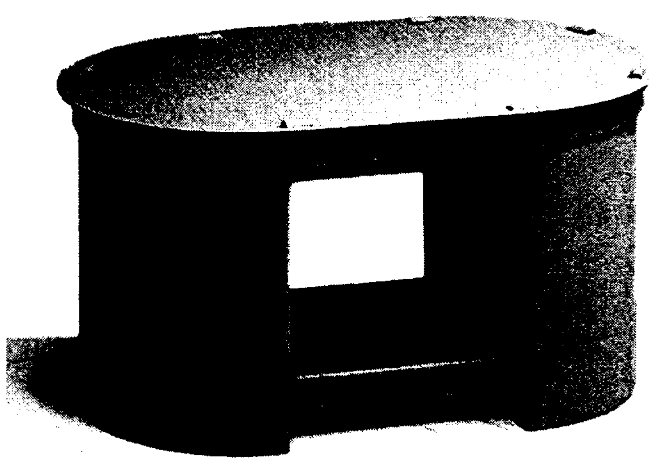


Figure 11 - Low Fidelity Full Scale Prototype

Iterations are done between the digital model and the prototype until the design is acceptable. Mr. Blue does not iterate toward higher fidelity models but instead prepares a rendering from the digital model to show clients. A similar rendering created in CAD software can be seen below in Figure 12.

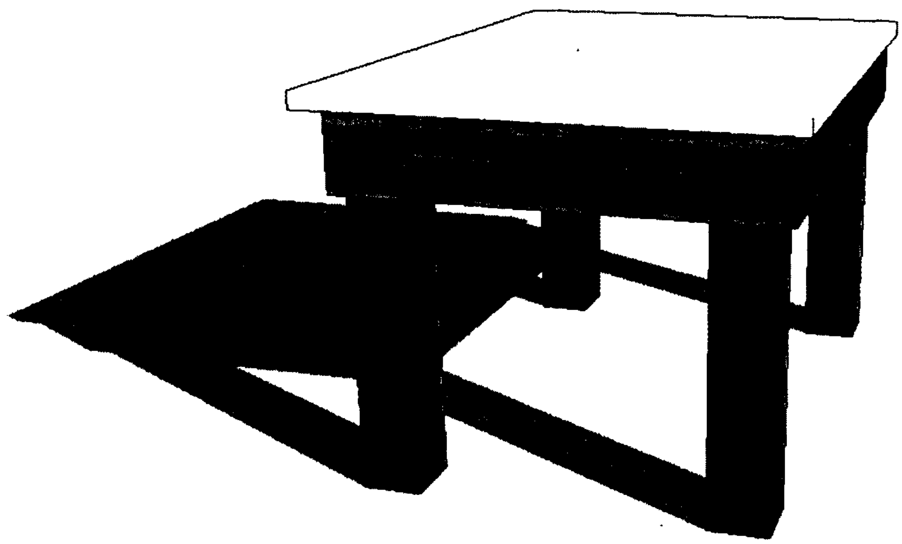


Figure 12 - CAD Software Rendering

Once production begins, the digital model is used to generate full scale drawings which are printed and used as templates for the creation of actual parts. On occasion, the digital model has been used to generate secondary tooling. The digital file is sent to a third party who uses the geometry to cut forms in low cost materials, which are then used by Mr. Blue as templates or forms for bending wood.

4.2.2. Ms. Tan

Ms. Tan's design philosophy in regards to studio furniture is that the design must be representative of the designer. Her design work begins by creating sketches in order to inform and develop the design of her pieces. Form and proportion explorations are continued through the creation of reduced scale prototypes in low fidelity materials. A similar scale model can be seen below in Figure 13 (Prototype: Jenna Stephens-Wells and Sichao Wu, Photograph: Author). These models typically feature material substitutions and pencil drawn lines that stand in for three dimensional details that are hard to realize at reduced scales.

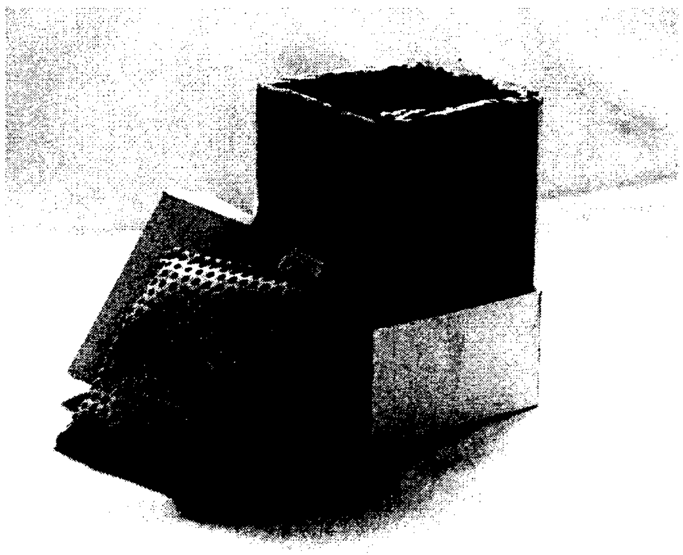


Figure 13 - Low Fidelity Reduced Scale Prototype

A set of full scale drawings are prepared as the design reaches maturity. From these drawings, a perspective drawing is created by hand with the use of Lawson drawing charts. This rendering is then used to inform the client of the design intent. The full scale drawings are then used as templates for the creation of final parts. On one occasion, Ms. Tan provided the full scale drawings to a third party who then created equivalent parametric models for the purpose of CNC machining secondary tooling. This secondary tooling was used as a bending form for production materials in the final piece.

4.3. Discussion

Industrial designers are now using many different digital tools in their design processes. These tools span the entire process from computer aided sketching software to rapid prototyping machines that can create fully coloured and dimensionally accurate physical models (Z Corp, 2011). This digital eco-system has been brought on by an ever increasing division of labour, a hastened delivery schedule fuelled by profitability, and a complicit education system. However, due to concerns about a lack of fluid interfaces, promoting functional fixedness, not aiding innovative thinking, and the removal of valuable physical information with respect to digital models, the value of these digital tools is widely debated. There is no doubt that they facilitate downstream movement in an organization and allow instant visualization of design ideas but their value to the quality of the design work being done is less apparent.

This study sought the opinions of studio furniture manufacturers in order to shed light on several issues surrounding the current state of industrial design. Viewed as a hybrid of designers and woodworkers, these individuals face little division of labour in their work and are intimately connected with not only their manufacturing processes, but the materials as well. The discussion is broken into two parts. The results from the interviews are commented on first, followed by a discussion of the process narratives. A general discussion follows these two sections.

4.3.1. Discussion of Interview Results

4.3.1.1. Division of Labour

The term studio furniture manufacturer implies the designer is intimately involved in the creation of the actual piece. The only exception encountered is Mr. Green who has moved into somewhat more of a designer / entrepreneurial role, but only due to the success of his products. Upon starting, Mr. Green was both designer and builder himself and still acknowledges doing work in the shop when it is required.

Aside from this one exception, all of the participants are directly involved in the production of their own furniture. Their work flow is typical of pre-industrial revolution craft production, where the designer and maker was one individual. They accomplish this through a sound knowledge of the methods of working with their materials of choice and a repertoire of skills that come with the territory.

4.3.1.1.1. Connection to Manufacturing

This direct connection with manufacturing is not possible in every medium or with every manufacturing method. Objects made from uniform materials like wood, metals like iron, and even glass can be successfully manufactured by individuals. However, as object complexity rises, the number of parts made from different materials also begins to rise. New materials such as plastics, polymers, and resins require the expertise of multiple disciplines from materials extraction, chemistry, to tool and die makers, etc. A perfect knowledge of manufacturing is not always possible.

In the case of multiple disciplines, strong communication between functions is illustrated by the participants. Mr. Green's strong advocacy for not only communication but teamwork shows that products are difficult to create in a vacuum. The whole of the final product can be greater than the sum of the skills of the disciplines that created it.

Digital models aid this communication between disciplines but its use should not be the sole channel of communication. Pye says "Design is what, for practical purposes, can be conveyed in words and by drawing: workmanship is what, for practical purposes, can not" (Pye, 1968, p.5). Even the most accurate digital models shared between designer and manufacturer can be spoiled without care. Likewise, a design may be thwarted in execution if the designer does not understand the weaknesses of a given process, or exploit the strengths of another.

4.3.1.1.2. Craftsmanship

It is generally the small scale of production that allows a studio furniture manufacturer to be both designer and maker. A single designer, asked to create hundreds of copies of a particular piece of furniture, all to the same quality as the first one, would find no time left for designing. As such, studio furniture manufacturers infrequently get to take advantages of economies of scale in their work. Six copies of a particular piece appears to be the magic number handed down from the Arts and Crafts movement that separated hand made from mass produced (Pye, 1968). Even at six, it is difficult to determine appropriate methods to use in production, and as the designer is also the maker, the methods will no doubt influence the design.

Acting as their own producers, furniture studio manufacturers are unable to shirk responsibility for poor quality. They are quality focused at all times, both in the design and in the production of their furniture. The ownership of the design and the manufacturing serves to act as a brand image for that particular designer and any design decisions or manufacturing decisions must be weighed not only in terms of value, but in terms of quality.

It is not a stretch to call a studio furniture manufacturer a craftsman; the title is well earned. Their manufacturing methods echo those of a bygone era of craft production, attention to detail, and the pursuit of a job well done for its own sake. Above all, they are the designers of not only their own furniture, but their method of work, and their commitment to quality.

4.3.1.2. Innovation and Process

4.3.1.2.1. Use of Digital Tools

As self employed individuals, studio furniture manufacturers dictate their own tools and processes for design and making, rather than having to conform to pre-existing eco-systems. They bring their own history, education, preferences and safety to bear on what they consider the correct use of what they consider appropriate tools and processes.

As noted above: “I don’t have any more respect for a computer than a table saw. If it works it works, if it doesn’t, I don’t want to have anything to do with it” says Mr. Green.

A tool that “works” is a powerful way to determine its appropriateness. Clearly any tool can be made to work, and by most definitions, a tool must do some sort of useful work. It might be advantageous to ask “Does a tool work in the context of the work that is to be done?” This begs the secondary question “Does this tool require a change in process?”

There is no magic ratio between digital and traditional design tools that is universally appropriate. Simply, they must fit into the already established process to be considered useful. If at that point they provide an advantage over an existing tool, their use becomes appropriate. As an example, digital sketching has reached a point of maturity such that the only remaining barrier is the disparity in the cost between it and traditional pencil and paper sketching. The interface for digital sketching is a digital pen and screen which acts as a similarly blank canvas. Users can intuitively make use of their drawing skills without having to learn a new system by which lines are drawn and erased. Additionally, digital sketching systems can make use of drawings featuring multiple layers, different drawing tools can be selected at will and the digital eco-system allows the users to print, save and email drawings easily. Rather than attempting to bring the user to the digital tool, sketching as a digital tool was brought to the user.

One must be careful however to judge that benefit and to ensure that the tool is not providing that benefit at the expense of another. A CAD model that is beneficial for communicating with co-workers and downstream functions is inappropriate if it is created in lieu of a physical model. The conversation that the designer has with the concept or with his or her self about the concept has been discarded.

With no pressure from above, some studio furniture manufacturers have found extensive uses for digital design technology. Mr. Teal and Mr. Brown use CAD exclusively as a visualization aid for their customers. They do not report using CAD for any specific design development work, nor do they use digital models for CNC manufacturing. To them, the value in CAD is purely as a communication tool with clients. The change in tool for this task has not changed their over-all process, either leading up to the use of this tool, or afterward. The value they have found is the ability to communicate an already completed design to the client more effectively. Skill is required to create a highly detailed rendering, both in software and with pens and markers. In comparing a basic computer rendering to an unskilled hand drawn sketch however, there is little competition. CAD provides straight lines, and correct perspective for free. It allows the customer to experience the end product without asking them to use their imagination to see past poor technique.

Mr. Blue's use of digital design tools is the subject of a detailed discussion in the next section. However, Mr. Blue has found value in a digital design tool that allows him visualize his design more easily than with traditional media. It also aides, rather than impedes an iterative conversation between two different models, one visual and one physical.

Finally, Mr. Green has embraced digital tools as an aid to production; his design development still happens in traditional media. Once he is satisfied with the design, an employee creates digital models which are used in the creation of CNC templates that guide the production activities for a particular of furniture. Due to the popularity of his furniture, the ability to recall and recreate designs has been of great value to Mr. Green.

Ms. Tan, Mr. Plum and Mr. Orange all report no use of digital tools in either the design or production of their furniture. What deserves mentioning is that all of the participants had professional websites for their businesses. As such, none of the participants could be said to be completely anti-technology in their stance. Their reasons for not pursuing digital tools, however diverse, can be distilled down to a simple judgement of value.

The cost to not only purchase a new tool but to train oneself to use it cannot be ignored. Likewise, digital tools may not provide such an advantage to some studio furniture manufacturers in terms of visualization, communication or production, as mentioned above. While an unsteady hand may be thankful for the smooth lines and graceful shading that a computer rendering offers, a practiced visual artist may find any digital drawing tools cumbersome and unnecessary. During a conference on practical furniture design, Vic Tesolin suggested that when presenting a client with a computer rendering, they always assume that the design is flexible and that changes are easy to make. His solution is to do his drawings by hand, as both a sign of design skills, and to discourage any attempts to suggest changes (Tesolin, 2010). Studio furniture manufacturers are selling not only a piece of furniture, but a piece of furniture that they themselves designed.

In certain processes, no digital design tools, or traditional design tools can ever be possible. When one approaches the design of furniture as an evolutionary process or as a conversation with the materials themselves, no design tools are appropriate. It can be argued that neither of these two processes are design and have no place in this discussion. Evolution is generally seen as antithetical to design, and a conversation with the materials may be more at home under the heading of art or sculpture. However, both of these practices can be valid in the production of some or many components in a piece of studio furniture. Mr. Orange states that his furniture production and design is intentionally computer free. For him, no value, perceived or otherwise would cause him to adopt digital tools.

For the rest, the balance is struck when the overall process remains the same. The unspoken key to successful adoption is to ensure that one is not cutting corners. The studio furniture manufacturer must be honest to process because they are stuck with the result.

Mr. Green's quote is worth reiterating: "I don't think computers are going to make us any better designers." A designer's abilities are not simply improved by using digital design tools any more than a cabinetmaker's abilities are improved by using power tools. A powered table saw allows a cabinetmaker to cut wood more quickly, easily, and accurately than with a hand saw. It also allows the operator to harm that same piece of wood and themselves more quickly and easily. McCullough draws the comparison: "The relief the computer provides from tedious thinking corresponds to the relief machine power provided from strenuous work" (McCullough, 1998, p.73).

Any useful thought directed toward an end goal should not be considered tedious but should be considered valuable and productive. It is precisely this concerted effort that is part of the design process. While the exact nature of how a design arises is still under investigation, researchers have used such words as Combination, Mutation, Analogy, First Principles and Emergence to describe the process (Cross, 2007, pp.73-76). These words imply a concerted mental effort in order to arrive at an idea. The bolt of lightning from above is only an accurate description of the sensation of realising that idea, not a description of where it comes from.

While digital tools may facilitate design work, there are no power tools for the creative process. Studio furniture manufacturers are aware of this, if only subconsciously, and choose their tools accordingly. They are using digital tools that don't sacrifice quality, in a way that allow them to remain in control, and don't require them to change their overall process.

4.3.1.2.2. Sources of Innovation

While none of the participants mention innovation specifically as a goal or object, they do exhibit behaviour that according to the literature ought to aide in it.

Mr. Green offers: "I'm quite happy being in the studio on a Saturday morning with a cup of coffee and the table saw and some crazy ideas to try and figure out." The literature would support that his hands-on, experimental nature is one of the reasons for his successful designs (Alesina & Lupton, 2010). In others, it is the emphasis on iteration that is the key to innovation (Schrage, 1993). Mr Blue moves between a cardboard prototype and a visual model in CAD software until he is satisfied with the design.

Ms. Tan's process involves physical modelling, which even at scale, has been shown to reduce fixation on a particular form during the design process (Youmans, 2011). This can be extremely valuable for woodworkers. Due to the similarity of all dressed lumber it can be difficult to think outside the board.

In terms of tools and processes used to generate innovative designs, there are no clear winners. Mr. Blue, whose work was featured on the cover of a major trade publication, uses digital tools several ways in his process. Ms. Tan describes her design process as "getting into trouble." It is likely this problem solving that has earned her award recognition.

The case for innovation is difficult to measure. All of the participants are designing and building original works by employing various design methods such as sketching and physical prototyping. Their choice of design models is a mix between purely traditional and a combination of traditional and digital models. It is worth noting that none of the designers eschew a physical model for a parametric model done in CAD and they all have formalized ideation / sketching phases.

4.3.1.3. Education and Culture

4.3.1.3.1. Education

Two important themes present themselves in terms of education. The first is that the most successful studio manufacturers are pairing a sound body of woodworking knowledge with design skills. The second is that one must make a concerted effort to learn not only how to use digital tools, but how to use them appropriately.

None of the participants of the study received what would be considered a traditional education in woodworking or cabinetry i.e. formal apprenticeship. Likewise, none of them were educated as industrial designers. As such, they are free from many of the pedagogical dogmas of both disciplines. For the most part, the participants are self taught woodworkers and what woodworking training they do have was gained in advancement of their careers as studio furniture makers.

It is likely that their knowledge is not as well rounded as that of a licensed cabinetmaker but apropos, they are only interested in a subset of the work done by them. Their skills as designers are also a subset of that of an industrial designer's, but assuredly they have taken the necessary segments: a toolbox of design methods, an awareness of form and colour, and a working knowledge of ergonomics.

Studio furniture manufacturers have also cobbled together whatever additional tools they feel are useful. Mr. Blue uses digital tools in his process while several others do not. In examining Mr. Blue's biography, one wonders if the combination of his relative youth and university degree in science facilitated a computer presence in his craft. He cites no particular training or ability with design software in particular and even voiced some previous concerns about using it. The computer, however, became part of his tool kit. As mentioned earlier, all of the participants had professional websites for their businesses. In fact, all of the participants were contacted via email to arrange for interview times. To a certain degree, they are all accepting of certain uses of digital tools.

Unlike hand tools or even machine tools, software offers a decidedly different interface which doesn't particularly lend itself to intuitive use. As such, user manuals for CAD software are weighty tomes and outside of a classroom situation, the only comprehensive source of information. One thing that can be as intimidating as a blank screen is one thousand pages of instructions on how to fill it. Mr. Teal feels that this is just part of the job and that even the simplest of woodworking tools can be reduced to useless objects without proper instruction.

Studio furniture manufacturers need to be provided the opportunity to be taught not only how to use digital tools but taught in the context of what a studio furniture manufacturer actually does. They also need to be taught that digital tools don't have to be used in a completely digital eco-system. They can be used as supplements to regular design methods, and possibly even production methods. What studio furniture manufacturers are lacking in terms of education is a clear, cohesive source. On some level, the culture around them seems to suggest that acting the part is as important as knowing the lines.

4.3.1.3.2. Culture

"Woodworking as I do it is about my humanity rather than technology" says Mr. Plum. "If a specific technique becomes relevant within the framework of the commission then it has validity." At first, the statement appears to be staunchly anti-technology in its treatment of what constitutes valid woodworking practice. As a studio furniture manufacturer, the work being created is tied explicitly to the individual creating it, e.g. a

Michael Fortune chair. Ms. Tan believes it is her manual involvement that not only imbues the piece with humanity, but character as well. While character resulting from the workmanship of risk may not transcend into the workmanship of certainty, the humanity remains as long as the namesake was instrumental in its creation.

In a field such as studio furniture manufacturing, where the division of labour is minimal, it becomes impossible to draw a line in the sand at which point the production moves from studio furniture manufacturing to mass production. Mr. Green's involvement in every single operation on a particular piece of furniture is no longer possible due to the added responsibilities associated with running a successful business. However, it would be unthinkable to question that one was receiving a "Mr. Green" coffee table or a "Mr. Green" dresser. The definition offered by Gotlieb and Golden even allows that studio manufacturers can acquire parts fabricated elsewhere and then finish or fine-tune them in house (Gotlieb & Golden, 2005).

When the human agency remains, Mr. Plum's statement moves from being anti-technology to pro-human and technology agnostic. Mr. Blue's opinion that the work be judged on its own and not by how it was made echoes Pye's statement "The tree is known by its fruit" (Pye, 1968, p.54). Pye's view is in contrast to the Arts and Crafts' list of criteria for what constitutes craftsmanship, the majority of which cannot be determined by visual inspection of a piece. Perhaps Mr. Blue's opinion is the signal that the attitudes toward technology in the context of craft are becoming more relaxed.

4.3.2. Discussion of Process Narrative (Case Studies)

The similarities between the two design methods explored are quite striking on their own, but even more so once the mention of specific media is removed.

Both designers begin their processes with exploratory sketches. These are completed in the traditional manner with pencil and paper. The value of sketching is recognized and practiced by both, regardless of any academic pressure for or against.

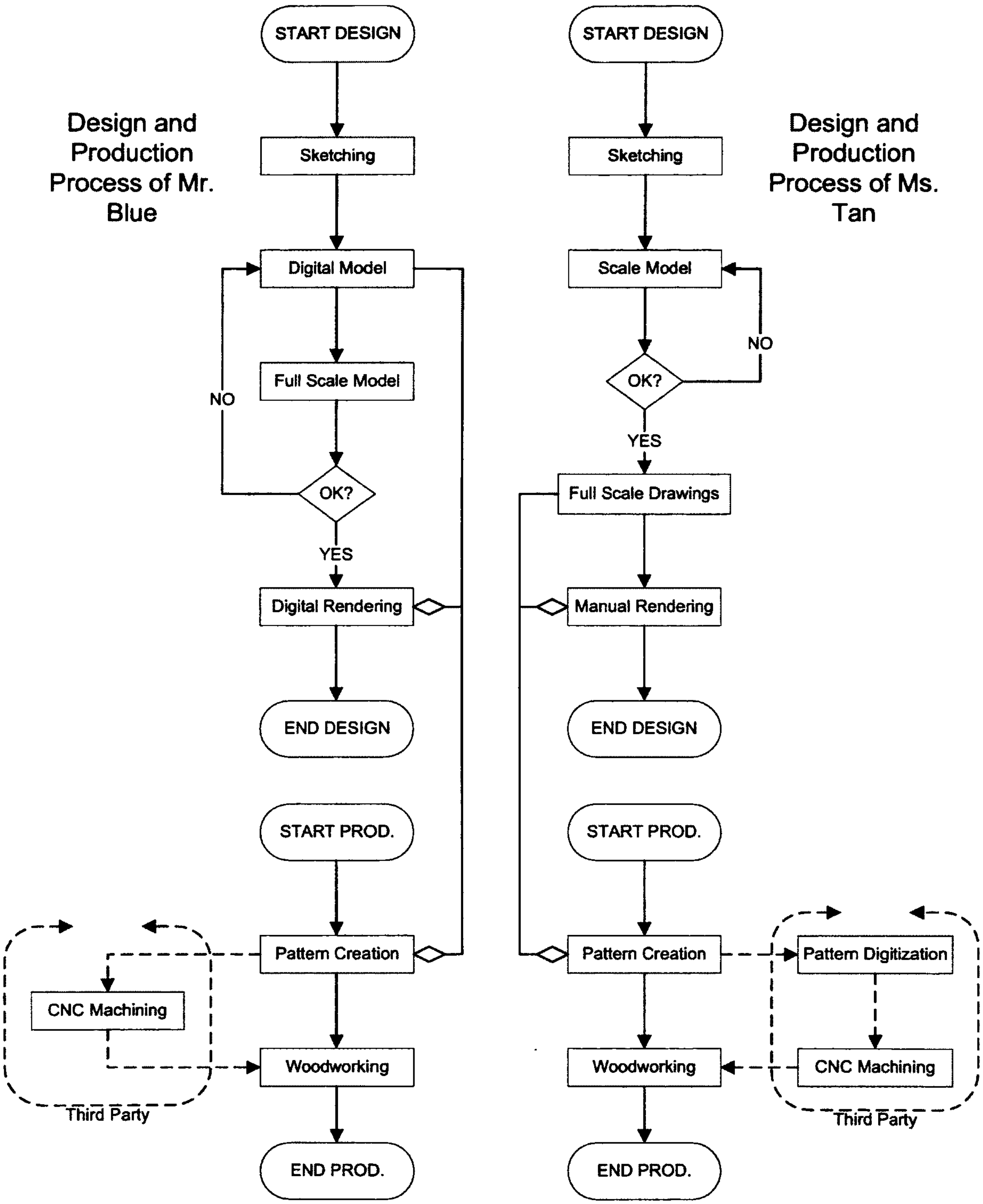


Figure 14 - Process Flow Chart

The next step sees the designers taking slightly different paths (See Figure 14 above for a graphic representation). Mr. Blue moves to the creation of drawings which are then used to inform a model; while Ms. Tan creates a model which is used to inform a set of drawings. These two divergent paths taken as unit can be seen to be quite similar. Both have a preferred starting medium, which is used to inform a more highly developed model in a second medium; both utilize low fidelity prototypes to explore form; and both create a detailed, accurate drawing of the design concept.

Taken as separate steps, the processes are indeed different. Mr. Blue's drawing is created digitally in CAD software as a parametric model. The interface of Mr. Blue's particular tool, Google SketchUp is seen in Figure 15 below. At this point however, the parametric model is only being subject to high level visual inspection for scale and proportion. While the model is drawn full size in the CAD software, the visualization is limited by the computer screen it is displayed on; roughly the size of a toaster.

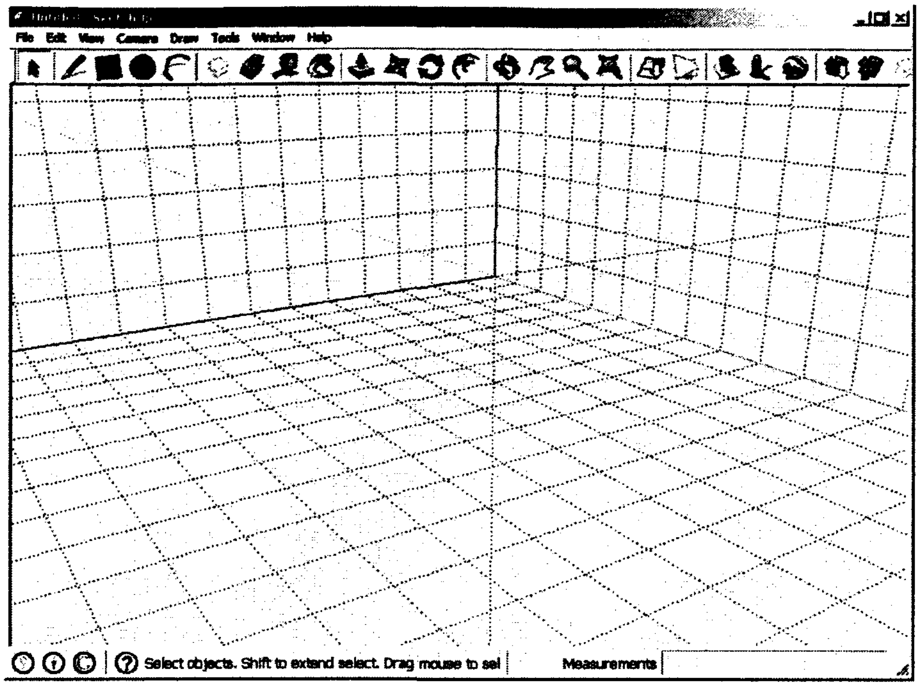


Figure 15 - Google SketchUp Interface

Ms. Tan's prototype is created after her exploratory sketching. This reduced scale physical model is made from low-fidelity materials to explore form and proportion. The size of the model lends itself to visual inspection and easy manipulation in the hands. At 1:10 scale, it is also roughly the size of a toaster.

The next step for Mr. Blue is the creation of a full scale prototype in low fidelity materials. He uses this size-accurate model to determine the presence of the finished piece in the room. Similarly, Ms. Tan's next step is the creation of a full scale detailed drawing. Both of these steps are informed by the previous step and may inform a further iteration between the two.

Once the design has been settled upon, both participants create perspective drawings to communicate with clients. These drawings typically show a realistic view of the finished design and may show colours and texture in addition to form and proportion. The movement to a high-fidelity visual model is an easy transition from Mr. Blue's digital model. Typically the geometry is lined up in a pleasing manner to show the form, lighting can be altered, and materials are chosen. Mr. Blue has also substituted a photo of a client's house in lieu of a blank background to aide in their visualization of the finished piece.

Ms. Tan prepares her perspective drawing through the aid of perspective charts. She cites the usage of Lawson brand perspective charts, however a similar but different brand is shown in Figure 16 (Howard, 2009) below. These charts are placed underneath the medium of choice, typically vellum, and allow the designer to maintain not only proper perspective in a drawing, but scale due to the measured grid. Ms. Tan is able to take measurements from her full scale drawing, and systematically add features to the drawing. The size envelope of a particular part is added as a rectangular volume and then slowly refined and detailed. Curves are added via template or free hand.

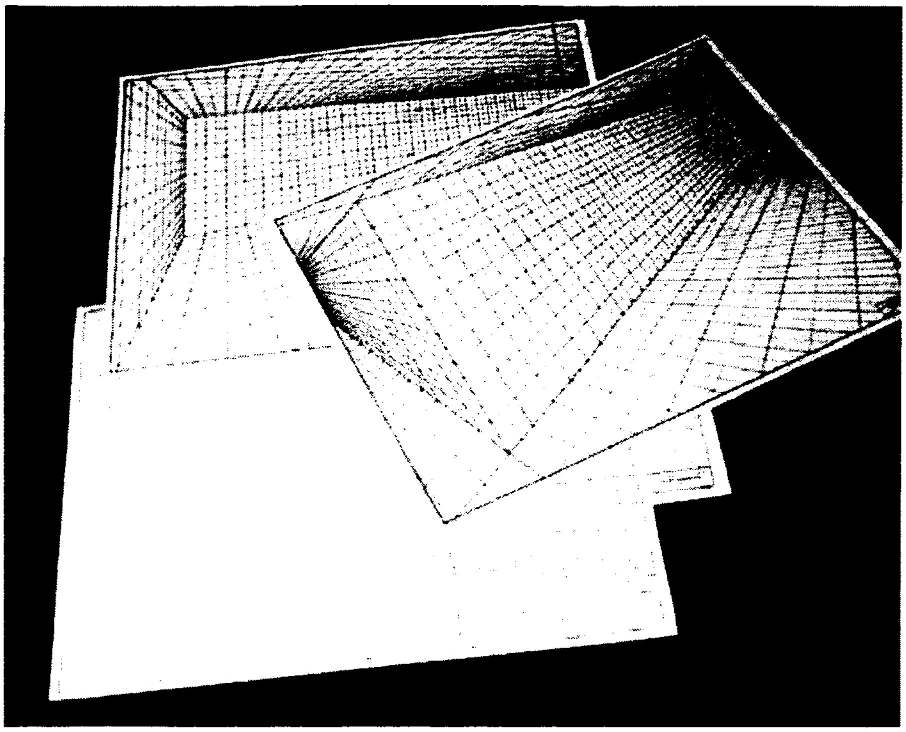


Figure 16 - Perspective Charts

At the point that the work begins, both participants use their detailed drawings to prepare the components of the finished piece of furniture. This is accomplished either through taking measurements for a component piece, or transferring the form directly to the work by gluing a print out copy or tracing the master drawing. In rare occasions, CNC parts may be created by providing a third party with either the parametric CAD model, or the full scale detailed drawings, which are then converted to a parametric model.

The bulk of the differences between the two design methods are difference in specific tools. The overall difference in process is negligible.

What benefits Mr. Blue, is that he's in control of his process in rare cases of outsourcing. As the actual creator of his digital part drawings, he can be assured that he has done everything in his power to ensure accuracy. It also gives him the freedom to move toward CNC machining, should it become appropriate in the context of his process in the future. His process allows him to print multiple copies of the plans; he needn't worry about spilled coffee or gluing a plan right to a work piece.

Ms. Tan stays truer to a traditional process which may have benefits in terms of being viewed as such. It also allows her to do her design work without the capital outlay required for digital design tools (software and computer hardware). There is no requirement for her to have a fully resolved drawing before she begins her work. This can be both a blessing and a curse, but Ms. Tan seems to have used it to her advantage.

4.4. General Discussion

4.4.1. Division of Labour

Studio furniture manufacturers represent a unique place in the professional realm as they work virtually devoid of a division of a labour. Save for the felling and seasoning of the trees that make up their furniture, these designer / makers typically handle every aspect of the production of their product from design and conception right down to delivery. Their craft approach keeps them, not only well versed in the manufacturing methods of their chosen material, but in touch with a time before the industrial revolution.

Studio furniture manufacturers must always be concerned with manufacturing, and the nature of their materials. It is they themselves who must coax their materials into form; they cannot pass the buck or hide behind well intentioned drawings. However, it is this intimacy with materials and knowledge of the process that serves to inspire their next piece of furniture.

4.4.1.1. Craftsmanship

Studio furniture manufacturing is represented by two separate ideas that are interconnected. The first is that the work of studio furniture manufacturers is identifiable by its craftsmanship. As defined earlier, craftsmanship is a witness-mark to the physical and mental skill, care, and attention that goes into the production of an object. Secondly, studio furniture manufacturers are concerned with a personal brand identity.

Knowledge that their identity is tied inextricably to the pieces of furniture that they not only design, but create, means that studio furniture manufacturers are quality focused in every aspect of the job. Their delivery of well made and well designed product only works to increase the value of their personal brand. Interview data suggests that studio furniture manufacturers are wary of outsourcing finished components to others. Even if the work is no longer handled exclusively by the studio furniture manufacturer, the work is still typically done in house under their auspices.

Industrial designers can look to studio manufacturers to have a closer connection to the materials and methods of manufacture. This intimate connection then serves to inspire the designer in future work.

4.4.2. Innovation and Process

4.4.2.1. Digital Tools

Studio furniture manufacturers have struck their own balance when it comes to using digital design tools. Only when a particular tool demonstrates its value, fits into the context of use, and doesn't significantly alter the design process does it get used. As studio furniture manufacturers are driven by quality, and renown for a high attention to detail, they are not looking to cut corners in their process. Three distinct uses for digital design tools were found through interviews.

The use of digital tools for the creation of full scale drawings has been reported. Employed in the middle of the design development, these digital models are used in place of creating full scale drawings on large sheets of paper. It is important to note that this usage was linked in a strong iterative cycle between drawing, and a full scale low-fidelity prototype.

Digital design tools have found use as communication tools between studio furniture manufacturers and clients in regards to the preparation of visual renderings. These drawings are typically done at a point in the process where the design work is complete and the task is easy to isolate from other aspects of the work. These drawings are not confused with any element of the design development process.

The final use of digital design tools was for digital manufacture; the use of parametric models for the outsourcing of CNC machined secondary tooling. These parts were used as forms for bending and were not included in the final product. They represented a repetitive job, done in low cost materials that were not to be used again. The margin on the work is reported to have been slightly more than it would have cost to have the required materials alone delivered to the workshop.

In a direct comparison between a traditional and a digitally augmented design process, no noteworthy differences were found either in the process or in the results. Aside from particular media, both processes shared similar progressions and characteristics.

Designers must learn to judge the true value of any given design tool and not to misuse it. One of CAD software's strengths is its ability to create digital models to communicate with others involved in the process. They must be careful not to confuse creating a drawing to communicate with others and creating a drawing to communicate with themselves.

4.4.2.2. Innovation

The use of digital design tools by designers as accelerators of innovative output is highly suspect. Sennett believes that CAD offers the ability to short circuit many beneficial design practices (Sennett, 2008). When a computer is used to abort sketching (Verstijnen et al., 1998), a sequence of prototypes (Schrage, 1993), hands-on prototyping (Youmans, 2011), or even a proper period of user analysis (Cagan & Vogel, 2002), it may have detrimental effects on the ability of designers to create innovative products.

Digital tools do not increase the power of the designer's abilities in the same way that a power drill increases the ability of a woodworker to drill holes. Due diligence and a commitment to the requisite thinking is the only way out of design. The results of this study show no difference in apparent innovative abilities between a traditional design method, and one that has been augmented with digital design tools. What can be shown is that, studio furniture manufacturers, of their own preference and free will, are relying on traditional methods such as those mentioned in the preceding paragraph for their design processes.

Industrial designers should take note that using an innovative tool does not guarantee innovative designs. The immediacy and the visual polish offered by digital tools can seduce a designer into believing they accomplished their task. There is no substitute however for design thinking.

4.4.2.3. *The Value of Sketching*

The value of sketching to the design process is impossible to overstate. While the mentions of sketching are relatively short, the consistency of where it is mentioned in the design process is cause for a second glance. All of the participants not only admit to sketching, but they admit to starting with sketching.

Once they have admitted to sketching, they are quick to mention what comes next in the process. Sketching appears to be something that many designers do out of habit. It certainly does not have the visual appeal of a fully realized rendering in marker or CAD, or the same presence in a room that a prototype does. Sketching gets a similar amount of respect to the foundation of a house. While it is arguably the most important part of the structure of a house, it is the most easily overlooked.

Mr. Green went on record to say that he has spent days doing nothing but sketching. When he runs out of new things to sketch, he opens old sketchbooks to take a new spin on old ideas. His tenacity for sketching is likely at the root of the success of his furniture.

Even though sketching has been called the "characteristic medium of design" (Menezes & Lawson, 2006) it may still deserve a larger period of time in the design process. Mr. Green aside, it appears that many studio furniture manufacturers are anxious to move to different media from sketching. It is entirely possible that this comes from a lack of skill in sketching and a desire to realize the furniture more quickly; studio furniture manufacturers are hands-on people. However, they should be careful not to dispense with the quick iteration that sketching affords as well as the ambiguity which has been identified as the main driver of creativity in sketching (Buxton, 2007; Huang, 2008; Ibrahim & Rahimian, 2010; Israel et al., 2009; Pei et al., 2011).

4.4.3. Education and Culture

The education of a studio furniture manufacturer is entirely up to their discretion. Their skill sets are largely of their own design, as neither cabinetry nor industrial design requires that one be licensed to practice. In that regard, they choose tools and processes that they find beneficial and are comfortable with. By the same token, they also lack specific channels for the dissemination of educational information. As such, the use of digital design tools is governed also by a cultural influence.

Currently, educational institutions flirt with the removal of non-digital skills from industrial design curriculums. Perhaps strengthening the cultural identity of industrial designers would retard the ability of educators to jump on the latest craze in design tools and remove valuable skills unnecessarily.

4.5. Discussion of Research Limitations

Due to the unregulated and multidisciplinary nature of studio furniture manufacturers, it is difficult to obtain a consistent sample population. In this study, participants generally answered along similar lines to those who shared a background.

Mr. Blue and Ms. Tan came from technical backgrounds, Mr. Teal and Mr. Brown obtained their starts as commercial cabinetmakers, and Mr. Orange and Mr. Plum came from fine arts backgrounds. This however may speak to the incongruous nature of studio furniture manufacturing and the likely continued difference in opinions. In an attempt to mitigate this disparity, case studies that explored the difference in process between Mr. Blue and Ms. Tan were used as they helped to control the background and training as a variable.

In light of how often he is mentioned, it would have been valuable to interview Michael Fortune himself, as a voice for the archetypal studio furniture manufacturer. Unfortunately Mr. Fortune's schedule did not accord with that of the researcher.

Finally, in regards to innovative designs, it is only possible to comment on what tools were used by a studio furniture manufacturer in a given process, and if these tools are seen as typically producing innovative designs. No measurement was made of actual design output from the participants and comments were made only where the final product was publicly lauded.

CHAPTER

5. CONCLUSION

The purpose of this research was to investigate how a study of craft and craftsmen can help influence a balance between the physical and digital tools used by industrial designers in their design activities. Digital tools increasingly dominate the nature of the work done by designers to the point that an understanding of the benefits of traditional tools and methods of working is vital. Whereas digital tools will continue to evolve, the designer's alienation from materials and process continues to grow due to the division of labour.

The study was driven by two main questions: "What can be learned about the appropriate use of digital design methods by studying studio furniture makers?" and "What does being intimately connected to the manufacturing process do for the design of an object?" As such, studio furniture manufacturers were the focus of study as they represent a cultural subset of industrial designers. Studio furniture manufacturers enjoy a relationship to the worlds of both production and design. Adherence to the craft production model and an almost non-existent division of labour also puts studio furniture manufacturers at the heart of a simplified product development process. This simplification acted as a control for the variety and complexities of the industrial design practice.

As determined earlier, part of the culture of studio furniture manufacturers is an affinity for highly skilled manual work. This manual work is not due to any lack of training or resources. Rather, their attention to the process, familiarity with the materials, and respect for tradition are integral to their way of working.

When adopting digital design tools, studio furniture manufacturers do so in a way that allows them to maintain their presence in the physical world. Even with the creation of a digital model, the physical model was not far behind. As designers and producers of very real material objects, they appreciate the resolution of details (Bahar Sener, 2007) and inspiration (Alesina & Lupton, 2010) that happens in the real world.

Industrial design curriculums have taught, and still teach skills such as sketching, rendering, and physical prototyping in a studio setting. These skills have traditionally been part of the designer's toolkit can be positively linked to inspiration, innovation, and a relationship to production activities. It is unclear how a suggested move toward completely digital eco-systems (M. Yang et al., 2005) will impact these qualities, but it is clear from the studio furniture manufacturers studied that physical models, particularly early hand made models, are important to ascertain certain qualities about the product that are currently not fully realized in a drawing or digital representation.

Studio furniture manufacturers are aware and understand that the final outcome of their design work is not set in stone and is free to change. As craftsmen, they are free to set their own path through the production of a piece (Pirsig, 2006). Their choice of low-fidelity physical models shows that they're not attached to a specific form. As designers they understand that what they're doing is indeed part of the iterative design process (Schrage, 1993) and beneficial to the development of the physical design (M. C. Yang, 2005).

Regardless of any one studio furniture manufacturer's adoption of digital design tools, all of them began their design process with simple pencil and paper sketching. While digital models produced in CAD software are valuable in many aspects of a new product development process, their creation is fundamentally at odds with that of the ideation process. The benefit of sketching has as much to do with the ambiguity of what is shown (Huang, 2008; Ibrahim & Rahimian, 2010; Israel et al., 2009; Pei et al., 2011), as it does with what is not shown; the so called 'holes' (Buxton, 2007, p.115). Both of these qualities are the antithesis to what a digital model provides: a resolution of ambiguity (Cook & Agah, 2009).

Whether conscious of these reasons or not, studio furniture manufacturers understand the value of sketching and start their design processes there. Digital design tools are only used when they demonstrate value and do not significantly alter the design process.

Finally, studio furniture manufacturers maintain a quality focus from beginning to end both in regards to the design and the production of fine furniture. This standard of work is what typically earns them the title of craftsmen. They pursue quality for it's own sake (Sennett, 2008) and in doing so, increase the value of their personal brand. This creates a positive feedback loop which ensures a personal responsibility for the design, the materials, and the work.

5.1. Future Research

As shown, studio furniture manufactures have a vested interest in the quality of their work as both designers and makers. Industrial designers may never receive personal recognition for a product that is manufactured in the tens of thousands. The division of labour that is absent for the studio furniture manufacturer may serve to be a division of responsibility for the industrial designer. A study of what quality means to industrial designers may aid in determining how best to achieve quality results in design thinking.

In a more direct extension to the research in this thesis, a large quantitative study is possible. Data of particular interest would a comparison of how age, education, and socio-economic status affect the usage of digital tools. Would a generation that has grown up with digital technology be any more or less likely to adopt digital design tools than one who had not?

Finally, with regards to those who are not adopting technology, a study of the particular challenges that are presented when learning CAD software could be completed with both an education and a human-computer interaction lens. In a similar vein, it would be worth comparing the learning curves of several software packages, and comparing them to learning curves associated with becoming a skilled artist or draftsman.

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GLOSSARY

Cabinetmaker: For the purposes of this thesis, the Statistics Canada "National Occupation Classification - Statistics 2006" system of occupational classification has been used. The definition for Cabinetmaker (H122) is as follows: "Cabinetmakers use a variety of woods and laminates to construct and repair wooden cabinets, furniture, fixtures and related products. They are employed by furniture manufacturing or repair companies, construction companies and cabinetmaking contractors, or they may be self-employed" (Statistics Canada, 2006a). Excluded from this definition are: Carpenters; Foremen/women of cabinetmakers; Workers that use woodworking machines to produce wooden furniture parts and furniture on a mass production basis in manufacturing plants; Furniture and fixture assemblers; Furniture finishers and refinishers (Statistics Canada, 2006a).

Industrial Designer	The definition for Industrial Designer was obtained from the National Occupational Classification – Statistics used by Statistics Canada. The entry for C152 Industrial Designers reads as follows: "Industrial designers conceptualize and produce designs for manufactured products. They are employed by manufacturing industries and private design firms or they may be self-employed" (Statistics Canada, 2006b). The definition also includes the following exclusions: interior designers, graphic designers and other non-industrial designers (Statistics Canada, 2006b).
Studio Furniture Manufacturer	A studio furniture manufacturer is a furniture designer/maker who has embraced the pattern of studio manufacturing, as described in Gotlieb and Golden's 'Design in Canada'. These individuals have chosen a middle ground between craft and industry by maintaining control of their own small scale production runs while employing craft techniques and aesthetics (Gotlieb & Golden, 2005, §Craft, Design and Industry). The typical studio

manufacturer is functionally a hybrid between an industrial designer and a cabinetmaker, though they need not officially be considered either. They are responsible for both the design and production of various articles of furniture that are sold in a boutique fashion. Due to a high attention to detail and excellence in execution, they are typically bestowed with the title of craftsmen.

Appendix A. Informed Consent

Introduction

The purpose of an informed consent is to ensure that you understand the purpose and your involvement in the study. After reading the informed consent, you should be able to determine whether or not you wish to participate in this study.

Study

This study will examine the barriers to the adoption of computer numerical control (CNC) equipment by traditional woodworkers.

Research Personnel

The following personnel are involved in this research project and may be contacted at any time. Ehren Katzur, ekatzur@connect.carleton.ca (principle investigator). Dr. Gitte Lindgaard (Co-supervisor), 613-520-2600 ext. 2255, gitte_lindgaard@carleton.ca or Lois Frankel (Co-supervisor), 613-520-5675, lois_frankel@carleton.ca. If any ethical concerns about this study should arise please contact Dr. Monique Sénéchal (Chair, Dept. of Psychology Ethics Committee), 613-520-2600 ext. 1155 monique_senechal@carleton.ca. Should you have any other concerns about this study, please contact Dr. Janet Mantler (Chair, Dept of Psychology,) 520-2648, psychchair@carleton.ca.

Purpose

The study aims to determine why professional woodworkers may/may not embrace CNC, in an attempt to generate a list of design opportunities for future systems.

Task Requirements

During this interview you will be asked about your career as a woodworker and your opinions concerning woodworking and CNC equipment. There are no correct or incorrect answers; I am seeking your opinion.

Duration and Locale

The duration of this interview will be between 30 minutes and one hour. The location of the interview depends on the interviewer and the interviewee.

Potential Risk or Discomfort

There are no potential risks or discomforts in this study. You will be allowed to take rest and take any breaks as needed.

Permission to audio record the interview

With your permission, I would like to audio record the interview. Once the data have been transcribed, they will be destroyed.

Confidentiality

All data will remain strictly anonymous. As a result, you will be ensured 100% confidentiality. The data collected will be coded in such a manner that your name will not be associated with the data. Only the researchers involved in this project will see the data.

Right to Withdraw

Your participation in this study is entirely voluntary. At any point during the study you have the right not to complete certain questions or to withdraw from the study without any penalty whatsoever.

This study has received clearance by the Carleton University Psychology Research Ethics Board.

I have read the above description of the study and understand the conditions of my participation. I agree to participate in this research project.

Participant Name: ____
Participant Signature: ____
Researcher Name: ____
Researcher Signature: ____

Appendix B. Interview Protocol

"This interview will last between 30 minutes and one hour. There are no correct or incorrect answers to the questions; I am seeking your opinion and personal views. If at any time you don't want to answer a question, simply let me know and we will move on; or if you wish to terminate the interview at any time, please feel free to do so. This interview will be used for my research purposes only. Only my thesis supervisors and I will see or hear any recordings or transcripts."

Appendix C. Debriefing

This interview was conducted to identify barriers to CNC adoption by professional woodworkers. CNC systems involve machinery driven by a computer, allowing both repetitive and unique parts to be created quickly and safely. However, such systems have not seen widespread adoption by smaller-scale traditional woodworkers. By identifying the barriers it will be possible to suggest design improvements to future versions of these systems.

Thank you for your participation in this research. Your time and effort are greatly appreciated! If you would like to obtain a copy of this interview or a summary of all the interviews upon completion, or if you have any questions about the research, please do not hesitate to contact me, Ehren Katzur, 613 898 5289, ekatzur@connect.carleton.ca.

If you have any complaints, concerns, or questions about this research, please feel free to contact, Dr. Gitte Lindgaard (Co-supervisor), 613-520-2600 ext. 2255, gitte_lindgaard@carleton.ca or Lois Frankel (Co-supervisor), 613-520-5675, lois_frankel@carleton.ca. If any ethical concerns about this study should arise please contact Dr. Monique Sénéchal (Chair, Dept. of Psychology Ethics Committee), 613-520-2600 ext. 1155 monique_senechal@carleton.ca. Should you have any other concerns about this study, please contact Dr. Janet Mantler (Chair, Dept of Psychology,) 520-2648, psychchair@carleton.ca. This study has received clearance by the Carleton University Psychology Research Ethics Board (ethics file number will be inserted here)

Thank you again for helping with this research.

Appendix D. Interview Questions

Warm Up Questions

1) Biographical information including:
   a) Highest level of formal education attained (*prompt: high school, trade school, college, university*)
   b) Please tell me about your work experience.
      i) How long were you there?
      ii) What were your duties with that company?
      iii) Did you enjoy the work; why or why not?
2) Have you ever seen any CNC machinery?
   a) What types of CNC machinery have you seen?
      i) Have you heard of any of the following: Routers; saws; lathes.
   b) Where have you seen these? (prompt: Video, magazines, paper promotions, trade shows)

Main Questions

3) Please describe what you believe are the benefits of CNC machinery?
   a) Which of these issues would be the most important to you:
      i) Interviewee's answer(s)
      ii) Safety
      iii) Productivity
      iv) Flexibility
4) Can you think of reasons why some other woodworkers haven't embraced CNC technology?

5) How do you think that using CNC machinery may affect the validity of the work done by a woodworker?

6) Do you own a personal computer?
   a) If not, have you ever used a personal computer?
   b) What do you use it for?
   c) Do you use a personal computer at work? What for?
   d) On a scale of one to ten, how proficient would you say you are at using a computer? One being not proficient at all, and ten being very proficient.

7) When faced with a decision of completing an operation with hand tools, or machines, what factors do you consider?
   a) Does safety factor into your decision?
      i) How?
   b) For which kinds of tasks would you use hand tools instead of power tools?
   c) Describe the skills needed for using power tools…
   d) …and the skills needed for using hand tools.
   e) Would / Do you outsource work to someone else? Please describe.
      i) What factors affect your decision to do this?

8) In your opinion, which requires more skill, perfect copies, or perfect one-offs?

9) What is the most expensive tool you use?
   a) How does it earn its keep?
   b) If owned by interviewee, was it a tough decision to buy it?
      i) Why?

c) How long do you estimate it will take to pay for itself?

10) When you buy a new tool, either for yourself or for business,

a) What sources of information do you use?

b) Do you have any allegiances to particular brands?

c) What characteristics do you look for in quality tools?

11) Have you considered purchasing a CNC machine to automate any aspect of your business?

a) What stopped you from making the purchase?

b) What would make you purchase one right away? (Recommendation, Ad, etc)

12) If not, why?

13) Do you use relief carvings in your work? What method do you use?

a) Large curves? Method?

b) Lines of holes? Method?

Cool Down Questions

14) Now tell me about your favourite piece of furniture that you've made.

15) Tell me about a piece of furniture that you've made where nothing seemed to go right.

16) Is there anything else you'd like to tell me, comments or questions that you have before we finish?

Appendix E. Initial Interview Questions

Could you please give me a short biography on yourself including any woodworking experience?

What CNC machines have you encountered or know to exist?

Please describe what you believe are the benefits of CNC machinery?

Would you associate CNC with any of these words: Safety, Productivity, Flexibility

Can you think of reasons why some other woodworkers haven't embraced CNC technology?

What is an acceptable a learning curve for a new piece of machinery?

Which instructional methods work best?

Where have you seen CNC machines advertised?

Appendix F. Results from Interview Questions

This table contains the results of the interviews that were conducted. Answers are abbreviated and simplified where necessary. Similar answers are noted by counters.

#	Question	Responses
1	What is your educational background?	University Engineering Degree (2), Art School (2), Some University (2), None (1)
	Do you have any formal woodworking training?	None (4), Private training (3)
2a	What types of CNC machinery have you seen?	Router (6), Waterjet (2), Lathe (1), Panel Cutter (1)
i	Have you heard of CNC saws or lathes?	No (4), Yes (2)
b	Where have you seen CNC machines?	Other Shop (4), Magazine (3), Show (2), School (2), Sign Shop, In person, Conference, Video
3	Please describe what you believe are the benefits of CNC machinery?	Production (3), Accuracy (3), Repeatability (3), Reads Drawings, Forms and Templates, Cost effective service, Safety, Flexibility, Versatility
a	Which of these issues would be the most important to you?	Accuracy (2), Flexibility (2), Freeing up labour, Repeatability, Safety
4	Can you think of reasons why some other woodworkers haven't embraced CNC technology?	Money (3), Missed the boat technologically, Foreign to them, No knowledge of CAD, Don't use computers as a design tool, Rebellion, No computer skills, prefer bench work, fear of learning something new, assumes less skill, Education, Computer phobia,
5	Do you think that using CNC machinery may affect the validity of the work done by a woodworker?	No (4), No but others think so (2), Yes but it depends
6	Do you own a personal computer?	Yes (6), No (1)
c	Do you use a personal computer at work? What for?	Email (6), Web (4), Design (3), Google Images, Research, Bookkeeping
d	On a scale of one to ten, how proficient would you say you are at using a computer? One being not proficient at all, and ten being very proficient.	4, 7, 9, 3, 2, 5, 5.5
7	When faced with a decision of completing an operation with hand tools, or machines, what factors do you consider?	Speed (6), Accuracy (3), Pleasure (2), Safety (2), Quality, Labour, Repeatability, Ability of the tool
a	Does safety factor into your decision? How?	Yes (5), Yes but it dictates which machine rather than hand vs. machine,

		No
b	For which kinds of tasks would you use hand tools instead of power tools?	Finishing (3), Details (3), Where there is heavy investment in a piece, Styling, Tasks requiring speed, Planing
c	Describe the skills needed for using power tools?	Knowledge of Safety / Danger (5), Knowledge of Tools (3), Knowledge of Material (2), Machine / Jig Savvy (2), Common Sense, Respect, Light Touch, Physics, Attention, Ability to learn
d	And the skills needed for using hand tools?	Sharpening (5), Dexterity (3), Knowledge of Tool (2), Knowledge of Material, Patience, Reading, Passion for handwork
e	Would / Do you outsource work to someone else?	Yes (6), Yes but only certain things
i	Please describe	Cost (3), Work is undesirable (2), Lack of knowledge (2), Speed, Accuracy, Work is stressful, Work monopolizes resource.
8	In your opinion, which requires more skill, perfect copies, or perfect one-offs?	Equal (2), Copies (2), Neither, One offs, Copies require more technical skill while one offs require a broader range of skills.
9	What is the most expensive tool you use?	Table Saw (4), Routers (2), Jointer (2), Lathe, Space, Experience, Labour, Me
a	How does it earn its keep?	Breaking down sheet material (2), Space saving, Insert tooling, Keeping fingers attached, Required Tool, Producing sellable goods, Versatility
c	How long do you estimate will it take to pay for itself?	Almost immediately (2), After two jobs, In the first year, Never considered it, When the safety mechanism fires it will have paid for itself,
9a	When you buy a new tool, either for yourself or for business, what sources of information do you use?	Fine Woodworking (4), Internet (3), Employees, Old Fine Woodworking, Woodwork Magazine, American Association of Wood turners, Friends, Furniture Society, Books, Local dealer, Other woodworkers, E-letters, Manufacturer specifications, Personal impressions
b	Do you have an allegiances to any particular brands?	No (5), Bosch (3), Dewalt (3), Makita (2), European manufacturers, King Industrial, Delta (Rockwell), General

c	What characteristics do you look for in quality tools?	Ease of Adjustability / Use (3), Cost (3), Fit and Finish (2), Durability (2), Service, Comfort, Overbuilt, Quality castings, Well made, Accuracy, "Good Enough", Minimal level of accuracy and quality, Weight
11a	Have you considered purchasing a CNC machine to automate any aspect of your business? What stopped you from making the purchase?	No (6), Space is a concern (2), Machine is not inspiring, lack of knowledge, Yes but price, space and computer kill prevented purchase
11b	What would make you purchase one right away?	Paid for itself (2), Price came down, Job required it, Move to production work, Only hope to utilize one more, Versatility, Unsure, Floor space is too much
13	Do you use relief carvings in your work? What methods do you use?	No (3), Yes with a chisel (3), Yes with a machine and a chisel
a	Large curves?	CNC prepared template, Router on a trammel (5), Bandsaw, Chainsaw, Mill, By hand
b	Lines of holes?	Drill press and a template (7)

Appendix G. Activity Theory Description and Justification

Activity Theory

Activity theory is a framework for studying human behaviour. It is not, as the name would suggest an actual theory (Kuutti, 1996; P. Turner & Turner, 2001). Engeström explains that "Cultural-historical activity theory was initiated by Lev Vygotsky in the 1920s and early 1930s. It was further developed by Vygotsky's colleague and disciple Alexei Leont'ev" (Engeström, 2001). Engeström himself has now become one of the main proponents of activity theory, particularly in his research into Finnish healthcare (Engeström, 1999, 2001).

Engeström credits Vygotsky with the creation of the concept of mediation (Engeström, 2001); that an individual and their actions must be thought of in terms of a mediating artefact. Leont'ev furthered the concept by refocusing the unit of analysis from individual human action to include the context of the action, which we now refer to as an activity (Kuutti, 1996). In 1987, Engeström expands the model further to include Rules, Community, and Division of Labour. The model is commonly represented graphically, as shown in Figure 1 - Basic structure of an activity, below. Activity theory has found success as a tool for requirements gathering and systems design in the field of Human Computer Interaction (HCI). Bonnie Nardi's book <u>Context and Consciousness</u> contained treatise on the topic of activity theory and HCI by Kari Kuutti, Victor Kaptelinin, Susanne Bødker, and Engeström himself, amongst others. Activity theory is defined by a few basic principles which are addressed in turn.

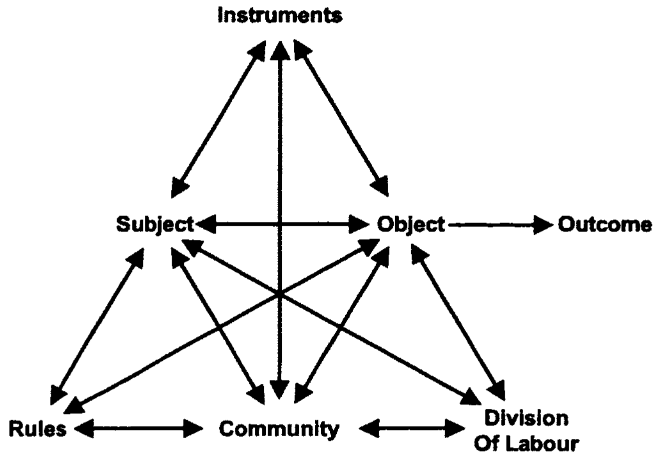

Figure 1 - Basic structure of an activity

Unit of Analysis

As mentioned above, there is a minimum unit of analysis necessary to make sense of human actions and that can include other individuals as well as society and culture. Activities are made up of actions, and actions in turn are made up of operations. Kuutti refers to these as the "hierarchical levels of an activity" (Kuutti, 1996). The reason for pulling back to a higher level of analysis is that the actions of individuals may not make sense unless viewed in terms of the larger activity. Kuutti cites Leont've's example of a tribe of hunters who split into two groups: catchers and bush beaters. If the goal is to catch wild game for sustenance, the actions of the group that beats the bush and scares out the animals, when viewed on their own, make no sense.

Multi-voicedness

Engeström explains that because of the collective unit of analysis, the division of labour, and the attention to historical context, an activity system is one with many voices (Engeström, 2001).

History

In order to understand an activity, one must understand the activity in the context of its own history. Activities can change and evolve across time yet certain artefacts may be carried forward. An understanding of the history may be the only way to determine why certain tools or rules exist.

Contradictions

Contradictions are points of stress between two nodes in the activity theory framework. The theory also recognizes these tensions between different activity systems. Engeström is careful to point out that "Contradictions are not the same as problems or conflicts" (Engeström, 2001). Contradictions have a historical precedent which in turn generates problems and conflicts. Four distinct levels of contradiction are specified in Engeström's <u>Learning by Expanding</u>:

Primary Contradictions – Originally, the primary contradiction was seen as a conflict between use value and exchange value in capitalist societies. Others do not appear to limit themselves to this definition, merely stating that primary contradictions are those which occur inside a node (Kuutti, 1996; P. Turner, Turner, & Horton, 1999).

Secondary Contradictions – These contradictions appear between nodes in the framework.

Tertiary Contradictions – These conflicts arise when a new activity is introduced into the current activity. Engeström uses the example of hospital administrators asking doctors to employ new procedures to embrace holistic medicine. While those procedures may be implemented, they may be resisted in favour of the old activity.

Quaternary Contradictions – These contradictions arise between activities that happen concurrently.

By gathering and analyzing the disturbances and conflicts as symptoms, the contradictions should be revealed.

Transformations

The last principle is that the possibility exists for participants transform the activity under the stress of contradictions.

Summary

Activity theory was chosen as the theoretical framework for this research for several reasons. Woodworking has a long history which features countless artefacts. As mentioned above, Activity Theory is rooted in the concept of artefact mediation and it requires careful study of the activity's history. Roman hand planes have been found which date 79 C.E. (Hack, 1997). The practice boasts scores, if not hundreds of different tools. The Lee Valley Fine Woodworking Tools catalogue now contains 268 pages of tools (Lee Valley, 2010). The main goal of this thesis is to determine why a new tool is not being adopted by participants in the woodworking activity. Activity Theory has actively been considered as a tool for diagnosing IT uptake issues by Turner and Turner (P. Turner & Turner, 2001). This thesis, while not limited to an analysis of the human computer interaction aspects of CNC, will address them. As evidenced by Nardi's volume, Activity Theory has been found to be compatible with HCI research (Nardi, 1996).

Appendix H. Activity Theory Method & Analysis

In accordance with Goulding's methods, the data was analyzed while it was being collected so that new areas of inquiry could be addressed. Questions were subject to change and would be updated, changed, or dropped as the interviews progressed. Interviews were transcribed in full and codified, looking for themes, keywords and patterns. Once recurrent themes were identifiable, the interviews were no longer transcribed in full, only coded.

Once each transcription was prepared, it was analyzed for strong opinions concerning CNC machinery. Most items involved mentioning CNC in negative contexts such as expressing short comings or limitations. Other items were comparisons between CNC and current methods or tools in which the later was spoken of very highly. These items became that interview's conflict contribution. Each was linked back to the specific location in the particular interview for easy cross referencing.

Conflicts were inserted into Microsoft Visio which facilitated easy graphic manipulation. The first interview conducted proved to be quite lengthy and was a beneficial starting point for the creation of the working framework.

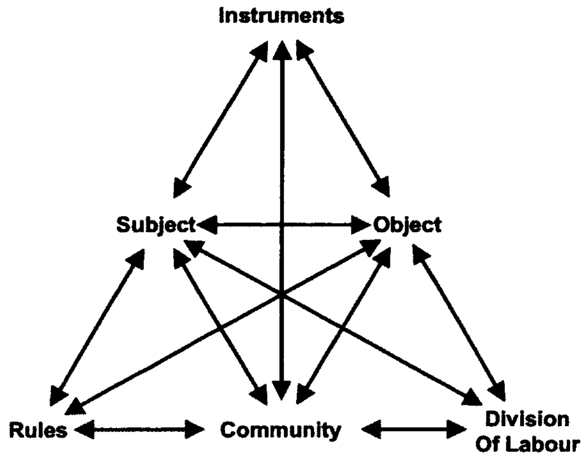

Figure 1 - Empty Framework

Working Framework

Each conflict was initially linked to only one node on the empty framework. Initial nodes were chosen by cursory examination of the context. Comments beginning "CNC is too x" were attached to the Instruments node, and so on. During a second pass, conflicts were examined for connections to a second node. A complaint that woodworkers have not been educated about CNC created a link between the Subject node and the Community node.

After the entire interview was analyzed in this manner, topics of concern at each node were extracted and placed beside the node. This working framework, found below, became the starting point for the next interview and was a method to enforce, at least initially, a common starting point for each analysis.

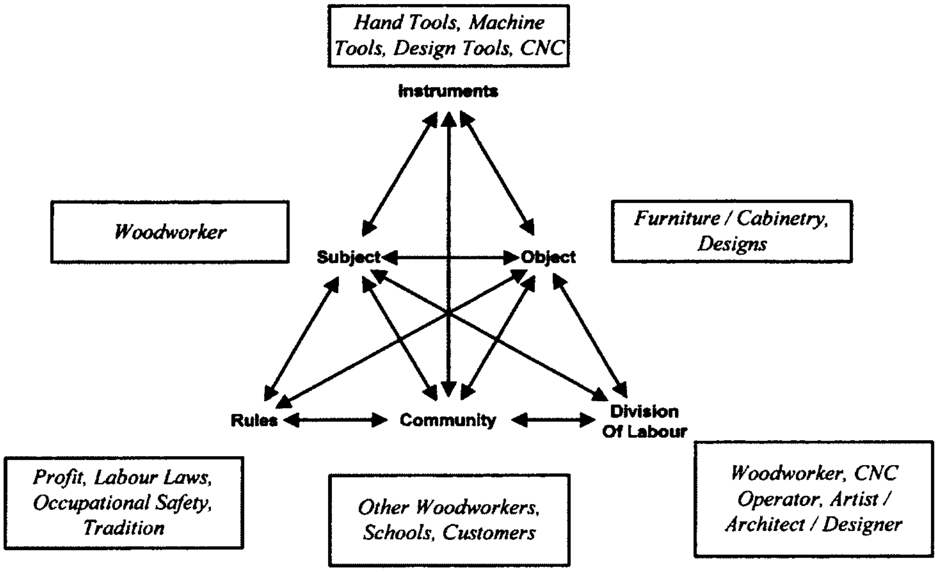

Figure 2 - Working Framework

This process was repeated for each interview until interviews ceased to provide new themes. At this point the frameworks and conflicts from each interview were layered upon one another to identify trends and patterns. Multiple identical conflicts were compiled and simplified. Some conflicts were moved under light shed by later interviews. To show what later became a quaternary contradiction the framework was split in two at the activity boundary. Any conflicts not having second nodes were considered primary conflicts.

Appendix I. Activity Theory Results

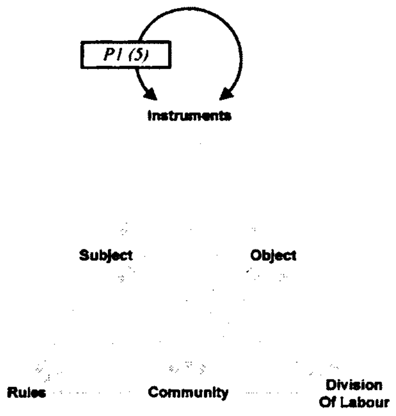

Figure 1 - Primary Conflicts

P1 Instrument Conflicts			#
1	Cost	A major concern of the participants was the cost of CNC machinery. Comments were limited not only to sticker price but also the costs associated with tooling and educating themselves to run the machine. Alternatively, paying someone else to run the machine was also seen as prohibitively expensive. One participant suggested that the machine should be able to pay for itself in one job, while another simply did not have the throughput to justify the cost.	11
2	Physical Characteristics	The physical size of the machine was brought up as a negative aspect. Interviewees felt that a machine wouldn't fit in their shop, or would take up valuable floor space. One woodworker cited the noise and the dust they create as being a reason to stick with hand tools.	5
3	Quality of Work	The view held by some is that a CNC machine does not produce good quality results and that they were able to achieve a higher attention to detail with hand tools. Another furniture maker was disappointed by CNC work he had seen claiming that it was less impressive than work done by hand.	3
4	Reliability	There was some concern that like other simple machine tools, CNC does not function perfectly all the time and can exhibit (like a computer) erratic behaviour.	2
5	Ability	In a point relating to both Cost and Physical Characteristics, one cabinetmaker claimed that affordable CNC machines are seldom big enough or feature rich enough to be valuable to the purchaser.	2

Table 1 – P1 Primary Conflicts

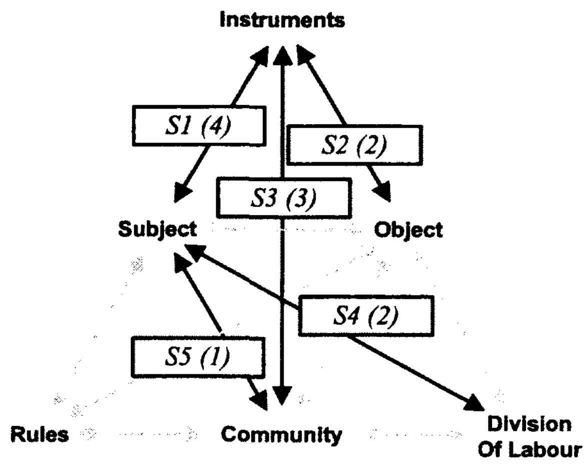

Figure 2 - Secondary Conflicts

S1 Instrument / Subject Conflicts			#
1	Technology is Foreign	One of the two main instrument / subject conflicts was that the technology (CNC) is completely foreign to woodworkers. One woodworker described himself and others as being "good old boys" that "missed the boat". Another suggested that woodworkers lack knowledge of CNC machinery, not the ability to comprehend it.	5
2	Computer Skills	Related to the first issue, but more focused is the computer barrier. Responses ranged from a lack of knowledge to an outright disdain for computers.	5
3	Impersonal	One furniture maker suggested that as opposed to CNC, hand tools can be custom fit to the owners hand and are very personal items.	1
4	Preference against	Simple preference for using hand tools over machine tools, let alone CNC machinery, was suggested by one woodworker.	1

Table 2 – S1 Secondary Conflicts

S2 Instrument / Obj[illegible]			[illegible]
1	Incorrect Tool	A major conflict between instrument and object can be expressed as CNC being the wrong tool for the job. One woodworker perceives CNC to be for mass production only, while another two express that the cost is inversely proportional to the length of the run. "The stuff I build just isn't that complex", says one cabinetmaker. In contrast to an earlier concern that CNC machinery is not very precise, two interviewees said that the accuracy and repeatability can be problematic. One claims that the accuracy involved in carving would cause the piece to loose character, while the other lamented that the repeatability would cause identical copies instead of creating unique pieces. One final concern was that CNC machinery would not respect the materials the same way woodworking tools do.	7
2	Tool overshadows work	One furniture maker expressed concern that the CNC machine became the focus of the work instead of the piece itself.	1

Table 3 - S2 Secondary Conflicts

S3 – Instrument / Community Conflicts			#
1	Affects validity of the work	While the majority of those interviewed had no problems with work done by CNC, several expressed that 'others' would say the skill had been removed. One woodworker recognized that customers would be more sensitive to what is made by hand but also stated that perceptions are changing.	3
2	Availability	One furniture maker recalled having seen many inactive CNC machines.	2
3	Consumer preference against	Slightly related to the above comment about customers, another woodworker recognized that there is a niche market for work that is impossible to do by CNC.	1

Table 4 - S3 Secondary Conflicts

S4 – Subject / Division [illegible]			
1	Enforces a division of labour	One furniture maker was very concerned about CNC enforcing a division of labour in a field where it is possible for a worker to do the entire job. Hiring of a CAD/CAM expert is still only half of the battle because being an expert in that field does not guarantee expert woodworking knowledge.	3
2	Concerns with outsourcing	There was apprehension on the part of two cabinetmakers to outsource CNC work to third parties.	2

Table 5 - S4 Secondary Conflicts

S5 – Subject / Community Conflicts			#
1	Education Issues	Lack of education about CNC was seen as a reason for poor adoption by three woodworkers. One suspects that the reduction in high school wood shops can be blamed.	3

Table 6 – S5 Secondary Conflicts

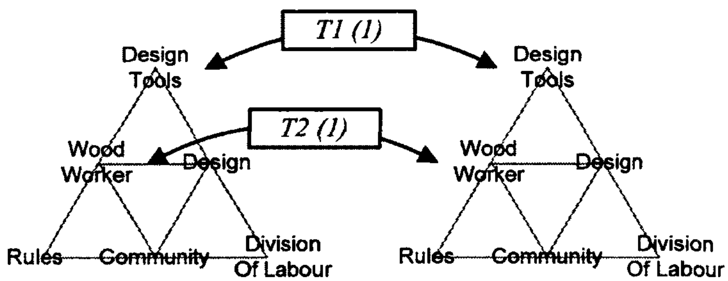

Figure 3 - Tertiary Conflicts

T1 Instrument / Subject Conflicts			#
1	Problems with Design Tools	Perhaps one of the single largest conflicts runs between the current activity and the proposed activity. For CNC to be used, the work must be designed with CNC in mind on a CAD platform. Woodworkers were concerned that they lacked the specific CAD skills necessary and that the tools were intimidating even for experienced computer users. Another concern was that designing on a computer provides no sense of scale. CNC was also mentioned as not being part of the creative design process and not inspirational. One woodworker felt that CNC will not make us better designers.	10

Table 7 – T1 Tertiary Conflicts

T2 Woodworker/[illegible] Conflicts			
1	Problems with woodworkers	One furniture maker suggested that perhaps woodworkers were afraid to learn something new.	1

Table 8 – T2 Tertiary Conflicts

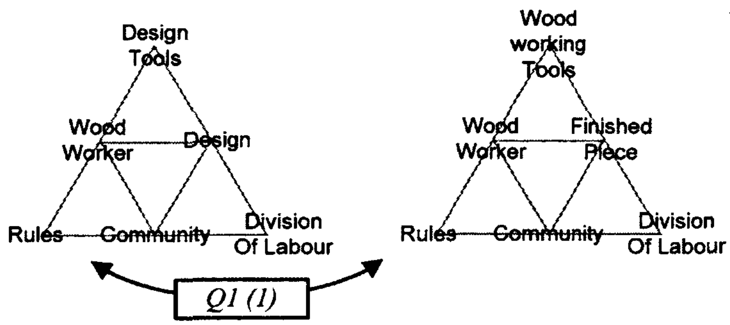

Figure 4 - Quaternary Conflicts

Q1 Instrument / Subject Conflicts			#
1	Workflow Restrictions	Relating to the tertiary conflict above, one furniture maker suggests that CNC enforces a division between two separate activities of designing and building, which normally coexist.	2

Table 9 – Q1 Quaternary Conflicts