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I, Nicholas M. Germann, hereby submit this original work as part of the requirements for the degree of Master of Design in Design.

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An Argument for Modern Craftsmanship: A Philosophy of Design, Materials, and Process in a Post-Industrial Environment

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An Argument for Modern Craftsmanship:
A Philosophy of Design, Materials, and Process in a Post-Industrial Environment

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by

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I see myself as a Digital/CNC Craftsman. What does that mean? It means that I utilize new and emerging tools to produce quality objects. The criterion for what constitutes “quality” emerges from my contemporary redefinition of what “Craftsmanship” means and its use applications. For too long, the idea of craftsmanship has been relegated to the unsubstantiated realm of “hand work” and “non-machine made” with no consideration for the processes involved. However, it is exactly the processes involved, and how well they are holistically integrated into the built object that this new redefinition of Craftsmanship argues for.
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INTRODUCTION: DESIGN, MAKING, AND CRAFTSMANSHIP

When one talks about craftsmanship to others, you are heading into a semantic nightmare; it is (in the words of David Pye) “a word to start an argument with”(1). Everybody seems to have a vague notion of what craftsmanship is and its associations with Making, but are not able to define its attributes. With no objective criteria to be utilized, one is left to the individuals subjective emotional response; or the “I’ll know it when I see it” response.

It is the purpose of the thesis to clarify this haze of vagueness. To form a clear line of understanding between Making and Design, and its context within the ideal that is Craftsmanship. The end goal is not to end the craftsmanship argument, but to shift arguments away from what craftsmanship is, towards its particular attributes and applications of built artifacts.

IN THE BEGINNING...

It is proper to begin within the context of the origins of Making and by association Design. It has been theorized by modern anthropologists and evolutionary biologists that the origins of homo sapiens and their dominance of over other animals is due to the evolution of the human hand and its capabilities to make tools that aid in the quest for survival combined with the human brain and its superior ability to reason. As new tools evolve through improved hand functionality, the brain’s rational capabilities on how to utilize new tools evolves simultaneously. This then is the cyclical process of evolution based upon tool behavior and utilization not just brain size or hand development.

The current model of thought is that Man reached its current anatomical form about 200,000 years ago and adopted “modern” behavior around 50,000 years ago. What is meant by “modern”
behavior “is specialization of tools, use of jewelry and images (such as cave drawings), organization of living space, rituals (for example, burials with grave gifts), specialized hunting techniques (such as using trapping pits or driving animals off cliffs), exploration of less hospitable geographical areas, and barter trade networks” (2). Material manipulation during this time was minimal utilizing found objects that fulfill necessary requirements of use. The exception to this was the utilization of formed stones used as arrow and spear points, and as cutting edges for butchering animals.

This technique is called Stone Knapping (or litchi reduction) in which a hard rock with a cryptocrystalline makeup in either the sedimentary variety (flint or chart) or the volcanic natural rock glass variety (obsidian or tachylyte) is struck to produce flakes (also called lithic flakes) with distal edges that are only a few molecules in thickness making them extremely sharp but also very brittle. It is this method of fabrication that employed the emerging humans’ progressively evolving hand dexterity and with it complex thought and planning.

During the Stone Age, utilizing stone knapping to create tools was considered to be high technology. The next leap forward did not happen until 3,300 BCE and the beginning of the Bronze Age. Bronze is the combination of copper, tin, and/or arsenic that have been extracted from their respective ores by the process of smelting. The result from this process is a material that can be manipulated in many different ways. It can be cast, beaten, bent, sharpened, re sharpened, polished, and generally worked to create a large variety of objects (tools, weapons, armor, utility objects, and luxury objects). The Bronze Age represents the overall context of Making the emergence of large scale manipulation of raw materials (or base materials), and the development of tools that in turn make other tools.

With the introduction of bronze, material manipulation was able to happen on a much larger scale. Wood and stone could now be formed and processed using tools that can better maintain their cutting edges and shape. With these new and advance tools,

the types of artifacts that could be created by Bronze age artisans expanded exponentially and showcases the thought of tools to make tools to make objects and the emergence of man as HOMO FABER.

MAN AS HOMO FABER:

The term Homo Faber (meaning Man the Maker) was first coined by the Roman dictator Appius Claudius Caecus (340 BCE - 273 BCE). He talks about the “ability of man to control his destiny and what surrounds him: Homo Faber suae quisque fortunae (“Every man is the artifex of his destiny”) (3). Man the Maker is the one who shapes the world, he/she who builds, creates and manipulates. These are people who are considered not only problem solvers but also problem finders. The difference being knowledge as static contemplation verses knowledge as active engagement. Richard Sennet makes the differentiation as follows:

When practice is organized as a means to a fixed end, then the problems of a closed system reappear; the person training will meet a fixed target but won’t progress further. The open relation between problem solving and problem finding...builds and expands skills, but this can’t be a one-off event. Skill opens up in this way only because the rhythm of solving and opening occurs again and again. (4)

Man as both problem solver and problem finder coincides with the fundamental difference between what would be considered skilled verses unskilled labor. Examples of each being a master carpenter that “designs” and builds (skilled) verses a general construction laborer that follows a specified direction (unskilled). This is not to say that an unskilled laborer is “bad” but represents the current duality of thought.

These aspects of Homo Faber in conjunction with individual


Man being a skilled or unskilled worker, introduces aspects of learning and its applications with Making. In the learning of a particular skill and/or technique there develops an understanding between the Hand and the Head or Theory and Application. When our ancestors were creating the stone tools necessary to survive in a hostile world, they were not just beating two rocks together, and then “POOF” a fully formed cutting blade would appear. Firstly, it took careful observation of what specific types of core stones produced the best types of fractures, along with careful observation of what type of percussers were best for the three different types of lithic reduction. Secondly, it would have taken careful observation of someone else performing these actions to learn the basic principles of design and production (what shapes seem to be the best for a specific application, how to hold the core, where to strike, best type of materials to use, and where to find them). Thirdly, the individual’s own production experiences would have been the best method of solidifying the observed Theory and Application. Although one can observe how to hit, there is no way of really knowing how hard to hit until one does it for themselves and then it would take many failures to learn the proper technique and to learn what constitutes failure or success. This experience then reaffirms the lessons learned by addressing both Theory and Application as a continuum and not two aspects to be considered separately.

This dynamic interplay of Theory and Application teaches not only the What but more importantly the How and the Why. Sennet says that:

In learning a skill, we develop a complicated repertoire of procedures. In the higher stages of skill, there is a constant interplay between tacit knowledge and self-conscious awareness, the tacit knowledge serving as an anchor, the explicit awareness serving as critique and corrective. Craft quality emerges from this higher stage, in judgments made on tacit habits and suppositions. (5)

It is a corrective critique, in conjunction with craft/craftsmanship, which the Unskilled laborer lacks. Theirs is a job of performing a predetermined series of steps, whether it is a worker on an assembly
line doing the same action repeatedly for thirty years or the roofer carrying buckets of tar up and a ladder to the roof of a new building. There is a straightforward set of criteria for determining success or failure for these types of work; were the correct number of bolts installed on the manifold, was a sufficient thickness of tar laid down so that there are no leaks. Again, this is not to say that an unskilled laborer is “bad” but represents the current duality of thought; there is no shame in honest work.

The quality of the work produced is a direct showcase of the set of skills, knowledge, and technique that a Maker has developed. What constitutes quality for a particular trade is usually developed for long periods of time, sometimes generations depending on the trade in question. Man the Maker has the desire to produce quality work in all aspects (from design to execution). It is this characteristic that helps to define Craftsmanship and its relationship to Man the Maker.

THE MANY FACES OF CRAFTSMANSHIP:

Craftsmanship, like design, has an elusive definition. It has the multiple connotations from the mundane to the philosophical, as evident from the following definitions and explanations:

-Richard Sennet says that:
Craftsmanship is the skill of making things well...Craftsmanship names an enduring, basic human impulse, the desire to do a job well for its own sake... (and) it focuses on objective standards, on the thing itself...Every good craftsman conducts a dialogue between concrete practices and thinking; this dialogue evolves into sustaining habits, and these habits establish a rhythm between problem solving and problem finding. (6)

-Peter Dormer says that:
Craftsmen and (C)raftswomen may be considered as people who direct the whole of their work process as well as the design of their artifacts. (7)

7: Dormer, P. (1990), p. 30
- Juhani Pallasmaa says that:
The craftsmen needs to develop specific relationships between thought and making, idea and execution, action and matter, learning and performance, self-identity and work, pride and humility. The craftsmen needs to embody the tool or instrument, internalize the nature of the material, and eventually turn him/herself into his/her own product, either material or immaterial. (8)

-Malcolm McCullogh says that:
Craft remains skilled work applied to practical ends, It is indescribable talent with describable aim. It is habitual skilled practice with particular tools, materials, or media, for the purpose of making increasingly well executed artifacts. Craft is the application of personal knowledge to the given form. It is the condition in which the inherent qualities and economics of the media are encouraged to shape both process and products. It is not about standardized artifacts, however. It is not industrial design. It remains about the individually prepared artifact, which is newly practiced due to digital computing. Craft is certainly an application of skill, and it may yet involve the skilled hand. (9)

-David Pye says that:
Workmanship of the better sort is called, in an honorific way, craftsmanship. Nobody, however, is prepared to say where craftsmanship ends and ordinary manufacturing begins. It is impossible to find a generally satisfactory definition for it in face of all the strange shibboleths and prejudices about it which are acrimoniously maintained. It is a word to start an argument with...If I must ascribe a meaning to the word craftsmanship, I shall say that as a first approximation that it means simple workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends upon the judgment, dexterity, and care which the maker exercises as he works. (10)

From these various quotes we begin to see a pattern, that craftsmanship emerges from the inherent combination of a particular idea and the necessary skill to bring that idea into the physical world. Moreover, it is from this combination that craftsmanship
creates an additional value to the object (regardless of scale) that it did not have already. This value is therefore personified through the knowledge, execution, and determination of the craftsman/craftswoman. He/She provides not only the “What” and the “How,” but also the “Why”. The interesting thing about Why is that it moves beyond the notions of Theory (the inherently virtual What), and Making (the physical process of materials and their manipulation). The Why focuses on these two elements and brings value (either physical, spiritual, or both) to the object being created. From this explanation, one can begin to see the reasoning behind objects that exhibit “good” craftsmanship being worth more in a monetary sense. More so than the inherent worth of the objects raw materials; more than the producers $ per/hour rate; or the objects necessary up-charge in order for the producer to stay in business. The craftsman is able to take different material elements, and through their tools of choice, personal vision, technical expertise, and personal experience, transform them into things of greater worth than they had previously.

The best example of this concept is illustrated by the preparation of a meal. If for example a classically trained chef with years of culinary experience, and an average home cook were to take the same ingredients, and make the same dish, with the same tools, in the same kitchen, to give to the same people; the chef’s dish would (in theory) be superior (of more value) than the home cook. Why? The chef, having all of his/her experience, and expertise has an intimate understanding of the variables at hand. He/She understands how to bring about the best aspects of the ingredients no matter what the quality (as long as it is usable) using the available tools and work setting and is able to adapt these variables to their advantage (from the ingredients at hand, and the available tools, the chef can tweak the recipe to their advantage). The home cook however follows the recipe that they have and hopes for the best. They do not have the understanding or the experience with their ingredients or tools and are unable to produce the quality meal. They are unable to adapt.

The potential quality of the meal we are discussing has to do with the initial mindset of the producers, is their intention to produce a high quality meal at all. If the answer is no, they both have no
real intention of producing a quality meal, it makes sense that the chef could prevail or it is a tie. This depends upon each producer’s personal definition of quality that defines their work or upon external qualities imposed upon them. It can be said though that if their intention is not to produce quality, then the value created would be of extremely less value than if their intentions were to produce quality end products.

Out of this explanation, the best quote that personifies quality/value argument comes from Howard Risatti. He says:

Craftsmanship is a kind of activity that can be said to fuse theoria and poiesis because it has both an abstract and a practical, material aspect. It involves risk at the level of workmanship through technical manual skill, as Pye claims, but it also involves an element of abstract conceptualizing as in design. In other words, craftsmanship is not limited solely to the execution of sophisticated technical manual skill (whether risky or not); it also involves the creative imagination in the employment and guidance of sophisticated technical manual skill through the hand (i.e. human control). Thus craftsmanship should be seen as existing within the realm of praxis because technical skill and creative imagination come together in craftsmanship to bring the thing into being as a physical-conceptual entity. Craftsmanship, like praxis, should be understood as a creative act in which actual physical form is brought together with an idea/concept. This is the creative act at the basis of every original craft object. In this sense, craftsmanship is a process of formalizing material and materializing form that results in the creation of an original craft object. (11)

This introduces interesting aspects of Classical philosophical thought into the discussion Craftsmanship and its value enhancing ability, in conjunction with the ideas of Theoria, Poiesis, and Praxis.

THEORIA, POIESIS, and PRAXIS

These Greek elements were derived from Aristotle to explain the three types of activities that Man engaged in.
Theoria: The root for the English word “Theory”, in the original Greek means “things looked at, speculation, contemplation”. Can be thought of as “intellectual seeing” or “knowledge of reality itself, it is a search for truth.

Poiesis: “to make, making, productive activity”, relies on a kind of knowledge that Aristotle termed techne, or expertise. From a production standpoint, the ends are set.

Praxis: “Doing, practical activity, purposive action”, relies on a kind of knowledge termed phronesis, or practical wisdom. In relation to poiesis (which on requires skill), praxis requires virtue, requires knowing which activities and ends are worth pursuing, a value oriented action, has no defined limit by which it ceases at some time (i.e. no set end).

As with the meal example from before, it is through ones abstract conceptualization and technical knowhow of the ingredients and tools utilized that creates a higher quality end product. However, it is only through the combination of these two aspects that the concept of “higher quality” is able to take place. The examination of Praxis highlights this idea.

Aristotle says this about Praxis in relation to Poiesis (and by extension Theoria)

Thought itself moves nothing; but only thought that is for the sake of something and practical. This indeed rules productive thought also, since he who makes something always has some further end in view; that which is produced is not an end in itself, it is only for something and someone. Whereas that which is done is an end in itself, since doing well is the end, and it is at this that desire aims. (12)

This centers Praxis as a holistic and cyclical mediator between thought and production - for Praxis, as a value-oriented action, has no set ending. Praxis utilizes experiences to inform future thought and production and therefore furthers knowledge or “practical wisdom” (Phronesis).

The importance of Phronesis within the Praxis framework lies
not only in the attainment of experiential knowledge, but in how it is to be utilized within Theory and Poiesis. For Phronesis involves the ability to decide how to achieve a certain end and the ability to reflect upon and determine that end. This requires not only knowledge of "universal" principles but of "particulars". Aristotle says:

(Phronesis) [is not] a knowledge of general principles only; it must also take into account of particular facts, since it is concerned with action, and action deals with particular things. This is why men who are ignorant of general principles (Theory) are sometimes more successful in action than other who know them...And (Phronesis) is concerned with action, so one requires both forms of it, or indeed knowledge of particular facts even more than knowledge of general principles. Though here too there must be some supreme directing faculty (Theory). (13)

Phronesis is concerned with particulars, because it is concerned with how to act in singular situations. One can learn the principles of "universal" (by my argument an overall Theory (theory of action, intent, purpose)), but with the understanding of the particular, one enables their application in the real world, in situations one could not have foreseen. But this sort of understanding requires the worldly experience; experience of the particular "actions" involved. (14)

Through this established definition of Phronesis, Praxis can be seen as establishing a process of utilization. A process (as defined as a series of progressive and interdependent steps by which an end is attained; or implies a formal or set order of doing a thing) of utilization requires a fluidity of implementation, especially if that particular overarching process is to be used for multiple applications. This process utilization is the foundation for my redefinition of modern Craftsmanship.
I see Craftsmanship as a process, a combination of both “processes of thought” and “processes of action.” What this means is that an intended “object” (physical or virtual, of any scale) that is said to have characteristics of craftsmanship, showcases this combined process. This involves the holistic integration of three aspects, Design, Materials, and Means. These aspects can be further broken down as follows:

- **Design as the “process of thought”**: Its main purpose is to establish a set of underlying principles. This would include aspects of object philosophy of intent, utilization, functionality, form, aesthetics, problem solving. It also has other specifics dictated by the other fields that utilize it. These would include (but are not limited to) architecture, industrial design, graphic design, fashion design, engineering (and its various subcategories), transportation design, etc, etc. Design is an inherently virtual and internal thing, existing in the head of the designer. The designer then tries to communicate what is in his/her head by drawing, sketching, modeling (in the computer or physically), explaining what their idea is in all of its many aspects. The more comprehensive the explanation, the better it is interpreted and understood by others. However, this design comprehension is never absolute. A communicated design can never fully say everything; there are always some parts that can only be realized through a “process of action.”

- **Materials as one part of the “process of action”** are the means by which an interpreted design enters the world, whether physical and/or virtual. Each material has its own unique set of characteristics that either work with or against a particular design. Such aspects for physical objects would include inherent strength, weight, density, available dimensions (raw or standardized), usable manipulation methods, economic costs, etc. What material(s) get used (type and amount) is one part of establishing objective value.

- **Means is the other part of the “process of action”**. It is the means by which raw materials are manipulated into their intended designs.
Means can be further broken down into two parts, “technology,” and “skill of use”. Technology is the tool(s) needed for a particular material’s manipulation, which would include traditional tools such as chisels, saws, and drills; but extends to other things such as computers, software, and machinery. “Skill of use” can be interpreted as tool expertise, how to utilize each tool, what tool is best for a particular material, what tool is best for a particular process, and “skill” of execution. This knowledge not only includes aspects of technology, but of the material(s) to be manipulated and how the materials that manipulate other materials interact with the action(s) of manipulated.

The application of these processes in relation to a produced artifact is one of degree’s and not absolutes. This means that a given observer’s interpretation of an artifact’s Craftsmanship characteristics depends upon their own personal levels of experience with the given material(s) utilized, method of manipulation(s), and design/theory. What this process interpretation eliminates is the notion of craftsmanship being defined by the tools used, but how well or poorly the tool(s) are utilized. It is used as a critique of the object based upon the integrated processes/methods utilized, not on processes that somehow “define” the artifact (i.e. Hand-made verses Machine-made)

Traditionally, it is through the “process of action” and its Materials and Means that Craftsmanship as an ideal is traditionally associated; an association of “making by hand”. A more philosophical understanding of this statement could be understood as manipulation directed by and dependent upon the human mind and its judgment articulated by Man’s interaction with the process. Such a view would fall directly in line with David Pye’s theory that craftsmanship defining element is what he calls “Workmanship of Risk” where the end product is directly dependent upon the skill and dexterity of the workman, it is in constant danger of being destroyed by worker. This is contrasted by the “Workmanship of Certainty” where the end products defining characteristics are “predetermined and unalterable once production begins” (15), as in mass production. Nevertheless, like our modern re-definition of Craftsmanship, Pye also agrees that
the distinction between Risk and Certainty is one of degrees, not absolutes. He says:

Typewriting represents an intermediate form of workmanship, that of limited risk, you can spoil the page in innumerable ways, but the N’s will never look like U’s, and however ugly the typing, it will almost necessarily be legible. All workman using the workmanship of risk are constantly devising ways to limit the risk by using such things as jigs and templates. If you want to draw a straight line with your pen, you do not go at it free hand, but use a ruler, that is to say a jig. There is still the risk of blots and kinks, but less risk. You could even do your writing with a stencil, a more exacting jig, but it would be slow. (16)

Pye’s notion of limited risk by the utilization of “jigs” has interesting applications in conjunction with our redefinition of modern craftsmanship. The jig is an aid to simplify tasks that would otherwise be more complicated to perform. But the aided task is still dependent upon the user controlling the action. The jig, although it might speed up the process, does not guarantee that the process will correct. This is dependent on the initial setup done by the user, and his or her skill at performing those actions. A straight line, no matter how well it may have been executed, is useless if the initial measurement is incorrect. Moreover, from the other end of the spectrum, it does not matter how certain the process is, if the assembly line is producing high tolerance parts that are not what the customer ordered because of a mistake made by the technician(s) that did the initial setup, is not going to keep them from being sued.

The dependence on the user understanding the relationship of how initial actions then influence latter actions is a major aspect to our redefinition of modern craftsmanship. The “processes of thought” and the “processes of action” are integrated aspects of how Man controls the processes of Making. The ranges of its utilizations span the entire spectrum, from hand-planning to CNC machining. In fact, it can be argued that the more front loaded the processes (like what is found in CNC fabrication technology), the more necessary a holistic view of thought and action is needed. However, these front loaded processes inevitably lead to questions of how much control do we really have over the making process.
CRAFTSMANSHIP AND THE INDUSTRIAL REVOLUTION

This issue of who or what controls the making of objects and artifacts has its roots in the stances taken during the Industrial Revolution. It is during this time that manufacturing machines became an efficient and cost effective alternative to the traditional and established production methods (i.e. traditional artisans). It is also the advent of the factory as a manufacturing entity. Of the many reactions to the Industrial Revolution, the view that the machine replacing the human maker is the most prevalent. Most craft discourse starts at this assumption. This view sees the machine as a usurper of the traditional artisan, taking away their work and pride and reducing them to a lever puller within the production process. The argument essentially boils down to issues of control, does man or machine fundamentally control the process of production. It is this perceived loss of control to the “machine” that lead to the many reactions against it and to the artifacts created by it. This led to the view that “hand work” is better than the machine made, has higher aesthetic qualities than the machine made, and is the only method to create Craftsmanship quality objects. This is best seen in the writings of such critics as John Ruskin and William Morris and popularized stylistically with the Arts and Crafts movement (approx 1880 - 1930ish)

But is this loss of control actually true, or is it based on nostalgia for the past that was severed by the rise and continual progression of technology? My research indicates the latter verses the former. One aspect that gets overlooked within this discourse is who was it that built the machines and made them functional enterprises of high quality and precision? The answer is a craftsman. The major difference between these craftsman and the ones of nostalgia is that of technological utilization in terms of the objects being made, materials being used and the process of material manipulation. Glenn Adamson makes this argument:
There are several ways in which one might rewrite craft history during the industrial revolution. First, and most obviously, the machines in question had themselves to be made. Metalworkers, in particular, had never been so in demand, so various in their skills (working to widely divergent degrees of tolerances’ in many materials), or as crucial to the economy as a whole. Breakthroughs in design and engineering were often premised not on the elimination of hand tools, but rather on their improvement...By 1800, the trade focused more and more on base metals instead of silver, and there was an unprecedented level of respect and autonomy afforded to the invention and skill of the ‘industrial artisans’ who made such things as bridges, steam engines, and machine tools. As the industrial booster Samuel Smiles noted...‘it is one thing to invent and another thing to make the invention work.’ In this sense, the modern industrial artisan may have had more control and autonomy that any craftsman (especially the vast majority working outside of elite patronage structures) had previously enjoyed. (17)

From this examination we can see that the Craftsman ideal shifted more into the developing industrial sector, a sector that required persons of knowledge, skill, vision to produce the technology which in turn is utilized (in conjunction with a unskilled labor force) to make mass produced artifacts. Rafael Cardoso says:

By the early twentieth century, the technological development of machines had changed the industrial scenario considerably. Poor finish was no longer a perceived quality of mechanically made goods. Marcel Duchamp’s supposed 1912 comment to Brancusi (Romanian Sculptor 1876-1957) to the effect that painting was washed up because no artist could do better than an aeroplane propeller, reveals a novel attitude to machine production. Here--perhaps for the first time from the mouth of an artist--is frank admission that industrial artifacts possess an elegance and integrity of their own, quite divorced from any considerations of the nobility of handwork [as it relates to the nostalgic sense]. The perfection of mass-produced technology signaled a new perfectibility of industrial artifacts...[t]hrough informed effort and precise methodology, design is able to guide mechanical work and render it superior even to handwork...[Re]gard[ing] the Morrisian cult of craftwork [as defined by the nostalgic view of the artisan] in such as context, there is little option but to accept grudgingly the technical superiority of machines and retreat to the moral high ground. Though craft is clearly unable to compete with the efficiency of machines, it purportedly retains some sort of Benjaminian aura, grounded in the uniqueness of

17: Adamson, G. (2010), p. 43
individual manufacture. Imperfections and deviations come to be seen as legitimizing characteristics. The historical roles are reversed—perfect machine work is depicted as bad and imperfect hand work is good. There is not a particularly convincing stance for a consumer society in which more, better and cheaper artifacts are made continually available through the improvement of mass production. Craft is eventually cornered into a position of terminal nostalgia or, worse, of elitism, via a notion of consumer exclusivity. (18)

The technological advancement flood gate that was opened during the Industrial Revolution can be seen as shifting the focus from tradition to future oriented; from ‘this is what has been done’ to ‘who knows what is possible’. This shift is significant in that it marks (in the prevailing Morrisian craft theory) the end of the critical engagement of Man and his manufacturing method, and produced the view that man is subordinate to the machines and the “modern” methods of making (the machines controls the Man). In this fractured state, each part (Design, Materials, and Means) is perceived as separate and competing elements. The role that Craftsmanship (as I define it) plays within this context is to reestablish the holistic and cyclical nature of artifact production. Reestablishing this viewpoint abolishes the handmade vs. machine-made argument, and introduces evaluation criteria for made artifacts.

But in what way can this new definition be applied to the process of Making? As a general theory of application, the possible utilizations are near endless. Richard Sennet makes an eloquent argument for Linux programmers having Craftsmanship characteristics, by utilizing a complex medium that requires skill and forethought to produce a desired end result. Due to the fact that there are multiple ways to get to a functioning end result, issues of methodology, proper thought processes, and quality (good, bad, good but not good enough) of the end result come into play. A majority of those who hold to a Craftsmanship philosophy/ideal take issue with associating digital constructs with Craftsmanship qualities due to any lack of “physical” interactivity (you can’t hold a web site in your hands, admire its materiality, its finish, or the means in which it was created). I would say that this viewpoint is based on a
misunderstanding on the “Materials” and the “Means” that go into the creation of digital artifacts.

The particular application that this thesis intends to explore is the within the utilization of CNC (Computer Numerical Control) process of material manipulation as a means of creating a Homo Faber centered Craftsmanship philosophy. The reason behind this investigation is to showcase how emerging decentralized CNC technology can be utilized as a controllable tool that would enable the Craftsman to produce quality, customized artifacts at scalable outputs that are able to compete economically.

THE UTILIZATION OF CNC AS A METHOD OF FABRICATION

The widespread use of NC technology has been around since the 1940’s and 1950’s. The NC methodology differs from other manufacturing machines in that NC machines use a pre-programmed encoded tape or card to produce desired movement. This program is created by a human programmer that develops intended motions and operations that the NC machine then performs. The machine operator then feeds the encoded cards into the machines reader that in turn produces machine movement. Other prominent manufacturing process utilize either more mechanical means of control (like cams controlling the movement of engine pistons) or through manual means utilizing leavers and wheels (like manual machining mills, lathes). The essential difference between NC technology and others is that NC is able to be a tool for automation that can also be made to make vastly different variations of artifacts (within the confines of the build envelope, material capabilities, tolerances, and hold down) by a simple change in program. Unlike the machines based on mechanical control (were the machine/mechanism itself has to be changed, rearranged, or augmented to produce different results) adapting to new production scenarios often requires extensive capital investment that only happens within high volume production. Manual machines (were the skill and experience of the operator/machinist dictates not only the quality of the end product)
product but who produces the parts; the more complicated the part going to the more skillful and experienced operator/machinist), are more adaptable to changing work but has historically suffered from competition of high volume machine production but excel at low volume, specialized work. But by utilizing NC technology, one can straddle the fence and take advantage of the pros from each (adaptability with the possibility of higher volume output).

The switch from NC to CNC came as a direct result of advancing computing technologies. Instead of using punch cards/tape, programs were created on the computer and then transferred directly to the machine. These programs utilized G-code (a type of preparatory computer code) which in its earliest incarnations was written by a programmer to drive machine motion and action. This code specifies tool motion within the build envelope, rpm of said tool, and feed rate through the material with the end result being an artifact of specific dimensions and within specified tolerances. The writing of these programs necessitates the extensive pre-definition and forethought of the artifact being created. Not only does the programmer need to know what the object is, but the material properties that the object will be created in, how the geometry of the object will react to the material properties, how best to cut away excess material, what tools to use, how fast to move a specified tool through the material, and at what rpm the tool spins. These variables are dependent on the capabilities of the machine being used, such as its build area, spindle type, possible torque output, rpm output, range of tools that can be utilized, machine rigidity, and (possibility the most important aspects) the machines overall specificity and/or versatility.

With the introduction of CAD (computer-aided design) and CAM (computer-aided manufacturing) programs, came the ability to have a true end-to-end production method. This means that the digital artifact created in a CAD software program (either a 2D drafting, or 3D modeling program) has a direct impact on the toolpath and program creation that takes place in the CAM software which that map out tool movement based upon specified user input and tool selection against the imported digital model. The “success” of the end result artifact is therefore depended upon the accuracy and quality of the digital geometry (whether 2D or 3D) and the quality of
The start of the new millennium saw the beginning of widespread decentralization of CNC technology as a general fabrication tool. As with the proliferation of the personal computer, increased access is made possible due to the falling costs associated with these machines, and the increasing amount of open source information. This unprecedented access to technologies with far ranging capabilities has amassed staggering interest in the design world, especially in the field of architecture. One can almost view this stage as a natural extension to the “Blobitecture” craze of the mid 1990’s, where the introduction of robust 3D modeling programs enabled the creation of new forms never before seen, let alone producible within traditional Cartesian space. CNC technologies are being utilized to create in the physical world, digital forms defined by scripted, generative, algorithmic, parametric, and other computational means within 3D modeling software.

Current utilization of these digital fabrication tools is that of experimentation; pushing the boundary of what is new and possible with these technologies. However...can this area of research sustain itself over the long run? The answer is no. The “Cult of the New” only survives by “one upping” previous attempts, to do things bigger, “better”, and more outrageous than the ones before. At some point though, maximum saturation occurs, and interest dies down and shifts to another areas (and if history is any indication, this shift seems to go to the opposite end of the preverbal spectrum). The curse of the “Cult of the New” only seems to happen when the only legitimizing factor of the thing created is that you use the new popular process without any further criteria for success; it is seen as the end product verses as a means to an end. By relying on the mystique of the process, there is no need to provide additional reasoning for justifying what you are doing. It can (and has) been used to cover up for bad and poor design of all types; but when you are able to see through the mystique, what is left may only be a poorly designed artifact whose only apparent function is visual stimulation. But the utilization of digital fabrication has much more potential than just making interesting visual artifacts, I see it as a vehicle for the re-establishment of a Craftsmanship ideal.
DIGITAL FABRICATION AS A TOOL FOR A CRAFTSMANSHIP IDEAL

CNC technology as a tool for Craftsmanship has the immense potential to change the landscape of making through the realm of digital fabrication. One could argue that these new media and emerging tools allows for the return of the self sufficient artisan that Morris felt was usurped by the manufacturing machines of the Industrial Revolution. Of course, this argument would not gain much traction within the Morrisian camp due to the prevailing notion that ‘machines’ are not tools of Craftsmanship due to the lack of user “control”. However, this perceived notion (as stated before) is a historical misnomer; especially in the regards to CNC technologies. These technologies have “front loaded” operations that usually happen behind the scenes (such as developing the CAD model and programming for machine movement). This necessitates extensive preplanning and preparation before anything is manipulated by the machine. It is therefore a much more rigid overall process experience than one would have if using more hand-based tools (such as saws, chisels, or planes). But it is within this front loaded process that a Craftsmanship ideal can be found.

As with any new tool or any medium, there is a certain level of mastery required in order to bring about full utilization and “higher quality”. This mastery comes from direct experience with the processes involved and coming to understand their integral relationships to other applicable process. To further this point, Malcom McCullough says:

To reach a satisfying level of engagement, you much acquire and maintain an expertise: anything worth doing takes practice. With regards to tool and a medium, you might understand practice as acquiring a working knowledge, or becoming devoted to ever-improving execution. In practice, you aspire to transparency, that is, mastering your means to the point where they no longer interfere with attaining your ends. But as a beginner you may have difficulty reaching any subsidiary awareness, not only for lack of sensory-motor reflexes but also for lack of perspective on the process. habit hones skill, cut also expounds sensibility. Even first stages of practice
involve more than rote repetition...[L]earning a medium consists of exploring its affordances and constraints and developing a basic sense of how things work -- what psychologists call a cognitive background. We learn from our exaggerations and mistakes; we accept that beginning work in a new medium will be full of setbacks; but we also look out for discoveries.

(19)

The integral process knowledge that one needs understand within the realm of CNC is not simply limited to how digital CAD geometry relates to the programming procedure, and the versatility and specificity of the particular CNC technology being used (all Processes of Action) but how these aspects both inform and are affected by the design of the artifact (Processes of Thought). Nevertheless, it is through the Processes of Action that Craftsmanship has been traditionally associated, with Design/the Process of Thought is considered to be diametrically opposed to it. This view has its roots in history when, during the Renaissance, the architect left the building site and set up shop in an office; they became a manager overseeing the process. Traditionally before this break, the architect was a master stone mason, someone who knew the materials being used, methods to manipulate that material, and (most importantly) knew how to build with it. This knowledge was then applied to the construction of a particular building. After this break, the designer and the builder separated; the architect did the design of the proposed structure, and the contractor interpreted the drawings to build structure. What the architect lost because of this fracture was the direct link to control the quality of the building processes as they happen. This loss of process control means that the architect is dependent on the contractor for establishing Craftsmanship quality within the built artifact; for as David Pye says:

Gross defects of workmanship [Pye’s reference to Craftsmanship] the designer can of course, point out and have corrected, much as a conductor can at least insist on his orchestra playing the right notes in the right order. But no conductor can make a bad orchestra play well; or, rather, it would take him years to do it; and no designer can make bad workman produce good workmanship. the analogy between workmanship and musical performance is in fact rather close. The quality of the


Image 16
Cathedral of Our Lady of Chartres, Chartres France. Main construction occurred between 1193 - 1250, the names of the masters who built this structure have lost.
concert does not depend wholly on the score, and the quality of our environment does NOT depend on its design. The score and the design are merely the first essentials, and they can be nullified by the performers or the workmen. (20)

Within this framework of not only establishing design essentials but how they are then transferred across the gap to those who perform the actions of making, digital fabrication can be used as a bridge between these “opposed” areas.

Instead of using 2D methods of establishing form elements of artifacts (such as plans, section, elevations, and other orthographic images), 3D digital models can be viewed with full omni-directional capabilities. This model can then be used to derive tool paths and G-code that then drives CNC machine movement. Due to this dependency, it is up to the designer to establish within the overall concept how the materiality, the fabrication process, and their sundry effects play their parts and are either integrated or constrained into the overall design. Thus, if Craftsmanship quality is to be part of the desired end result of the physical artifact, it is dependent upon all parties involved (designer, digital 3D modeler, programmer, CNC machine operator) to have the same commitment and definition of Craftsmanship. The designer needs to understand how his/her design will impact the fabrication process to change/incorporate aspects accordingly; the 3D modeler needs to not only understand the intentions of the designer but the programmers requirements and (ideally) their process methodology; the programmer needs to not only understand (ideally) the intention of the designer (which flavors how the programmer utilizes toolpath strategies), but the capabilities, specificities, and versatilities of the intended CNC machine to change/incorporate aspects accordingly; the machine operator need to know how to properly set up the machine, be able to gauge the suitability of the cutting tools being used, understand how to generate high tolerance work (if high tolerances are required) and should (ideally) understand the design, and the methodology of the programmer in order to evaluate results being generated during the cutting process. These separate steps are therefore not only dependent upon the step before it to produce quality work, but
also dependent upon their own knowledge and medium mastery to produce quality work for the next steps. From this vantage point, David Pye’s view might seem somewhat simplistic and one sided. What could be added to this quote is that a bad conductor can ruin a good orchestra, and that a single under-qualified player can ruin the entire production.

The only way to reduce the above issue, is to have participants taking on more of the individual aspects of the process, with the ideal scenario being that one person takes on all aspects. This ideal (but mostly unfeasible) situation is the best case scenario for the holistic integration of the Processes of Thought and Processes of Action. Within this is strategy, there is potential for no information loss between the necessary processes. Moreover, as you gain user experience and medium mastery, so too does the understanding of what constitutes quality and of Craftsmanship’s various process evaluations.

One of the major variables within the digital fabrication Craftsmanship discussion is the specificity and versatility of a specific CNC technology, and the individual capabilities of that machine. It is these properties more than anything else that directs the overall programming strategy, and which needs to be integrated into the overall design of the physical artifact. Such variables include range of materials that can be cut, maximum build envelope, movement accuracy, repeatable accuracy, types of cutting actions, hold down method, and axis’ of articulation. The narrower the range within these variables the more the specificity in the intended output by a lesser skilled individual, the wider the range within these variable the more versatility you have in the output which necessitates an individual of higher skill and experience. The advantage that machines of specificity have over versatility is that of higher scale production, it does its limited number of actions that are fast and repeatable, whereas the more versatile machine requires more initial setup in order to do custom parts. However, once this set up has been done, the machine can then enter into high volume production of that part. The advantage that the more versatility machine has over the machine of specificity is that of variety of operations that it can do with different tools, and materials. It can be used as a tool to do one-
off prototypes, small scale output, and large scale production. This range of utilization then presents the opportunity to achieve higher levels of medium mastery, and apply that knowledge to a diverse range of applications. As with the Aristotelian notion of Praxis, this sort of knowledge then furthers ones understanding of the universal to specific applications. This makes the CNC technology of versatility the ideal tool/toolset to be utilized within our modern redefinition of Craftsmanship.

However, the final test of any theory is its application; how well the terms and conditions guide us to a successful end result established within the theory itself. And the best test for a theory based on making is (obviously) to make something. Now our redefinition of Craftsmanship encompasses all methods of making (analog to digital), but makes specific arguments on the validity of machine based fabrication as not only worthy of our Craftsmanship ideal but also as a potential means to reestablish Craftsmanship (as this thesis defines it) as a main stream paradigm.
JAPANESE JOINERY...MEET DIGITAL FABRICATION. YOU TWO ARE GOING TO BE BEST FRIENDS.

The design projects that I intend to do has two major overarching components; one is the application of traditional Japanese joinery/construction methodology, and the second is the utilization of CNC machinery as my fabrication tool of choice. These two aspects represent both:
- Modes of operation on opposite ends of the making spectrum.
- Closely related modes of thinking that exhibit many properties of our redefinition of Craftsmanship within both “processes of thought” and “processes of action”.

The inherent similarities between these two components have been some of the more interesting aspects of my thesis research. Both require extensive first-hand experience in order to master these mediums; both have deep relationships between their materials and tools; and both have deep associations between Man the Maker and their methods.

THE TRADITIONS AND METHODS OF JAPANESE JOINERY AND “THE WAY OF THE CARPENTER”

The two oldest wooden structures in the world that are still in use, are at the Horyu-ji Gakumonji (Learning Temple of the Flourishing Law) Buddhist temple complex in Ikaruga, Nara Prefecture, Japan. Originally founded in 607 ad (and still currently in use), the Goju-no-To (Five-Story Pagoda) and the Kondo (Main Hall) were built in 730 but many of their timbers were harvested before 670, the oldest of which being the central pillar of the Five-Story Pagoda which, according to dendrochronological analysis was felled in the 590’s. These structures represent what is possible within a committed craftsmanship based tradition that has spanned nearly 1,500 years, it represents not only a way of working but of a way of life. It represents the “Way of the Carpenter”. The concept of
“Way” is central to Japanese culture as whole and shapes all aspects, it “serves as a direction, route, course, or path...[i]t forms patterns of thinking and action” (The Ways of the Carpenter pg. 3). William Coaldrake (the first non-Japanese to be admitted to the Kyoto Dento Kenchiku Gijutsu (Kyoto Guild of Traditional Master Builders)) says:

The concept of Way is crucial for understanding carpenters and their tools in Japan. The term dogu, which is most commonly used for tool in Japan, means literally “the way of the tool.” It reflects the association of the process of building with a broader pattern of meaning best defined by the concept of Way...When a carpenter’s chisel for plane is called a dogu therefore, it is being recognized as an implement or means of a special Way. When the Chinese characters for dogu were adopted on the Japanese language many centuries ago, they did not refer to carpenters tools at all. They designated the important implements used in Buddhist ritual as aids to enlightenment...The adoption of a work with deep religious associations like dogu to designate carpenters’ tools is neither sacrilege nor a violation of sacred tenets. Historically, Japanese carpenters were far more than manual workers because the process of designing and erecting a building was more than a routine construction procedure. There is a universal association between the process of creating buildings and the spiritual dimension of the human psyche...The creativity necessary for sustaining the process of construction is sparked by the same impulses of imagination and awe as fire spiritual beliefs, and the process of building shares many of the same attributes as religion, including sequence, order, orthodoxy, hierarchy, organization, and awareness of higher imperative...The Japanese carpentry profession like the guilds of Europe, reflected religious piety and ritual in its professional activities, having much of the character of an enclosed religious order. the kami [spirits, personified natural forces, or essence of being with no association to good or evil] who watched over the carpenters were “kindred spirits” to the patron saints of the European building guilds. A meticulous process of selection and initiation into its various secret practices lat at the basis of the like and strength of the carpentry profession...Carpenters followed the customary pattern of training in which manual skills were mastered within a disciplined way of life governed by a strict sense of ritual and hierarchy. Reverence for tradition was paramount. The body of precepts and practices of one’s predecessors in the tradition were held in sacred trust to be mastered, followed and passed on to the next generation. Carpentry was as worthy of devotion as any religious faith and never lacked suitable aspirants to its life of discipline and devotion. (21)
This sort of spiritual devotion to holistic processes of thought and action sheds a revealing light not only on the profession as whole, but more specifically on the construction process, the types of joints used, and the tools that developed to facilitate their fabrication. The types of joints utilized are complex to say the least. Most feature interlocking, overlapping and intersecting elements that transfer stresses (compression, tension, and moment depending on the joint in question) from one piece of material to the other. Several different factors define the level of success of this transfer. Such factors include the suitability of the joint for the handling of the type stress(es) at that particular location, the precision of the parts created, the devotion of the carpenter to spend the time to achieve the necessary precision, the experience, mastery, and ability of carpenter to achieve the precision necessary, the suitability of the material being used, and the use of the right tools to create that joint in that material. The types of joints used are also dependent on the type of structure they are (Shinto shrines, Buddhist temples, and residences). This is due to:

...the vastly different histories and design and engineering requirements of these varied structures resulted in, among other things, a seemingly endless proliferation of joints with a combined total of several hundred distinctly different joints. Surprisingly few of these joints are used in all three types of construction, and some are reserved for only one type of construction. (22)

The joints used by Japanese carpenters (from buildings to furniture and interior elements) fall into two main category types, shiguchi (connecting) and tsugite (splicing) joints. As these names imply, connecting joints are used when two pieces of wood come together out of axial plane form one another where a splicing joint is used to create a longer piece of material from two shorter ones. The major characteristic that these two joint types share is that traditionally they and are all dry joints (meaning they are put together with no glue) and only use nails, pins, dowels, straps, bolts, or screws as secondary joint reinforcement. The utilization of dry joints with secondary reinforcement is important to note because it shows the reliance of material - material connections which more readily
transfers stresses over a wider area, where as joints that only use nails, bolts, and screws to form the connection, the stress transfer is focused through the connector which is not an efficient method of transfer and requires additional reinforcement (such as shear panels, straps, and brackets) to resist rotational and tensile forces. The major factor that makes nail/screw/bolt joints more of a viable economic option is the fact that a cheaper, unskilled labor force can then be used to build the structure, whereas they type of labor force needed to do the traditional Japanese joint method are of much higher skill and training and therefore the fabrication time and by association the costs are more expensive. However, with the utilization of digital fabrication, the time it takes to make the necessary parts can be greatly reduced, and reliably repeated (within the repeatability tolerance of the machine being used, usually 0.002” - 0.0001”).

The design and fabrication of connecting and splicing joints have two components, the male and female parts. One of the best examples of this is mortise and tenon joints where the projected tenon (male) is inserted into the recessed mortise (female). This joint in and of itself can be used either as a splicing or a connecting joint requires secondary reinforcement in order to be usable. The Japanese splicing joint KOSHIKAKE-KAMA-TSUGI (lapped gooseneck joint) however does not require secondary reinforcing. This joint is used primarily for DODAI mudsills, OBIKI beams (a girder to support floor joist), MOYA beams (a type of purlin) and other simple structural members. The lapped gooseneck is a joint devised specifically to resist tensile forces. The tenon is oriented vertically and has a projection on the end (the “gooseneck”) which acts as the interlocking element within the female mortise. Some joints, primarily splicing joints, have no distinguishable male/female halves, but have both male and female elements. This is found primarily in scarf joints such as KANAWA-TSUGI (half blind tenoned, dadoed, and rabbetted scarf joint) and the DAIMOCHI-TSUGI (stub tenon scarf joint). These joints can be used in both horizontal and vertical applications such as beams, and lintels or as underpinnings in columns due to the joints resistance to both tension and bending stresses. The structural integrity, versatility, and sheer number of joints utilized (over 400) highlight a very refined mastery of wooden construction that is unsurpassed by any other. The uniqueness of its joinery and construction techniques can only be
matched by the uniqueness of its tools that are used to make these joints.

The dogu (tools) used by the Japanese carpenter who was responsible for the design and execution of buildings, fall into four main categories:
1. Design tools: which would include marking and measuring tools necessary for designing like ink pot/snap line, carpenters squares, measuring rods, and plan boards
2. Cutting tools: such as saws, chisels, axes, adzes
3. Finishing tools: such as planes
4. Tools for maintaining tools: such as whetstones and files for sharpening

From this, we can then say that there are both “instruments of the mind” and “tools of the hand”, which “link the men, materials and methods in the vocation of building carpentry” (23) and “reflects the dual vocation of the carpenter as designer-builder” (24). For these tools not only enable the creation of these types of joints, they also reflect philosophy of “The Way of the Carpenter” in and of themselves.

The two main differences that Japanese tools have, when comparing them their western (American, European) counter parts, is the use of the pull stroke, and the advanced metallurgy of tools and tool parts. The use of the pull stroke for both saws and hand planes stems from the preference of Japanese carpenters preference of sitting to perform tasks, which enables feet to be used to hold parts if necessary. From this position, it is easier for the body to perform pulling actions (a perfect example is the rowing action of row boats and competition rowing). The pull stroke is also a more efficient means of cutting action especially with saws. Push stroke saws have blades of much greater thickness to resist the buckling/compressive forces that are created by the teeth of the saw working against the material. Where as in pull stroke saws the major stress is in tension, which is a more efficient use of the material. This allows the saw to have a thinner blade, which reduces the kerf of the cut. The pull action is also a much more accurate cutting method that is necessary for the high tolerance joinery technique employed by the Japanese carpenters.
The advanced metallurgy of Japanese smiths is perhaps best personified by the Samurai sword (the katana); considered by many experts to be the best sword type ever created. The reasons for this praise stems from the use of selective steel hardening techniques, and the use of high carbon content outer jacket with softer steel core in conjunction with the overall sword geometry. This makes the sword an excellent cutting (specifically slicing vs. chopping) weapon. This material specialization was not only used for weapons, but also extended into the production of tools such as saws chisels, and plane blades. The need for sharp tools is of course a necessity, without a quality edge, it is impossible to get quality cuts. For better edge retention, a harder type of steel is used. This prevents the cutting edge from deforming during the cut and therefore maintains the cutting edge longer. The drawback of hard, high carbon content steel is that it much more brittle and therefore tends to fracture and not bend. This is an immense drawback when tools such as chisels are routinely hit with a hammer to produce cuts. Softer steels (steels with lower carbon content) however are much better at taking impact forces due to its malleability. This characteristic however is an issue for maintaining sufficient cutting edges. The Japanese method takes the positive characteristics of both metal types to reinforce the negative aspects of both. These tools (like the katana) use different metal types on different parts of the tool. High carbon steel is used on the back of the chisel, which forms the cutting edge with a softer, lower carbon content steel, on the front which then flows into the tang. These parts are heat welded and forged by smiths to form a seamless piece with two distinct zones. This showcases the Japanese essentialist mentality, that when two separate aspects come together, they make something more than any single aspect could achieve on their own, but are still seen as separate aspects. It also highlights the similarity of thought and application to our redefinition of Craftsmanship in relation to its design, materials, and means.

This production method produces tools and tool parts of superior quality but are extremely time and labor intensive to make and therefore much more expensive. This method is fundamentally different from the way most western saws, chisels, and planning
blades are made. These have homogeneous mixes of steels that include both high and low carbon steels. However, this method disregards the specific functionalities of the tool parts and treats the material as two parts to create a separate third. This method is however much easier to mass produce, and creates tools that may not live up to extremely exacting standards, but are fine for most other applications.

The specialized production of tools for the Japanese carpenter can be equality matched to the specialization of tool purpose and function. When we talk about “saws”, “chisels”, and “planes”, we are talking about their shared aspects under the umbrella of tool type, within this type there are numerous variations in size, shape, and function. Generally speaking, there are about eight different types of saws (not including different sizes), about seven different types of chisels (usually coming in sets of varying sizes), and about eight core types of planes (with a variety of sizes and an endless variety of chamfer and molding planes). The utilization and retention of these many tool types has to do with the particular production output type, such as Shinto shrine construction verses making Geta (wooden) sandals. Although they may be considered at opposite ends of the object spectrum, the one link that unites them is the material used.

Japan has a very temperate climate with high relative humidity and large amounts of rainfall. Because of this, it has always been a highly forested country, which helped to establish a making culture based primarily on wood. Wood construction is better suited to wet and humid climate because it able to breath, and does not promote condensation like stone or brick. The island nation is also part of the Pacific Ring of Fire, which makes it highly prone to earthquakes. There have been over 28 major earthquakes (over 6.0 in the Richter scale) in the last one hundred years alone. The most recent being (as of this writing), the 2011 Tohoku earthquake. This event weighed in at a 9.0 with at least three aftershocks over 6.5 (7.1, 7.1, and 6.6 respectively). The Japanese’s traditional utilization
of joinery techniques that are able to transfer various types of stresses through the joints in conjunction with wooden buildings reduced mass, as compared to brick or stone construction, enabled them to better withstand these catastrophic events.

Due to the Way of the Carpenter philosophy, coupled with the spirituality of the Shinto belief system that permeates Japanese culture and its way of life, trees (in their alive and lumber form) still maintain deep respect and reverence. Many Japanese carpenters talk about kodama ("the spirit of the tree") which can be taken as the tree’s soul or essence. Kiyosi Seike says that:

In contrast with inorganic building materials...timber requires an almost animistic [the belief that natural objects, natural phenomena, and the universe itself possess souls (AAA)] faith of the people who work it. I suspect that even non-carpenters cannot escape the inclination to ascribe divinity to the mystery of nature that creates beautifully grained wood. In Japan, various myths and legends immortalizing the divine nature of particular trees survive even today in the stories recorded and handed down to us in literature and in picture scrolls...When I look at a beautiful example of wood construction, I cannot help thinking that the beauty of the architecture derives not only from its design and construction techniques but also from the very soul of the tree itself. At the same time, firm wooden structures seem to speak with the hearts of the master carpenters who constructed them with obvious respect for the soul of their timber. (25)

When trees are felled for construction timber, the Japanese carpenter sees this act as a pact of moral obligation to that timber, an obligation to utilize the material to the best of the carpenter’s abilities, and to make the tree “live again” within the artifact being created. The idea of wasting material due to incompetence, or fabrication mistakes is considered to be deeply shameful and the subject of much criticism. Careful layout, tool selection, and fabrication knowledge is necessary to avoid wasteful loss. This consideration of the tree’s spirit extended also to the building site. As “the way of the carpenter” and Shinto dictate:

The carpenter believed that spirit of the tree had to be accommodated in its new
location at the building site, but he had to know the environment in which it grew to maturity for practical reasons as well...The original orientation of the timber to the north south had to be respected. This was not only to placate its spirit but also to ensure the suitability of a timber to its new location in a building; south-side wood is better adapted to warmth should once more face south, whereas north-side wood is better able to withstand cold temperatures as it confronts the penetrating winds of winter. (26)

Of the two tree types “hardwoods” and “softwoods”, softwoods are traditionally preferred for building construction. These conifers include hinoki (Japanese Cypress), red pine, keyaki, black pine, horse chestnut, sugi (Japanese cedar). The first three of these are today only used for the construction of temples, monuments, and in homes of the wealthy due to its expense and status prerequisites. Of the three of these, hinoki is considered to be the best and has been traditionally used major structural components for the past 1500 years. It has a fine straight grain (with an average growth ring of only 1 millimeter) which aides in oil retention, which leads to its longevity and strength. Scientific tests show that hinoki “is 30 percent stronger two hundred years after it is first cut. Thereafter it gradually weakens until a thousand years later, when it has returned to its original strength” (27). The Goju-no-To, has surviving pillars made of hinoki.

The prevalence of coniferous timbers used in the traditional construction had a direct influence on the evolution of tools, especially cutting tools. The softer density that hinoki and other coniferous timbers have, requires a tool with a sharper cutting edge in order to make a clean cut, and a clean cut is an accurate cut. This material aspect helped to focus tool creation that catered to this constraint, and helped lead to the bi-steel chisels and plane blades.

With the choosing of the materials, the sharpening of the keen edge cutting blades, and the mastering of the joint types and their creation; the actual fabrication of parts for a building can begin. The main construction process for temples and houses is offsite prefabrication of major structural elements, with a speedy
on-site assembly. The Master Carpenter preselects timber for major structural components first, such as for columns, ridge poles, and hip rafters; this is called ki-dori or wood preparation. These timbers have the ability to set the tone of the entire construction by their size, grain and other characteristics, and is considered to be one of the most important stages of work because “the skills it requires are not physical but mental: imagination, visualization, an intuitive grasp of the wood’s personality” (28). The knowledge of these aspects, how to recognize them, and their application in regards to potential parts comes from medium mastery. The next stage consists of the Master Carpenter establishing templates of the parts to be made which are then disseminated to the assistant master carpenters who do the majority of the fabrication. The templates are used to transfer component information to the pieces being cut, in many cases, an assistant master carpenter will produce an entire set of identical parts. With so many parts to produce, the carpenter may not know who is producing parts that are companion to his. This means that trust in not only his skills, but in the skills of his colleagues, and the guidance of his superiors is paramount. The understanding of the methodologies of the process along with his superiors, colleagues, and underlings stems from the apprenticeships that are involved.

One of the more complicated construction elements that the Master Carpenter has to integrate into the design and its many component parts is the inherent shrinkage, sagging, and settling of the individual parts and with the building as a whole. Many of the joints are cut in such a way to have gaps when they are initially put together, but close as material shrinks and settles which then strengthens the joint. The dimensions that we are talking about are in millimeters. This requires a foresight that only comes from experience. The time frame that the Master Carpenter thinks in can range from ten to a couple hundred years.

Once the major components are pre-fabricated, they are moved to the building site where they are assembled to form the building as a whole. This process (depending on the complexity of the building), can be as short as a couple of days for a teahouse to as
long a month for large scale temples. This time period seems almost instantaneous when compared to the necessary fabrication time of component parts (upwards to six months), time to season timber (three to four years), and time for the trees to reach maturity so they can be harvested (600 - 1500 years depending on the species, and intended use). The advantage that his type of prefabrication and site assembly method has is the fact that all component parts are sheltered from the elements for the duration of the fabrication process whereas the speedy site construction limits the amount of time that material exposed to the elements.

The biggest advantage to using joints that do not require glue, or connectors is that you can take the joints apart from each other without damaging them or the rest of the material. If an entire structure is composed of interlocking joints with secondary reinforcing, that structure could be taken apart down to its component parts if necessary. This in fact is what does happen to these types of structures. There are many historical records of temples and shrines being dismantled and moved to new locations, one such example is the Yakushiji temple, completed in 698. It was originally located in the then current Japanese capital Fujiwara (now called Asuka), but as political climates shifted a different city, Heijo was made the capital city. To shift with the times, the temple was dismantled down to its component pieces and moved to the new capital city. The dismantle-ability of these structures also enables for large scale building restoration, especially temples and shrines. The structure is either completely or partially taken apart, and a meticulous log of parts that includes their locations assessments of damage is taken. If parts are too damaged, they are cut apart and spliced with a new material or completely new parts are created to replace them. The building is then put back together as it was taken apart and is ready to continue service. This mix of old and new can only happen when there are carpenters trained in the traditional ways, whose work is able to meet the standards set by over millennia of tradition. This ability, knowledge, and expertise are in danger of being lost; the pride and prestige of the Way of the Carpenter has been eroded away with no
clear way to bolster the core foundations.

The apparent cause that many historians and practitioners attribute to this shrinking tradition is Japan’s defeat in World War II. Due to this conflict:

…an entire generation of carpenters, not to mention roof tilers, plasterers, stonemasons and others was swallowed up during the eight long years [1937-45] of the war, as were stocks of building materials and Japanese cities themselves. For the defeated nation, there was a loss in confidence in tradition. Pragmatic Westernization, largely in the form of “Americanization,” became the order of the day in the decades after the end of the conflict. Industrialized mass production of housing components was the only solution to the chronic shortages of dwellings, skilled labor, and materials. Precast concrete panels, plastic and metal sheathing, and power tools together created a new prefabricated vernacular to re-house much of the urban population…In the space of a single generation, traditions built up over many generations were swept away. There was little room for the creative compromise between new and old in the pressing circumstances of postwar reconstruction. (29)

Similarly, to the break of Architect and Master stone mason that occurred during the Renaissance:

[the] Way of the Carpenter [diverged] from the way of most Japanese. It had suddenly gone from being a pillar of society, central to its industry and culture, to become a curiosity of another age. Cost-efficiency was part of the problem, but loss of respect and self-esteem through deprivation of design initiative was its root cause. The separation of the designer-architect from the carpenter-builder meant that the organic nature of the traditional architectural process was destroyed. Carpenters were demoted to the role of manual workers in a society which sets great store on high educational attainment. (30)

What is most interesting about this that the construction methods and materials that replaced the traditional consisted of steel, concrete, and 2x4 stud construction. These materials and methods do not work with the climate, promote condensation and by association mold,
are not made for long term utilization, and are of inferior quality (especially in relation to 2x4 stud construction method, and material choice) when compared to traditional methods. The relegation of the highly skilled carpenter down to a mere manual laborer is highly reminiscent to the perceived attributes of the Industrial Revolution. However, the biggest difference between what happened during the Industrial Revolution and the abandonment of Japan’s traditional joinery and construction techniques and philosophy is that during the Industrial Revolution the “traditional” artisan’s way of life was perceived to be usurped by the machine. Nevertheless, the memory of that culture remained and was romanticized by critics and theorists; in fact, there was instant reactionary stances taken against the machine when it was being introduced into manufacturing culture. Whereas in Japan, the culture as a whole has shifted away from the traditional methods to be marginalized and shunted aside with very little argument. The fear is that when today’s masters (the last to be trained by the traditional manner and methods) leave this world, that their knowledge, experience, wisdom, and philosophy will be lost. The knowledge of what the methods were will survive, but the ability to create them to the standards defined by over a thousand years of tradition will not. This can only be done under the guidance of a master’s stern gaze. It is my own personal fear that this joinery and construction method may meet the same fate as Antonio Stradivari and his shop, for when the master died his secrets and knowledge went with him and eventually there will be a time when the last of his artifacts fall prey to old man time and we will never hear again his masterful work.

In an effort to bridge the gap between the traditional and modern methods of fabrication, many smaller scale builders began to adopt joinery machines to produce the complicated joints and members. The companies that make these types of machines include Miyagawa Koki, Marunaka, (both Japanese), the Swiss company Krusi, and the German company Hunndegger. The use of these types of machines increases output of parts which enables the firm/shop to compete economically, especially in housing. However, this sort of production does not address the core problem. As Coaldridge says:
This new generation of tools makes the special spliced and angled joints which lie at the very heart of the Japanese building tradition, producing a quick fix solution to the crisis of cost-effectiveness in the conventional housing sector. A technician with no training as a carpenter is able to use these machines to make the complicated gooseneck mortise-and-tenon joint for splicing sills, taking only twenty seconds to complete a joint that requires twenty minutes of precise, arduous work by a trained carpenter using hand tools...The development of joinery machines is a demonstration of the Japanese carpenter doing what he has always done--creating tools based on long established principles but adapted to the needs of a particular situation. It is possible that this time he may have created a tool which, while preserving the physical forms of Japanese joinery, will threaten the existence of the carpenter himself. (31)

For these particular machines are not necessarily tools of craftsmanship, they are tools for manufacturing, not tools for fabrication, i.e. tools of specificity. The difference between the two being very similar to Pye’s argument of Workmanship of Risk vs. Workmanship of Certainty and the application of Poiesis and Praxis. These joinery machines has a very limited range of available joint outputs, they are very good at producing the joints within that range. They are meant to have certain outcomes with repeatable end results, which is what one wants within a given manufacturing environment. However, Craftsmanship (as we have defined it) is a process of application where the tools, materials, and the design interact in a holistic way. This means the active control of the tool being used is necessary, where the person’s skills, experience, and determination for particular results shape the end product. It means that the end does not rest with the completed parts, but with the continual utilization of the end product. In order for the Japanese joinery tradition to survive, it needs tools that reflect its processes, methodologies, and philosophy, without blindly copying their forms or their joints.
MY CHOSEN TOOLS OF THE TRADE...

My preferred fabrication method has to be the “machinist” method, which includes such tools as manual mill, manual lathe, but CNC machines being at the top of the list, specifically CNC routers. What these methods offer is finite process controls that directly influence the quality of the end product, the opportunity for technical mastery, and presents the opportunity for scalable production outputs. This last aspect falls almost exclusively within the realm of CNC production. This means that CNC machines have the ability to be both a tool for prototyping, and a tool for manufacturing. The ease with which CNC tools can do this again depends upon the versatility or specificity of the machine itself. It is my contention that the more versatile the machine, the better the modal transition, and the more apt to be used as a tool of craftsmanship. The heart of this ability to transfer from one mode to another is twofold: one is the programming for machine movement, and two is the necessary machine setup (which includes tool assembly, establishing hold down methods (such as high volume vacuum fixtures), and work coordinate verification (establishing X,Y,Z locations)). Depending on the complexity of the part(s) to be cut, more time can be spent programming the machine movement, than what it actually takes to do the actual cutting. This aspect is an important factor when you are only producing one thing. However, this work is not necessarily lost. Once the toolpaths have been calculated, and the program generated, the same part(s) can then be cut repeatedly, with no end. This is the key to scalable outputs. You can do the necessary programming for a particular cut, do an initial small machine run, and then be able to more runs of varying sizes down the road as needed.

My experience with CNC machines (which includes programming, operating, and utilizing it as a tool for fabrication) comes from my working at the College of DAAP’s (Design Architecture, Art, and Planning) Rapid Prototyping Center (RPC) at the University of Cincinnati. The machine that I worked with mostly was our KOMO VR 510 Mach III CNC Router. This machine features a 5’ x 10’ aluminum vacuum hold down table, 6” Z machining envelope, a ATC (Automatic Tool Change) with a 12 tool carousel, a
23 HP 24,000 RPM spindle, a 4th axis ring for 4 + 1 and live 4 axis machining, and a repeatable position tolerance of 0.0001”. This machine has the rigidity, accuracy, torque, and rpm to do a very wide variety of work; from full sheets of plywood to multi-positional/multi axial. It is truly a tool of versatility.

The other side to the capabilities of any CNC machine is the CAM software that drives it. When you purchase any CAM software, what you are paying for is functionality. This means that the more functionality you want/need the more expensive the software ends up being. The RPC uses Delcam’s Powermill, which is one of several industry standard CAD/CAM software packages. It has an extremely wide variety of toolpath strategy types, 3-4-5 axis programming capabilities, dynamic toolpath customization options, and powerful toolpath editing for post calculation. However, with added functionality comes the possibility of doing something really wrong, not only to the material being cut, but also to the machine itself. This is why experience and medium mastery is an important aspect with any tool. Understanding how the programming affects potential machine movement, how the machine aspects affects the programming, how this process drives quality, and how to foresee potential issues at the machine that are derived by the programming enables the creation of higher quality objects/artifacts by holistically integrating them into the design itself.

ITERATIONS INTRODUCTION

Now that we have established our areas of interests, methods of making, and an overall guiding process to work with, it is time to test and validate our theories through the making of physical artifacts. This seems the natural methodology to accomplish this because potential Craftsmanship characteristics of physical artifacts are defined by the “processes of thought” and “processes of action” that went into them. The application of our theory will be done through a series of fabrication iterations.
Design Projects

Iteration 1: This will act as an initial jumping off point. It will consist of making a series of panels where each panel explores the adaptation of a particular Japanese joint and joint type for CNC processes. This adaptation includes aspects of materiality, assembly methods, joint creation, joint tolerances, and CNC machines as a tool for fabrication, and issues of adaptability of Japanese joinery methodology to CNC processes.

Iteration 2: Based on the results of Iteration 1, and still utilizing its exploration particulars, this iteration will add a significant amount of complexity closer to “real world” applications by drastically increasing the output scale, the amount of joints and joint types used, and introducing aspects of real structural stresses. The intended output will be a site specific window screen for the Rapid Prototyping Center. It will act as visual primer for the sorts of activities that go on within, and indicate the philosophy they strive to achieve.

Iteration 3: This will be similar to the methodology of Iteration 1. It will be an exploration of adapting Japanese joinery and joint types to CNC production tools to create aspects of a buildings structural skeleton the same way that the traditional Japanese carpenters did it. This particular iteration is looking to validate CNC production as a potential way to preserve traditional Japanese construction methods. By showing how a production tool of versatility that can not only produce traditional joinery members, but is philosophically more in line with the traditions associated with the “Way of the Carpenter”

Iteration 4: This purpose of this iteration is to introduce something from the opposite end of the making spectrum, a chair. Furniture, due to its intimate contact with the human body, has its own particular set of evaluation criteria that can tested in a much different way, by simply using them. It will still use aspects of Japanese joinery but in a more restrained way. The focus will shift more towards aspects of CNC being utilized as a fabrication and manufacturing tool.
Some of the common elements that will be shared throughout these four iterations are the utilization of Japanese joinery and construction methodologies, material utilization, impact of the CNC machining process on the overall design and the design of component parts, and general aspects of CNC as a tool in line with our established notion of Craftsmanship and as a tool of production. These last two elements are major driving forces of potential joint adaptation and include aspects of material choice, machine setup, and cutting tools selection. The KOMO, although more than capable to do complex machining operations that require extensive machine setup, really excels at cutting flat stock material such as plywood. This material type requires relatively little machine setup, as compared to complex machining operations. This setup includes such things as cutting tool assembly and spoilboard facing operations. Due to the simplified nature of this setup and how it increases limited run machine productivity, the utilization of flat stock material (specifically plywood), as the main material of choice has been preselected for all iterations, and where this deviates, it will utilize the same hold down method.

The use of plywood as material of choice for our various iterations, poses an interesting design challenge. All traditional Japanese joints are made from larger pieces of timber. Not only that, these joints have complex 3D aspects and sometimes has multidirectional aspects to them to take into account multiple intersecting parts. To overcome this issue, the answer lies in the use of material lamination post machining. This means that the traditional joints will be broken down into simpler elements, which will be adapted to the dimensional capabilities of the material, and to the machining process, which will cut said material. The purpose behind this is not to simply recreate these joints with a different fabrication tool, but to adapt its utilization and methodology to a different fabrication tool. Given the nature of the joints, and limitations of the machining process itself, it would be impossible to do a faithful and quality recreation, and trying to do so would completely ignore the reasons and the philosophy behind the creations of the joints.
themselves. However, adapting their methodology and utilization to the intended fabrication tool retains and respects the traditional methods, and their associations to the “Way of the Carpenter” and our redefinition of modern Craftsmanship.

The method of producing any artifact with a CNC router is through the use of a rotating cutting tool such as a drill, a flat endmill, or a ball endmill. Where drill bits are only used to create cylindrical holes in a singular orientation (non-axial), endmills can be used for axial cutting movement. This is due to the vertical cutting edges on the cylindrical side of the cutter that allows for horizontal movement through a particular material. One potential limitation associated with the mechanics of this rotational cutting action has to do with inside corners. All inside corners associated with machine cutting will retain a fillet of material that cannot be reached. Should these fillets prove to be an issue, the best scenario to consider is to incorporate them into the overall design strategy. This option enable you to save on both programming time and machine time by not having to chase inside corners with additional cutters; secondly, it negates the need for any post process work (such as cutting them out with a chisel; and enables the designer to better control the overall aesthetic by pre-planning what cutters will be utilized for specific cutting operations. This can be extremely powerful if the designer is also the machine programmer because he/she can then have a seamless dialogue with these separate aspects and then come to a more holistic answer.

With these common aspects explained, fabrication can now begin. Their results will show (one way or another) the validity of Craftsmanship as a whole, and how it pertains to digital fabrication techniques and methods.
Iteration 1: Initial Inquiry Into Joinery Adaptation

Iteration 1 sets the tone for all the subsequent iterations to come by either validating or debunking many of our initial assumptions, the biggest of which being that Japanese joints and joinery methodologies can be successfully adapted to a CNC production. The method chosen to test these assumptions is through the creation of a rectangular frame that will hold a material panel. These panels are a secondary exploration looking at how different materials react to 3-axis milling and the different ways to represent a 3D surface.

The origin for this testing method comes from the open source digital joinery developed by Jochen Gros from the C...Labor at the HfG Offenbach; specifically the “C...Frame and Panel” application method. Gros has this to say about this method:

The construction principle of frame and panel has a long tradition in furniture construction. While the framing timbers are cut out of solid wood, the panels can be made out of various materials, like board materials, synthetic materials, or glass. The use of digital wood joints as joining elements for the framing timbers gives rise to interesting design solutions and, at the same time, greatly facilitates the assembly of the frames. (Gros 1998)

The difference between what Gros and his students did and what this iteration (and the iterations too follow) intends to do is not only adapt the joints themselves to a CNC method but more importantly, examine the overall production of the joint members.

The traditional Japanese method (and the method that Gros and his students followed) is to take pieces of lumber and either carve/CNC machine the specific joint types. My differing method is to buildup members by laminating several layers of material together to form the complex male/female members that are able to fit into/join with other members. This method entails the use of either board material (such as planks of hardwood) or flat stock sheets (such as plywood). As stated before, the use of sheet stock (in conjunction with
a CNC router with an integrated vacuum hold down system), means that little initial machine set up is necessary, unlike dimensioned lumber that would require special fixtures or clamps to hold the material in place. With sheet stock, you can cut multiple member parts at once and then laminate them after the cutting process. It is this method that will be used for this and other iterations.

Since my area of interest lies specifically within the realm of adapting Japanese joinery techniques and methods, each frame will utilize an adapted variation of a specific joint from either the “splicing” or “connecting” type. For the sake of fabrication unity, each frame will consist of three layers of 1/2” nominal thickness plywood cut from a full 4’ x 8’ sheet. This means that the joints to be selected need to have the ability to be broken down into three layers and still maintain their core functionality of interlocking elements with necessary secondary reinforcing, and maintaining that all joints are “dry joints” which allows for the frames to be disassemble-able if required.

In order to help visually distinguish between different member/part types (male, female, locking insert), each member/part type will be finished a different color. The male parts will be green, the female parts will remain natural, and the inserts will be dark brown/black. Each layer has several 1/4” positioning holes that are used to align parts to each other when they are being laminated together. This method enables precise alignment with all member layers, which is critical for high tolerance interconnecting joints.

Frame A:
MECHIGAI-KOSHIKAKE-KAMA-TSUGI
(lapped gooseneck mortise and tenon with stub tenons)
Splicing Type

Similar to the “Dovetail Key” from the “C...Frame and Panel” application method, the gooseneck becomes a corner insert that “splices” the corner together. Instead of only having one key that inserts from the top, this frame has two keys at each corner, one at the top layer and one at the bottom layer. This keep the rotational forces perpendicular and parallel to the laminations flowing through the
entire joint and not just through one of the key inserts. This type of method is generally not needed in traditional Japanese construction. The MECHIGAI-KOSHIKAKE-KAMA-TSUGI is generally use with mudsills which transfer gravity loads to the foundation. Therefore, they do not require multidirectional reinforcement.

Frame B:
KANAWA-TSUGI
(mortised rabbeted oblique scarf joint)
Splicing Type

Out of all four joints being explored with Iteration 1, the adaptation of the KANAWA-TSUGI splicing joint is the closest to the traditional Japanese method. Due to the multi-axial machining methods that would be needed to machine overhanging elements that can’t be reached from either the top or bottom side, this joint exemplifies the capabilities of our established laminating method. Instead of secondary reinforcement method of dowel pins that keep the corner inserts in place (like with Frame A), the KANAWA-TSUGI is unique in that the two members come together in a retracted way. In order to “lock” together, the two pieces have to expand apart which allows for a locking key to slide into the expanded space. The locking key prevents the joint from retracting back onto it and can only fail if the key itself is crushed. This point of failure can be overcome by using a differing material that is both denser and stronger than the material of the joining members. This particular joint is traditionally used to create underpinnings for columns, and is designed primarily with compressive forces in mind.

Frame C:
SAMMAI-GUMI & KONE-HOZO
(open slot mortise & rabbeted mortise and tenon joint)
Connection Type

At the opposite end of the four joints being explored within Iteration 1, the adaptation of these two connecting joints is the furthest away from the traditional Japanese, even though they are based on two traditional methods. The reasoning behind this particular deviation is because neither of these two joints utilize any interlocking
elements that would create overall joint integrity. The addition of a locking key element, which prevents the tenon from disengaging, enables the joint to have interlocking capabilities. The thru-tenon (taken from the SAMMAI-GUMI) helps to visually represent the methods of joint functionality.

Frame D:
SUMIDOME HOZO SASHI
(haunch blinded and collared tongue and groove miter joint)
Connection Type

This last exploration has some similar issues as Frame C such as the necessity of adding an additional method of “locking” the two members together to prevent them from separating, but still retain the ability to be disassemble-able. The main difference between this joint and the joints used with Frame C is that the SUMIDOME HOZO SASHI already has some interlocking elements, but requires a locking method to keep the joint from slipping apart. The answer to this problem can be taken from the “key insert” idea from Frame A and the use of a “locking key” as a secondary joint reinforcement from Frame B. Similar to the “key insert”, Frame D utilizes a secondary corner insert element that spans from the male structural member to the female. Once pinned in place, this secondary element has the ability to dramatically increase the structural strength of the joint itself; the percentage of this increase is dependent upon the material used. The corner insert also acts as a locking key which keeps the joint from coming apart due to the fact that (like Frame A and B) the members can only come together/apart by way of vertical/out of plane movement. Restricting this particular directional movement helps to keep the joint structurally sound by maintaining a tight, slip free connection. This double functionality of the corner insert method not only helps to create a more efficient joint overall but also helps to visually showcase the intricacies of the “dry joint” methodology.
Frame A:
MECHIGAI-KOSHIKAKE-KAMA-TSUGI (lapped gooseneck mortise and tenon with stub tenons)
Splicing Type with Alum Material Panel
Frame B:
KANAWA-TSUGI
(mortised rabbeted oblique scarf joint)
Splicing Type with Walnut Material Panel
Frame C:
SAMMAI-GUMI & KONE-HOZO
(open slot mortise & rabbeted mortise and tenon joint)
Connection Type with Plywood/Acrylic Material Panel
Frame D:
SUMIDOME HOZO SASHI
(haunch blinded and collared tongue and groove miter joint)
Connection Type with Corian Material Panel
Iteration 2: Site Specific Window Screen

Iteration 2 is meant to be a large scale “practical” application of the aspects learned from Iteration 1. The site for this installation is to be the main window wall of the RPC which measures approx. 13’-4” long x 7’-6” high. Besides being a part of my thesis’ supporting argument(s), the screen will act as a visual primer for the types of activities that occur inside the space and in general display a particular student’s area of interests and research (mine). Similar in premise to Iteration 1, the window screen is meant to be a closed loop external frame with an intersecting internal diagonal lattice. The closed geometry and its intersecting elements create the necessity for extremely tight tolerances and minimal compounding error. A successful assembly would go a long way in supporting our redefinition of Craftsmanship and that CNC machines can be a tool that enables this to be personified. The screen will again act as a supporting framework for secondary material/machining explorations.

The screen’s assembly will utilize many of the aspects developed and utilized during Iteration one, such as:
- The lamination of material that has been CNC machined to create complex structural members.
- The use of high quality Baltic Birch Plywood as the lamination material.
- The use of “key inserts”, “locking keys”, and “corner inserts”

However, unlike the frames of Iteration 1, this frame will take more of the “Japanese” approach and use multiple joints and joint types for different aspects of the screens construction. For there is no one joint that can be used universally in all instances and structural applications. Each joint and joint type has their uses for specific applications, and it is an integral part of this iteration, and this thesis as a whole, to honor that particular design mentality. The design will use five different adapted joints to create the necessary members. They represent the five different structural applications necessary for all parts/members to come together and act as a cohesive system. These include:
- The splicing joint OKAKE-DAISEN-TSUGI (rabbetted oblique scarf joint) to make longer horizontal frame members.
- The connecting joint HAKO-DOME (rabbetted tenoned miter joint) adapted to include “corner inserts” for the right angle corner connections.
- The connection joint HIRA-HOZO (true mortise and tenon) for the lattice - frame connections.
- The connecting joint ARI-KATA-SANMAI-HOZO (through single dovetail) adapted to include a “locking key” for the horizontal frame - interior vertical connections.
- And the combined adaptation of the “dovetail key corner” joint and the “triple dove tail” joint developed by Jochen Gros for the lattice - node connections.

As stated before, the “dry joint” criteria that we have established means that all of our joints need to have some sort of secondary (and in some cases tertiary) reinforcement to keep the joint together. An example of tertiary reinforcement can be seen with the HAKO-DOME joint being used at the all of the right angle connections. This joint was adapted to have secondary reinforcement by including a corner insert that prevents non-planer movement of the members. Tertiary reinforcement is then used to keep the corner insert in place. With Iteration 1’s Frame D, dowel pins were used, but with Iteration 2 machine screws in conjunction with knock in threaded inserts will serve the dual purpose of acting as a physical obstruction to prevent secondary reinforcement retraction and more importantly also add compressive forces to the joint which enables for more efficient stress flow through the joint. This mechanical advantage allows for better joint efficiency and permits joints to be taken apart more quickly if need be. Expedient access is extremely useful at the lattice - nodal connections of the screen. it allows for the quicker insertion and retraction of different material panels into the screen to facilitate secondary explorations.

The attributes of our fabrication tool of choice enables the production of complex objects at a higher rate then what could be achieved by manual means. With a tool of versatility, it allows for the creation of both custom “one off” parts and customizable
“standardized” parts that are achieved through the CNC machines high repeatability and motion tolerances. This means that projects that are “variations on a single theme” could have singular customized parts with standardized components that can be mass produced on an as needed basis. This iteration acts as an initial exploration into this area. Due to the vertical and horizontal “off centeredness” of the internal lattice, all of the parts for the external frame, as well as the verticals are all unique and require individualized programming. Whereas most of the components of the internal lattice are the same consisting of the male nodes and the female spanning members; this means that full sheet layouts for each part can be established, programmed, and cut as needed.
Iteration 2 Design Projects
Design Projects

Iteration 2
Iteration 2 Design Projects
Iteration 3: CNC Production of Japanese Structural Members

Iteration 3 is specifically meant to explore the idea of a CNC toolset being able to restore and maintain traditional Japanese construction methods and philosophies as discussed in the “Design Projects: working context” of my thesis document. The intention is to design a portion of a full scale traditional Japanese structural assembly, and fabricate it by means of a CNC router. In order to highlight the potentials for this method, the joint(s) should represent both the visual elegance and internal complexity of the traditional methods. One joint in particular, which fulfills these criteria, would be the YATOI-HOZO-SASHI (the four directional beam-to-post connection). As the name implies, this joint consists of a square post with four beams that connect to it, but all that the viewer sees is a clean transition of beam to post. However, what goes on inside is truly amazing. Two opposing beams act as male and female parts of a SAO-TSUGI, or lapped rod tenon with stub tenons. The male beam’s tenon passes through the center of the post and into the receiving mortise cut into the female beam. Secondary reinforcing is then inserted into the lapped tenon, which locks it into place. The stub tenons (located on the male and female members), are used to secure the beams to the post and to transfer the loads from the beams to the post and then to the foundations. In order to allow both lapped rod tenons of the two adjacent beams to both pass through the center of the post without interfering with one another, one tenon passes above in one direction while the other passes below perpendicularly. This method allows the post to flow uninterrupted from floor to floor, and allows for four beams to meet at one location without the need for any additional hardware. This is important because much of the interior structure is left exposed and is meant to be seen as finished surfaces.

The major design and fabrication issue that this particular joining method introduces is the designing for multi-directional components. Up until now, all of our connection types have occurred within the same plane as the laminations. This allowed for all male and female components to have the same thickness considerations, whereas laminated members perpendicular to each other poses an issue of compounded thickness error. Other important issues include the treatment of inside corners of the male and female members of the beam and post connections.
Iteration 3  Design Projects
Design Projects

Iteration 3
Iteration 4: Joinery Based Furniture

This last iteration will focus on CNC’s potential for scaled output production of object(s) that utilize the joinery and fabrication methods established in previous Iterations. The intended end product will be a series of chairs that have the same overall design and member types, but explore the establishment of adjustable price points and elements of mass customization. These two facets are inherently intertwined with the materials used, the translation of material type to programming and machining methods, and the consistency of parts produced in varying materials.

As stated previously, the material used to bring a particular design into the physical world is one part of establishing an objective value of the end product. A particular material is chosen based upon the necessary characteristics it needs to impart such as strength, available methods of manipulation and aesthetic appearance. Except for extreme engineering and mechanical constructions (such as a fighter jets, a satellite, or a nuclear reactor), most objects and artifacts can be made using different materials and still maintain their core functionality. The one attribute that would change is the cost of that object/artifact. This is especially true for things produced on a mass scale, which require large sums of money to establish production, assembly, and general logistical support. With the concept of “economies of scale”, the more widgets produced, the cheaper the per-unit cost of those widgets will be. However, a small change in the production (such as changing the materials being used, or the given amount of materials being used) can have far reaching consequences when multiplied out over the course of the widgets production lifespan. Decisions such as these often either cost the company producing the widgets millions of dollars, or it will save that company millions of dollars. However, as of this writing, the chairs I intend to produce for this iteration will not be engaging in air-to-air combat, attempting to orbit around one of Jupiter’s moons, or produce gigawatts for the local power grid. This means that the types of materials that could be used are potentially fairly wide. The material selection will therefore be based upon its manipulation appropriateness within our fabrication toolset.
The design of the chairs consists of three part types, linear components, joint inserts, and the seat/backrest. The seat/backrest can be further broken down into plain seat’s/backrest’s or seat’s/backrest’s with material inserts. The choice of either one does not affect the connections to the frame components or the joint inserts which would be the same. As established within our previous three iterations, our main production method is the machining of the part layers which are then laminated afterwards to form our member parts which are then joined with the our part types to form the finished artifact. In addition, as established previously, the base material, which will be used for our different part types, will be Baltic Birch plywood in either 5’ x 5’ or 4’ x 8’ sheet sizes. The reasons for this choice is due to the higher quality manufacturing, the predominance of the core having relatively few voids, the core consisting of the same material found on the exterior faces (verses veneered plywood which has a very thin face veneer of a higher quality wood such as birch, oak, or walnut with a core of lower quality wood such as poplar or pine), the large sheet sizes which allows for simplified machine setup, and its ability to resist warping and other deformations. The selection of a particular sheet size will depend upon which allows for the best layout efficiency. One of the self-imposed design criteria of this Iteration is that all base component parts have to come from a single sheet of material.

The design and production of the sides of the chair (consisting of linear components and joint inserts) is similar to the internal lattice configuration of nodes and connecting structure of Iteration 2, and the corner insert element of Iteration 1’s Frame A. The sides are first machined as simplified elements such as front leg, seat, back leg, and back rest. The joint inserts are then used to connect multiple linear elements together to form the chair sides. This allows for a higher material efficiency, which is a key part to establish a competitive selling price. The seat and backrest are also machined as two halves, which are then cut from pre laminated pieces of material originating from our single sheet of plywood. These two halves are then laminated together to form the seat and the back rest. The connections between the chair sides and the seat/backrest is a right angle, out of plane joint, similar to the Japanese ARI-KATA-SANMAI-HOZO-KOMISEN-UCHI (through single dovetail with pin)
joint. Through the lamination end grain of one element contrasting with the outer face layer of the perpendicular element, this method allows for the visual differentiation of the seat/backrest elements and the chair sides. It is a way to celebrate the joint between these part types and to display the overarching Craftsmanship characteristics of the Iteration.

The creation of this chair, out of a single sheet of Baltic birch plywood represents the base price point of the design. However, in order to explore the idea of mass customization, the design needs to maintain methods of adapting parts to different materials, or be able to incorporate ways to include other materials into the design. This can be done one of three ways. One way is to cut pockets into the plywood seat and backrest, which would allow for the insertion of different materials. The second method is to replace some or all of the three part types with different materials with the third method being a combination of the two. These three methods allow for customization of the final product without changing any of the digital geometry that drives the programming and CNC processes. The changes that do occur are with the augmentation of the programming to reflect different tooling strategies, cutter selection, and feeds/speeds that different materials require. However, if the same machining strategies can be maintained with different material types, then the core of the mass customization ideal can be realized.
Design Projects

Iteration 4
The four Iterations that have been designed and produced for this thesis are (in my own opinion) an overall success. They are successful in that they embody our redefinition of Craftsmanship, they showcase the abilities of CNC machines as tools of Craftsmanship, and show that overall control is still in the hands of the maker no matter what tool/toolset is being utilized. Nevertheless, aside from these successes, all four iterations suffer some flaws stemming from the simple fact that they are all inherently process prototypes. There is no way to solve all the issues, or to answer all questions in one go.

Iterations 1-3 are fairly closely related in that they are examining joinery methods on a “building” scale, following the Japanese construction methodology. One of the default aspects that this entails is the structural nature of not only the joints, but also the materials that the joints are made from. It is this last aspect that is lacking in these three iterations as a whole and even more so with iteration 3. The primary focus on with these three iterations was whether or not these complex joint types could even be adapted to CNC production methods and a layering fabrication at all and still maintain their core functionality, that of taking separate elements and jointing them together to act as one.

Iteration 4 however is the “odd man out” in that it is meant to be in intimate association to the human body verses being primarily visually stimulating. This attribute adds several layers of complexity to the designing process that the previous three iterations did not have. Not only does the fabrication process need to be explored, but issues of proper scale, and ergonomics need to be considered also. The biggest self-criticism I have with this particular iteration has to do with these last two aspects. Any further development will need to rectify them.

In thinking of the strengths and weaknesses of these four Iterations as a whole however, some are definitely stronger than others in terms of how convincingly they showcase the aspects they were meant to. If I were to rank them “strongest” to “weakest”, the list would be as follows:
1st: Iteration 2/Iteration 4
2nd: Iteration 1
3rd: Iteration 3

I consider Iterations 2 & 4 to be the strongest projects due to the fact they can be viewed as completed (verses being works in progress) projects. They sufficiently display the complexity of their designs and the established fabrication process’ in tandem with the material utilization and overall potential of their production methods. With iteration 1 being the initial explorations into “un-explored territory”, each frame has some sort of aspect or detail that I would do differently. Nevertheless, the bigger issue is the fact that the material panels (which I consider to be an interesting secondary exploration) visually appear to the main aspect with the frames being secondary. They appear as how most classically produced fine art appears which is not what the original intention of this iteration was. The reasoning for listing Iteration 3 as the weakest of the four is not because the structural joints do not work, it is that there is not enough of the project to actually test the joint adaptations in conjunction with the fabrication method to say whether they do or do not work. I was able to adapt and recreate the four sided beam-to-post connection, but there really should be more to the iteration in order to test other necessary aspects such as the joints resistance to shear, torsion, and moment stresses alongside assembly and production methodology. These things could only really be tested by producing a full sized structure like a shed or small cabin. Iteration 3 is the initial step and down the path of CNC produced structures, but shows promising results. It requires more research and development in order to be a more convincing alternative to an already established tradition.
It is the intention of this thesis to re-converge the apparently “separate” paths of the “hand” made and the “machine” through the bridge of Craftsmanship by establishing a clear and coherent definition of Craftsmanship, its individual aspects, how they form a holistic cycle, and its possible applications in conjunction with built artifacts. But why use Craftsmanship as the means for the reunification of these apparently disparate elements to begin with? This is because the idea of “craftsmanship” involves elements of creating quality objects. So if quality can be attributed to objects, then it can also be used as a means to evaluate those objects. As a culture, we do this automatically by simply saying that some objects have “good craftsmanship” or “bad craftsmanship”. However, I find it troubling that we use these terms seemingly with little/any objective criteria behind them. For when two people discuss (or more than likely argue) about a particular objects supposed good/bad craftsmanship characteristics with no established definitions or criteria, the discussion will inevitably boil down to what constitutes craftsmanship to begin with; verses focus on the object’s/artifacts design, use of material, and/or method of production.

However, instead of a black or white blanketing of craftsmanship, my argument is for degrees of application. This allows for a more comprehensive utilization of individual components that relate to the whole artifact. Therefore, if two people (who agree on a definition of craftsmanship) are evaluating a particular artifact, they can disagree on the design aspects but agree on the material utilization, and the production method; or agree on some aspects and disagree on others in regards to all three components. This particular methodology is better able to utilize a particular maker/evaluator’s area of expertise by allowing for focused areas examinations.

For the introduction of new tools necessitates the need for new criteria to evaluate the artifacts made by them; and this is where our redefinition of Craftsmanship is able to help by introducing a critical dialogue back into the discussion. For it has the ability to refocus the larger discussion away from the so called “abilities” of the new tool (be it software or hardware), and back toward the tangibles of the objects and artifacts themselves such as the process’s that went into their design and execution and the people who guided them.
In conclusion:

-Craftsmanship ability has never been lost within production, large or small, only its obvious methods of control has changed from “active” to “periphery”

-The “Hand-made” vs. “Machine-made” argument is reactionary misnomer; the type of tool(s) used has no bearing on creating Craftsmanship quality objects/artifacts.

-Our process based definition of Craftsmanship shifts the evaluation process back to the “What” and “Why” that went into the making of the object/artifact, verses the “How”.

-Critical understanding of how these processes work within a given production framework is a necessity to create quality objects/artifacts in any sense.

I hope that my arguments and presented evidence has been convincing to anyone who scoffs at the idea of quality machine made artifacts and Digital Craftsmanship. But at the very least, if we continue this argument into the future we will atleast be arguing about its core issues and not simply its manifestations.

Sincerely,

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Bibliography

Analog


Digital


Appendix A  Traditional Joint Fabrication Process
Traditional Joint Fabrication Process

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Traditional Joint Fabrication Process
Things are usually made by a succession of different operations, and there are often alternative ways of carrying any one of them out. We can saw, for instance, with a hand-saw, an electrically driven band-saw, a frame-saw, and in other ways.

To distinguish between the different ways of carrying out an operation by classifying them as hand- or machine-work is, as we shall see, all but meaningless. But if we make an estimate of the degree of risk to the quality of the result which is involved in each we have a real and useful basis for comparison between them. Let us take two extreme examples: (A) A dentist drilling a tooth with an electrically driven drill. (B) A man drilling a piece of wood with a hand-driven wheelbrace, using a twist-drill and a jig. A is a machine-operation and B is a hand-operation: or, if you like, we will say that both are machine-operations. Operation A which the dentist does with a power-driven machine-tool involves 100 per cent risk (and there is no man that it lies in his mouth to deny it!) but operation B merely involves a five per cent risk or so, and only that because, if the hand-workman is fool enough, he may break the drill. Otherwise he has only to keep winding the handle and the result is a certainty. The source of power is completely irrelevant to the risk. The power tool may need far more care, judgment and dexterity in its use than the hand-driven one.

Let us consider some possible definitions of handicraft, or hand-work, or work done by hand. ‘Done by hand’ as distinct from work done by what? By tools? Some things actually can be made without tools it is true, but the definition is going to be rather exclusive for it will take in baskets and coiled pottery, and that is about all! Let us try something wider and say ‘done by hand-tools as distinct from work done by machines’. Now we shall have to define ‘machine’ so as to exclude a hand-loom, a brace and bit, a wheelbrace, a potter’s wheel and the other machines and tools which belong to what is generally accepted as hand-work. So that will not do either, unless we propose to flout the ordinary usage of mechanics: which on the subject of machinery seems a trifle risky.

Suppose that we try ‘As distinct from power-driven machine tools’. Now we are faced with having to agree that the distinction between handicraft and not-handicraft has nothing to do with the result of handicraft—the thing made: for no one can possibly tell by looking at something turned, whether it was made on a power-driven, foot-driven, boy- or donkey-driven lathe. And then again, if we hold to this definition, do we say ‘made entirely without the use of power-driven machine tools’ or do we say ‘made partly without...’? If we say ‘entirely’, then all the carpentry, joinery, and cabinet-making of the last hundred years is excluded, pretty nearly: indeed for longer than that. Louis Mumford remarks [2] (in a different context) that ... ‘If power machinery be a criterion, the modern industrial revolution began in the twelfth century and was in full swing by the fifteenth.’ The sawmill is a very ancient thing and so, of course, is the water-driven hammer.

But if we take the other course and say ‘Partly without power-driven machine-tools’ we include in handicraft most of the worst products of cheap quantity-production. Perhaps we can save the situation yet, by putting in a disclaimer and saying ‘made singly, partly without power-driven machine-tools’. But now how do we know he hasn’t made two of them and kept quiet about it? There is nothing about the product, the thing made, to tell us. And if we say ‘in small numbers’ why, exactly, do we include six and exclude seven or such-like? It sounds more like an expedient than a definition.

Suppose that we make a last attempt, shape a different course altogether, and say ‘made by hand-guided tools, whether power-driven machine-tools or not’. By so doing we have written off every kind of drill, lathe, plane, and shooting board, all of which are shape-determining systems. So we shall now have to qualify the definition to include these tools which are only in part hand-guided; and then we shall have to try to exclude whatever machines we do not happen to fancy, from the same group.

Or shall we? Is it not time to give up and admit that we are trying to define in the language of technology a term which is not technical?

‘Handicraft’ and ‘Hand-made’ are historical or social terms, not technical ones. Their ordinary usage nowadays seems to refer to workmanship of any kind which could have been found before the Industrial Revolution.

Mumford, extending a conception of Patrick Geddes’s, described [3] three phases in the development
of European economy and technics, each phase having a
distinct pattern of economy and culture and a 'technical
complex' of its own, which might be roughly indicated
by referring to its principal materials and sources of
power. The Eotechnic phase was reckoned to extend
from about AD 1000 to 1760, and was a 'water-and-
wood complex'. The Paleotechnic phase, of the
Industrial Revolution, was a 'coal-and-iron complex',
and the Neotechnic phase of our own day, which suc-
ceeded it, is an 'electricity-and-alloy complex'
(Mumford was writing in 1930).

The essential ideas in his conception are, I think,
first: that the Eotechnic phase contained, not so much
the seeds, as the nine-month embryo of the Industrial
Revolution; for all the prerequisite ideas, devices and
techniques for it were already in being before it came
about. Secondly: that the different phases 'interpenetrat-
ed and overlapped'. That is to say that, just as the tech-
nical features of the Paleotechnic phase, such as quanti-
ty-production and the workmanship of certainty, were
in being quite early in the Eotechnic phase, so did tech-
niques and devices characteristic of that phase persist
through the Paleotechnic phase and even into our own
day. I lately saw a wooden barrel (Eotechnic) with,
beside it, a galvanized steel bucket (Paleotechnic) and a
thermoplastic watering-can (Neotechnic). As for the
workmanship of certainty having appeared during the
Eotechnic phase, to quote but two examples: the monk
Theophilus in the eleventh century gave a detailed
description of punches and stamps for producing quan-
tities of standardized ornaments in gold and silver [4],
and in or about 1294 a smith called Thomas, from
Leighton Buzzard, used stamping dies for forging stan-
dardized ornamental features for the grille of Eleanor of
Castle's tomb in Westminster Abbey, which still exists
[5]. It may be that in its earliest manifestations the
workmanship of certainty was used for the quantity-
production of ornaments more often than for utilitarian
purposes.

Now the current idea of handicraft and the hand-
made has been deeply colored by the Arts and Crafts
movement; and that became a movement of protest
against the workmanship and aesthetics of the
Industrial Revolution, which it contrasted with handi-
craft. As a result, I think, the idea has become accepted

that before the Industrial Revolution everything was
made without machines. This was certainly not William
Morris's idea. He did not consider that handicraft flour-
ished after the Middle Ages. But the fairly common
error of supposing a complete break and opposition
between the 'machine-made' workmanship of the
Industrial Revolution and the 'handmade' workman-
ship of the Eotechnic phase immediately preceding it is
presumably traceable partly to a misunderstanding of
Morris.

It seems fairly clear that to Morris himself handicraft
meant primarily work without division of labor, which
made the workman 'a mere part of a machine'. During
the Medieval period, he says, 'there was little or no divi-
sion of labor, and what machinery was used was simply
of the nature of a multiplied tool, a help to the work-
man's hand-labor and not a supplanter of it. The work-
man worked for himself and not for any capitalistic
employer and he was accordingly master of his work
and his time. This was the period of pure handicraft.' [6]
It will be noted that for him handicraft did not exclude
the use of machines and that the word had strong social
and historical implications. It was not a word referring
to any definable technique.

In this book there is no need for us to go into the
question of whether Morris's beliefs about the Middle
Ages are true.

One contributory cause of present confusions of
thought about hand-work and craftsmanship is perhaps
that people have generalized about it who did not
know, or did not think enough about, the way tools do
actually work. I am inclined to propose that the term
hand-work should be confined to the work of a hand
and an unguided tool; but that is an extremely restric-
tive definition. I do not think any woodworking tool
can be properly said to be unguided after the moment
when it enters the wood. They all cut their own jig as
they work and sometimes a pretty exact one, as with a
paring-chisel or a scribing-gouge. Workmanship in dif-
ferent trades differs so widely in its basis as well as its
practice, that the only common factor and the only
means of generalization in all the different branches of
craftsmanship is the element of risk we have discussed.

The extreme cases of the workmanship of risk are
those where a tool is held in the hand and no jig or any
other determining system is there to guide it. Very few things can properly be said to have been made by hand, but, if there are any operations involving a tool which may legitimately be called hand-work, then perhaps these are they. Writing and sewing are examples.