Università degli Studi di Ferrara

DOTTORATO DI RICERCA IN ARCHITECTURE AND URBAN PLANNING

CICLO XXXII

COORDINATRICE/COORDINATORE

Prof. Dr. Roberto Di Giulio

Post-Digital Craft: *Defining Digital Risk*

Settore Scientifico Disciplinare: ICAR/12

Dottorando

Dott. Stevens, James

____

(firma)

Tutore

Prof. Dr. Antonino Di Raimo

____

(firma)

Tutore

Prof. Dr. Theo Zaffagnini

____

(firma)

Anni 2016/2020

"If my nightmare is a culture inhabited by post-humans who regard their bodies as fashion accessories rather than the ground of being, my dream is a version of the post-human that embraces the possibilities of information technologies without being seduced by fantasies of unlimited power and disembodied immortality, that recognizes and celebrates finitude as a condition of human being, and that understands human life is embedded in a material world of great complexity, one on which we depend for our continued survival"

-- Kathrine Hayles, 1999

Post-Digital Craft: *Defining Digital Risk*

James C. Stevens

Figure 1 - Testing Vertical

Table of Contents

Preface

This thesis is the product of a tenacious curiosity of architecture, design, and making. Early in my education as an architect, I was seduced by the visual beauty of design, art, and architecture. I was bolstered by the knowledge that my collogues and I saw the world in a slightly different way. This realization also coincided with the introduction of the computer to the profession of architecture. In 1990 I sat at an IBM PC and learned AutoCAD V.11 on DOS. Some teachers told us this was the future, and most of what senior architects did would not persist for long. In hindsight, the predictions were mostly correct. However, I had no idea, nor did my collogues, how much digital applications would entangle our carriers.

In this early moment, seated at the brick-like PC, I was using a new tool. A tool, like many before that, would change my process and how I understood the material world. I now had a virtual world in front of me, void of consequence, gravity, material, or connection. It was liberating, and I committed myself to become an expert. Now, after many years of practice I sit still in front of a PC; however, almost everything has changed. What I have before me now is no longer a tool; it is an interconnected infrastructure. If the first CAD system I used was a tool much like a hammer, what I have now is more akin to the electrical grid. I can parametrically script and generate geometry. I can do this alone, but more likely I will do it in a team with members from different parts of the world. We can critique, code, shape, and design digital geometry together or in real-time on a vast interconnected network. I can then access digital fabrication tools to fabricate and assemble my creations. All the while, my work, and my design sensibilities can be coded and understood by Artificial Intelligence (AI) so that my intentions can be carried out even in my absence. I can, therefore, propagate my ideas beyond my human existence. This is indeed a long way from where I started.

Much of my work in the past ten years has been reflecting on this change and trying to make sense of where the profession is going and what insights I may contribute. The context provided by living through the advent of digital applications and now living in the post-digital condition allows me to seek out topics that I find essential, those that I can tease out new or explicit knowledge. In most cases, these topics reside in what I would call a contextual paradox between technology and architecture. Technology has generated many of these contradictory conditions. The profession seeks efficiency but also uniqueness, we desire traditional materials and methods, but require an industrial process. The contradictions of humanistic values alongside post-digital and post-Fordist conditions are the contradictions of our time. It is within this paradox that I find my work. In 2015 I published the book Digital Vernacular, Architectural Principles Tools, and Processes with my colleague Ralph Nelson. This publication defined what we saw as a strange and compelling contraction in architectural practice. We observed that as digital communication and digital tools were making everyone and everything more accessible and more alike that there remained a strong desire to express qualities of difference unique to each region, place, and designer. The book responded to the desire to be the same and different at the same time. The digital vernacular is an idea that combines vernacular design principles of the past and digital technologies of the present (Stevens, James C. 2015 p. 001). This work taught me the value of struggling to reconcile conflicting design conditions. It also provided the foundation for the work that is presented in this thesis.

The contradiction that is engaged in this work is the design certainty gained through digital applications and the essential element of risk needed for all innovation. As I worked in the area of digital fabrication, I began to realize that both the applications and digital fabrication tools I used eliminated most, if not all, risk. The work was safe and certain once it was translated from file to fabrication. This was achieved through practice and is indeed the goal of many who work within the profession. However, I was interested in probing what was lost when risk is all but eliminated in a post-digital condition.

Acknowledgments

In 2011 I boarded a plane with my student Pandush Gaqi bound for Tirana, Albania, a country I knew little about. I was convinced by Pandush to travel to Albania to teach a workshop on digital fabrication using a CNC machine we had designed to fit inside of a suitcase. At the time, I was interested in DIY tools that could generate architecture in emerging economies that had not yet benefited from the democratization of fabrication. This workshop and the people I met on my subsequent visits changed my life and carrier.

The work in this thesis and much of my work that preceded would not have been possible without my friends at Polis University in Tirana, Albania. In particular, I would like to thank Prof. Dr. Besnik J. Aliaj, who has always supported my research and teaching efforts. Along with Dr. Aliaj, I acknowledge all those that support the University, including Prof. Dr. Sotir Dhamo and Prof. Dr. Dritan Shutina. The founding of a design school in Albania is a selfless and demanding task, and I will always admire their efforts. There are many friends and colleagues I have met who supported me in Tirana during this time. Dr. Prof. Loris Rossi and Dr. Prof. Laura Pedata have helped me with my numerous trips to Tirana, and without them this work would not have been possible. My colleagues in the XXXII cycle have been a great source of support, providing everything from translations to a coffee at the canteen when things got tough. In particular, I would like to thank Eranda Janku, Sara Codarin, Gerdi Papa, Kejt Dhrami for their help and friendship.

My home institution of Lawrence Technological University is an indispensable source of support that was required to produce this research. The University facilitated many of the projects seen in this thesis by providing internal funding and by hosting my digital fabrication lab, the makeLab. In particular, I would like to thank the Dean of the College of Architecture and Design, Karl Dubmann. The Dean has provided advice on the academic content and inspired this work. I would like to thank my collogues in the Department of architecture that provided the backup I needed when traveling and working on this project. The Associate Dean Scott Shall was particularly supportive, and for that, I am grateful.

Most importantly, I would like to acknowledge the efforts of the research assistants that participated in many of the projects profiled in this thesis. Breanna Helkeima was invaluable in the design and fabrication of all three ceramic printers. Her skill as a craftsperson was essential to the project's ability to create and document the work necessary in this thesis. Most of what was made during this period would not have been achieved without the help of Breanna. She is the primary “craftsperson” referred to in this text. Janelle Schmitt worked tirelessly on many of the projects. Her ability as an assistant was important in constructing complex drawings, but I most valued her insights into the significance of the work. Nathan Ickes provided his talents as a craftsperson and maker for much of the work here. Nate was essential to keep the digital tool working as I neared the end of this project. Ian Timmis provided his coding expertise to the AI experiments in this project. Ian's help was invaluable, and many of the conclusions drawn in this work could not have been achieved without his contribution. Adriana Mantke kept us all on time and schedule. For this, we are all thankful.

I especially would like to thank my supervisor and co-supervisor Prof. Dr. Antonino Di Raimo and Prof. Dr. Theo Zaffagnini. Dr. Di Raimo provided critical readings and insights that informed the framework of the project. Without this guidance, the work here would not be possible. Additionally, I would like to thank my co-supervisor, Prof. Dr. Theo Zaffagnini. Dr. Zaffagnini helped me evolve my work with improved research methodology, and for this, I am grateful.

Lastly, I would like to thank my family. They make my life more vivid and fuel my curiosities.

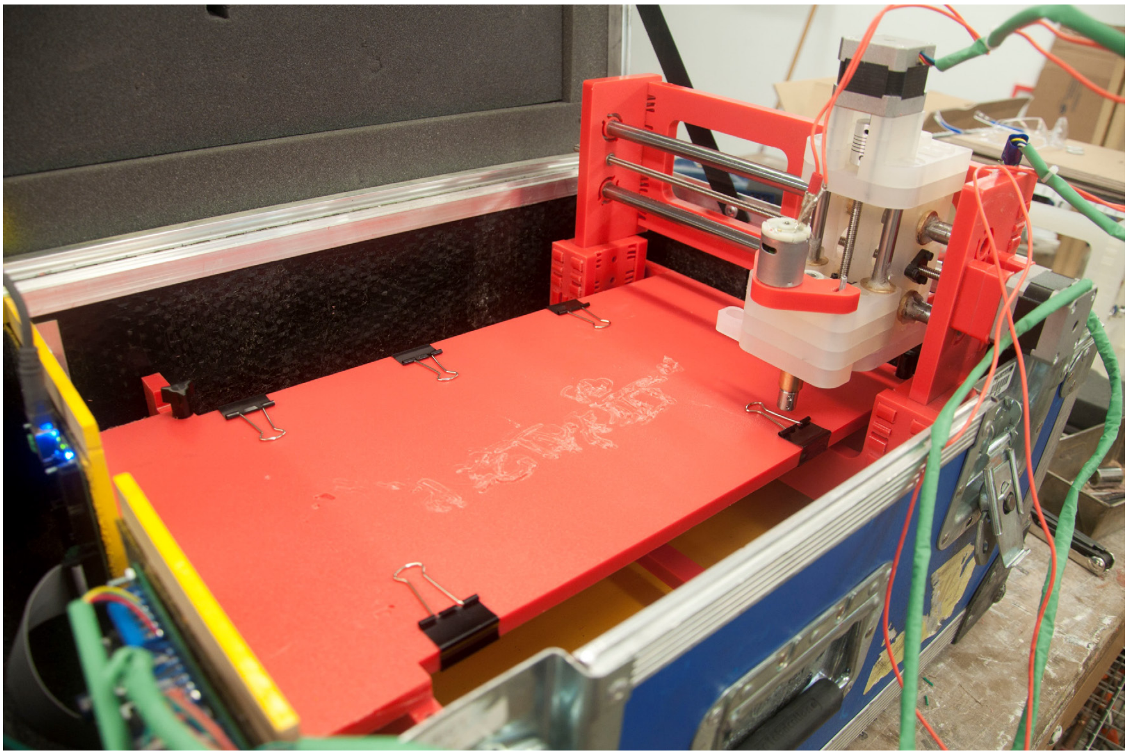


Figure 2 - Suitecase CNC, Tirana 2011

1 Abstract

This thesis seeks to define what the research refers to as digital risk. Risk in the making of an artifact was mostly eliminated with Fordist principles of manufacturing and efficiency. However, in a post-digital era, these principles no longer fully apply. Although mass-customization and micro-manufacturing still do not rival large industry, the process is demonstrating promise. The shifting to customization allows designers now to reengage in the production of custom artifacts with the aid of digital applications and fabrication techniques. Digital fabrication has been researched and is continuing to develop, but the unique post-digital question of this thesis is how risk, an element all but eliminated from our process, can be reintroduced productively. Intentionally taking risks while working with digital applications does yield results not otherwise achieved. This thesis demonstrates that digital risk is a valuable principle within post-digital processes.

The experiment in this thesis, Digital Ceramic Risk (Section 4), explores the entanglement of the post-digital and post-human condition by examining risk through the crafting of a hybridized digital and physically made artifact. These experiments were conducted in three phases. Phase one profiles the creation of a digital tool that enabled hybridized manual and digital ceramic printing. Using this 3D printer, the research Identified risk variables through documented tests. Variables such as material failure, tool failure, and digital errors were tracked and analyzed. Phase two demonstrates a high level of skill and craft through the use of hybridized methods. By applying the identified risk factors from Phase one, the outcomes of the experiments generated newly crafted forms that otherwise would not have been realized through an only digital process. Phase three demonstrated optimized printing skills and craft through sustained practice and improved digital tools. The outcomes of this phase created a visually distinct collection of vessels. Each vessel was modified as it was printed to create a version of the control vessel that was digitally modeled, and that generated the g-code controlling the 3D printer. These improvised artifacts were re-digitized and dimensionally quantified into data. This data was encoded into an Artificial Intelligence (AI) database for the propagation of an infinite number of new vessels. This extension of the handmade object into an AI database is a human infusion into the post-human cybernetic network. The case studies and experiments contained within this thesis demonstrate how craftspeople can now both exist in the material world while still existing in the broader post-digital and post-human condition.

Abstract – Italiano

La tesi intende definire ciò che nella ricerca viene chiamato rischio digitale. Il rischio coinvolto nel creare un artefatto fu principalmente eliminato attraverso principi Fordisti di manifattura ed efficienza. Tuttavia nell'era post-digitale tali principi non sono più pienamente applicabili. Nonostante la produzione di massa e il micro-manifattura non rivaleggiano con le grandi industrie, il processo si mostra promettente. Il passaggio alla customizzazione permette ai designer di produrre artefatti su misura con l'aiuto di applicazioni digitali e tecniche di fabbricazione. La fabbricazione digitale è stata ampiamente ricercata e continua ad essere sviluppata, ma la domanda post-digitale avanzata della presente tesi si concentra su come il rischio, un elemento che non è stato affatto eliminato dal nostro processo, possa essere reintrodotto in maniera produttiva. 'Rischiare' in maniera intenzionale mentre si lavora con applicazioni digitali può produrre risultati che non potrebbero essere altrimenti ottenuti. La presente tesi intende dimostrare che il rischio digitale costituisce un principio valido nell'ambito dei processi post-digitali.

L'esperimento della presente tesi, Digital Ceramic Risk (Sezione 4), esplora l'intricarsi della condizione post-digitale e post-umana, esaminando il rischio attraverso la creazione di artefatti digitali e fisici ibridati. Tali esperimenti sono stati condotti in tre fasi. La prima fase concerne la creazione di uno strumento digitale che ha permesso la stampa manuale e digitale ibridata di ceramica. Utilizzando la stampante 3D, la ricerca ha identificato le variabili di rischio attraverso test documentati. Variabili quali fallimento del materiale, dello strumento ed errori digitali sono stati osservati ed analizzati. La seconda fase ha dimostrato un alto grado di abilità e destrezza attraverso l'utilizzo di metodi ibridati. Applicando i fattori di rischio identificati dalla prima fase, i risultati degli esperimenti hanno generato nuove forme che non si sarebbero potute realizzare con l'utilizzo esclusivo di processi digitali. La terza fase ha dimostrato tecniche di stampa e abilità ottimizzate per mezzo di prove prolungate e strumenti digitali migliorati. I risultati di tale fase hanno generato una collezione di vasi visualmente distinti. Ciascun vaso è stato modificato durante la stampa in modo da creare una versione del vaso di controllo modellata digitalmente, e ciò ha generato il g-code che controlla la stampante 3D. I risultanti artefatti improvvisati sono stati poi re-digitalizzati e quantificati dimensionalmente per mezzo di dati. I dati sono stati codificati in un database di Intelligenza Artificiale (AI) per la propagazione di un numero infinito di nuovi vasi. Tale estensione dell'oggetto fatto a mano in un database di AI, costituisce un'introduzione umana nel network cibernetico post-umano. I casi studio e gli esperimenti contenuti nella tesi dimostrano come gli artigiani possano esistere sia nel mondo materiale che nella più ampia condizione post-digitale e post-umana.

1 Introduction

For many practicing architects, the complete digital takeover of the profession happened slowly; for others, it was at head-turning speed. Practice is now in a position, however, to look back with context at what has occurred and how it has changed the way we design and make. This context along with the propagation of all manner of digital applications and devices does provide the understanding that we are in a post-digital era. We are in a time where Henry Ford's manufacturing principles are foundational but no longer stand alone as the only avenue to efficiency. Design and making in the post-digital, post-Fordist era potions architects and researches to ask critical questions on how we are to proceed with the infinite possibilities our new-found mastery of data has provided.

This thesis seeks to define what the research refers to as digital risk. Risk was the enemy of Fordist principles of manufacturing and efficiency. Individual one-off artifacts were too expensive and time-consuming to produce, and the Industrial Revolution gave us the antidote to this by way of mass-production and materials of dimensional certainty. However, in a post-digital era, these principles do not fully apply. Although mass-customization and micro-manufacturing still do not rival large industry, the process is demonstrating promise. The shifting to customization allows designers now to reengage in the production of custom artifacts with the aid of digital applications and fabrication techniques. Digital fabrication has been researched and is continuing to develop, but the unique post-digital question of this thesis is how risk, an element all but eliminated from our process, can be reintroduced productively. Intentionally taking risks while working with digital applications does yield results not otherwise achieved. This thesis demonstrates that digital risk is a valuable principle within post-digital processes.

In 1996 Malcolm McCullough asserted that the operation of digital technology defines a new dematerialized craft. The tactile shaping of the material was viewed to have a parallel digital equal. McCullough maintains that the act of craft can occur entirely virtually without the requirement of a physical artifact. This is an impressive argument considering it was made in 1996 when CAD was emerging from DOS into the windows platform and only in the early stages of implementation in architectural practice. Ricard Sennett also reinforces McCullough by expanding his definition in *The Craftsman* to include many professions from surgeons to computer programmers. This thesis acknowledges these positions and understands them within their context. However, both positions were presented in the digital era whereby the digital and the material existed in two parallel systems, one digital and one physical with the human as the mediator and translator between information and material. In the post-digital context and the ubiquity of digital fabrication and the rise of Artificial Intelligence (AI), the material, the digital, and the human have become more intertwined in a cybernetic network. Therefore, McCullough's dematerialization still holds but cannot remain relevant without the introduction of material and human factors. His understanding was one provided by his in-depth knowledge of traditional craft and how new technologies and technicians were developing craftsmanship within dematerialized and virtual space. This virtual space now is no longer contained and is spilling over into physical material and human conditions.

When the material world in which we exist collides with the optimized and weightless world of a digital environment, new post-digital dilemmas manifest. Tolerance is of primary concern. As seen in the case study, Digital Barn Raising (Section 3.2), what is drawn in a digital application does not account for the inaccuracies of adjacent conditions such as unlevel ground conditions and existing structures. The post-digital has provided a new desire to not only generate new forms with digital tools but to capture physically made forms to further manipulate in a digital environment. Similarly, our ability to code new forms has also created a desire for our code to respond to outside forces, sometimes in real-time. As seen in the case study, Digital Corbelled Wall (Section 3.1), as the script can now guide a craftsperson in manual work but also respond by yielding to their judgment with the tools and materials on-site. Both examples begin to probe fundamental questions of how we craft objects in the post-digital, but they also expose how interconnected we are with both the application but the tools that produce the artifacts we desire. This interconnectivity and interdependence on digital applications and information not only defines the work as post-digital but also as post-human. More challenging to define, the post-human in this thesis is acknowledged as a condition of humanity's dependence on the interconnected cybernetic network.

The experiment in this thesis, Digital Ceramic Risk (Section 4), explores the entanglement of the post-digital and post-human condition by examining risk through the crafting of a hybridized digital and physically made artifact. These experiments were conducted in three phases. Phase one profiles the creation of a digital tool that enabled hybridized manual and digital ceramic printing. Using this 3D printer, the research Identified risk variables through documented tests. Variables such as material failure, tool failure, and digital errors were tracked and analyzed. Phase two demonstrates a high level of skill and craft through the use of hybridized methods. By applying the identified risk factors from Phase one, the outcomes of the experiments generated newly crafted forms that otherwise would not have been realized through an only digital process. Phase three demonstrated optimized printing skills and craft through sustained practice and improved digital tools. The outcomes of this phase created a visually distinct collection of vessels. Each vessel was modified as it was printed to create a version of the control vessel that was digitally modeled, and that generated the g-code controlling the 3D printer. These improvised artifacts were re-digitized and dimensionally quantified into data. This data was encoded into an Artificial Intelligence (AI) database for the propagation of an infinite number of new vessels. This extension of the handmade object into an AI database is a human infusion into the post-human cybernetic network. The case studies and experiments contained within this thesis demonstrate how craftspeople can now both exist in the material world while still existing in the broader post-digital and post-human condition.

1.1 State-of-the-Arts

Although there is a vibrant academic discourse around digital tools, craft, and tectonics, the epistemological foundation is still under development. All of the terms, their associated meanings, and how they are defined are still evolving due to the rapid development of digital toolsets and the uncertainty of how they will impact the profession long-term. However, this thesis is guided by significant publications related to digital and material issues while compiling this dissertation. David Pye wrote two very influential books: *The Nature and Aesthetics of Design* (Pye 1978) and *The Nature and Art of Workmanship* (Pye 1968). Together these books clarify the role of craft and workmanship in design. Significantly, Pye defines the craftsmanship of certainty and the craftsmanship of risk. Responding to a pre-digital world, Pye explains the craftsmanship of risk is a process where "the quality of the result" is frequently at risk during the process of making and is dependent on the judgment and care exercised by the craftsperson". The craftsmanship of certainty requires comprehensive planning of the process before fabrication and erection with all components predetermined and pre-tested to the greatest extent possible. At the time of its writing, risk and certainty were entirely separate and explicit, risk falling on the side of the craftsperson and certainty leaning heavily toward manufacturing and industrialization. Today the distinction between risk and certainty is not so clear. With new digital tools, it is not uncommon for a craftsperson to design and digitally make something that deals with both certainty and risk, with the variable shifting based on tools, materials, and context. This thesis will try and induce further understanding of these principles in a post-digital and post-human context.

Malcolm McCullough wrote *Abstracting Craft: The Practiced Digital Hand in 1996* (McCullough 1996). This publication was significant as an early text contributing to our understanding of craft and how it might relate to digital tools. Specifically, McCullough establishes a clear history of craft as it relates to computer technology and the processes and repetitive tasks undertaken by the users. A theoretical line between the handicrafts and the use of hands when controlling a computer. Although significant, this thesis departs from McCullough when he asserts that craft is dematerialized. Possibly this avenue of research emerged within the current limitations of computers when written. This thesis explores the material and tectonic variables not addressed by McCullough's insightful publication.

Kenneth Frampton's Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth-Century Architecture (Frampton and Cava 1995) is the seminal academic publication of academic understanding of tectonics as defined in contemporary architectural discourse. Frampton does, however, stop short of engaging with new digital toolsets, it was clearly outside the scope of the publication. This thesis continues the investigation of tectonics with the use of historical precedent with a focus on craft and digital tools.
The 1997 essay by Robin Evans, *Translations from Drawing to Building* (Evans 1997) chronicles the polemic that all contemporary architects face: they are authors of the drawings, not the final work, thereby elevating the importance of the drawing to the architect. The divergence of drawing and building is a constant struggle for architects. Recently within the context of digital fabrication, the drawing is facing yet another crisis and one that Evans does not adequately address: do drawings matter anymore? Given that when architects digitally fabricate projects, they are not only using their drawings to simulate and represent (as Evans explains) but to fabricate. This thesis asserts that drawings do matter more than ever, yet they have shifted in their role and meaning. Influenced by Evans' work, this work hopes to reveal that drawings do more than generate geometry for fabrication but are a generative tool that can influence, material, craft, and tectonics. Evans' contributions were preceded in his publication: *The Projective Cast: Architecture and Its Three Geometries* (Evans 1995). In this publication, Evans' considers the drawing more closely and in particular, the projected drawing. The role of drawing is presented clearly when he explains the operation of the trait, the 17th-century technique of drawing that allows an architect to draw accurately and ultimately carve stone to predetermined size and location. This method of drawing proved to be a highly sophisticated method to create complex masonry unit forms that were both structural and esthetic. Like Frampton, Evans limits his scope and does not address the pressing questions prompted by new digital tools.

Other contemporaries have begun to probe these topics with some clarity. Gail Peter Borden and Michael Meredith published *Matter: Material Processes in Architectural Production* in 2012 (Borden Peter and Meredith 2012). The publication serves as a survey of digital fabrication research in the academy at the time of publication. One project highlighted by Borden is Lawrence Blough's *Digital Tracery: Fabricating Traits.* In the introduction, Blough explains how he extended Evans' work by digitally replicating the Trait explained in the *Projective Cast*. A significant achievement by Blough and one that is influential to this thesis, but it did not engage the tectonic and craft implications in-depth (it was primarily a pedagogical and aesthetic exercise). These variables are used only in finding the form of digital tracery. In Blough's defense, this was the central point of Evan's article. However, we already know how to draw and isolate the geometry described by Evans. What is still difficult for architects, even with the aid of computers, is achieving the high level of craft and precision of tolerances seen in the 17th-century work profiled by Evans.

Neil Leach published a noted book that shares a research interest with this thesis. *Digital Tectonics,* published in 2004, uses a case-study approach of the use of the computer as a generative tool to create new architectural forms algorithmically (Leach, Tumbull, and Williams 2004). Leach's use of the term "tectonic" is due to his acknowledgment of the parametric aggregation of geometry and the tectonic conditions created that necessitate an understanding and control over materials and connection. The book is focused on form-finding, not the tectonic condition created by algorithmic aggregation. There is an opportunity to extend Leach's work to understand the craft implications of aggregated geometry.

In opposition to Leach is Matthew Crawford's *Shop Class as Soulcraft: An Inquiry into the Value of Work,* where he argues for the intellectual value of the skilled trades (Crawford B 2009). His writings explore the cognitive demands of what he refers to as "the useful arts." Crawford asserts that western philosophy shifted our understanding of wisdom, or an "understanding of nature," from one that was primarily observational to one that involves mental concentrations and mathematical constructs. This new value on intellectualism negated many investigations that require direct contact with the world - or practice within the world itself. This thesis puts forward Leach's work, along with many others that have limited intellectual inquiry by not engaging with material consequences. This thesis reengages with the understanding of the material world and its intellectual value.

Crawford's perspective is supported indirectly by Richard Coyne's publication *Technoromanticism: Digital Narrative, Holism, and the Romance of the Real* (Coyne 1999). Romanticism and the Enlightenment are analyzed and compared to the current narratives surrounding computer technology, whereby many architects are seeking a digital utopia by only focusing on a romantic future that will never exist. Coyne argues that given computer data is primarily made up of mathematical coded language, the outcomes are not "real" and cannot be represented. This idea is also in direct conflict with McCullough's ideas of the dematerialization of craft through digital technology. Both Coyne and McCullough do not address (due to time and context) the possibilities now created by accessible digital fabrication technology.

When architects wade into the narrative of craft and making it is hard to avoid the legacy of the Arts and Crafts movement. With its roots in 19th century Victorian England and led by John Ruskin and William Morris, the movement sought to resist what they viewed as the impurities of industrialization by advocating for the "truthful" or "soulful" handmade good. William Morris clarifies in the nineteenth century that because of nature, all men are required to work. The difference between work that is enriching to the laborer (useful work) and work that slowly kills him (useless toil) is hope. Three hopes expressly set apart work which is good from work, which is bad: the "hope of rest", the "hope of product", and the "hope of pleasure in the work" (Morris and May Morris p. 28). Lead by Morris and Ruskin It is hard to cite a reference that encompasses the importance of craft socially, economically, and ethically as was done by the Arts and Crafts Movement. However, it was the romantic notions of the past that hindered their work regardless of its proliferation. By focusing on the guilds of the Gothic and Middle Ages, this thesis asserts Ruskin and his contemporaries did not have the opportunity or would not conceive of a new method of working that aligned itself with the new industrial, social, and economic order. It further asserts that this is an opportunity for architects, that we can capture some of what is lost in craft and making, not by looking only to the past, but by operating entirely in the present. This construct of how to work with digital tools today is why Crawford is a protagonist in the research contained here, by emphasizing individual agency in one's discipline over romantic notions of a reprioritization of societal values. He also clarifies the importance of engaging with the final work and the importance of the hand as a counterbalance to the computer – to make the virtual real. The work of Glen Adamson frames many of the definitions and understanding of contemporary thoughts and debates around craft and craft artifacts. Adamson provides insights into how society views craft and craft objects in opposition to design and design objects. He notes in his book The Invention of Craft (Adamson 2013, p. 143) that if artisans were asked to come up with an object to be judged, then only their design skills would be critiqued and not their skill in making as would happen if they were asked to imitate a preexisting object. This gives the fundamental definition of craft a non-generative character, but Adamson explains how craftsmen such as Richard Redgrave and David Pye have used imitation to understand methods of making and lead to branches of craft diversity. The methods of making described by Adamson are a direct influence on the work of this thesis.

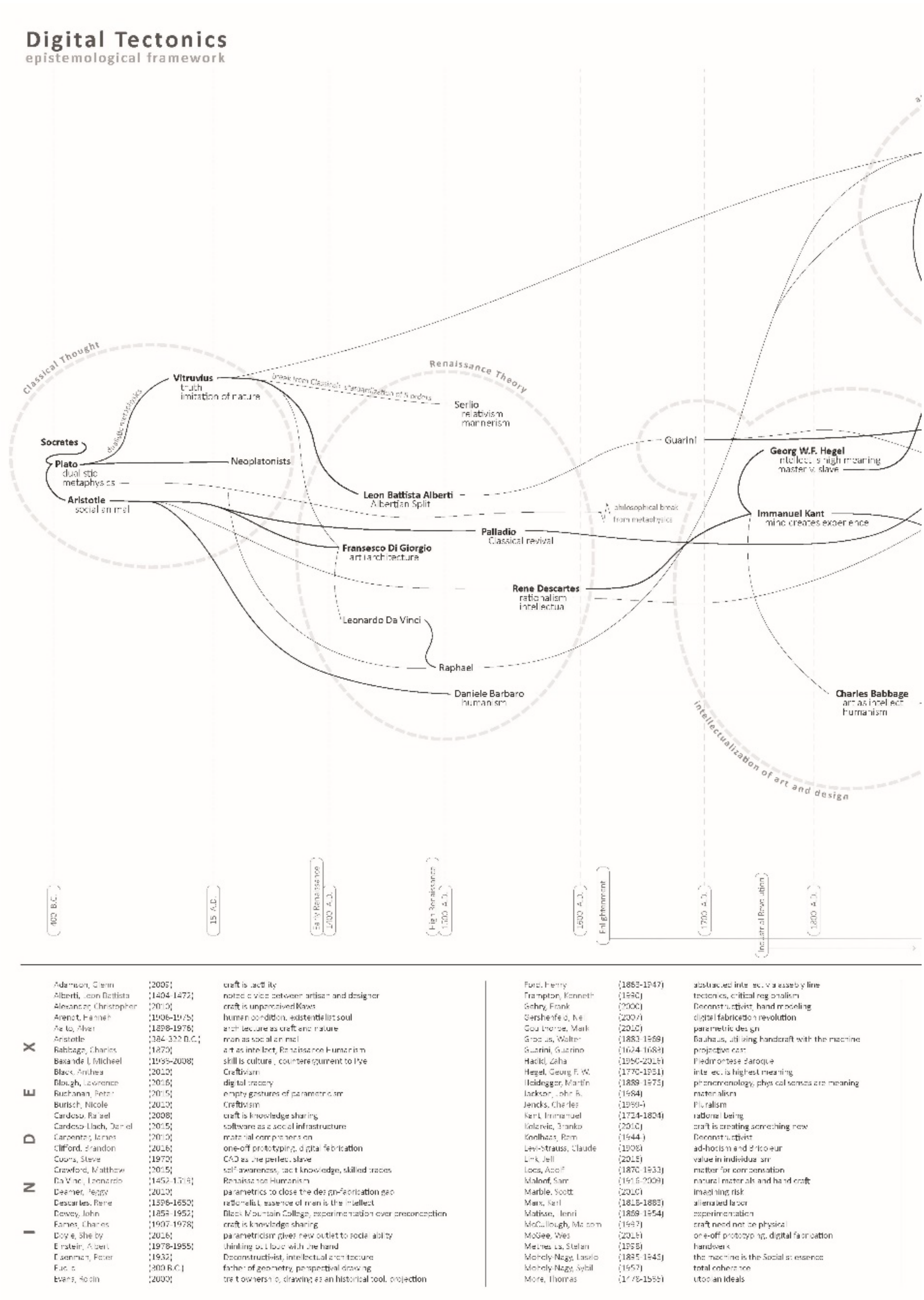
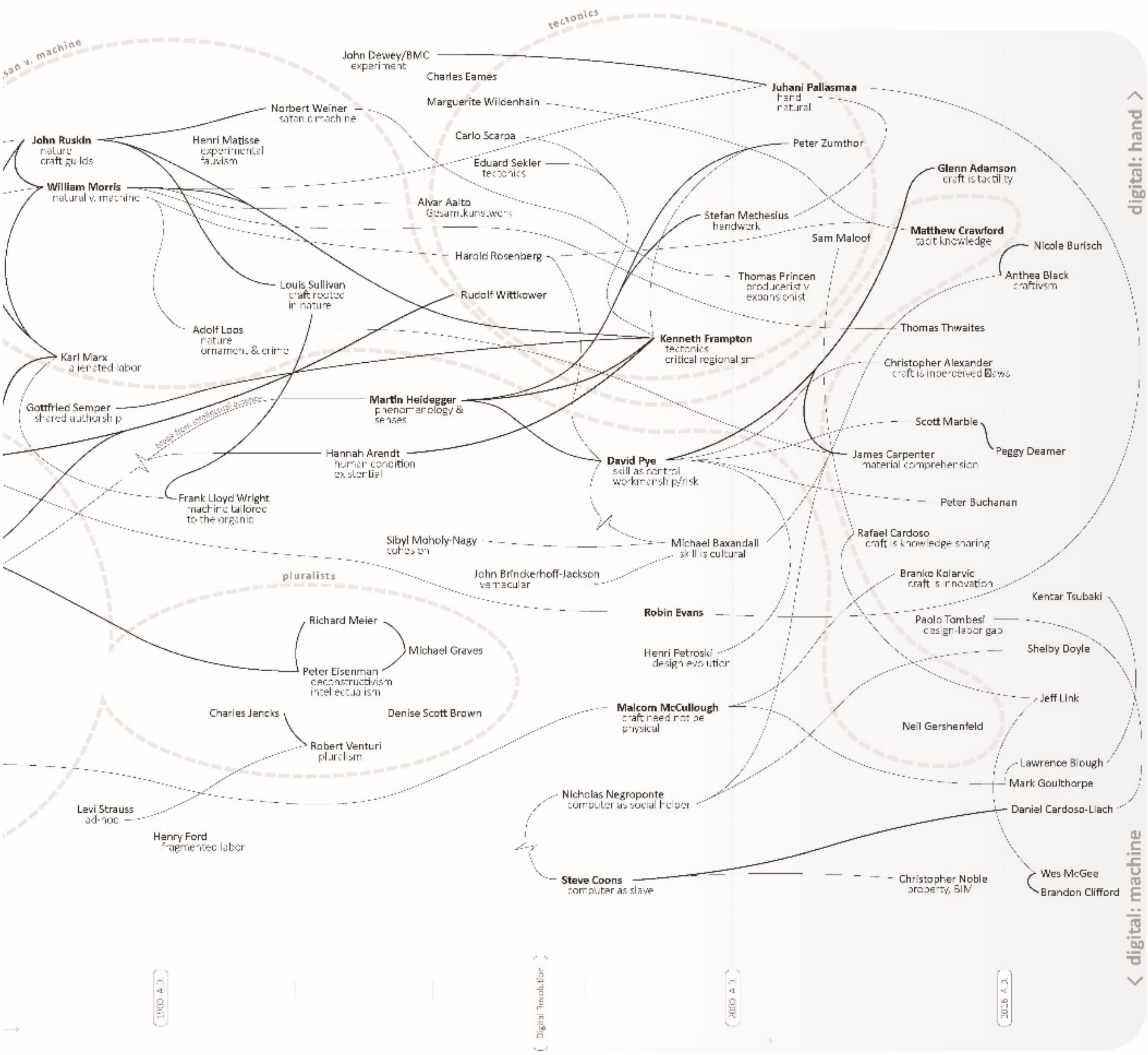


Figure 3 Epistemological Framework



Morris, William	(1834-1896)	nature versus the machine
Muthesius, Hermann	(1861-1926)	handwerk
Negroponte, Nicholas	(1970)	CAD as a social problem solver
Noble, Christopher	(2010)	intellectual property of BIM
Pallasmaa, Juhani	(2004)	natural world through the hand
Petroski, Henry	(1994)	evolutionary design
Plato	(427-348 B.C.)	dualistic metaphysics
Pollock, Jackson	(1912-1956)	experimentation, tactile art
Princen, Thomas	(2005)	producerists v. expansionists
Pye, David	(1978)	skill as constraint, workmanship
Raphael	(1483-1520)	Renaissance Neoplatonism
Rosenberg, Harold	(1965)	degradation of the machine worker
Rotmoe, Kevin	(2010)	markings in digital craft is code
Scarpa, Carlo	(1906-1978)	tectonics
Ruskin, John	(1849)	three hopes, nature versus machine
Sekler, Eduard	(1965)	tectonics
Semper, Gottfried	(1860)	detail as shared authorship
Serlio, Sebastiano	(1475-1553)	mannerism, the five orders
Sullivan, Louis	(1947)	craft rooted in nature, not form making
Thwaites, Thomas	(2011)	building from scratch, toaster project
Tombesi, Paolo	(2010)	design-labor gap
Tsubaki, Kentar	(2012)	fold out drawing
van der Rohe, Ludwig Mies	(1886-1969)	craft is essential to architecture
Vasari, Giorgio	(1511-1574)	Renaissance humanism
Venturi, Robert	(1925)	pluralist
Vitruvius	(15 B.C.)	truth, imitation of nature
Voulkos, Peter	(1924-2002)	experimentation
Weiner, Norbert	(1950)	satanic mills of industry
Wittkower, Rudolf	(1901-1971)	Renaissance historian
Wildenhain, Marguerite	(1937)	good design is quality products
Wright, Frank Lloyd	(1867-1957)	machine as handmaiden to art and craft
Zumthor, Peter	(1990)	hardcore beauty, phenomenology

1.2 Scope and limits

The purpose and goal of the research are to define principles of materialized and dematerialized craft concerning digital fabrication and parametric applications. The two variables of the digital and craft are defined at length in sections 2.1 and 2.4 and come together as a way of working with materials and computers to achieve a new Digital Craft (Section 2.4). The literature review and theoretical positioning of the project are intended to provide context for the project and its significance within the epistemological tradition of design and architecture. The new theoretical understanding, however, is not the goal of this work; it is carried out only for accurate interpretation and position within the practice and the academy. The research is an applied design process rooted in a tradition of design and making theory. Digital applications, digital scripting, and custom digital tools all play a central role in this study. However, they are not its central focus – the invention of digital tools is not claimed or attempted here. The custom tools and the knowledge used in their creation are profiled, yet the artifacts created within this study take central focus.

To reach a level of depth and breadth, and to give the project meaning, digital craft was examined and evaluated to seek what variable would be most fruitful in the study of digital craft. Early work found that the primary variable that separates traditional craft methods and new digital fabrication methods is 'risk.' The risk was found through early journal entries and reflections to be a peculiar variable, but one that warranted further examination and experimentation. The identification of risk led to an overarching research goal of understanding the value of 'managed risk' in digital craft and processes or – digital risk.

The desire to experiment both with material risk and digital control created a series of design experiments titled: Digital Ceramic Risk. The first step in the process was to create a tool that embraced both manual (hand) control and digital process. A large-format 3D printer was designed and fabricated to print custom ceramic masonry units (Figure 4). The 3D printer's design intentionally allows risk; it embraces failure and negates standardization. The digital tool is a scaled-up open-source Delta 3D printer configured to print ceramic clay.[1]

[1] There are multiple open source 3D printers available online that provide bill of materials (BOM) and online support. In the case of the digital risk project the three-rail system provided by the Delta printer was the closest example of what was needed to carry out the experiment. However, vastly increasing the size required many modifications to materials and extensive recoding of the Arduino control board. See more at: http://reprap.org/wiki/Delta

The principle that guided the tool’s design was to have distinct tasks relegated to the computer and the human hand (Figure 5).

The choreography is accomplished first by using the printer’s ability to control the movement of the ceramic extrusion in the x, y, and z directions. Therefore, the computer was used to shape the proposed artifact virtually and to accurately move the extruder along a path directed by G-code output. The hand of the craftsperson controls the material and is at risk while operating the tool. The clay is pushed through a chamber using compressed air, where the air pressure determines the flow rate of the clay. The flow is synchronized with the speed of the x, y, z movement of the printer. The air pressure was not calibrated to a standard measurement; it was monitored by the craftsperson that slowly adjusted the pressure responding to dry or sticky portions of the clay batch.

Figure 4 Custom ceramic 3D printer


Figure 5 Mixing clay before printing, photo by Author

The craftsperson in control of the printer is not merely an “operator” of a computer tool but is instead in a risky negotiation between the material and the digital. The digital tool exhausts its users; they move between mixing the clay to hours of closely monitoring the clay distribution. All steps are taken with a likelihood of failure. When the craftsperson is in sync with the tool, the clay runs smooth, and the craftsperson can achieve a valuable result. The imperfections of the produced artifact are evidence of the risk taken (Figure 6).

The 3D printer and the artifacts it produced have been recorded and analyzed both qualitatively and quantitatively for insights for future iterations. The 3D printer was dismantled and rebuilt to produce more outcomes for evaluation to provide further clarity on how risk can be used to create new and innovative artifacts not possible in a risk-averse environment. (See Section 4)

Figure 6 Early artifact produced by the printer

1.3 Research Positioning

The Digital Risk project is not one that seeks to find new forms, nor is it an exercise in geometrical complexity. This project seeks to clarify the variables embedded in digital making and how designers can seek new processes by learning from past traditional techniques. Specifically, the project has a narrow focus on risk and its inherent benefits to digital craft. This focus is analyzed by a series of experiments that tease out detail about how we work with our hands and digital tools and how those might align to create new opportunities.

This narrowing of the research position has eliminated many distinct outcomes and avenues of dissemination. Although it uses parametric software, the research may be of little interest to those seeking insights from specific digital scripting strategies around geometrical emergence and complexity. The geometry and complexity of digital parametric modeling in this work does reach a level of sophistication but only to serve as testing limits of tool, material, and maker. Despite achieving objects of high quality, this research also may be of little interest to those seeking to learn how to make specific objects well; this work is not a how-to of for craft and making. Multiple custom digital tools based on open-source technology were designed and built for this thesis. However, those seeking in-depth instructions on how to build and maintain these tools will not find the results here. The digital tools were built to test ideas, and their design and documentation reflect this fact. The audience for this research is those who are interested in learning the impact of the digital process on traditional means of craft and how these interruptions may provide unique possibilities for the craftsperson in the future.

1.3.1 Research Audience

Those engaged in academic, professional, and studio-based practices that depend on traditional craft will be interested in so far that the reader seeks or keeps an open mind to the inevitable disruptive technologies that this work recognizes. The contemporary craftsperson will find useful the research position of maintaining essential elements of skill, risk, and material resistance when conducting experiments and analyzing findings. Although not intended to be replicated inexactitude, the research parameters will allow a traditional craftsperson to frame their digital risk variables in their unique way of working. It is the hope that this work will allow for future exceptional outcomes not always achieved here.

As stated prior, the custom digital tools profiled here are built to test specific ideas, not as a future tool or product, to be replicated by others. However, engineers and designers engaged in the making of digital tools will find the concluding principles of interest (Section 5). Most of the digital tools used in the profession of architecture, design, and craft are not built by designers; they are built by engineers. In most cases, these tools are created for manufacturing – not design (Llach Cardoso 2012, pp. 73-82). Therefore, this work seeks to communicate the principles of specific concern from designers and craftspeople to engineers that will create the next generation of digital tools. Nowhere is the need and potential for these principles so great as it is with the future interruption to design craft, and making by artificial intelligence (AI), Augmented intelligence, and robotic automation. As outlined in section 0, this technology will disrupt our current methods of making in ways we cannot yet imagine. It is also likely this will happen quickly with new tools that can learn from makers and replicate their actions. At the writing of this thesis, there is no consensus on what will become of the craftsperson in the age of AI, but most agree that the one shortcoming of this technology is a lack of consciousness (Harari 2017, pp. 313-314). For now, at least we will remain the dominant terrestrial with empathy and creativity. As hallmarks of human behavior, AI's shortcoming also remains essential to craft, design, and making. If, therefore, an engineer is to create a digital tool that is both controlled by a human and an AI computer using the principles found here will frame a successful strategy that is both machine and human, one working with the other, each learning from the other.

Perhaps the most relevant audience is those of policymakers for our nations and their institutions. Nowhere is this truer than in emerging economies like Albania. With the rise of AI and other disruptive technologies, both manufacturing and the service industry (such as call centers) may no longer exist and, therefore, will not be outsourced to emerging economies with low wage bases. Some reports indicate that up to 40% of current jobs may be eliminated over the next 30 years (Schwab 2016). As with many of the past economic and social upheavals, these jobs will be replaced with new, but this time it will likely be with fewer jobs and ones that are very highly skilled technology jobs. For those countries like Albania that are just emerging from years of economic and social crises, it will be challenging to position the workforce for these new jobs. Of course, these are only economic speculations, but they do carry with them an undeniable warning: our policymakers must engage in and understand technology so that they can lead their nations to a sustainable future. Developed economies like Italy and the United States are far from insulated from these changes. Many may argue that given the substantial infrastructural obligations of these nations, their stability could unravel given the potential that AI and robotic automation may have. What this work provides to policymakers is a potential third path, one that is not purely a technological utopia of digital making that excludes the human and minimizes labor but one that uses technology to extend human creativity and human potential. It is the nature of capitalism and liberal democracy to maximize profits and minimize labor obligations so such a third proposal may seem idealistic and naïve. However, the leaders of our nations in the future may once again become vexed by even further social inequality. Marx identified the conditions of mass inequality in capitalism and predicted a revolution in industrialized nations where manufacturing degraded the worker and built wealth for the industrialists (Marx 2009, p. 07). Although his predictions did not come to pass, the principles identified in his concerns were the impetus of the rise of the Communist Party, the Soviet Union, and various dictatorships, including Albania, around the world that had their origins in protecting the worker from mechanization. As we know, today, the capitalist system has prevailed with few exceptions. However, the social implications of capitalism have yet to be tested when AI and robotic automation supplants workers into a new useless class (Harari 2017, p. 322).

It is not the intention of this study to be nihilistic or to provide a bleak view of the future. In contrast, the work is more an investigation into what makes us human, more specifically, what makes us humans that are compelled to create and make what we imagine real. Further, this work seeks to maintain the human and the tacit knowledge of their skill while improving efficiency and innovation through a choreography between man and machine. Without such an approach country like Albania may find themselves reverting to an agrarian economy, suffering significant job losses, and missing an opportunity to join the age of AI. Without leaders in the European Union, the United States and other world economic powers recognizing these fundamental truths about how we work, how we create and find meaning in our work. If our policymakers are unable to foresee the importance of craft and other humanistic values, they may find they have lost what it means to have a nation or society. The solutions embedded here are not abstract and apply to many different processes in many different cultures. This work hopes to provide some insight into one process that could work to maintain both humans and machines.

1.4 Research Methods

Digital Risk produces multiple outcomes and variables to be measured and clarified. It is the intent of section 1.4 to describe how information, outcomes, and evaluations provide significate studies within architecture and design. Following the survey of design, the research debate is section 1.5 that makes an effort to describe the methods deployed in the Digital Risk project. The methods seek to make the conclusions of the study explicit and transferable. To this end, the following data sets were collected for this study:

- Interviews – with the critical designer (graduate student subject) in the Digital Risk project
- Observational - Quality and performance of made outcomes
- Quantitative – Measured factors relating to the design process
- Journaling – Reflective statements during and after the design process that inform future iterations.
- New artifacts – The documentation and demonstration of new tacit knowledge in the creation of unique artifacts.

The methods deployed continue to evolve but are routinely evaluated for their position within the current discourse and debate of architecture and design research.

1.4.1 Design Research Debate

The term *research* has always been in question regarding its description and purpose. This question is especially true for doctoral research in architecture and design. Victor Margolin, Professor Emeritus of Design History at the University of Illinois, Chicago, posits while “it is clear that the principal purpose of the Master’s degree was to prepare teachers of design by offering more advanced design courses and the opportunity to engage in a modest research project, the purpose of a general doctorate in design has never been well-articulated” (Margolin 2010, P. 05). As a result, even though a doctorate has become a requirement for design teachers in many countries, it has become associated with a symbol of research, according to Margolin. This, however, has led to a doctoral degree to becoming “more symbolic than pragmatic,” which has consequently resulted in “the need to do research that is not driven by a shared research problem or set of problems but instead by the need to maintain the status of the degree” (Margolin 2010, p. 05) . The dilemma many architecture Ph.D. research projects find themselves is further explained by Richard Buchanan when distinguishing between paleoteric and neoteric thinking (Buchanan, 2001, p. 07). Paleoteric thinking identifies discreet subject matters that can be studied in detail to add incrementally to a subject's body of knowledge. This is common in most universities and has reinforced disciplinary boundaries in research topics. Neoteric thinking, on the other hand, is "based on new problems encountered in practical life and in serious theoretical reflection" (Margolin 2010, p. 01).

Christopher Frayling of the Royal College of Art asserts the notion of research has lead to confusion and attempts to break the term *research* down by claiming "much of the debate so far has been revolved around stereotypes of what research *is*, what it *involves* and what it *delivers"*. Frayling goes on to explain *research* by categorizing the term with a little *r* and a big *R*, describing "research with the little *r* as the act of searching, closely or carefully, for or after a specified thing or person" according to the Oxford English Dictionary. This definition also includes 'investigation, inquiry into things'; "it is about searching." However, when *research,* as it relates to the big *R*, is conducted, it is within the realm of professional practice, which earns it a big *R*. The big *R* entails research which includes "work directed towards the innovation, introduction, and improvement of products and processes" as defined by The Oxford English Dictionary per Frayling. While this breakdown of the term *research* by The Oxford English Dictionary is helpful, it does not fully explain its significance as it relates to doctoral research in design. Why is this definition breakdown of the term *research* necessary, and what is its significant connection to doctoral research? This has to do with the purpose of research once it has been hypothesized, studied, conducted, and concluded – the result of this process should produce the ability to "tell someone about it," explicitly. The significance of research as it relates to a doctoral degree is the ability to make findings explicit. Frayling supports this notion of making things explicit through critical rationalism as a way to reveal the "methods of one's logic and justifying one's conclusions, which has at the heart of its enterprise a belief in clarity" (Frayling 1994, p. 01-05). It is also Frayling who suggested that design research be conducted in three primary categories: "Research *into* art and design, research *through* art and design, and research *for* art and design. Research *into* art and design could include art, design or architectural history, or it could be the study of design processes and the cognitive understanding of designers". Most controversial and some debate, underdefined: Research *through* art and design that involves research that comes out of design work, including studies of aesthetics and perceptions. Research *for* design is the broadest and includes many areas of study, including social, economic, political, ethical and cultural issues. Fifteen years later, Ken Friedman pushed against these categorizations citing the lack of clarity and critical debate among scholars who use them to justify their work (Friedman 2008, 153-160). Despite the debate around these three categories, they have persisted in framing the debate around design research. It may be in part because Frayling suggested them based on what he saw as what designers "already do." Indeed, there is value in structuring research around design activates to ensure factual findings. Friedman does take issue with all three, but mostly his criticisms are due to the lack of interrogation, not the validity of their existence. Frayling himself suggested in the final paragraphs of his essay that much work will need to be done to understand and clarify the suggested structure.

Further clarification of Fraylings categorizations has occurred. Findeli et al. provided further definitions to clarify Frayling's early work (Findeli et al. 2008, 67-88). A narrative of Findeli et al. 's work is as follows:

Research for Design

"Research for design is highly relevant for designers". This is because its purpose is to ensure the various parameters are handled adequately. "These parameters are dependent on the output of the process design, such as technological, ergonomic, economic, aesthetic, psychological, and others". This research, however, is not considered scientifically acceptable for various reasons. These reasons include: the research draws on already available knowledge; new knowledge produced is "not done with the same rigor expected by scientific standards, this is because the 'researcher' does not have the necessary qualifications" or time constraints do not permit, which is usually the case; and lastly it "is not meant to be published or discussed by the design research community" as it is mostly tacit, and perhaps even kept confidential (Findeli et al. 2008, 67-88, p. 70) . While this work still has value, it differs in the "respective aims, validation and assessment criteria, as well as public and contexts," which means one researcher should not be evaluated with the standards of another.

Research *about* design

"Research about design is performed by various disciplines" that are different from design, but according to scientific standards. This type of research is published because of its rigor and acceptance by the scientific community. "The problem we encounter with this kind of research is its relative lack of relevance for design" (Findeli et al. 2008, 67-88, p. 71). Findeli et al. define "design" as a design practice, design education, or design research. Findeli et al. postulate the reason for its lack of relevance is because "the research is carried out *about* design (*i.e.* about its objects, its processes, its actors and stakeholders, its meaning and significance for society, business, culture, etc.) by scientists (like anthropologists, archeologists, historians, cognitive psychologists, management scientists, semioticists and

many others whose main goal is to contribute to the advancement of their own discipline, not particularly of design" (Findeli et al. 2008, 67-88, p. 71) . Mainly this is because they have not been trained in figuring out how the "knowledge they produce in their research is relevant for design". Findeli et al. assert such knowledge is better suited for designers to decide if it is relevant for them, and if so, how it can be implemented in their respective practice.

Research through design

Research through design is conducted while engaged in the act of design. Findeli et al. assert this must be based on the research *for* and *about* design, so to satisfy two crucial criteria: research must be *rigorous*, and it must be *relevant*. Because research *through* design is the outcome of research *for* and *about* design, therefore, research *through* design *must* contain the virtue of both, this is critical, Findeli et al. postulate. It is a "one *and* the other" situation. Findeli et al. propose three domains of assessment for design research project conclusions. The first is common, and states "an original and significant contribution to design knowledge." The second states, "an expected improvement of design practice and consequently of user satisfaction." Moreover, the third states some fruitful consequence for design education" (Findeli et al. 2008, 67-88, p. 72). Therefore, research *through* design must be done rigorously and "stand up to the usual scientific standards" while also being relevant by contributing to design practice (Findeli et al. 2008, 67-88, p. 71). The clarification goes further by pointing out that most designers work simultaneously in all three areas: *about, through* and *for*, and recognizes the way designers work, much like Fryling hoped to structure design research when first proposed. They point out rightfully that designers cannot work comprehensively without combining them. From this Findeli et al. called their approach project-grounded research (*recherche-projet*), a process of research through design while incorporating elements of both about and for design.

Nigel Cross talks of design and science in his essay *From a Design Science to a Design Discipline*, asserting the desire for "works of art and design based on objectivity and rationality," A Professor Emeritus of Design Studies at The Open University, United Kingdom, Cross talks of Scientific Design as a mere reflection of the reality of modern design practice. More specifically, Cross talks of what he calls 'Design Science,' which was a term first used by Buckminster Fuller, and who's aim of *Design Science* was to "recognize laws of design and its activities, and develop rules," constituting a 'systematic design' – "procedures of designing organized in a systematic way." While some authors may have narrowed down the notion of *design science*, Cross claims the definition extends beyond it, concluding that "*design science*" refers to an explicitly organized, rational and wholly systematic approach to design; not just the utilization of scientific knowledge of artefacts design being in some sense a scientific activity itself" (Cross 2007, 41-54).

Cross goes on to explain design research, citing Archer's definition of research, stating, "'[R]esearch is a systematic inquiry, the goal of which is knowledge.' Our concern in design research has to be the development, articulation, and communication of design knowledge," alluding to the notion of making design explicit. As a way to reinforce the notion of explicit design research, Cross identifies characteristics related to it, including the characteristic of "*Communicable* – generating and reporting results that are testable and accessible".

1.4.2 Quantitative Methods

According to Groat and Wang, quantitative research is that which "depends on the manipulations of phenomena that can be measured by numbers" (Groat and David Wang 2002, P. 69) This differs from qualitative in that qualitative is evidence that is non-numerical, but instead can be verbal (oral or written), experiential or artificial (objects, buildings, urban areas). Whereas "qualitative research assumes a subjective reality and views the researcher as interactive with the subject of inquiry, quantitative research assumes an objective reality and views the researcher as independent of the subject of inquiry:. A "quantitative paradigm is seen as involving a deductive process of inquiry" on a methodological level. It seeks cause-and-effect explanations. In general, most research conducted is done so utilizing both quantitative and qualitative tactics. "Many research studies employ a combination of quantitative and qualitative tactics" (Groat and David Wang 2002, p. 72). This includes research that is typically associated with a qualitative paradigm, as well. Groat and Wang emphasize the "importance of both numerical and non-numerical evidence" being deployed in multiple systems of inquiry in a service. One example they provide to support the notion of using multiple systems of inquiry is how quantitative research is "assumed to be manifested in deductive methodology that seeks to discover cause-and-effect explanations." They go on to cite how numerous "authors in other disciplines attempt to address the quantitative science and qualitative humanities dichotomy that exists by incorporating the two epistemologies" into a single research study due to its optimally effective outcome. In one example, Groat and Wang cite a space study conducted by Bill Hiller is used to study "how patterns of social behavior relate to space adjacencies". They cite this study as a significant example as it integrates both qualitative and quantitative dimensions of environmental design for the research.

Conversely, they state that while it is common to find case studies that employ both quantitative and qualitative methods, “it is relatively rare to find case studies employ exclusively quantitative data” (Groat and David Wang 2002, p. 437). According to Groat and Wang, most authors describe a combination of quantitative and qualitative data techniques when it comes to the mixing of methods of a given study, regardless of the dominance of a particular school of thought. A mixed-methods approach seems to yield the most effective results. Therefore, they argue that “emphasizing the level of tactics in a mixed methods research may obscure the broader issue of research design that may be central to the complex fields of architecture and design research” (Groat and David Wang 2002, p. 443).

1.4.3 Qualitative Research

In their book *Research Methods*, Groat-Wang describes qualitative research as a “multi-method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret phenomena in terms of the meanings people bring to them” (Groat and David Wang 2002, p. 218). Qualitative research also consists of “the studied use and collection of a variety of empirical materials.” There is, however, another aspect of qualitative research, and that is the “underlying emphasis on an inductive process.” This means open-ended research questions are asked, which is then shaped after the exploration takes place. As part of the process, as the understanding of the problem increases, the questions change to reflect that understanding.

In quantitative research, there are five key components. 1. An emphasis on Natural Settings. “Natural settings” means objects being studied remain in the “venues in which they typically exist as part of everyday life”. This is significant as primary data is gathered based on observations and interactions of subjects in said settings for the study. Research tactics that “engaged people within the context being studied, while the context itself was studied in its natural state” (Groat and David Wang 2002, p. 219). It is necessary to not only ground the work of the researcher in “empirical realities of the observations and interviews,” but the researcher plays a vital role in the interpretation and making sense, or coding, of the collected data. While in-depth engagement with the subject will foster communication and understanding for the researcher, Groat-Wang notes it is fundamentally up to the researcher to interpret the coding process of interview texts. 3. “A focus on how the respondents make sense of their circumstances”. This component focuses on the subject matter and how the researcher should “present a holistic portrayal of the setting or phenomenon under study” as the subjects understand it themselves. In other words, it is necessary for the researcher to understand the subject’s views, feelings, experiences, and outlook on the topic under study through a series of questions and interviews. 4. The use of multiple tactics. This component of qualitative research focuses on research as *bricolage*, which is a "pieced-together, close-knit set of practices that provide solutions to a problem in a concrete situation" (Groat and David Wang 2002, p. 220). *Bricolage* suggests implicitly "qualitative research will employ a range of tactics that are both particular to the context being studied, and of course appropriate to the research question(s) being asked," in other words, a multitactical qualitative study. Such tactics could include "structured, in-depth interviews, location mapping, photo-documentation, architectural inventories, place-centered behavioral mapping, and focused observations, along with an image-based visual exercise known as experiential collage". The idea behind the collage is to have the subject elicit insight about what she is doing and how she feels about it as well as what it means to her. This set of data collection tactics is intended to focus "on the experiential qualities and conceptualizations of the subject's work. 5. Significance of inductive logic. This component suggests that the research question initially investigates through a qualitative study "frequently evolves in an iterative process." Due to ongoing observations and interviews, the initial question is refined, resulting in new or follow-up interview questions. In short, "the strategy of qualitative research is one of first-hand encounters with a specific and defined context. It involves gaining an understanding of how people in real-world situations 'make sense' of their environment and themselves, and it depends on, rather than rejects, the researcher's interpretation of the collected data. Finally, it achieves this understanding employing a variety of tactics, employed through a primarily inductive process" (Groat and David Wang 2002, p. 222).

1.4.4 Grounded Theory Research

Groat-Wang defines Grounded Theory as: "grounded theory seeks to investigate a setting holistically and without present opinions or notions" (Groat and David Wang 2002, p. 234). The authors note that a defining characteristic of grounded theory approach "is its stated aim to identify an explanatory theory as it emerges from the analytical process" (Groat and David Wang 2002, p. 235). First, however, a theory must be proposed. The emergent theory can then be studied in another similar context to see if it has explanatory power after it is proposed. The idea behind *grounded theory*, which is associated with sociologists Barney Glaser and Anselm Strauss, is to move the prevailing norms of qualitative research of the '60s and 70's "from purely descriptive studies toward explanatory theoretical frameworks." Groat-Wang offers a couple of different ways to describe further grounded theory, the first being dependent on "intensive, open-ended, and iterative process that simultaneously involves three tasks: data collection, coding (data analysis), and memoing (theory building)". This process – which is a part of grounded theory research – assumes "the object of study is not fully explained ‘on the first take,’” instead, it is “repeated observations, data collection and structuring the data into a working explanatory framework that are all part of an iterative process that leads to an emergence of a theory” (Groat and David Wang 2002, p. 235). Friedman defines grounded theory as “a ‘grounded’ theory is an inductive theory emerging or rising from the ground of direct, empirical experience” (Friedman 2003, 507-522). This is one major issue Friedman notes exist in design research – “it is the failure to engage in grounded theory, developing theory out of practice.” This is due to the fact many designers confuse practice with research, mistakenly arguing that practice is research rather than theory from practice through inductive inquiry and clarity. A second feature that defines grounded theory is the “ongoing role of memoing in theory building.” This is a process that consists of “substantial and ongoing memoing” throughout the research being conducted. It is a phase where theoretical ideas are recorded, “continuously linked and built up by means of theoretical memos” (Groat and David Wang 2002, p. 237). These memos are also to be examined and sorted, resulting in new ideas and new memos, and both can occur at any phase of the research. The outcome of “examination and sorting” is that “memos of greater scope and conceptual density” are produced. This entire process consisting of iterative data collection, coding, and memoing cycles, which leads to emerging theory, becomes characterized as an “*exclusively* inductive process.”

1.4.5 Tacit Knowledge

The term *tacit,* as it relates to this study, emerges from Michael Polanyi in *The Tacit Dimension* (Potanyi and Sen K 2013). According to Friedman, Polanyi “distinguishes between tacit knowledge and theory construction, asserting that tacit knowledge to be embodied and experiential knowledge, whereas theory construction requires more”. Ken Friedman, of the Department of Organization and Leadership Norwegian School of Management, Norway, expresses his view regarding tacit knowledge by positing a theory, or theory construction, cannot come from the tacit aspect alone, instead requires more. According to Friedman, Polanyi posits this includes “a significantly different mode of conceptualization and explicit knowledge management,” if we are to attain the task of solving problems and moving away from a general theory of design (Friedman 2008, 153-160). While it seems tacit knowledge of design practice has been confused with design theory, the two are not identical. To all fields of practice, tacit knowledge is essential. However, a category confusion is involved when confusing tacit knowledge with general design. This comes as a result of “failure to develop grounded theory in practice, and designers are often confusing practice with research” – a problem in design research. This is based on the argument designers make, and that is practice *is* research, and that theory construction is practice-based research itself. “All knowledge, all science, all practice relies on a rich cycle of knowledge management that moves from tacit knowledge to explicit and back again." (Friedman, 520)

Friedman rebukes tacit knowledge as the primary foundations of design research, noting there has been confusion about tacit knowledge, with only a surface acquaintance with the concept, laying blame on ignorance and failure to read what Polanyi articulates about the topic. Tacit knowledge is a vital knowledge category, Friedman posits. "All professional practice – including the practice of research – rests on a rich stock of tacit knowledge" (Friedman 2008, 153-160). Friedman goes on to note that tacit knowledge is equated "with design knowledge, where tacit knowledge and design practice are a new form of theorizing". This is mainly due to the adoption of the misunderstood term "for its sound-bite quality," which leads to ill-defined notions that the two are equal. It is because of this that Friedman postulates that "tacit knowledge is valuable," and "is central to all human activity," and it is the "embodied individual and cultural knowledge which provides an existential foundation of all activities including intellectual inquiry". Friedman stresses the point that the "craft tradition of design has relied more on tacit than explicit knowledge" and that explicit knowledge should be more so considered to build design theory.

1.5 Digital Risk Research Methodology

When starting a large research project such as a Ph.D. dissertation, a well-crafted proposal is the result of broad inductive reasoning from past research. This is to say, a candidate proposes a body of work that asks questions yet to be answered or questions that evolved out of opportunistic areas of knowledge that appear to provide the promise of new knowledge or new clarity to the discipline. It is typical and was the case in the proposal for this work that the candidate postulates that they have defined research questions, defined research methods, and expected outcomes. However, this process conflicts with established research methodologies for design and architecture (section 1.4.4).

As defined in the Design research debate, all valuable research use aspects of many different research methods. It is unusual to find projects of note that only collect, analyze, and conclude a question by only using one model (section 1.4.3). To do so would negate the essential human qualities of logic, reason, and extrapolation. Rigidity in the method would stunt creativity and improvisation. A single method would also imply that research is linear and not circular. A liner model of thought presupposes what the question is and what the answer is expected to be, not allowing for essential inductive reasoning to build new questions. However, it is necessary to define, within reasonable limits, the process by which research is being conducted and the value placed on each method.

Given the multiple research methods and the fluid way they connect within a design process, this document seeks to clarify how established methods are interpreted. These methods have been used to collect data, make observations, and to produce meaningful and transferable information. The Grounded Theory Method (section 1.5.1) is used primarily to organize the work and to maintain an iterative process of design and investigation. Within the research process is both quantitative (section 1.4.2) and qualitative methods (section 1.5.2.1) of research and data collection.

1.5.1 Digital Risk Grounded Theory Methods

As stated, Groat and Wang define Grounded Theory as a method that "seeks to investigate a setting holistically and without present opinions or notions" (Groat and David Wang 2002, p. 234). The scenario whereby a method allows for both "holistic" considerations and is void of "preset opinions" is one that aligns with exploratory design and experimentation. Indeed, the grounded theory method is exploratory and seeks to identify what emerges from the work. For the digital risk project, this circular and iterative nature of the method allowed for continuous improvement in the artifacts but also the collection of valuable data that tracked multiple variables from tool performance to human error (section 1.5.2). To align Grout and Wang's method of Grounded Research, the Digital Risk Grounded Research Method was created based on how the research was conducted when starting the first investigations. The diagram provided in Figure 7 Digital Risk Grounded Research Method, Adapted from Groat and Wang, 2013, provides not only a record of the research but provides a map as future cycles of inquiry occur. The process is circular; however, there is a beginning and an end when appropriate. The beginning always starts with the literature review. The literature allowed for a theoretical basis that forms research questions, hypostasis, and quires to extend understanding to form experiments. Each project or experiment was a proposition that evolved out of a historical precedent or open questions provided by the epistemological body of work that preceded this dissertation (See section 1.1). This step in the research manifested as an experiment, test or prototype and was many times repeated multiple times to confirm consistent findings. Following each experiment was a period of journaling. This is an essential step in the method that allows for critical reflection. From these reflections the research bifurcates to allow for documentation or a return, if necessary, to the theoretical analysis to refine the variables of evaluation. When a sufficient volume of significant outcomes are produced documentation occurs that manifested into journal publications, conference proceedings, and exhibitions. Following the documentation phase it is possible, but not always achievable, to make knowledge explicate as a final result and conclusion of the documentation phase. When transferable knowledge is not the outcome of the documentation, the research returns to Journaling to revise the assumptions of the work. Beginning the research method cycle again, the research seeks relevance and significance.

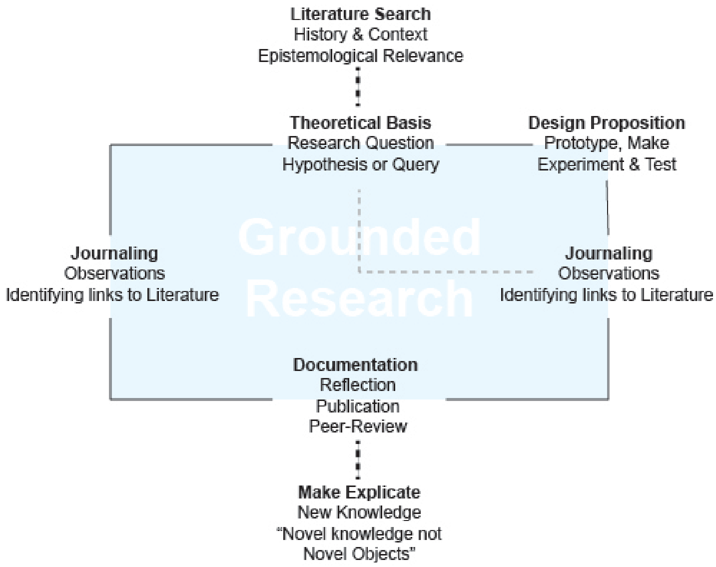


Figure 7 Digital Risk Grounded Research Method, Adapted from Groat and Wang, 2013

1.5.2 Digital Risk Quantitative Methods

Despite the research being primary qualitative, the addition of quantitative methods provided the critical data necessary to make explicit judgments of value. As stated prior, "qualitative research assumes a subjective reality and views the researcher as interactive with the subject of inquiry, quantitative research assumes an objective reality and views the researcher as independent of the subject of inquiry" seeking cause-and-effect explanations (Groat and David Wang 2002, p. 72). The digital risk project always required an evaluation of made artifacts by the craftsperson. This evaluation was analyzed and categorized into a series of criteria to track and evaluate based on the Likert Scale.

1.5.2.1 Likert Scale

The Likert Scale (lick-urt) is a rating system developed by American social scientist and phycologist Rensis Likert (1932). It was "designed to measure people's attitudes, opinions, or perceptions". The scale is based on a five-point linear continuum of responses that range from one extreme of the spectrum to the other, and everything in between. An example of this would be similar to responses that would include "strongly agree," agree," "neutral," "disagree," and "strongly disagree." However, the Likert scale "is not limited to social science but is used in educational research as well".

In the case of the Digital Risk case study, the Likert scale was adapted to describe the outcome of the 3D prints through various phases and tests. Still maintaining a five-point scale, the categories were manipulated to reflect test results, which included: “poor,” “fair,” “good,” “great,” and “excellent.” Each of the categories of responses was defined based on the user’s experience and feedback from all five components involved in the case study, including digital command, user-material, user-air regulation, geometry, and tool. Thus, this allowed for further understanding of the impact of skill, risk, and certainty within the process of making (see Section 4).

1.5.3 Digital Risk Qualitative Methods

As stated prior, qualitative research as a “multi-method in focus, involving an interpretive, naturalistic approach to its subject matter.” “This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret phenomena in terms of the meanings people bring to them” (Groat and David Wang 2002, p. 218). This also assumes that a more significant process is framing the “setting” and the “phenomena” evaluated. The digital risk project was burdened by the same dilemmas facing most research surrounding tacit knowledge, making, and design. Therefore, it was necessary to clarify how the research is framed through the defined categories of research *About, Through, From* and *For* design. The research method positions itself within research *Through* design - conducted while engaged in the act of design.

1.5.3.1 Digital Risk, About, Through, From and For Design

As stated before, Findeli et al. assert that research Through design must be based on the research *for* and *about* design, so to satisfy two crucial criteria: research must be *rigorous*, and it must be *relevant*. Because research *through* design is the outcome of research *for* and *about* design, therefore, research *through* design *must* contain the virtue of both. This categorization is clearly illustrated in Figure 8 by showing how each method relates to existing and established research methods and to whom the work impacts and benefits.

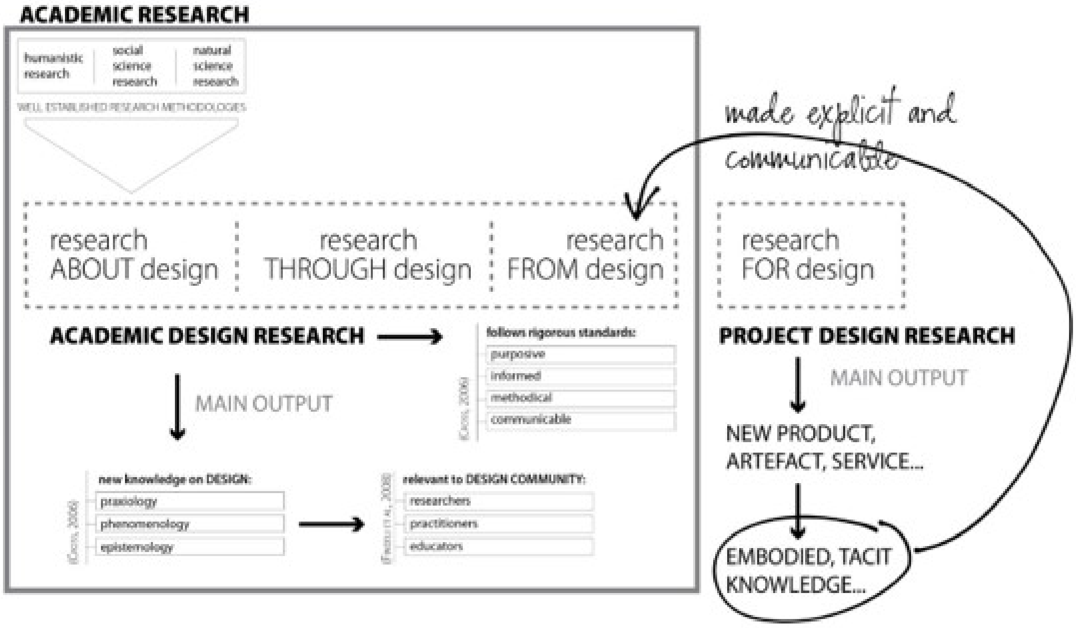


Figure 8: Academic Design Research: by courtesy: Clemente Violetaa, Tschimmel Katjab, Pombo Fátimac*

It is important to note that the "proposed scheme, project design research, or research for design, is placed outside the academic research boundaries". However, it is recognized that "design practice produces tacit knowledge that, if made explicit and communicable, contributes to the advancement of the design field". As stated by Cross, for works of practice to qualify as research, "there must be a reflection by the practitioner, on the work, and the communication of some reusable results from that reflection" (Cross 2007, 41-54). According to that proposal, "research *from* design arises from tacit knowledge made explicit and communicable, moving from a succession of unique cases to broad explanatory principles through an author's reflection and analysis. While research *for* design aims to generate novelty to the user, academic research aims to generate novelty for the design body of knowledge". Therefore, the research positions itself primarily inside of the research through design category but acknowledges that the outcomes and evaluations are based on tacit knowledge embedded in research for and from design. The primary element separating significance is the ability to make knowledge explicit. This is why this framework is paired with the grounded theory method (Section 1.5.1). A summary of all methods and their respective roles can be found in *Table 1*.

Research question	**Research nature/classification**			**Research aims**	**Data collecting instruments**	**Data source**	**Data analysis**
The purpose and goal of this research are to bring new understanding to materialized and dematerialized craft as it relates to digital fabrication and parametric applications.	Design authors classification		Social sciences authors classification				
Design project methodology?	Praxiologic (Cross, 2006)	Research *through* design (Findeli 2008)	Qualitative: Grounded Theory Research	To establish best practices when engaging with intentional risk methods and digital tools.	Activity record based on Logbook and reflection (Clemente, 2016)	A single graduate design student over entire testing process	Content and journal reflections. Evaluation of improved artifacts.
Designer's individual cognitive process?	Epistemology (Cross, 2006)			To collect data on the craftsperson's cognitive understanding of the digital tool and craftsmanship.	Cognitive styles record based on the logbook (Clemente, 2016) and structured interviews	A single graduate design student over an entire testing process	Likert scale analysis of artifacts to determine outcome variables and level of success.
Final products/artifacts?	Fenomenologic (Cross, 2006)			To generate new artifacts not possible with digital tools that negate risk.	· Artefact documentation and evaluation	Observational - comparison of exceptional external examples.	Evaluation grid (criteria to be defined)

Table 1 Research classifications. by courtesy: Clemente Violetaa, Tschimmel Katjab, Pombo Fátimac*

2 Craft and Risk

Control-Z is a ubiquitous command to those familiar with almost any desktop computer. It is a virtual safety-net to undo the most common mistakes. The digital environment and the post-digital and post-human world we are now navigating provides these digital protections and almost every level of information technology. This safe environment, however, breaks down when engaging with physical material. With practice, a maker can further extend these digital safeties in the material world through digital fabrication (as seen in case study 3.2). In what David Pye describes the craftsmanship of certainty, we can extend our digitally safe environments into manufactured certainty. Risk, however, is essential to craft. It provides the counter to skill and is the resistance to all accomplished makers. Therefore, it is essential to understand both craft and risk both in the past and the present. This study seeks to provide the state of the arts in this area of study while also attempting to make connections the provide insights into how we can operate digitally, whiles still embracing both craft and risk.

2.1 Defining Craft

Craft is typically defined as a skill that has been practiced to achieve consistent outcomes. One might think of a potter at the wheel consistently creating the same vessel to near perfection or a welder fusing steel that can achieve an expected shear load. Most agree that craft is achieved by practice and that it provides consistent outcomes that are exceptional. The Encyclopaedia of Diderot & d'Alembert described craft as the “name given to any profession that requires the use of the hands and is limited to a certain number of mechanical operations to produce the same piece of work, made over and over again' (Gendzier J 2009).”

Preceding organized industry, the ancients used utilitarian objects solely created by artisans. In the absence of industry, craftspeople played a defined role within society, tending to a body of knowledge handed down through generations of masters, journeymen, and apprentices. The Industrial Revolution interrupted the relative stability of craft through mass-production machines and the division of labor. The cultural response was to preserve and protect the handcrafts, and this manifested in the political writings of Marx, and the critical writings of John Ruskin, which were aligned with the Arts and Crafts movement. These reactions were rooted in an appreciation for craft that differentiated it from industry. The duality of industry and craft set up opposing views of material culture. On one end, the view of craft was nostalgic and sought material links to a pre-industrial past; on the other was the view of modern efficiency defined by speed and egalitarian distribution of a product.

It is true that many of the craft processes share lineage with their pre-industrial precedents, but it is essential to understand that modern craft is not a result of the past; modern craft is a manifestation of industrialization itself, developing alongside industry, both benefiting from the other (Adamson 2013, p. pp. xiii-xv) . The opposition between viewpoints only reinforced the importance of both.

David Pye clarified the distinctions between craft and industry by identifying the craftsmanship of risk and the craftsmanship of certainty (Pye 1968, p. 20). The craftsmanship of risk is a process where the "quality of the result is" frequently "at risk during the process of making" and is dependent on the judgment and care exercised by the maker. The craftsmanship of certainty requires comprehensive planning of the process before manipulation of the materials with all variables predetermined and pre-tested to the greatest extent possible. These definitions still hold today in that they define the primary differences between industry and craft by highlighting industries aversion to - and craft's requirement for - risk.

2.2 Defining Risk

To achieve efficiency, the industrial complex worked vigorously to eliminate risk. Risk was equal to laziness when formulating efficiency. However, there is value in evaluating the benefits of risk and what we have collectively lost by eliminating it. Risk is essential to all craft by regulating our progress and providing the necessary feedback from our errors. Risk can also be managed by the experienced craftsperson by allowing for necessary feedback to improve their craft. Before the advent of digital technology, most making involved risk or sought to eliminate it. As defined by David Pye in a pre-digital context, the craftsmanship of certainty and the craftsmanship of risk were two distinct modalities of work; not that Pye argued that the two could not be combined, but before digital technologies, most artifacts fell clearly into one of the categories. The variables of risk today are no longer so clear. Digital technology has introduced a level of control that allows the craftsperson the opportunity to use risk as a decisive variable while also maintaining an acceptable level of efficiency. For a risk to be useful, it must be manageable. The craftsperson must have a command of the tool and material to a level that does not leave them a victim of risk, but rather a benefactor of the feedback the risk provides.

2.3 Industry and Craft

Our understanding of time and efficiency as a variable of labor fundamentally changed with the advent of the industrial revolution. In a preindustrial world, time was regulated by daylight, and labor was mandated by need. Industrialization brought mechanized labor and, as a result, time and production no longer followed the natural cycle of the day but by a clock that measured output and efficiency. A significant challenge in the early days of industrialization was training workers to abide by the clock and a new mandate of efficiency. As industrialization matured, so did workers' understanding and dependency on the factories and wages they supplied. Time spent working was no longer measured by the quality of the artifact but in the number of pre-engineered artifacts produced. In America and Western Europe, it became a measure of a person's value and lead to common Puritanical descriptors as 'work ethic.' This cultural shift from the agrarian to the industrial provided apparent benefits to human existence, eventually providing wealth to a new class of citizenry. Countering this benefit was new problems that arose, such as pollution, labor exploitation, and mechanized warfare.

2.3.1 Wedgewood, Ford and the Isolation of Risk

Wedgewood Pottery was one of the first instances of the systematic division of labor in Western culture. Taking place in the 18th century, Josiah Wedgewood sought to raise productivity by dividing labor in a way that ultimately isolated the craftsperson from the entirety of the process. Wedgewood distributed the sequenced process of clay pottery between separate workshops and divided tasks between specialized workers. This was not done on what is thought of like an assembly line per se, but in a single "factory" containing workshops for each step in the process. Doors to the workshops where intentionally misaligned to discourage a craftsperson from interacting with others working on different steps in the process. The consolidation into Wedgewood's factory was significant because it departed from the prior system of "put-out shops." This system relied on dividing the production of craft objects between individual workshops, where each workshop was typically maintained by a master craftsman along with their journeyman and apprentices. Put-out shops would be located adjacent to each other for ease of shipping and shared labor of lower-skilled workers. This would lead to urban and rural districts that specialize in garments, metals, and other crafts. These districts can still be seen in many urban areas today. However, Wedgwood still depended on skilled artisans who had specialized knowledge in a portion of the process while not having detailed knowledge of unique techniques, ingredients, or patented processes. All of the steps in the creation of the pottery as a whole would remain secret. Wedgewood had legal patens, but - like today - those were difficult to enforce, and many times, lawyers would be the primary beneficiaries of the intellectual property. Therefore, Wedgewood Pottery relied on secrecy. Significantly, Wedgwood's labor separation was a first step in degrading the century-old process of apprentice, journeyman, and master craftsman. Before industrialization, craft objects were made by master craftsmen, and the knowledge was maintained through the apprenticeship system (Allitt 2017 Lecture 09). Master craftsmen would accept apprentices in their workshops who would spend years learning the skills, tools, and secrets of a given trade. Apprentices were many times the children of the master craftsman or came to the master craftsman by way of a child's family willing to compensate for their instruction. Regardless of the relation, the apprentice would live and work with the master craftsman for several years until they rose to the level of journeyman. A journeyman would seek work from multiple master craftsmen and maintained a certain level of autonomy. In preindustrial times, an ambitious journeyman would build the capital necessary to purchase the tools and workspace required of a master craftsman. Then the cycle started once again along with the knowledge maintained within the craft. It is necessary to recognize the impact that industrialized division of labor had on the craftsperson. However, it is essential to note that many of the divisions of labor and resulting specializations were created by master craftsman, and the skill and craft embedded in each specialization were still present and serving as an early example of craft developing and evolving alongside industry (Adamson 2013, p. 22). Furthermore, Wedgewood’s division of labor into specializations isolated the risk in production. Having the very best craftsman who would perform a specialized task repeatedly lowered the inherent risk when compared to a single craftsman responsible for all stages of the work. The result was higher production with high-quality results.

Industrialization of the trades not only divided the labor of the craftsman but created a much more significant barrier of entry for the journeyman. With new technology and the advent of the factory, goods had become less expensive, requiring production on a larger scale. The required volume necessitated a much more significant initial investment. The result was comparable to the narrowing of who became a master craftsman and who remained a journeyman. This progressed aggressively into the early 20th century, culminating in Henry Ford's assembly line.

Ford consolidated knowledge from multiple disciplines and distributed it linearly along an assembly line. Ford’s assembly line, derived from early meat processing systems, not only divided labor - it de-skilled the labor required. Each person working was doing an abridged - many times mundane - a task that culminated in a vehicle, yet no individual task required a high level of craft or skill. Ford benefited from the process of carriage-making because it was highly complex and relied on multiple disciplines and craft trades. This allowed Ford to abstract tasks and simplify them so that workers were unaware of the role each of their tasks played in the assembly of a vehicle (Giedion 1948, p. 115-126). The real power was not in the products, but the consolidation of personal knowledge (Crawford B 2009, p. 37-

53). This allowed Ford to hire unskilled labor to assemble his cars at a lower price. The personal knowledge of the carriage maker was no longer valuable or marketable. By de-skilling and dividing the labor, Ford all but eliminated the risk in the creation of a vehicle. Unlike Wedgwood, who still depended on a specialized craftsperson, Ford relegated the "skill" to mechanization and de-skilled labor to the worker. There is evidence that Ford understood this and was motivated by this new-found truth. He famously said: "If money is your hope for independence you will never have it. The only real security that a man will have in this world is a reserve of knowledge, experience, and ability."[2] The word "reserve" is curious, in that it implies that it is beyond any one person's capacity to have more so that it must be acquired from others. This quote is often used as an inspiration to young people for them to seek education and self-betterment. Carefully read, it does not seem so generous; it appears to inform us of his arguably negative impact on the craftsman of America.

2.4 Defining Digital Craft

The use of digital tools for communication, design, and fabrication to produce craft objects has profoundly influenced material culture. The most apparent influence is in the limitless possibilities of generating complex forms. The computer allows for unlimited possibilities and complexity that are not dependent on the material world. Digital modeling tools such as Rhinoceros and Grasshopper are acting in response to the demands of digital practice. Perhaps the most profound influence is the streamlining between digital design tools and digital fabrication tools. What is designed can now be readily and directly fabricated using digital technology. Practicing digitally has created a process-based change to craft disciplines. Digital Craft is the practice of use digital tools in the creation of crafted artefacts.

The Digital Revolution has brought numerous remarkable and productive virtues, but it has also introduced some potentially inhibiting deficiencies. Most profound is the increased abstraction and tendency toward loss of human touch introduced with digital tools. Because electronic digital tools are ultimately based on numeric control, they require specialized knowledge of an abstract set of commands and symbols. Digital tools do not yet emphasize intuitive and physical interaction and response. They require constant precision and inhibit most rough estimation. Digital tools can create a world unto themselves, with a tendency for an operator to lose themselves in a self-referential world of simulation and required

[2] Ford has many quotations attributed to him. This quote is one of the most repeated. There are many lists compiled of these quotes in multiple sources yet there is little definitive proof of when and if he said them at all. More significantly, it is attributed to him and it has impacted and or reflected the manufacturing and capitalist culture of the West.

procedures divorced from representing reality or intuitive process. The tools tend to guide the craftsman, not the craftsman guiding the tools. Outcomes often resemble abstract mathematical models more than haptic experiences defined by a craftsman through real material and specific historical lineage and context (Stevens, James and Nelson 2015, p. 09).

Although debated in the academy and popular culture, this study does not exclude media, material or tool types; instead, it debates the use of the digital and the hand in a productive negotiation, viewing craft as a process or activity rather than a category (Adamson 2013, p. xxiii). When viewing craft through the lens of processes - rather than categories such as pottery, weaving, and metalsmithing - the processes become complicated with the loss of the binding traditions embedded in the trade. As early as the nineteenth century, craft was most commonly viewed through its material and disciplinary category. The material artifacts produced were guided by “conservative” links to a “traditional” past (Adamson 2013, p. xvii). This view of craft, fair or not, did provide the craftspeople a set of longstanding and generational knowledge, and more importantly, principles and limits to guide their work.

The word “craft” has evolved along with these changes. Now, disciplinary activities ranging from surgical procedures to brewing beer is self-categorizing as a craft. Richard Sennett describes Linux systems programmers as “a community of craftsmen focused on achieving quality and doing good work” (Sennett 2009, p. 29). Preceding Sennett, Malcolm McCullough explored the idea of virtual and dematerialized craft asserting that “digital practices seem more akin to the traditional handicrafts, where a master continuously coaxes a material. This new work is increasingly continuous, visual, and productive of singular form, yet it has no material” (McCullough 1996, p. x). The pre-digital tactile shaping of material was viewed to have a parallel digital equal in computer clicks and bits. McCullough maintains that the act of craft can occur entirely virtually without a physical artifact.

Craft evolved through incremental improvements while maintaining a connection to the past. However, the social, economic, and global change that has upended many handcrafts has occurred so quickly that we are just now beginning to understand the immense complexity and opportunities that are provided to a craftsperson engaged in the use of digital technology. Scott Marble observed that digital processes in design have evolved into three distinct systems (Deamer and Bernstein 2010, Marble p. 39-43). The first is the replacement of formal geometry with mathematical algorithms. Prior to the virtualization of geometry craftspeople shaped material by hand. These shapes can now be mathematically defined, controlled, and generated in unlimited quantities. Second, the designer has new control over organizational complexity. This allows now for designs to have imbedded data ranging from cost to weight, thereby extending the craftsperson's control in production. The third, and most significant for this study, is the development of digital fabrication. This development now provides the link between McCullough's dematerialized craft, allowing for the materialization of digital media. Most significantly, this materialization is controlled by the direct actions of the craftsperson.

There is value in looking closely at dematerialized and traditional craft not only through the lens of outcomes and their quality but the process variables engaged by both crafts. It would be impossible to identify and list all specific actions, variables, and decisions made jointly by materialized and dematerialized craftspeople. However, the creation of craft always includes the variable of failure. There is no better teacher than immediate consequences for our actions and the clarity and impact of these consequences that enlightens the wise craftsperson to further their skills. Dematerialized virtual craft has protected the craftsperson from these consequences allowing for decisions between correct and incorrect to be simply toggled by a software command without material repercussions. Digital fabrication introduces material to the digital and provides the material resistance necessary for corporeal craft. However, as these processes have improved, they have reduced the risk associated with the manipulation of material. It is undoubtedly riskier to fabricate material where undoing an error is not an option, rather than working in a safe, virtual environment where decisions can easily be reversed. However, the digital tools used by most craftspeople are ones developed and predicated on the principles of industry: reducing risk and increasing speed. Within the system, there is an opportunity for intentional disruption by creating productive digital risk.

2.5 Defining Digital Risk

Certainty and absolute efficiency are the desire of industrialization - not of craft. Material craft, regardless of media, is inherently inefficient, but it is within this "lost-time" where the material is shaped, and the craftsperson is given the space to meditate with their movements, actions, and errors. It would be pious to rebuke McCullough and dematerialized craft by merely stating that you cannot have a practiced craft without material. It would be short-sighted to believe that craft cannot exist with a keystroke toggle to remove error; that only real craft is governed by material resistance. It is not the intent of this study to claim one practice more virtuous but to situate itself inside of a productive tug-of-war between the digital, the human, and the material.

Digital Risk is the willful action of a designer to allow him or herself to fail due to material behavior and human errors while fully engaging in digital applications. This action is not intended to be less productive but to allow for productive learning that eliminates useless iterations. To embrace Digital Risk is to allow the designer to speed up by slowing down.[3] To make errors in the present is to avoid more significant errors in the future and to embrace the truth that only material can provide.

Anyone who has failed and been punished by a table saw, or an angle grinder can attest that errors are not easily undone. In most cases, this failure is due to material resistance. The craftsperson is pushing the tool through the material, and it resists; if a blade is not held true it resists. No matter the error, the material is the final judge. Material and our desire to shape it provides conflict, and the skilled craftsperson can work the material with the least resistance. This leads to the common observation "they make it look easy." It is not; it is earned skill that turns material resistance into an artifact of beauty. Material resistance is the communicator of failure in traditional crafts, and this lesson is transmitted to the craftsperson independently with consequences. The craftsperson does not decide they are wrong and undo or redo; they are told they have made an error, and they pay in lost-time, material, and sometimes injury. This consequence is absent from virtual simulations. The digital designer can make quick and fluid decisions about proportion, scale, and form but this fluidity does not extend to judgments regarding material, density, fit and finish. This leaves the digital craftsperson to speculate, and in some cases guess, how the material will respond. To avoid material and assembly errors, many craftspeople rely on case studies and abandon material experimentation, relying on manufactured tectonics as opposed to haptic crafting of materials. The identified shortcomings of the digital processes provide a territory to investigate digital risks and its potential benefits.

2.6 Digital Risk and the Post-human

Risk is an essential element of the human experience. Although, in a broad definition, risk is seen as correlated with negative human experiences such as an accident or a failure. However, most accomplishments and self-edification come from systematic strategic risk. Digital technology has, in large part worked to eliminate risk from our actions by providing digital protections. Blatant examples such as the control-z function to undo the last command and auto-save that archives in the background on our behalf. Most would be hard-pressed to find anyone working with digital technology that would be willing to sacrifice

[3] This play on words exposes the paradox of time as it relates to design. When a designer or craftsperson attempts to reduce time spent on early conception and testing this time is normally lost later when poor early decisions cost time in required revisions.

these commands. However, as computing has become more common, applications have gone well beyond saving us from common errors or losing our data by failing to save the file. Therefore, an examination of how to view risk in context with the current digital context is necessary. Risk has been examined thus far using the pre and post-industrial eras. This is due to the historical context that can be traced through widely available research publications and due to the clear examples it provides in hindsight. Digital Risk today is less clear, but it can be assessed through an understanding of the post-digital and post-human contact. Although debated in the academy and popular culture, this thesis identifies post-digital craft as craft produced in a time where digital technologies are ubiquitous. Post-digital craft views digital operations as one of many tools or processes that can be used to generate work with many times the digital and the hand in a productive negotiation. The post-digital has dismantled traditional frameworks of craft and views craft as a process or activity rather than a category (Adamson 2013). When viewing craft through the lens of processes - rather than categories such as pottery, weaving, and metalsmithing - the processes become involved with the loss of the binding traditions embedded in the discipline. As stated prior, Scott Marble observed that digital processes in design have evolved into three distinct systems (Deamer and Bernstein 2010). The replacement of formal geometry with mathematical algorithms, the designer's control over organizational complexity, and the development of digital fabrication. Marble, however, does not wade into the post-digital age of robotics and AI that will undoubtedly add new systems of making not imagined or understood. All the systems outlined have a clear demarcation between the human and tool and are positioned in the historized Humanist tradition. These new systems will take the ideas of dematerialized craft and direct digital making for granted as a standard process of craft and will challenge the duality between human and machine. Now that machines can learn and participate in the act of craft, new questions will need study that helps the craftsperson understand the cognitive and sentient elements of craft and how a craftsperson can improvise and take risk when a tool can learn how to be error-free or how to emulate our errors. Questions about how and why this will occur are at the center of understanding what makes us human and how human imperfection and desire is one of the reasons that handmade artifacts are coveted.

2.6.1 Situating Humanism and Post-humanism

Since the inception of Humanism in the Renaissance, the philosophical perspective has evolved and bifurcated to include multiple realms of understanding. Humanism shaped civic life through liberal democratic principles and framed a path to a more reasoned life as an alternative to mystical and religious positions (Keeling and Lehman 2018). Architects in the post-war area began to revisit Humanist architecture that not only considered human proportions as paramount but situated the human as the primary receiver of the built environment. It is when humanism is framed as a body of literature and discourse that it provides insights into craft and making through its assignment of agency and autonomy to the human. The human action of craft and the embodied actions required in the making align with the humanist literary discourse by "attributing the conscious and intentional human subject as the dominant source of the agency most worthy of scholarly attention" (Keeling and Lehman 2018). Keeling and Lehman summarize the values of literary humanism as a human being constituted as follows:

1. Autonomous from nature given the intellectual facilities of the mind that controls the body.
2. Uniquely capable of and motivated by speech and reason
3. An exceptional animal that is superior to other creatures

Keeling and Lehman continue by reaffirming that humanist principles are infused in all "Western philosophy and reinforce a nature and culture dualism where human culture is distinct from nature", a dualism that is also apparent in the act of craft. It is this duality that is in question in post-humanism discourse. The humanist assumption that we are liberal subjects of autonomy is rejected for the view that agency is distributed through an environment or network that the human participates in but does not intend to control. To illustrate, Keeling and Lehman summarize their different points for what constitutes post-human thought:

1. Physically, chemically and biologically enmeshed and dependent on the environment
2. Moved to action through interactions that generate effects, habits, and reason
3. Possessing no attribute that is uniquely human but is instead made up of a larger evolving ecosystem.

An environment and ecosystem defined in this discourse are related to a complex network or interconnected network. Therefore, not necessarily or excluding an architectural environment or the ecosystems of the physical environment. As humans developed sophisticated systems of architecture to separate themselves from the physical environment and intellectual structures to stand apart from other terrestrials, the humanist values reinforced what we observed in ourselves as superior enlightened beings. This historicized certainty was to be challenged, however, with new networks and new cybernetic environments of our own making.

2.6.2 Cybernetics and the Discourse of Post-humanism

At the close of the 20th century, Katherine Hayles published How We Became Post-human (Hayles 1999). Her publication searches for answers to the boundaries between humans and machines and how we are evolving or devolving with technology. It probes the question of what makes us “human,” and if we will continue to value the “liberal subject” or alienate it. The inclusion of this text is an epistemological transfer of domain that could be seen as invalid. Therefore, the validity for craft is narrow in scope to include the primary characteristics of inscription and incorporated knowledge. Indeed, the discourse of post-humanism preceding and following this publication is robust and divided into many valuable philosophical positions. However, an account of these positions and their place within this discourse are outside the scope of this work. Therefore, the boundary provided by Hayles is just one of many possible frameworks to speculate on a multitude of scenarios whereby technology and the human are intertwined. This framework allows for valuable discourse around what is essential to humanness and what is not. It allows this article to ask the question: are we extending our abilities or devolving into information.

Provided is an outline of discursive understanding of cybernetics, or the science of communication and automatic control systems. These critical moments of understanding resulted from what is known as the Macy Conferences held between 1945-1954 and helped define the epistemological foundation of cybernetics. Hayles explains this in three plateaus of understanding (Hayles 1999, pg. 10-11):

1. The first model of cybernetics grew out of an understanding of the biological systems of homeostasis. The concept is founded on the idea that living organisms have the ability to maintain steady states regardless of environmental changes. Therefore, information was seen as a quantifiable choice in a feedback loop with the organism regardless of environmental conditions. The programmer feeds input data, and the machine returns output in a binary loop.
2. From dialogue and debate of the first model of thought came the understanding that cybernetics may also emulate the biological system of autopoiesis or a self-

encoded system that develops not by what it observes but how it is encoded to respond to its unique needs. The ideas presented the possibility that systems construct reality rather than observe it and that system components could work together to replicate themselves. By removing the observer, cybernetic information could be defined as an entity separate from material instantiation and could be "calculated as the same value regardless of the contexts in which it was embedded, which is to say, they divorced it from meaning" (page 53-54). This isolation of information is in her view of how information lost its body.

3. Autopoiesis leads to a larger understanding of emergence. This is to say that the system has the ability to evolve on its own. This is seen in contemporary systems of augmented reality (AR), virtual reality (VR), and Artificial Intelligence (AI). Emergence uses the feedback loop of information understood by homeostasis but adds both an input and output of information, thus collecting, processing, and evolving independently.

Hayles provides the following "suggestive" rather than a prescriptive list of what post-human view is (Hayles 1999 pg. 03):

1. The post-human view privileges informational pattern over material instantiation, so that embodiment in a biological substrate is seen as an accident of history rather than an inevitability of life.
2. The post-human view considers consciousness, regarded as the seat of human identity in the Western tradition of long before Descartes thought he was a mind thinking, as an epiphenomenon, as an evolutionary upstart trying to claim that it is the whole show when actuality it is only a minor sideshow.
3. The post-human view thinks of the body as the original prosthesis we all learn to manipulate so that extending or replacing the body with other prosthesis becomes a continuation of the process that began before we were born.

4. The post-human view configures human being so that it can be seamlessly articulated with intelligent machines. In the post-human, there are no essential differences or absolute demarcations between bodily existence and computer simulation, cybernetic mechanism and biosocial organism, robot technology, and human goals.

Hayles divides human practice and knowledge into two dualities: first, “an incorporating practice that is encoded into bodily memory by repeated performances until it is habitual”. Opposing is inscribing practices that can be cognitively mapped and encoded (Hayles 1999 pg. 199). Hayles continues by providing five distinguishing characteristics of knowledge gained through incorporative practices (Hayles 1999, pg. 205).

1. Incorporated knowledge retains improvisational elements that make it contextual rather than abstract that keep it tied to the circumstances of its instantiation.
2. It is deeply sedimented into the body and is highly resistant to change.
3. It is incorporated knowledge is partly screened from conscious view because it is habitual.
4. Because it is contextual resistant to change and obscure to the cogitating mind, it has the power to define the boundaries within which conscious thought takes place.
5. When changes in incorporation practices take place, they are often linked with new technologies that affect how people use their bodies and experience space and time.

Hayles continues to summarize by stating: “Formed by technology at the same time that it creates technology, embodiment mediates between technology and discourse by creating new experiential frameworks that serve as boundary markers for the creation of corresponding discursive systems. In the feedback loop between technological innovations and discursive practices, incorporation is a critical link”.

3 Case Studies

The following case studies were conducted during the research period of this thesis. Although not intended to serve as experiments or tests, the projects influenced the final project, ceramic risk, by defining principles and generating explicit findings. Three case studies are profiled here with summary findings below:

Digital Corbeled Wall

- Demonstrated how to align a digital script with the improvisations of a manual craftsperson
- Demonstrated the ability to digitize a manually made object for analysis.
- Positioned the digital algorithm as something that would serve as a guide to a craftsperson and then be subsequently mutated by their improvisations, changing and adapting, as the project was built.

Digital Barn Raising

- Analyzed how the craftsmanship of risk and the craftsmanship of certainty manifest in a digitally fabricated project.
- Demonstrated how to use a traditional wood-frame building typology and translate it through new digital toolsets.
- Demonstrated the changing role of the drawing within digital fabricating and assembling a structure.

Finding Obsolescence

- Tested the digitization of a historic drawing technique.
- Demonstrated that drawings and projections do not provide the same material resistance found in the digital risk factors.

3.1 Case Study Process - Digital Corbeled Wall

This case study is represented by four stakeholders: an architect and professor from the United States, an architect and educator from India, a design journalist as an observer, and a local skilled mason.[4] The academics of the group conceived of this collaboration to test ideas related to digital applications and traditional craft methods. As researchers, we sought to work with students to test context, material, and our culturally preconceived notions of design. We valued the haptic knowledge imbedded in design and the immediate and natural consequences of its process and outcomes. As author David Pye has noted, "Design, like war, is an uncertain trade and we have to make the things we have designed before we can find out whether our assumptions are right or wrong (Pye 1968, p. 27)." The case study

[4] This project was completed with the cooperation of CEPT University in Aminabad, India and in collaboration with James Stevens (Co-Primary Investigator), Architect Ayodh Kamath (Co-Primary Investigator) and journalist Komal Sharma (Investigator). Portions of the same were published during the research period of this thesis in the Proceedings of the 12th European Academy of Design Conference, Rome, Italy, 2017.

strategy was to lead the team through experiences that simultaneously engage the real and the representational in a productive tug-of-war and to understand the value of craft and local craftspeople while still fully engaging with digital tools.

Our theoretical framework is defined by practice and inspired by the struggle to make what has been designed. The design team recognized that digital tools are embedded in contemporary design practice and are rapidly being integrated with all phases of design and making. The project also recognizes that design traditions are embedded in traditional craft principles founded in the memory and transfer of craft knowledge and collaborative processes of design. To this end, the team included a pair of local masons as equals within our team of experts. Inclusion of the masons was critical to our process to ensure craft knowledge was fully presented and engaged in the process.

This case study illuminates the premise of traditional craft and digital applications through a specific design project - The Digital Corbeled Wall. Reflection on the questions raised through the process and outcome of this project and through lessons learned that have influenced this thesis.

3.1.1 Process

The approach is explained through a narrative of a three-week workshop in India that involved architects, digital fabricators, parametric modelers, and a mix of Indian and American students. This team collaborated with a pair of local masons to construct a geometrically complex a parametric mud-brick wall. The workshop was positioned in the pre-modern notion of craft and a post-digital notion of design, between a pedagogical approach of learning-by-doing and a grassroots approach to design practice. The team designed and utilized a parametric software to model a prototype and describe the complex three-dimensional geometry of the wall. This parametric model was continually evolving and re-making itself in response to the physical wall, the hand of the mason, and the variations in the non-industrial materials. The adaptive choreography between the mason, the students, and architects revealed an alternative practice model where knowledge does not flow in a linear format of digital-to-physical, but a back and forth between the two, where each informs the other, doing what each does best.

It was the result of a synchronized process of laying bricks determined by a parametric model, measuring and logging the positions of the laid bricks into an algorithm, milling the bricks, and in totality, achieving the desired corbelled effect through open dialogue amongst the masons, architects, and students

3.1.2 Place and Time

Aligning both new realities of disruptive technologies and valued principles of place shaped the design process and the outcome. Each work of design has the potential to be responsive to the particulars of each place where a design is to be situated. “Place” is defined in The Digital Corbeled Wall project by recognizing the unique physical and ephemeral characteristics of India and the vernacular mud brick. These characteristics include both the visible as well as the unseen, including recognition of the hidden economic forces from the West that degrade Indian craft tradition and cultural history.

3.1.3 Guiding Precedent

In selecting a precedent for The Digital Corbeled Wall, the student and faculty considered the place and time and the digital tools available to create a nonlinear wall. The challenge not only required coordination of the digital script with the mason but also to use a CNC machine to modify a large number of bricks to conform to the designed form. This led the students to a process from 17th century England, where it was common to remove clay from pre-fired bricks in a process called “cut and rubbed” or gauged brickwork. Brickmakers would take a standard unit and, using a wood jig, would rub the clay to remove material to create a unique profiled shape with specific practical and aesthetic characteristics. This process created brick units that could form twisting chimneys, roof coping, and other ornate masonry features common at that time. Using the process of the Digital Vernacular the design students studied this historic example (precedent), identified that it is a thoughtful and measured removal of material to create custom units that perform a specific role (principle), and then proposed a new masonry design employing a removal process from a hand-formed unit using digital tools and techniques (proposition). This process guided the students to achieve mass customized masonry units using sound principles and processes established in the vernacular tradition while employing appropriate traditional and contemporary digital tools, all while collaborating with a local mason.

3.1.4 Aligning Tools, Materials, and Skills

The guiding precedent, the sensitivities to place and time, only prepared the team for the design challenge; it did not define it in detail or even provide a visual image of a potential outcome. The Design Challenge was only conceived as a collision of the tools, materials, and skills available. Therefore, the team set out to define a wall within these limits and opportunities. What ensued was a series of proposals and tests to verify feasibility. The mason engaged with the students to find the maximum corbeling for the mud bricks (Figure 9). Students worked with the primary fabrication tool, a CNC machine designed to fit into a suitcase that was transported by the students to India from the US (Figure 11). Given the tool had been built and tested in the US, the students did not know how the mud bricks would respond to the milling. Initial tests proved it was feasible, and the machine was modified onsite to allow it to mill the header of the mudbrick. Students used these tests to inform a series of scaled models using wood blocks and clay to represent bricks and mortar (Figure 10). Through physical testing, the variables were defined and used in the creation of the parametric model.

Figure 9 Finding the maximum corbelling limits of the masonry

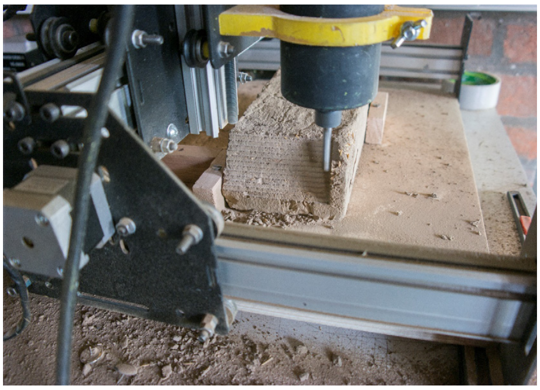


Figure 11 A CNC machine designed to fit into a suitcase was transported by the students to India from the US

Figure 10 - Students testing scaled models using wood blocks and clay to represent the bricks and mortar

3.1.5 Parametric Model

The parametric model used for the workshop was developed during the workshop itself. The model was developed after observing the construction of a test wall by the masons. The test wall aimed to build as many courses as possible while corbeling each course as far out as possible until the wall collapsed. This test provided data directly from the haptic knowledge of the mason regarding how far and for how many courses we could corbel before needing to balance the wall by corbelling back in the opposite direction. Using this knowledge, we created a curved non-uniform rational basis spline (NURBS) surface with curvatures within the limits of the corbeling that served as the wall design limits. This NURBS surface formed one input for the parametric model. The other input parameters

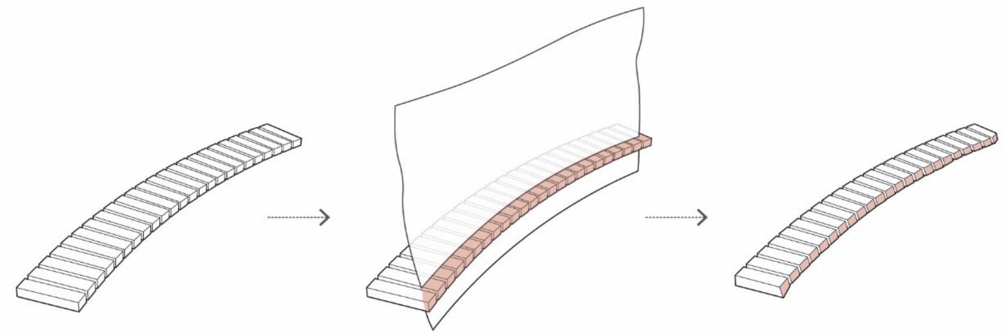


Figure 12 - Left to right: positions of bricks recorded, NURBS surface sliced bricks, bricks returned to original positions on wall

were dependent on the irregularities of the sun-dried mud bricks and the response of the masons – the length, width, and height of each brick, and the position of each brick as placed by the masons. The positions of the bricks were recorded through the X, Y, and Z coordinates at two corners of each brick measured from a datum line using plumb bobs and right angles. The on-site student team recorded their measurements on a cloud-based spreadsheet. The data from the spreadsheet was input into the parametric model in real-time by the second team of students. The parametric model virtually placed each brick relative to the designed NURBS surface and sliced any portions of the bricks that might be projecting beyond the surface. The resulting sliced brick shapes formed the output of the parametric model. The sliced brick geometry was shared through the cloud, with a third student team operating the CNC router to shape the bricks (Figure 12). Once milled, the bricks were returned to their original positions on the wall, as placed by the masons, using the measured coordinates of the two corner points. The masons then spread mortar on the bricks and began the next course.

3.1.6 Stakeholder Interviews and Outcomes

The final result was a Digital Corbeled Wall that undulates along a curve, sometimes obediently and sometimes abruptly. Each brick was placed with the aid of the digital script, while the skill of a mason then re-informed the script based on the requirements of the material. When the bricks went beyond the prescribed corbel distance, they were milled by

Figure 13 - Milled markings match the typography of the surface

the CNC. This gives the wall a unique milled marking with curved patterns that match the typography of the surface (Figure 13). Understanding the process and the stakeholders allow the designer to see each brick in a struggle to align with physical and virtual commands. Their final project taught a valuable lesson: sometimes, the design is not conceived of visually and predetermined by our genius alone. Design is a result of conditions, tools, and material realities that are many times outside of our control.

Furthermore, the final wall and the process that lead to its creation showed the potential of incorporating haptic craft knowledge into a digital workflow, allowing both to inform each other to generate an outcome that could not be preconceived. A significant outcome for The Digital Corbeled Wall was the diversity of people who collaborated and brought unique sets of knowledge. One of the participants, Sujauddin, has been working as a mason for over 35 years. His father was a mason, and his sons are following in his footsteps. He works in the construction business with traditional masonry techniques, and takes pride in his expertise of making domed structures (Gumband), the Mughal tower (minar), and floral and filigree patterns. It became clear early in the project that the students and faculty depended significantly on Sujauddin's material knowledge and skill. Before building the actual wall, the team decided to build a test-wall to find the maximum number of mud bricks that can corbel before they overturn. The measurements from this test wall were crucial. It is difficult to arrive at such figures from first principles because of variables such as the stickiness of

Figure 14 - Sujauddin beginning another course

the mortar. Sujauddin, in retrospect, talks about this test wall and says: "We did five courses. At one place there was a little extra weight, so we tried to balance it by putting weight on the opposite side. I expected it to fall any time after the fifth or sixth course but hoped that it would stand. By the time we did the tenth course, it was down." That Sujauddin could speculate what would practically work, how many layers of bricks would stand, and at which point they will fall over, is the knowledge that comes from experience, that could perhaps be called instinct or tacit knowledge developed over time working intimately with brick and mortar (Figure 14).

Similarly, the skill of laying bricks might appear reasonably straightforward to onlookers, but like most craft forms, the simplicity is somewhat deceptive. On one occasion, Sujauddin and his sons were absent from the site, so the other members tried to lay a set of bricks themselves. It took them three times as long, and it still turned out uneven. This is not to imply that students of design are inept at laying bricks, but to bring attention to alternative sets of knowledge that are an inherent part of the system, yet theoretically they are dismissed or ignored in progressive experiments and arguments. For example, a student may be adept in the design of a building but lack awareness of what is actually represented by the poche in their architectural drawing. One innate purpose of building this wall that emerged was to shorten the distance between textbook knowledge and practical know-how and to sensitize students—future architects, designers, thinkers, policymakers—towards the value of traditional knowledge systems and craft.

In the time lag between milling the bricks and laying them, Sujauddin and his sons could be seen waiting patiently, sitting in the shade, observing the little army of architects, designers, coders, professors, and students, puttering around with their measuring tapes and plumb bobs. In conversation with Sujauddin after the project was over, his remarks were a mix of curiosity, optimism, and self-awareness. "I expect that down the line, these machines will play a big role in our work." Does that worry him? Sujauddin answered: "These craft traditions are age-old and time-tested, and they will be taken care of, as they always have been."

In this seemingly casual remark by a craftsman, perhaps the essential purpose of a project like this is reflected in a purpose that is bigger than the wall, the codes, or the workshop. In the words of authors Wilkinson-Weber and DeNicola, the expanse of such research has been captured. "We believe that research on craft and artisanship has the potential to open up new and evocative questions about the ways that we construct some of anthropology's most critical contemporary concerns: technology, access to markets, means of production, control over work practices, tradition and innovation, urban and rural spaces, human rights and the environment to name just a few" (Wilkinson-Weber and DeNicola 2016, p. 02).

Apart from the overall aim of the project, different agendas were at play. Another participant, a student at CEPT, Kaninik Baradi, has assisted his parents, both of whom work in the construction business, and has hence witnessed the local context closely. He concludes through our interview with him that construction projects are primarily driven by economic viability. He wants to find a way to work with concrete, which is cheap and readily available, and employ local labor, again a resource at hand, but be able to create diverse, new forms with it. "One of the challenges we face in both traditional masonry and concrete formwork is that you have to build very rigid, square boxes because they are cheap." In combining the two—digital and handwork—Baradi believes that you can create opportunities for the craftspeople to remain a part of the process, as well as create architecture that is more efficient, sustainable, and aesthetically variable. "The advantage of a method like this is that it is not tremendously expensive to build something more complex. You can make it respond precisely to your site conditions," says Baradi.

For local architect and researcher Ayodh Kamath, a similar agenda informed his exploration: how to make the most of digital tools and local craft techniques, especially in a context that does not have complete standardization. In the Western context, a seamless transition and integration of digital calculations and physical construction can be expected because the materials and conditions of working are highly standardized. However, that may not be true of many local contexts like India. Contrary to the textbook understanding of digital technology, that it is perhaps appropriate only for highly developed working contexts, Kamath wants to find ways for digital technology to be beneficial to semi-standardized working conditions primarily because digital tools offer their own sets of freedom and power.

"The primary advantage of designing on the computer is able to iterate and evaluate designs easily and quickly. It is much easier to change digital geometry than it is to change a physical object. There is no undo button in the real world," he says. An implication of this in local construction contexts speaks to Baradi's earlier point as well that with the help of digital tools, you could build-out of the concrete box, so to speak, and know beforehand—before actually building it and employing resources—whether it will work or not.

Among the students, there could be sensed anxiety around the success of the project; that their measuring is imprecise, that it is taking too long, that there was a lag between transferring information from the physical to the digital modes, and how efficient that was. Nevertheless, to an outsider, it seemed that what looked like idling was time and space made available for discussion, for thinking things over, for considering other options. The time is taken up in measuring, milling, trial and error, and re-doing, was not entirely time lost or wasted. Instead, such hands-on learning impacts a student at a deeper, more involved level than reading case studies in a textbook.

When the wall was complete, the students, faculty, and the masons gathered together to have a final reflective discussion. The students agreed that working with digital technology and with something as traditional as un-fired mud bricks; a material that is readily available in the context, suited to the climate, and indigenous to the mason was challenging and upended their understanding of how digital technology engages with material. This shift in understanding was particularly true for the American students that have worked their entire academic careers only using manufactured standardized materials. Further, the students expressed a new appreciation of the benefit of combining computational tools of architecture in a culture and economy that is primarily labor driven. They discussed the potential for the process used in the workshop to acknowledge labor, skill, and craft traditions and how that might prevent them from being made obsolete by conventional one-size-fits-all modalities of design imported directly from the West.

3.2 Digital Barn Raising

The Barn project began with a small grant from the Coleman Foundation to support entrepreneurial activity within a design curriculum at Lawrence Technological University.[5] Students and faculty framed the proposal collaboratively to explore new methods of

[5] The Digital Barn project was completed with cooperation from the Coleman Foundation and Lawrence Technological University. The project team consisted of James Stevens (Primary Investigator), Ralph Nelson (Investigator) and Natalie Haddad (Investigator). Portions of the same were published during the research period of research for this thesis in a book titled: Designbuild Education in North America, Chad Kraus, Ed., Routledge Architectural Press, 2017

construction with traditional craft-based methods that could be applied to a simple building typology. The practical objective of The Barn was to design, develop, iterate, and fabricate an architectural structure built solely out of plywood sheets, digitally fabricated primarily with a CNC tool, then finished and assembled with hand tools. The research objective of The Barn was to provide an opportunity and experience to develop an architectural experiment from the initial design through fabrication and construction of wood fabricated system at full-scale. The prototype was based on simple traditional Michigan, USA Barn precedent that provided principles and traditional methods of framing and spanning. Conditions for the experiment were set to demonstrate how an outcome is influenced by tool, material, and process when engaging traditional methods with digital tools.

A programmed use was not defined for The Barn; rather, the structure was imagined to accommodate a range of possible functions. It was expected that the budget would not allow for the construction of a full building, rather it allowed for the creation of prototyped sections that could be extended longitudinally. The narrow width of The Barn was initially defined relative to the estimated structural spanning limits of the plywood construction and by the size limits established for construction modules that could be moved or lifted by two or three people. The goal was to be able to accomplish any process from digital design to prototyping and fabrication without the use of heavy machinery or complicated tools. The factors of weight and size guided the limits of element and component profiles. They were consistently discussed as variables throughout all iterations.

The research team started by researching traditional platform, balloon, and heavy timber framing. Both have long been the dominant techniques in the construction of vernacular wood-frame buildings in North America. The systems use wood studs placed in frequent succession, which are then sheathed with boards or sheet goods, forming a structural diaphragm for lateral stability. This method has persisted because of the relatively low cost of new-growth lumber and sheet goods such as plywood, and also the persistent vernacular knowledge of wood framing. Dr. Larry Sass, a professor and researcher at M.I.T., transformed this system through the use of digital technology. In the YourHouse project, Dr. Sass replicated a New Orleans shotgun house using only CNC-cut plywood and assembled it using only friction-fit joinery. Platform framing and the YourHouse project served as the initial precedents for The Barn (Sass 2015).

Engaging these initial precedents, the team digitally replicated significant details of the precedents and considered how they could be adapted to a new construction context. The team wanted to maximize the material potential of plywood and initially questioned the spacing of the structural elements. In traditional platform construction, the studs are typically placed at 40.5cm or 61cm on center. For The Barn, the first structural modules were considered at 70cm to take advantage of the modular size of the plywood.

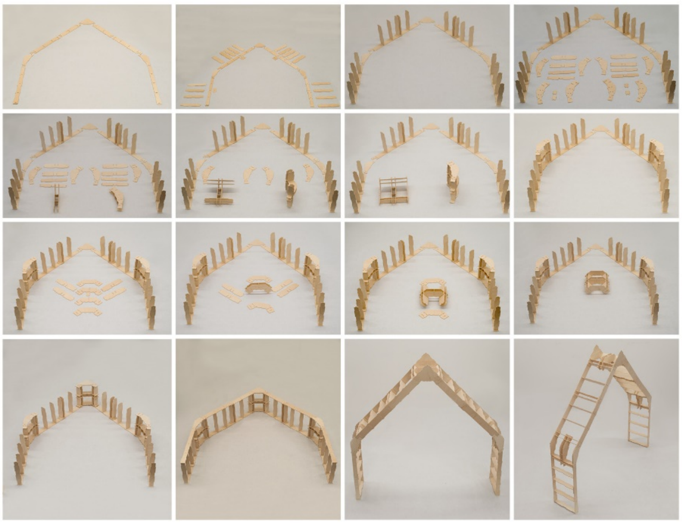


Figure 15 - Model of wall, eave, roof and ridge

This led to exploratory models of four repetitive structural components – the wall, the eave, the roof, and the ridge (Figure 15). Focusing on the structural conditions of the ridge and eave led the team to a precedent study of pre-engineered steel buildings, which typically are defined as rigid portal frames, created by structural sections known as bents that taper following the load paths. In simple terms, form follows force. Most manufacturers taper the steel sections to allow the width to increase at the eaves in response to the maximum moment at the eave. By understanding the structural principle of

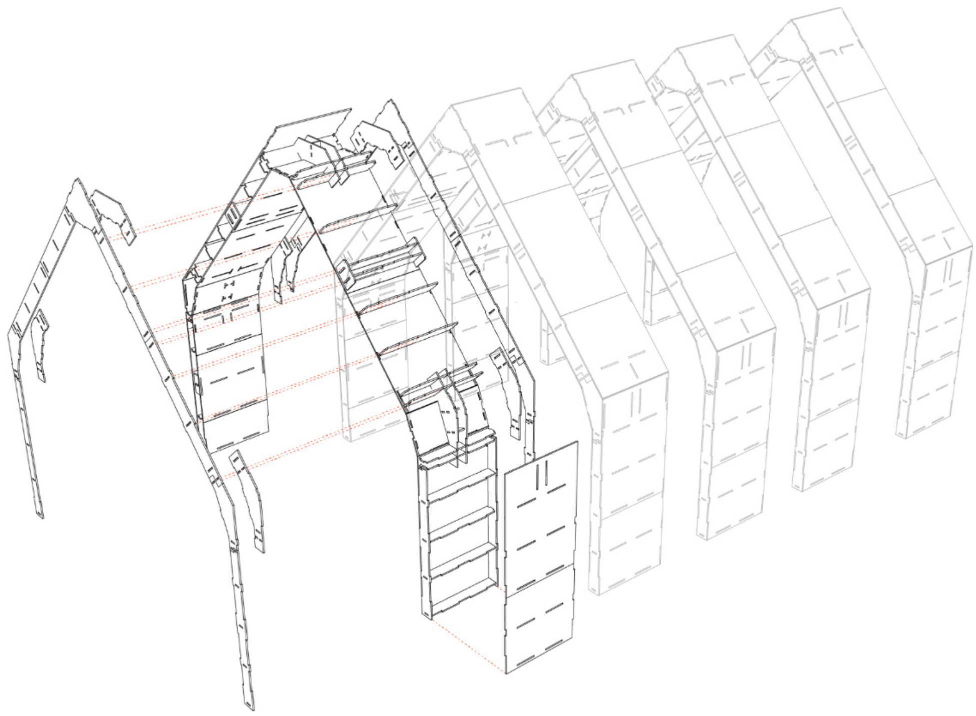


Figure 16 - Structural assembly strategy

the vernacular portal frame, the students were able to integrate the principle into their plywood design. What resulted was a digitally fabricated plywood bent that influenced a new type of structural prototype, assembly strategy, and the formal configuration of a clear-span building section (

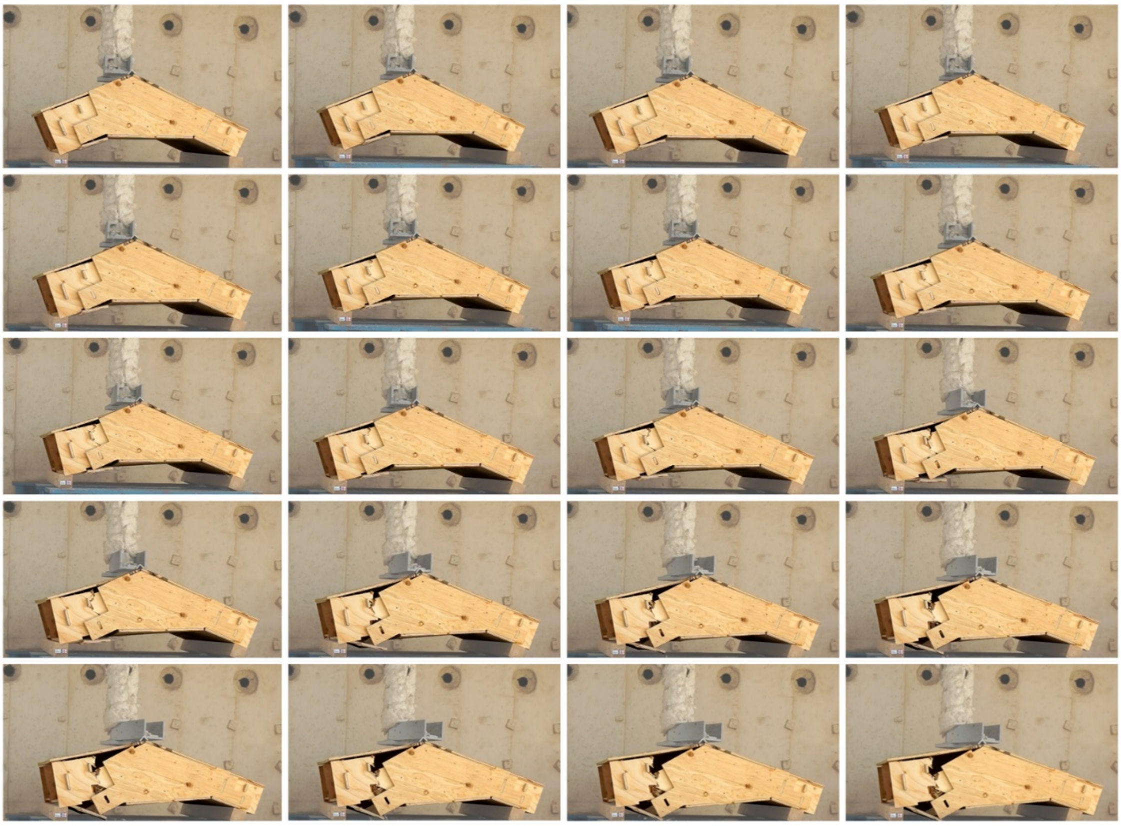


Figure 17 - Photo sequence of ridge compression test

Figure 16). With important details and challenges identified, the next step was to prototype, at full scale, an eave and ridge condition in response to the moment and shear forces. These prototypes allowed a comparison of the scaled fabrication model to the full-scale component and to test its strength against structural calculations. The eave and ridge components were compression-tested to determine their shear and moment strength (Figure 17). Tested in a controlled environment, both components resisted more than twice the necessary estimated force load from the structural analysis. The structural tests allowed the research team to observe how and where the details failed and also how well the connections worked in resisting the reaction forces. The test affirmed that the connections were the most vulnerable to failure. The research team responded to the test data and created a new iteration that reinforced and reconfigured the areas of the previous failure.

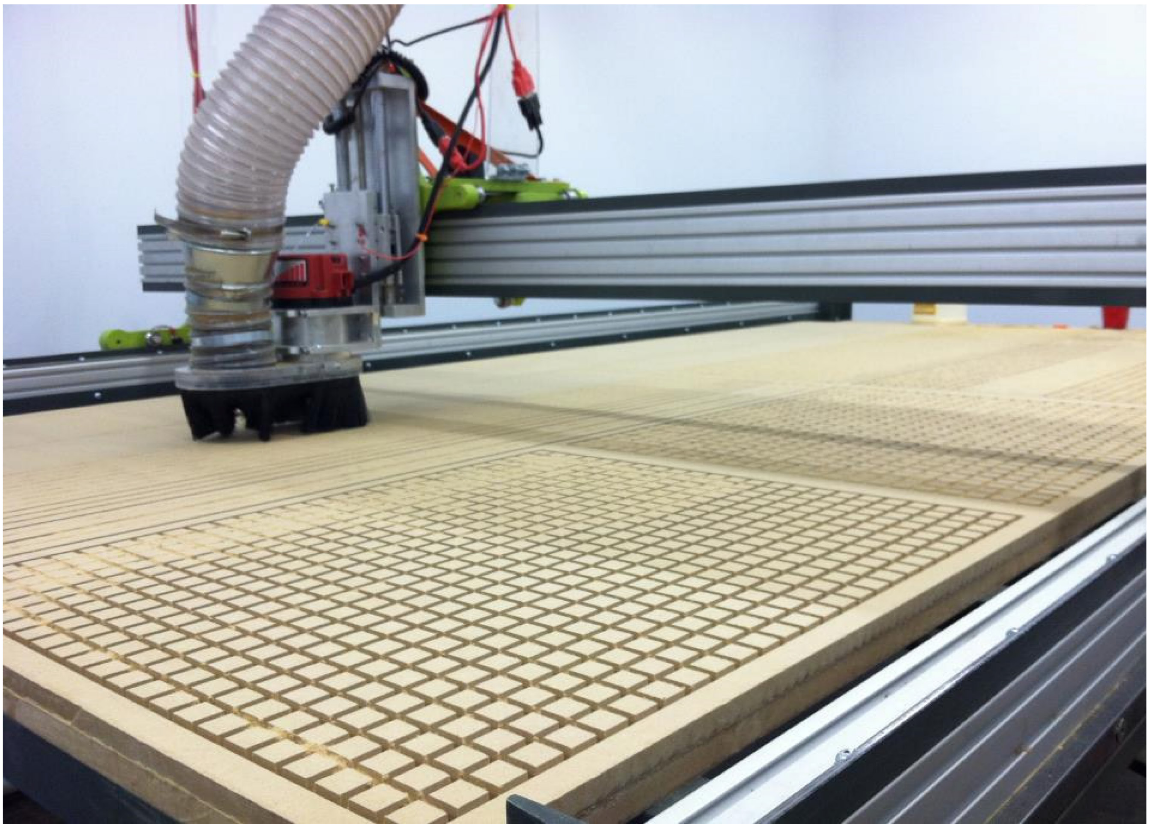


Figure 18 - 3-Axis 152cm’x304cm’ CNC machine

The final components of The Barn were fabricated using only 1.22mx2.44m sheets of plywood milled on a three-axis 1.52mx3m CNC machine (Figure 18). The final building construction system was comprised of 152cm wide structural bays of interlocking plywood sheets – joined with friction-fit tab-and-tenon connections and minimal screw fasteners to articulate continuous space and form (Figure 19). Each structural bay was subdivided into the wall, roof, eave, and ridge components that were limited by the overall dimensions of the 1.52mx3m plywood sheet. The weight of each component and bay module was considered for ease of transportation to a site and lifting by two or three persons into Position. Once on-site, each bay was tilted up into place on a pre-constructed foundation. A significant constraint on The Barn project was the absence of a crane. Faced with plywood modules that weighed over 450Kg, the team sought ways of lifting the units into place. Two 450kg capacity wall jacks were used for lifting in combination with guidelines tied to the ridge and temporary wood stops that prevented each module from tipping beyond its resting point. The jacking points were located at the outer edge of the eave moment, evenly distributing the weight between the width and height of the structure.

The hand-cranking of the jacks was a slow and sometimes a scary process, but ultimately the module was lifted to a point where the guidelines could be pulled by two persons to

Figure 19 - First two sections assembled

settle the module into place. The process, relying on the precision of the digitally fabricated structure and the strength of a typical jack, made for a stressful but effective "barn raising" (Figure 20) [6]

The module raising exposed the research team to the virtues and potential drawbacks of digital pre-fabrication. The experience demonstrated David Pye's distinction between the craftsmanship of risk and the craftsmanship of certainty (Pye 1968, p. 20). The craftsmanship of risk is a process where the "quality of the result is frequently at risk during the process of making" and is dependent on the judgment and care exercised by the maker. The craftsmanship of certainty requires comprehensive planning of the process prior to fabrication and erection with all components predetermined and pre-tested to the greatest extent possible.

[6] "Barn raising" is a colloquial term in American English with origins in 19th century barn building. This term is defined by a community coming together, many times with neighboring farmers, to use common tools and skills to raise large sections of barn structure. These events were many times accompanied by a feast prepared by the host family as a thank you to their neighbors. The term has further evolved in American English to signify an event where you are receiving help from the community (or helping) to accomplish a task that otherwise would be impossible alone. Thus it is a term of endearment and represents the best of human cooperation and community.


Figure 20 - Jacking first section onto the foundation

The process of making The Barn exhibited traits of both certainty and risk, the barn-raising leaning heavily toward the side of risk. The team had worked for months to design, test, fabricate, and assemble components in multiple iterations. They were confident and satisfied that the fabricated components would perform as expected once lifted into position. Standing on site on a cold Michigan night, the team faced the reality of lifting the modules into place and the actual risk that this entailed (Figure 21). The prospect of failure was tangible. The reality of the design decisions came to bear as the jacks lifted a module into place. The team discovered that even the craftsmanship of certainty is fraught with risk and when experimenting with a new idea and all the upfront planning can never remove the responsibility to exercise continual judgment, care, and creative improvisation.

Balancing certainty with risk introduced the recognition of tolerance as an important factor for all construction, and especially critical for digital fabrication. If a wall or module is not placed square and level, it will be challenging to adjust unless tolerance is designed into the component and the erection process. To further complicate the issue, each bent, even if square, true, and stable prior to lifting, could develop slight settling and misalign the joint between multiple panels. To correct this problem is not as simple as shimming an 816Kg assembly. The misalignments in the foundation proved to be an issue when attaching the modules together. There were slight shifts in all directions due to the differences between the precision in the plywood structure and a pre-built foundation. This required adapting the design to account for this necessary tolerance. The team introduced a new set of holes at

Figure 21 - Hi Low lift used for safety during jacking

the base of each module at strategic points for the insertion of circular drift pins to assist with the alignment of the modules and accomplish smoother transitions from bent to bent.

The Barn prototyping was completed after raising three full-section modules over a foundation. The team considered interior and exterior cladding applications as well as insulation strategies, though these were beyond the scope of the initial grant-funded research. The team covered The Barn in tarpaper to protect the plywood and monitored the structure over the winter to observe changes in response to temperature, humidity, snow load, or connection failure.

3.2.1 Questions Identified

The most significant outcome of The Barn was the questions that the project revealed and inspired, which guided new projects. Not surprisingly, most of the challenging questions resided in the paradox between the digital realm and the haptic world. Working at full scale allowed this paradox to present itself on a frequent basis, providing a broad range of learning opportunities. In addition to the insights of the project, the following questions were presented and discussed by the research team:

Are construction drawings necessary for digital fabrication construction projects?

Robin Evans states in Translations from Drawing to Building that "[denying drawn communication] would be possible, yet seems very unlikely to occur because, for architecture, even in the solitude of pretended autonomy, there is one unfailing communicant, and that is the drawing." Traditional construction techniques require interpretation of design drawings by builders; the drawings are only a representation of what is intended. Yet, digital fabrication processes remove the builder's interpretation, via file-to-fabrication, providing an outcome directly fabricated from a digital file. Despite these factors, the team discovered that new sets of information were necessary to effectively communicate and document beyond the construction drawing. The research team questioned traditional construction documentation by supplanting many standard orthogonal drawings with exploded isometric drawings focused on significant points of assembly (Figure 22). As researchers trained in traditional practice and the rigorous application of graphic standards for construction drawings, this was a methodological challenge.

What advantages are provided in traditional craft when working in the context of digital design?

An advantage of physically making what you digitally design is the ability to understand material, tool, and construction issues that may arise and must be addressed in the design process prior to and during construction. The team was in control of the design, fabrication, and assembly process, and this full scope of responsibility profoundly influenced the approach to design. A digital workflow provided the opportunity for timely on-site adaptation and allowed changes to continually cycle through the full design, fabrication, and assembly process. It was recognized the importance of working in a continuous fluid motion between design and making. This design advantage comes with caution. It took time, skill, and effort for the team to reach the fluidity of making and craft necessary to achieve the advantages of digital fabrication. This was only realized toward the end of multiple projects over a period of multiple years.

How is complexity handled when practicing digital craft?

During a discussion of the project one student, Jia Liu noted that "the digital finger is prone to fatigue, and the digital computer is prone to stamina." In her words, digital tools "push human production capacity to unprecedented heights" to deal with an overwhelming "mass of accuracy of information." The computer's stamina far exceeds the threshold of the number of component locations and orientations that one designer can memorize. Since most digitally designed and fabricated projects have some form of uniqueness, the

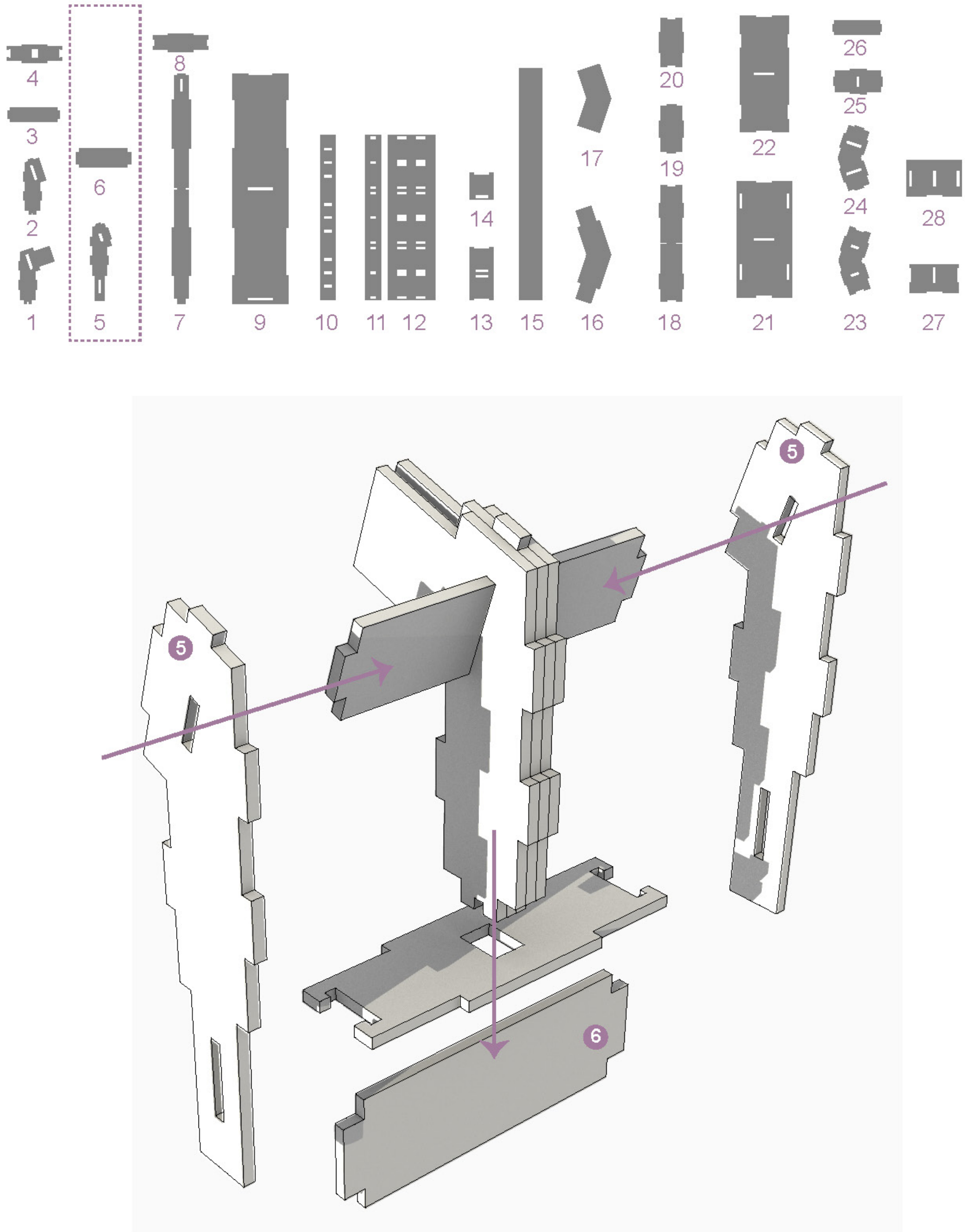


Figure 22 - Assembly drawings

unfamiliarity provides a need for clarification and review before the assembly process commences. The team was able to identify and conceptually determine the location and orientation of individual components at any stage in the making process. However, the team agreed that the complexity of the design and the efforts required to communicate the location and orientation of all components at all times is an overwhelming task. To improve digital craft, there is a need to engage craftspeople and designers in challenges that test new ways of managing complexity. These investigations will need to go beyond drawings and documentation and reach into the simulation of assembly and management of workflow and improvisation and implementation of craft.

How important is tolerance in digital craft?
All successful construction techniques have a tolerance; without this, they fail to respond to an inexact world. Material limits need to be defined, and a designer and craftsperson need to understand what this limit is and how it may change for each material and environmental condition. Given that digital fabrication lends itself to the control and creation of multiple components and assemblies, tolerance knowledge is essential. It was important for the research team to understand that most craftspeople and designers are aware of the need and consequences of tolerance, but few are able to skilfully make the necessary accommodation. Mastery of the tolerance variable is of paramount importance and requires rigor and time.

3.2.2 Reflections

The demands of design craft inherently require a craftsperson to fully engage tangible circumstances that promote honesty, integrity, and a robust work ethic. By doing so, one becomes familiar with a range of design and construction limits and begins to respect their value as catalysts for creative thinking and action. The team reflected that contemporary digital tools for both representation and fabrication have opened up new avenues of design exploration and work-flow management that now make digital craft both more accessible and more enriching than ever before. But these digital tools must be utilized within a practical and ethical perspective that demands a greater understanding of how not only something can be made but also why it is made. The team recognized the continued importance of designing and building by hand, to maintain a tangible connection to work that may be conceived in an electronic realm but must live in the haptic realm.

3.3 Finding Obsolescence - Stereotomy Drawing

The role of the drawing has shifted in architecture. In the past, the act of drawing was the primary communicator and touched all aspects of design from conception to construction documentation. Drawings not only generated design ideas but also served as the primary descriptor of the architecture. This changed little in the early advent of computer-aided design (CAD). Most drawings where drawn orthographically in a digital interface. With the rise of parametric modeling and digital fabrication, the architect’s relationship with drawing fundamentally changed. The architect now conceives of space and understands the building through digital modeling. Drawings are now extracted from the model and are simply an outcome of the three-dimensional volume.

In the 1997 essay by Robin Evans, Translations from Drawing to Building chronicles the polemic that all contemporary architects face: they are authors of the drawings, not the final work, thereby elevating the importance of the drawing to the architect. The divergence of drawing and building is a variable that architects constantly struggle with. Recently within the context of digital fabrication, the drawing is facing yet another crisis and one that Evans does not address: do drawings matter anymore? The shift from the production of drawings, to extraction to drawings, provides a unique opportunity to study the role of drawings in architecture and to extend our understanding. This case study explores this topic by examining the 17th-century stereotomy drawing method of the trait. As a mechanism, a

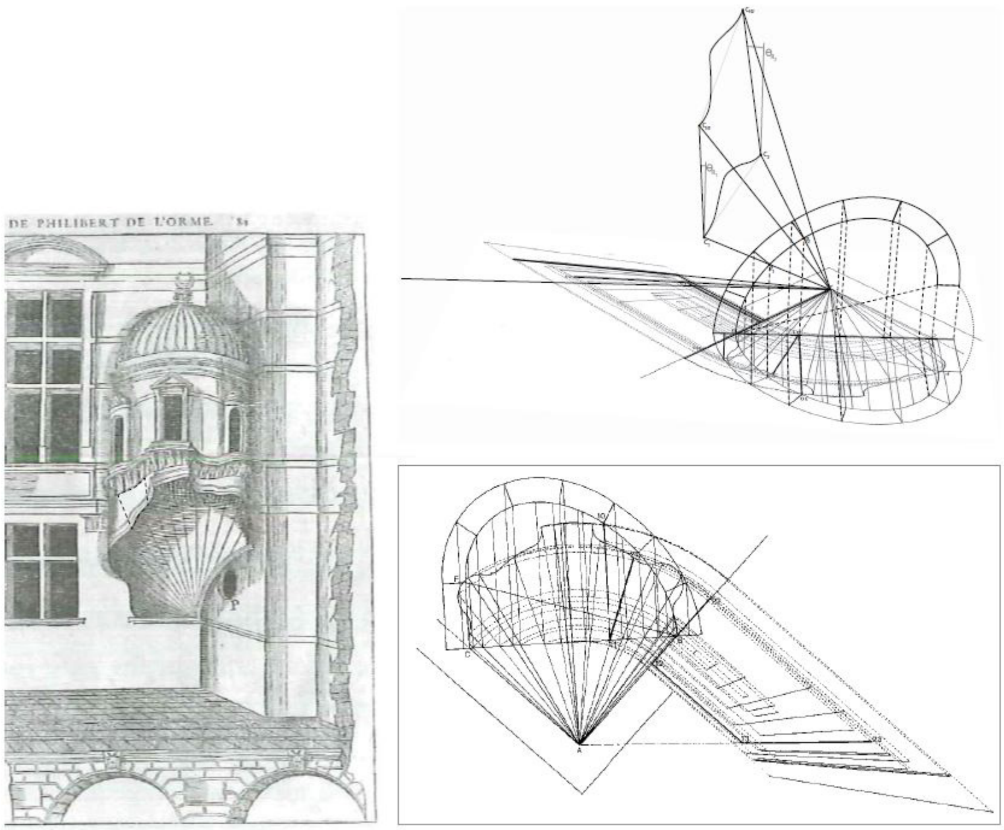


Figure 23 - 17th century stereotomy drawing from Drawn Stone, Evans 1997

trait's primary purpose is to ensure the precise cutting of blocks that comprise a masonry vault form; these drawings are the basis of the process of stereotomy (Figure 23).

"Stereotomy, which means the cutting of solids, was a seventeenth-century French rubric under which were gathered several existing techniques including stonecutting…" (Evans 1995, p. 179). As a tool, a trait lends itself to two functions. First and foremost, traits inform cutting templates that are applied to stone stock so that it can be accurately cut into blocks. Additionally, precedents indicate that traits were a response to the need to infill, and they produced forms that were completely dependent on the surrounding site. A trait drawing employs a floor plan and surrounding conditions to formulate a list of section drawings. As the plan and existing site circumscribe the perimeter for infill, section drawings are produced to occupy the space immured. As the final product, consecutive sections are hypothetically folded up 90 degrees and aligned to their actual position on the plan to create a proverbial "3D model" (Figure 24).

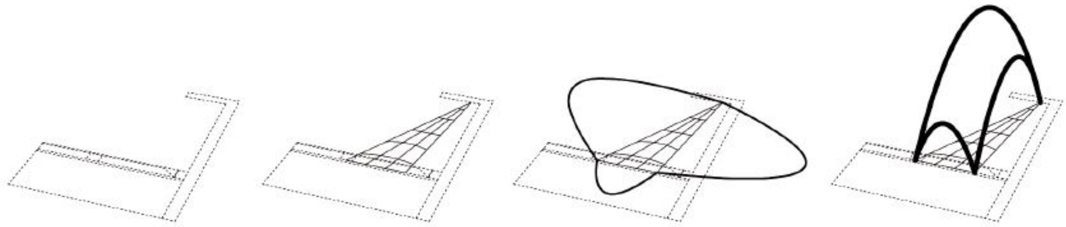


Figure 24 - Trait drawing by Janelle Schmitt

3.3.1 Understanding the Trait

Though technology has rendered many processes obsolete, the trait's enigmatic nature has preserved its place in the world of intellectual intrigue. While many have studied the mechanisms of its aesthetic complexity, and some have even learned its principles enough to reconstruct past drawings, the question of the trait's functional relevance has yet to be affirmatively answered. For instance, Robin Evans further sought to thoroughly disassemble a trait drawing and provide a dense history of its prior use. The chapter entitled Drawn Stone undoubtedly has become a foundation for succeeding research of the same topic – this research included – since it explains a specific trait's step-by-step construction (Evans 1995, p. 179-239). Another example is the writing of Kenneth Frampton, who quotes architect/historian Gottfried Semper as he employs the word "stereotomic" to describe heavy masonry units, without any reference to a trait: "Semper's emphasis on the joint implies that a fundamental syntactical transition is expressed as one passes from the stereotomic base of a building to its tectonic frame and that such transitions are of the very essence of architecture". In his reference to the transition between below and above ground construction, Frampton simply implies that "stereotomic" is synonymous with "foundation" based on its inherent mass and referring to it in the realm of "heavy" while framing is "light." Additionally, Tsubaki, in his 2012 article: Foldout Drawing, argues for "…reactivating the agency of drawing as a primary means of mediation between design and fabrication" (Tsubaki 2012, 98-106). His drawings utilized projection to document an empty fabric mold's formal transition to one filled with concrete. A trait drawing is secondarily characterized as a necessary and only means of visualization before the form is constructed, while Tsubaki's drawings focused more on the documentation of a process. While his research fastidiously recorded the transition of the material, it does not aid in the initial hypothesis regarding the practicable functionality of a trait drawing. Likewise, Lawrence Blough's research that was documented in his article, "Digital Tracery: Fabricating Traits," focuses on mass production. He refers to the trait's inherent process of finding all information of one type through the same system and deploys that in his research focused on joinery and part-to-whole relationships. When concluding his results, Blough cited the traits as the "technical and conceptual joining principals" of the project, in that he extracted the trait's algorithmic tendencies of following the same system to produce infinite information. However, this assembly line-esq principle has origins elsewhere than the trait, so Blough's findings are not synonymous and do not support the finding here.

3.3.2 Testing Trait Methodology

The case study demonstrates the functional obsolescence of the trait by citing 18 months of research that was intended to prove the opposite.[7] Past researchers of this topic tend to either end of the spectrum of perceived relevancy. On one side, scholars that are seduced by the trait seek to either teach its process or extract principles of the trait's aesthetic to be applied in their own work. We do not find ourselves in this group because it was our goal to build upon the understanding set up by Evans and Frampton, and employ that analysis in a principled fabrication process, which contrasts Blough and Tsubaki's output of imagery. Alternatively, designers based at the other end of the spectrum are familiar with these drawings and conclude that they're irrelevant. Trait drawings arguably manifest the first principle of three-dimensional drawing systems, and we would not have the drawing tools that we have today without the creation of this process; for this reason, this case study does not subscribe to this opinion either. This case study focuses on the trait's principles in terms of the grounds for its conception. A trait's extraordinary property is that it is a device to

[7] The trait and stereotomy research was completed in collaboration with Janelle Schmitt and funded by Lawrence Technological University Presidential Undergraduate Research Grant during the research period of this thesis.

design for infill, which uniquely forces it to equivocate site and intended form as forces of the same priority and subsequently use 2D drawings to create a 3D model. Without this component, any remake of a trait drawing is not a pure manifestation of its actual function. The research processes included conducting five experiments that tested the various properties of a trait drawing and effectively illuminated each one’s ability to be replaced. In the first experiment, we attempted a trait drawing by hand and uncovered that every trait would be different by two degrees of discrepancy: a trait’s construction will vary depending on who creates it and what information the trait is being employed to find. Our next test uncovered the laboriousness of the process in that it required around nine steps to find one coordinate of one block (Figure 25). The project following was the first that ended with masonry construction, and the many errors illuminated an overall misunderstanding of traits at the midway point of the entirety of the research. The conclusion of this third test provided speculation of a trait’s real purpose: we considered that the drawing’s mystique is not merely

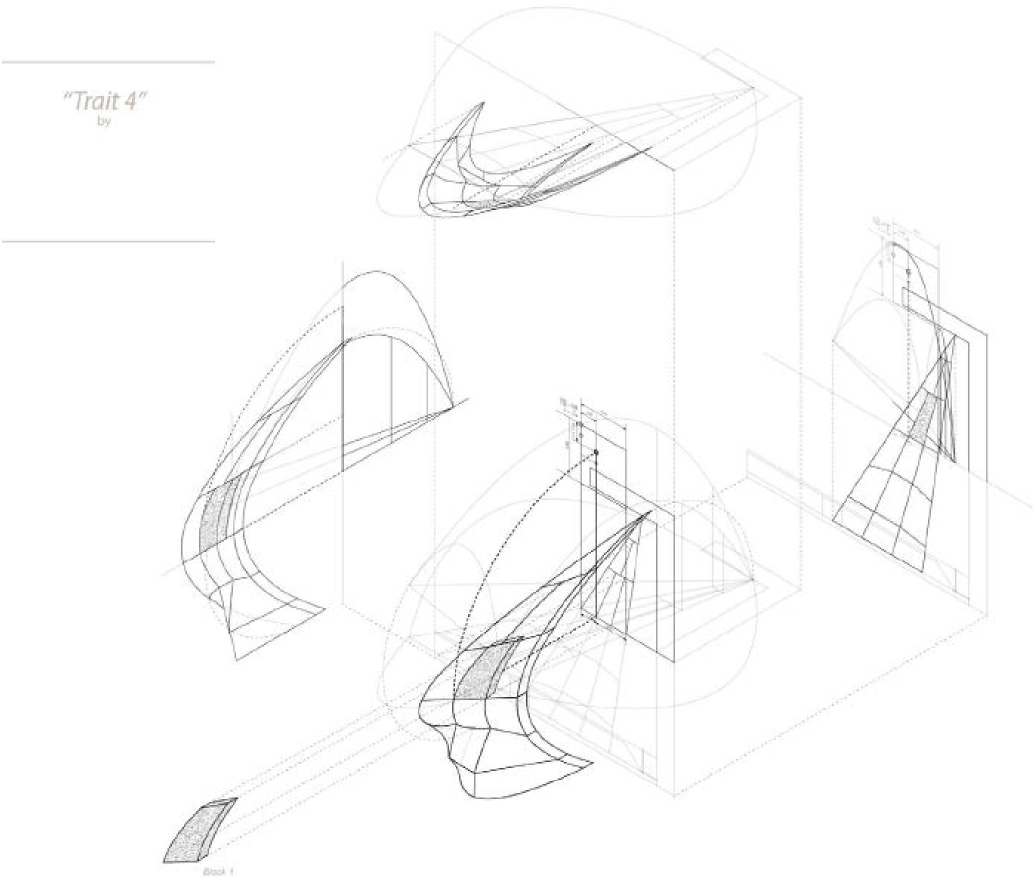


Figure 25 - Trait line drawing finding one block, drawing by Janelle Schmitt

a result of such a complicated process, but also intrinsic to the trait's existence. The fourth experiment prompted us to develop a method that was a useful hybrid system of traditional knowledge and modern tools in that it utilized multi-axis 2D drawings in a parametric workspace to solve. However, the manual method could not be translated linearly into an algorithm because it was too reliant on visualization, even though the use of parametric speeded up the process immensely. Each experiment built upon the next producing graphical and built outcomes that provided insight into our findings.

The trait drawing has been a subject of architects' interest for centuries, but possibly, widespread interest-only stems from the drawing's intricate beauty and apparent dynamism. If so, then it is relevant now for graphic qualities, which is the exact opposite of the reason for the trait's evolution. Surely there is nothing wrong with preserving past processes as engaging representations for the constraints of their time period, but it's possible that architects' perseverance for proving a trait's current functional significance is characterized by a misunderstanding of the system's core purpose. However, a trait's timeless extraction of constraints to output a three-dimensional map of coordinates illustrates the value of the drawing's principles; they manifest a fundamental of 3D modeling, and they did so 400 years before the conception of computers. The research sought to extract these principles and further apply them, and through building vaults, we were able to break down the design process into meticulously defined categories. Every category of the process had a specific intent, and recognizing this caused us to make the distinction between block finding and form-finding. Stereotomy is definitive "block finding," as the etymology of the word indicates when breaking it down to stereo:stone and tomic:cutting. Yet because a trait is a response to the need to infill, trait creators are prompted to do both: a form must be found to fit within a site, and then that form must be separated into parts. In the past, both processes were completed manually, even though the answer to one is objective and the other subjective. Through this insight, we are now able to understand better the role of the computer and the role of the human as we move forward with our stereotomy research (Figure 26).

Figure 26 - Drawing and building a vault condition, image by Janelle Schmitt

3.3.3 Concluding Obsolescence

It is admitted that the hope for this line of inquiry was that drawing was intrinsically linked to making. That somehow, the drawing was a comparative equal to the physical outcomes of digital fabrication, that they were the resistance or “material” required by craft. That drawing a trait would provide a similar feedback loop that digital 3D modeling alone could not provide. To some degree this may be true, yet to provide detailed research, a method of drawing needed to be tested for such an outcome (Figure 27). The stereotomic drawing was selected for its complexity but also for its circular process of common reference points and the culmination of multiple orthogonal views. Therefore, this method was studied with hopes of a clear link that did not manifest.

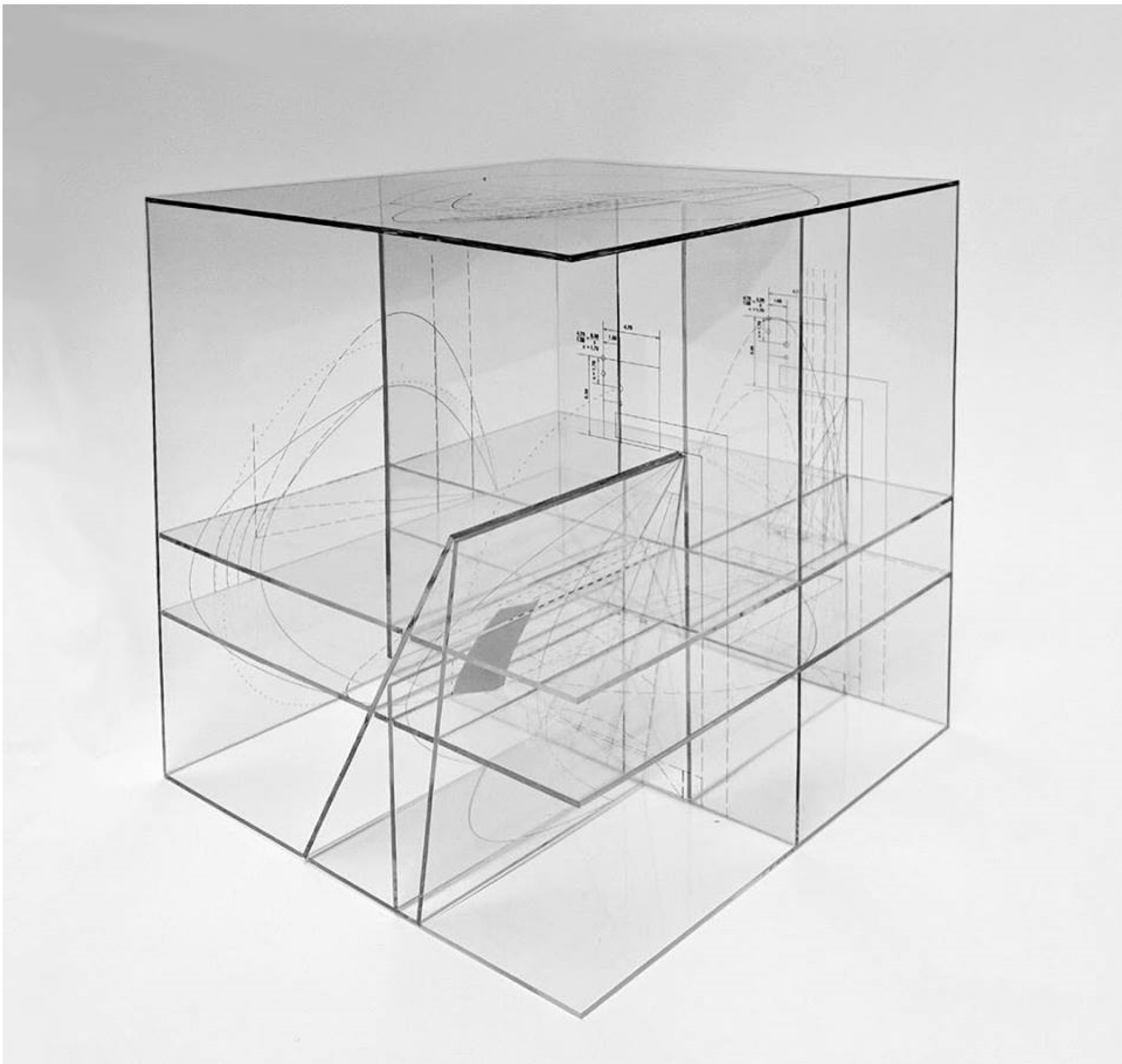


Figure 27 - Trait drawing on acrylic holding 3d printed block, by Janelle Schmitt and Breanna Scranton

The conclusion of obsolescence of drawing methods of the past does not, however, signal the total failure of a link between making and drawings. It only demonstrated through multiple trials that extracting orthogonal drawings from a model is a full equal to the manual methods of the past. To some, this may be self-evident, but the research methodology requires verification.

4 Digital Ceramic Risk

Digital ceramic risk is a series of experiments and tests intended to identify, apply, and extend risk factors used in all manual and digital making. The project is divided into three primary investigations, Phase 1-3 with listed summery outcomes below:

Phase 1 - Identification

- Hypostasis: Can a digital tool be crated to enable hybridized manual and digital ceramic printing?
  Outcome - Confirmed
- Hypostasis: Can risk variables be isolated and identified through documented tests?
  Outcome - Confirmed

Phase 2 - Application

- Hypostasis: Can a craftsperson demonstrate a high level of skill and craft with hybridized digital and manual methods of making?
  Outcome - Confirmed
- Hypostasis: Can the application of identified risk factors (Phase 1) be used to generate newly crafted forms?
  Outcome – Confirmed

Phase 3 – Propagate

- Hypostasis: Can a craftsperson demonstrate optimized printing skill and craft?
  Outcome - Confirmed
- Hypostasis: Can hybridized methods create of visually distinct collection?
  Outcome – Confirmed
- Hypostasis: Can hybridized and improvised artifacts be Re-digitized?
  Outcome – Confirmed
- Hypostasis: Can AI coding be used to propagate hybridized and improvised artifacts?
  Outcome - Plausible

4.1 Ceramic Risk - Phase 1: Identification

To test digital risk, an experiment was proposed to build a 3D printer that could design and fabricate custom ceramic masonry units. The 3D printer's design intentionally allows risk; it embraces failure and negates standardization. The digital tool is based on an open-source Delta 3D printer configured to print ceramic clay. The principle that guided the tool's design was to have distinct tasks relegated to the computer and the human hand. This was accomplished first by using the printer's ability to control the movement of the ceramic extrusion in the x, y, and z directions. Therefore, the computer was used to virtually shape the proposed artifact and to accurately move the extruder along a path directed by G-code output. The hand of the craftsperson controls the material and is at risk while operating the tool. Before printing, the clay must be mixed with the correct viscosity (Figure 28). The mix cannot be explained through simple mixing instructions, and the craftsperson must consider multiple factors. Along with the composition of the clay, the volume of the print, how long the clay will be in the extruder, and the height of the artifact all factor into finding the correct viscosity. After practice and failure, the viscosity can be judged with tacit knowledge where the craftsperson knows and feels "when it is ready." The clay is pushed through a chamber using compressed air, where the air pressure determines the flow rate of the clay. The flow must be synchronized with the speed of the x, y, z movement of the printer. The air pressure also cannot be calibrated with a standard measurement; it must be monitored by the craftsperson that slowly adjusts the pressure responding to dry or sticky portions of the clay batch. If the pressure is too high, the stratification of clay will press over the edge of the layer below, too low, and the clay will not flow.

Figure 28 - Mixing clay Prior to printing

The craftsperson in control of the printer is not merely an "operator" of a computer tool but is instead in a risky negotiation between the material and the digital. The digital tool exhausts its users; they move between mixing the clay to hours of closely monitoring the clay distribution. All of this is done with a likelihood of failure. When the craftsperson is in sync with the tool, the clay runs smooth, and the craftsperson is able to achieve a valuable result. The imperfections of the produced artifact are the only evidence of risk (Figure 29).

Figure 29 - Early attempts at hand control of clay flow rate

The first phase of the study was to determine the material, geometrical, and scale limits of the printer. To better understand the relationship between skill, risk, and the craftsperson's interactions with the tool one graduate student was assigned to the task (Figure 36). A multitude of prints began that initially, all ended in failure with uncertainty of cause. Each print was methodically documented with evaluations by the student (Table 3). As the student's skill improved the prints become more consistent, and lower levels of failure were achieved. This allowed for higher risk prints to find limits of geometry and scale; in many cases, printing until failure was the objective (Figure 35). The student reflected: 'The larger the print is, the more control of the process you need to have to achieve a successful print' (Breanna Hielkema 2017). Over time, a knowledge of printer limits, material understanding, and the skill of the student was aligned. This allowed for a design challenge to test the process of digital risk and its relevance and usefulness in the design of custom masonry units.

To test the skill of the student and the tool, a study was created to design and print twenty-four unique masonry units, also referred to in this study as "the collection" (Figure 39). Each unit would need to align with its adjoining unit, and each was shaped using the geometrical limits tested in prior experiments. The collection of units shows remarkable consistency, yet on closer inspection, the variable of hand control is revealed (Figure 42). Most significantly, the study shows that tool behavior can be learned and responded to accordingly, thus managing risk to reap its benefits without total loss of productivity. As a result, many things that were considered a risk when the student first began the case study were no longer a factor due to the student's mastery of the processes. It became clear that the student had achieved mastery of the tool and had become a craftsperson yielding consistent and exceptional outcomes. When asked what the student learned as a result of this process, the student answered, 'craft.'

4.2 Ceramic Risk – Phase 1: Tool Drawings

The phase 1 3D printer is designed with the following primary systems (Figure 30):

- Digital command and control (g-code + control board): G-code generated from software based on digitally modeled artifacts and used by the control board to control the movement of the x-y and z-axis.
- Mechanical: All moving parts of the printer are controlled by the control board (in phase 1 and phase 2 only).
- Material control: Compressed air controlled by hand dial. It requires constant monitoring by the craftsperson. Material viscosity Is controlled by the craftsperson and mixed by hand.

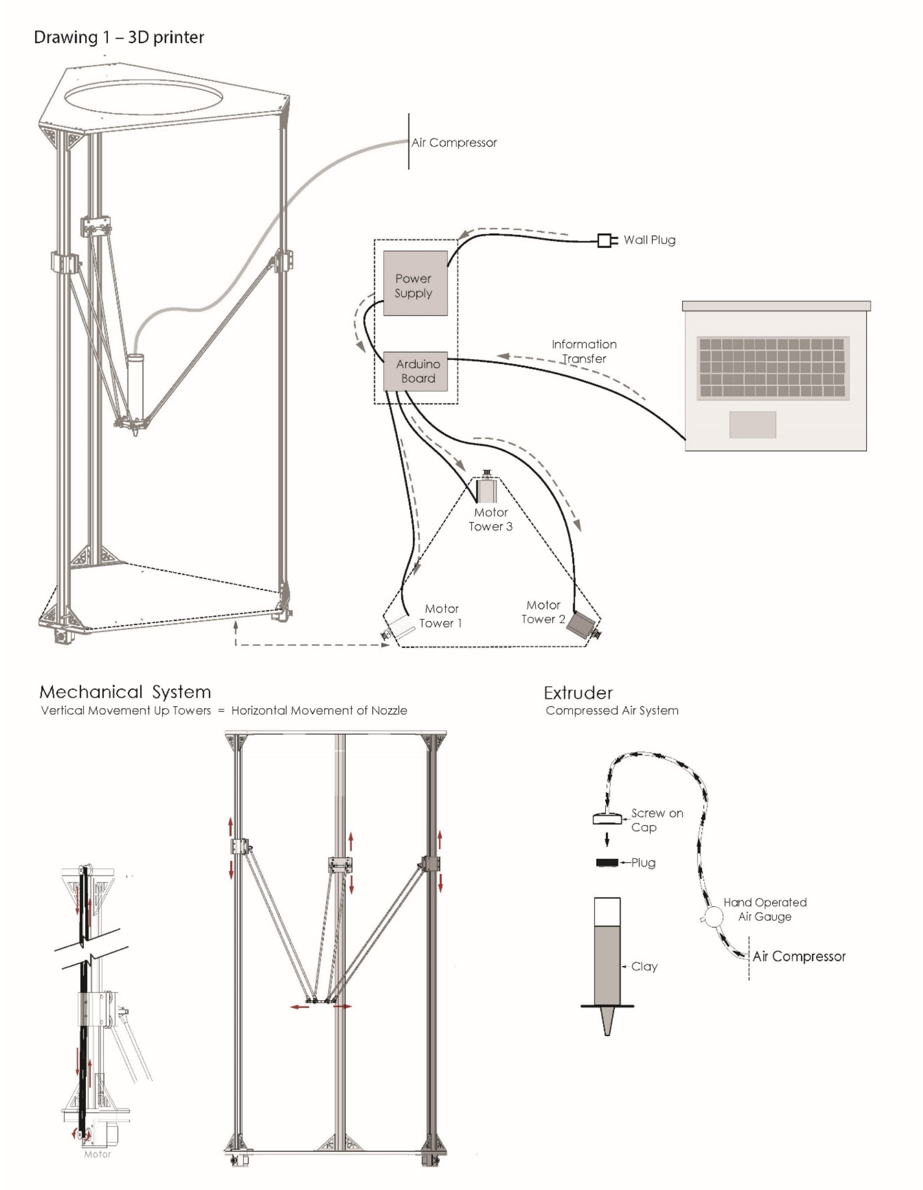


Figure 30 - Phase 1 3D printer

The phase 1 printer was composed of reused parts, plywood, HDPE to form the structure (Figure 31 - Figure 32). The printer was stable, but when printing taller artifacts, the printer did have a tendency to move laterally.

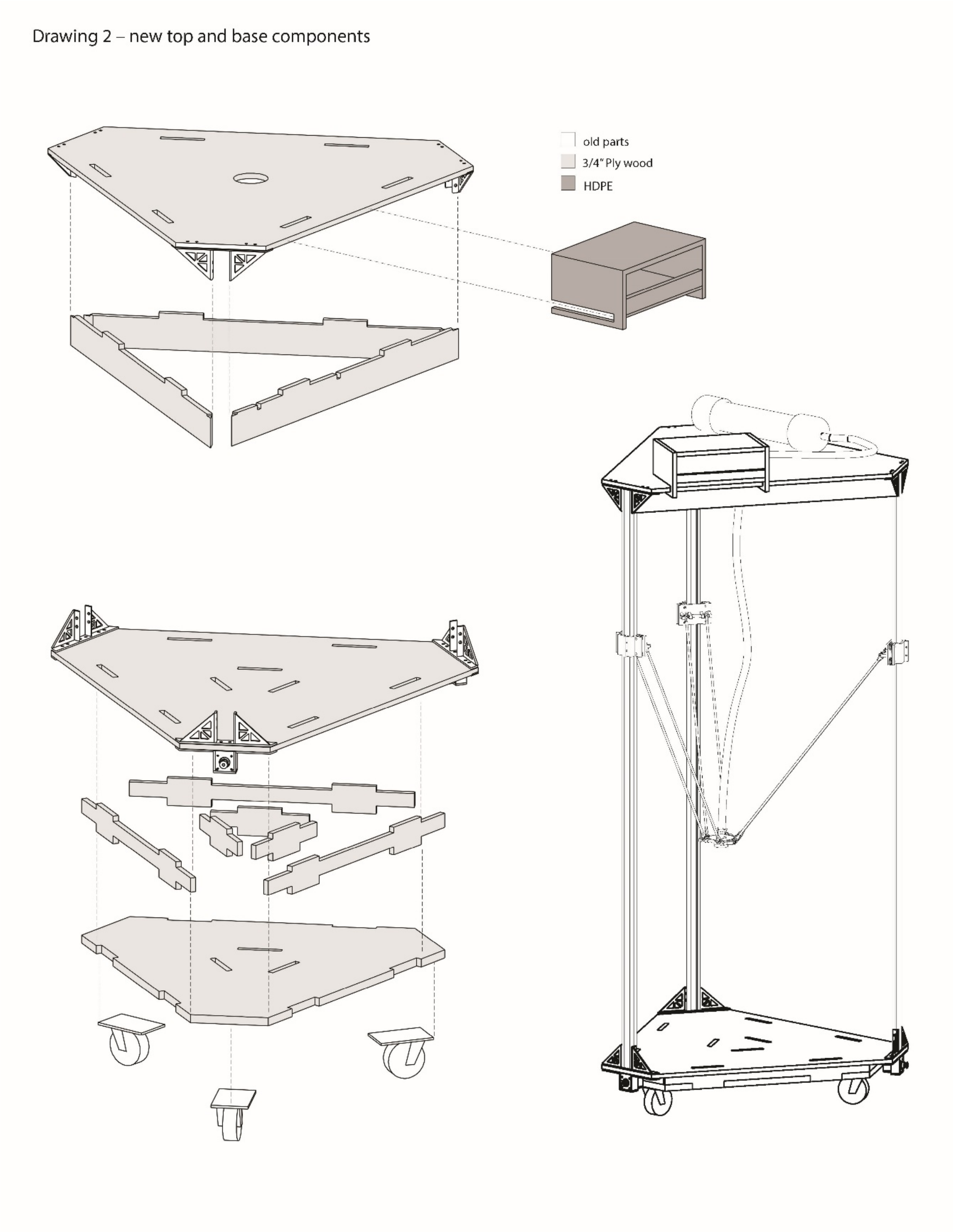


Figure 31 - Structure of phase 1 3D printer

The extruder in phase 1 3D printer was designed specifically to allow for haptic control over the air compression and the resulting flow of the clay (Figure 32). This allowed the experiment to test the risk involved with only one variable in phase 1 of the research.

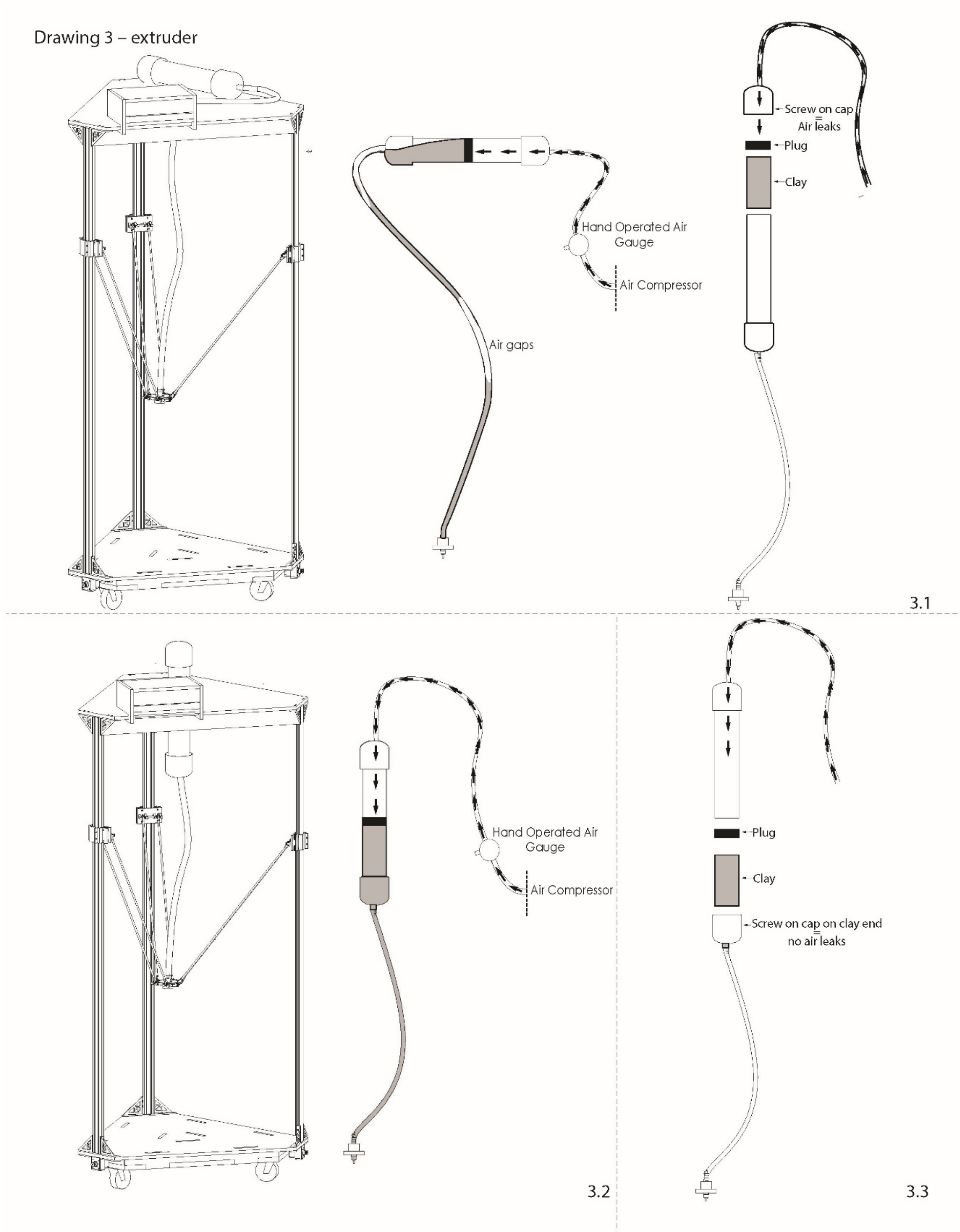


Figure 32 - Phase 1 3D printer extruder

The open-source Delta 3D printer used as the basis for the Phase 1 3d Printer is typically used to print small artifacts. For the purposes of the Digital Ceramic Risk project, it was important not to be limited in size. This, however, posed a problem with the firmware used to communicate between the software and the control board. Multiple trials yielded an updated firmware that allowed maximum dimensional printing (Table 2).

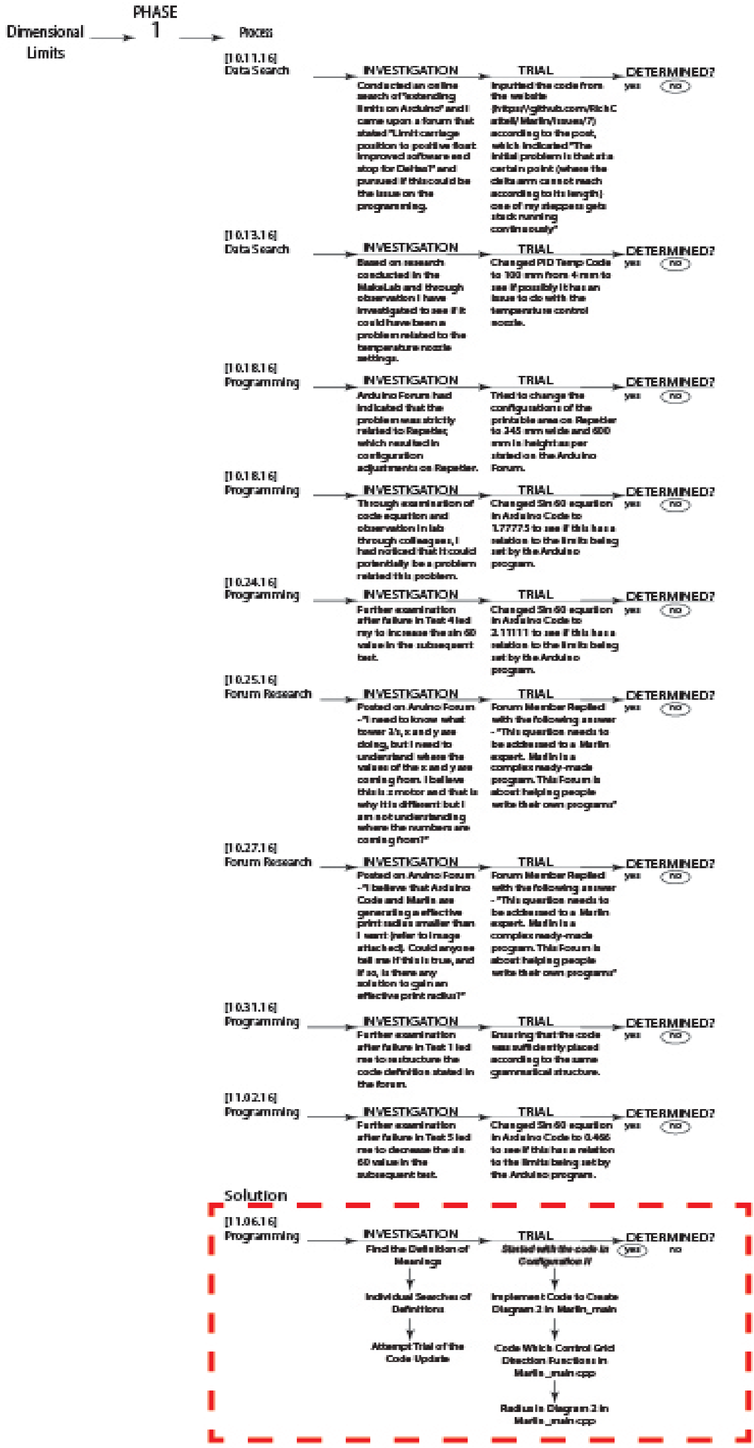


Table 2 - Documentation of trials used to modify the 3D printer's firmware

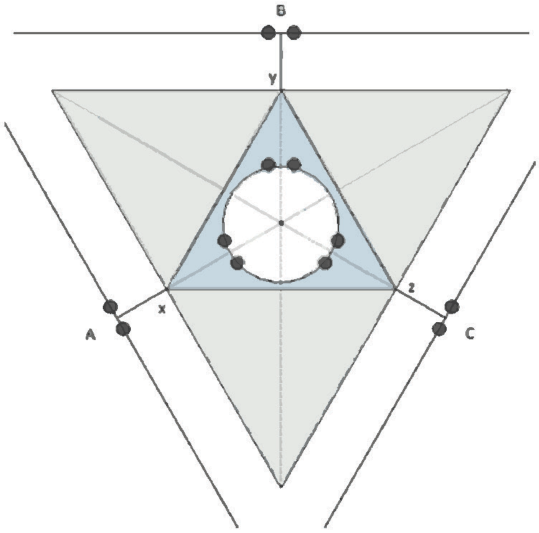
To understand how this update related to the dimensional properties, the following online forums were consulted to understand what portion of the script controlled the dimensional properties (Figure 33).

Drawing 4 – arduino scritp
Online source - User: RichCattell

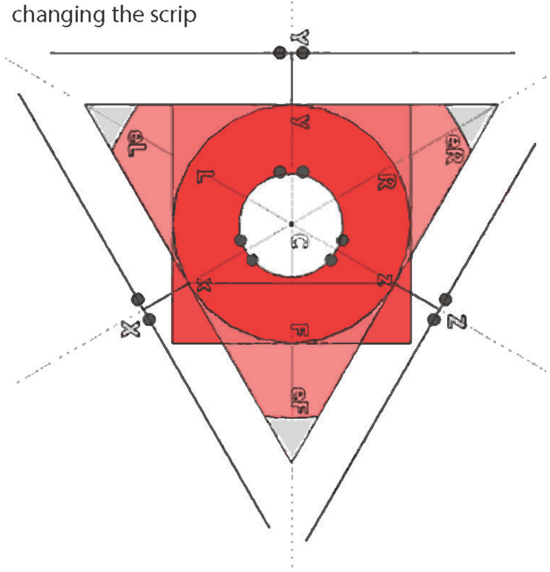
```
void calculate_delta(float cartesian[3])
{
 delta[X_AXIS] = sqrt(sq(DELTA_DIAGONAL_ROD)
            - sq(DELTA_TOWER1_X-cartesian[X_AXIS])
            - sq(DELTA_TOWER1_Y-cartesian[Y_AXIS])
            ) + cartesian[Z_AXIS] ;
 delta[Y_AXIS] = sqrt(sq(DELTA_DIAGONAL_ROD)
            - sq(DELTA_TOWER2_X-cartesian[X_AXIS])
            - sq(DELTA_TOWER2_Y-cartesian[Y_AXIS])
            ) + cartesian[Z_AXIS];
 delta[Z_AXIS] = sqrt(sq(DELTA_DIAGONAL_ROD)
            - sq(DELTA_TOWER3_X-cartesian[X_AXIS])
            - sq(DELTA_TOWER3_Y-cartesian[Y_AXIS])
            ) + cartesian[Z_AXIS];
 /*
 SERIAL_ECHOPGM("cartesian x="); SERIAL_ECHO(cartesian[X_AXIS]);
 SERIAL_ECHOPGM(" y="); SERIAL_ECHO(cartesian[Y_AXIS]);
 SERIAL_ECHOPGM(" z="); SERIAL_ECHOLN(cartesian[Z_AXIS]);

 SERIAL_ECHOPGM("delta x="); SERIAL_ECHO(delta[X_AXIS]);
 SERIAL_ECHOPGM(" y="); SERIAL_ECHO(delta[Y_AXIS]);
 SERIAL_ECHOPGM(" z="); SERIAL_ECHOLN(delta[Z_AXIS]);
 */
}
void adjust_delta(float cartesian[3])
{
 int grid_x = (max(0, min(7, int(cartesian[X_AXIS]/25.0 + 3.5))))/2;
 int grid_y = (max(0, min(7, int(cartesian[Y_AXIS]/25.0 + 3.5))))/2;
 float offset = bed_level[grid_x][grid_y];
 delta[X_AXIS] += offset;
 delta[Y_AXIS] += offset;
 delta[Z_AXIS] += offset;
 /*
 SERIAL_ECHOPGM("grid_x="); SERIAL_ECHO(grid_x);
 SERIAL_ECHOPGM(" grid_y="); SERIAL_ECHO(grid_y);
 SERIAL_ECHOPGM(" offset="); SERIAL_ECHOLN(offset);
 */
}
void prepare_move_raw()
{
 previous_millis_cmd = millis();
 calculate_delta(destination);
 plan_buffer_line(delta[X_AXIS], delta[Y_AXIS], delta[Z_AXIS],
        destination[E_AXIS], feedrate*feedmultiply/60/100.0,
        active_extruder);
 for(int8_t i=0; i < NUM_AXIS; i++) {
  current_position[i] = destination[i];
 }
}
```

RichCattell's Explanation of what the function in the script is doing



RichCattell suggestion for changing the scrip




```
open marlin_main.cpp and search for this function:
void calculate_delta(float cartesian[3])
{
delta_tmp[X_AXIS] = sqrt(DELTA_DIAGONAL_ROD_2
      sq(delta_tower1_x-cartesian[X_AXIS])
        sq(delta_tower1_y-cartesian[Y_AXIS])) + cartesian[Z_AXIS];
delta_tmp[Y_AXIS] = sqrt(DELTA_DIAGONAL_ROD_2
        sq(delta_tower2_x-cartesian[X_AXIS])
        sq(delta_tower2_y-cartesian[Y_AXIS])) + cartesian[Z_AXIS];
delta_tmp[Z_AXIS] = sqrt(DELTA_DIAGONAL_ROD_2
        sq(delta_tower3_x-cartesian[X_AXIS])
        sq(delta_tower3_y-cartesian[Y_AXIS])) + cartesian[Z_AXIS];
/*
SERIAL_ECHOPGM("cartesian x="); SERIAL_ECHO(cartesian[X_AXIS]);
SERIAL_ECHOPGM(" y="); SERIAL_ECHO(cartesian[Y_AXIS]);
SERIAL_ECHOPGM(" z="); SERIAL_ECHOLN(cartesian[Z_AXIS]);
SERIAL_ECHOPGM("delta x="); SERIAL_ECHO(delta[X_AXIS]);
SERIAL_ECHOPGM(" y="); SERIAL_ECHO(delta[Y_AXIS]);
SERIAL_ECHOPGM(" z="); SERIAL_ECHOLN(delta[Z_AXIS]);
/
/ <-remove this line
if ((delta_tmp[X_AXIS] > 0) and (delta_tmp[Y_AXIS] > 0) and (delta_tmp[Z_AXIS] > 0)){
delta[X_AXIS] = delta_tmp[X_AXIS]; delta[Y_AXIS] = delta_t-
mp[Y_AXIS]; delta[Z_AXIS] = delta_tmp[Z_AXIS];
} else SERIAL_ECHOLN("ERROR: Invalid delta coordinates!");
*/ <-Remove this line
}
```

Remove the two lines as shown to uncomment the code at the end of this function and add the "_tmp" to the three lines at the beginning (to make them Delta_tmp as shown).

Figure 33 - Suggested firmware script changes

Using the suggested changes to the script, a final firmware was updated to allow for a maximum outer dimension and a maximum z-axis movement that matched the printer's physical dimensions (Figure 34).

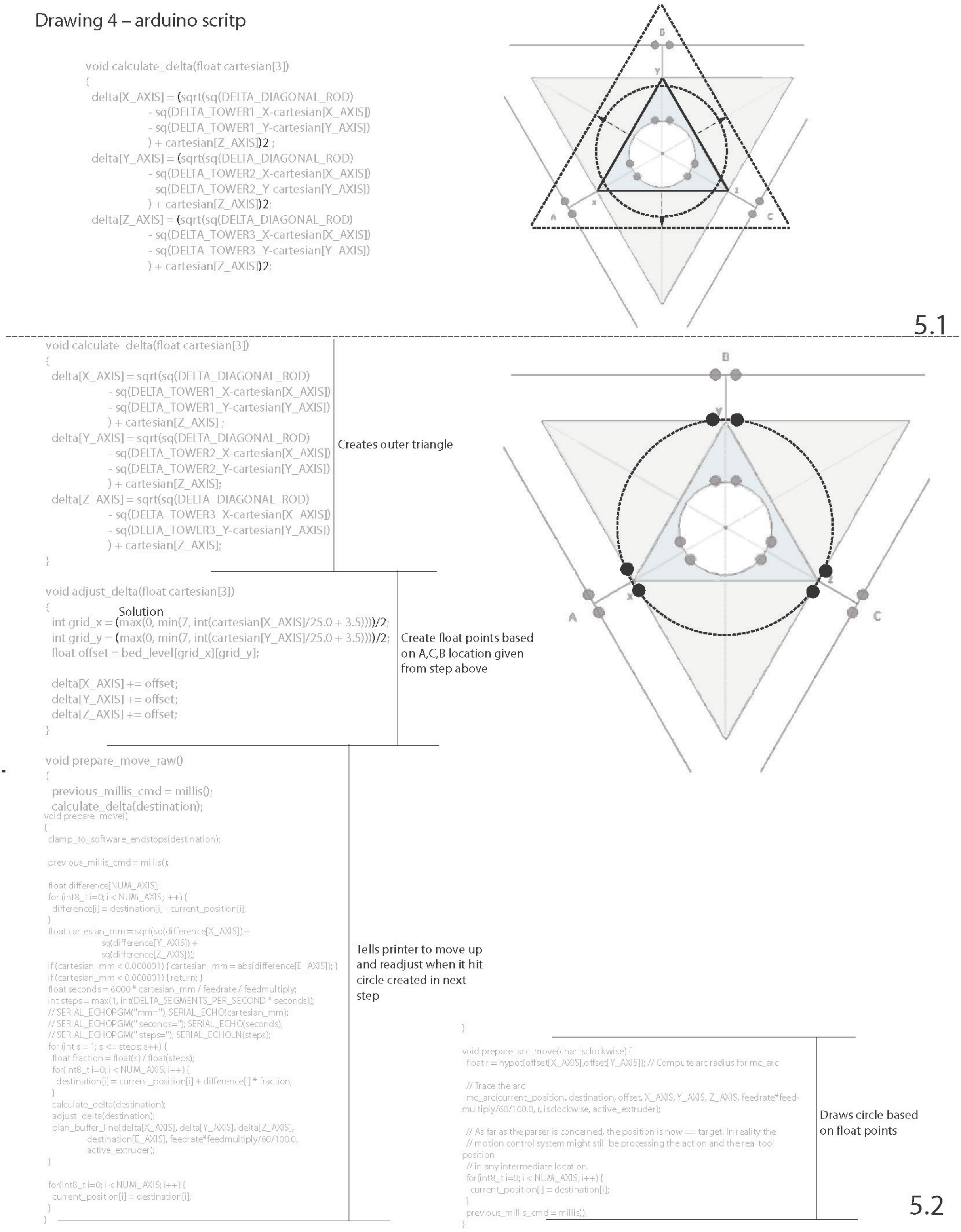


Figure 34 - Final firmware script

4.3 Ceramic Risk Artefacts, Phase 1

The objective of the phase 1 experiment was to begin to understand the variables of risk by parsing out what errors occurred, why they occurred, and if they were mechanical, digital, or human-induced. This required a large number of prints to test geometrical and material limits that, if not successful, would provide insight into the cause of the errors (Figure 35). This was essential because to study digital risk, and the experiment had to ensure that the craftsperson was in total control of the tool. This also required that one research assistant was selected to complete all the printing (Figure 36). This allowed for the data not only to

Figure 36 - Craftsperson Breanna Helkeima

Figure 35 - Practicing to achieve tallest print

show when the tool or material failed but also the improvement of the craftsperson's skill. From the multitude of prints, twenty-one were carefully documented to reveal the variables required to understand digital risk. The sample-set were selected because they represented the most common outcomes achieved and displayed the most common shortcomings of the printing process. The lab notes can be reviewed for all twenty-one artifacts in the Appendix of this document.

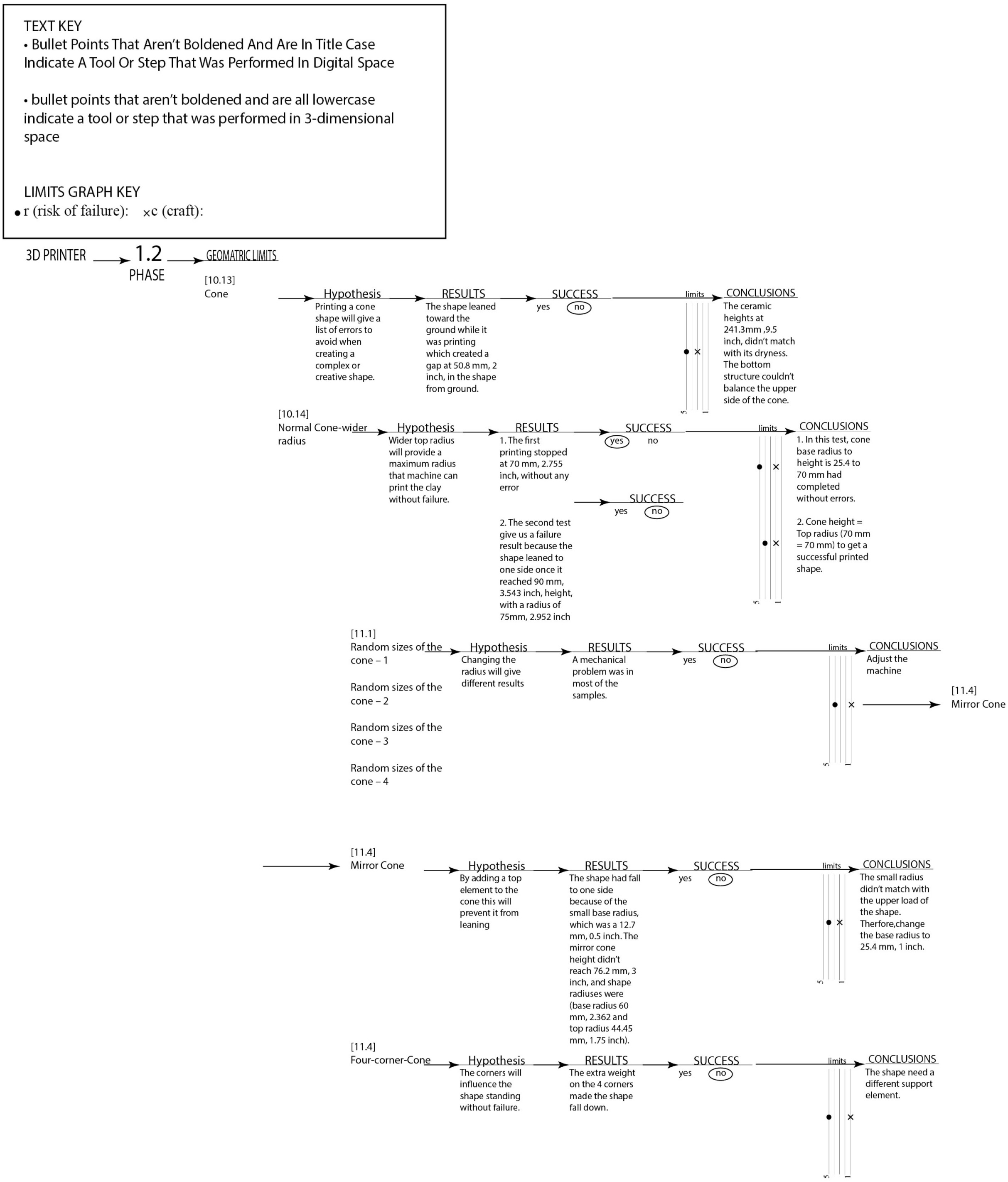
The lab notes only recorded the craftsperson's observations during the printing process. There is a multitude of factors that can contribute to the failure of a print. Therefore, each print was also tracked for all digital and physical factors feasible within the scope of the experiment. The collection of twenty-one prints were recorded with a variety of primary geometries (Table 3) along with further documentation of the variables of risk in (Table 4).

3D PRINTER: PRINT TEST CASE STUDY (Phase 1, twenty-one test prints)

		TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9	TEST 10	TEST 11	TEST 12	TEST 13	TEST 14	TEST 15	TEST 16	TEST 17	TEST 18 - N	TEST 18	TEST 19	TEST 20	TEST 21
TEST SET 1	Date	8/15/2016	8/16/2016	8/16/2016	8/17/2016	8/17/2016	8/17/2016	8/17/2016	8/17/2016	8/17/2016	8/18/2016	8/18/2016	8/19/2016	Unknown	Unknown	Unknown	9/9/2016	9/23/2016	9/29/2016	9/29/2016	9/29/2016	10/3/2016	10/6/2016
	Nozzle Dia. (mm)	1.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	6	6	6	6	6	6	6	6	6	6
LAYERS + PARAMETERS	Layer Height (mm)	1.7	1.7	3.4	2.8	2.8	1.8	1.8	1	1	1	1	1	3	4	4	3	3	3.8	3.8	3.8	3.8	3.8
	1st Layer Height	1.7	1.7	3	3	3	3	3	1.8	1.8	1.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Parameters	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Solid Layers (Bott.)	1	1	0	0	0	0	0				2	2	2	2	2	2	2	2	2	2	2	2
INFILL	Fill Density			0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fill Angle			45		45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
SKIRT + BRIM	Loops	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Min. Extrusion Length	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPEED	Parameters	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	25 mm/s	25 mm/s	25 mm/s
	Small Parameters	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	25 mm/s	25 mm/s	25 mm/s
	External Parameters	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	25 mm/s	25 mm/s	25 mm/s
	Infill	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	25 mm/s	25 mm/s	25 mm/s
	Solid Infill	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	25 mm/s	25 mm/s	25 mm/s
	Bridges	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	25 mm/s	25 mm/s	25 mm/s
	Travel	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	25 mm/s	25 mm/s	25 mm/s
	1st Layer Speed	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	25 mm/s	25 mm/s	25 mm/s
	Max Print Speed	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	25 mm/s	25 mm/s	25 mm/s
ADVANCED	Default Ext. Width	2	2	4	4	4	4	4	4	4	4	4	4	7.5	5.5	5.5	7	7	7	7	7	7	7
	1st Layer	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Parameters	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	External Parameters	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Infill	2	2	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	Solid Infill	2	2	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	Parameter Overlaps			15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	Bridge Flow Ratio			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Threads			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
OBSERVATION	- Layer height is			Retaining										Air is 4.1									
	- Make small objects			No slumping at all on bottom layers																			
	- The smaller The nozzle The softer The material nee			Not right because the layer height is too high; want to try this consistently with a much smaller layer height in next round.																			
OUTCOME	Successful										X	X	X?	X							X		
	Unsuccessful	X	X	X	X	X	X?	?	X?	X?					X?	X?	X?	X	x	X		X	X
SNIPPET																							

Table 3 - Phase 1, twenty-one test print data

The initial investigation and the documentation of the primary twenty-one prints allowed the craftsperson to gain skill with the tool and confidence to begin testing the geometric limits of the tool and material. This was the first opportunity to try and measure the risk associated with the tool and process. Referred internally in the lab as Phase 1.2, the prints were a series of seventeen cones that allowed the testing of the varying angles of repose. Lab notes were taken on each print with an indication of the limits of craft and failure, as judged by the craftsperson (Table 5).



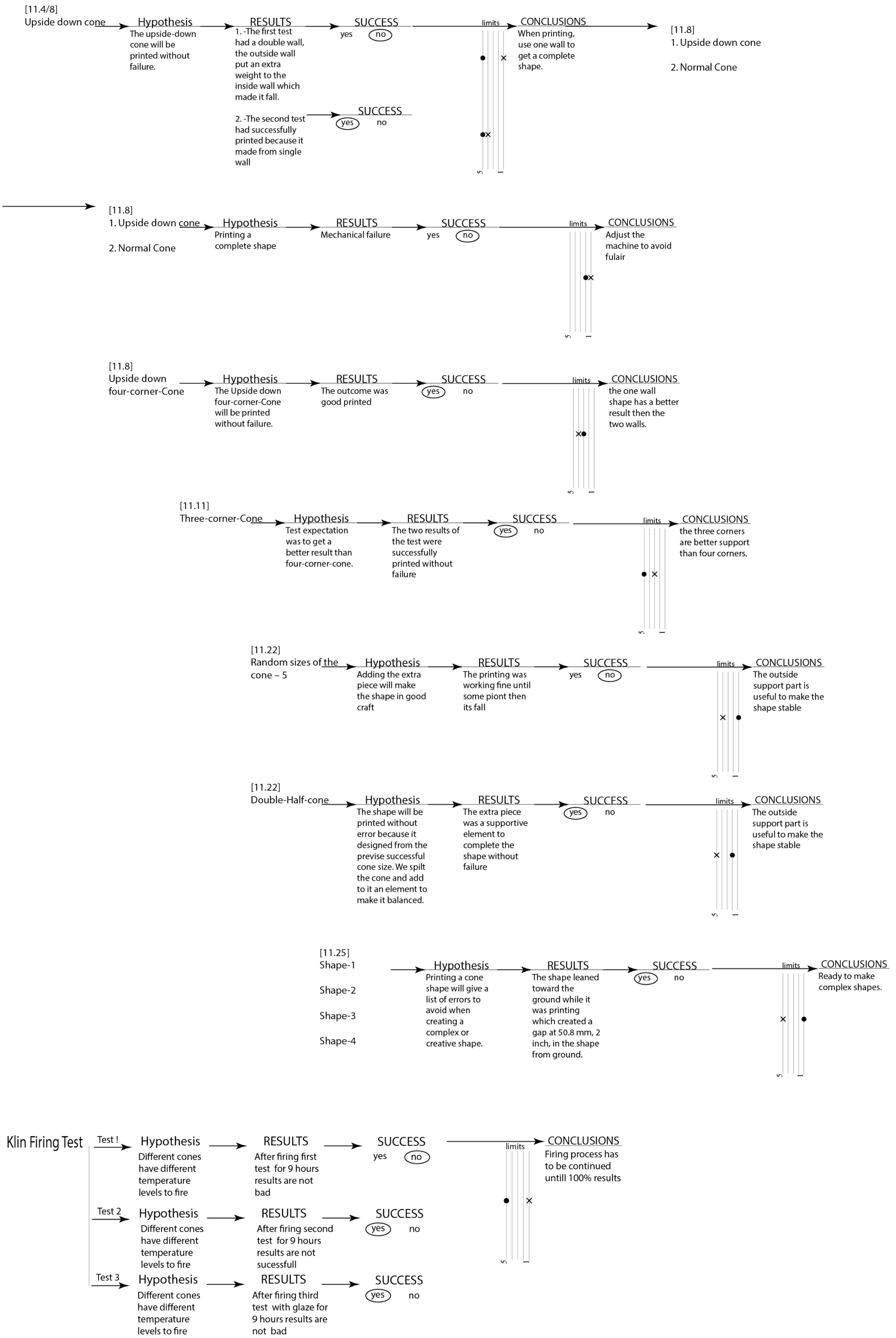


Table 4 - Risk journal phase 1.2

3D PRINTER: PRINT TEST CASE STUDY (Phase 1, geometric limts)

TEST SET 2																Test Cone 15 11/24/2016 6	Test Cone 16 11/24/2016 6	Test Cone 17 11/24/2016 6	Test Cone 18 11/24/2016 6
LAYERS + PARAMETERS	Layer Height	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	1st Layer Height	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Parameters	2	2	2	1	1	1	2	2	2	1	1	1	1	1	1	1	1	1
	Solid Layers (Bott.)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Seam Position			Aligned	Aligned	Random	Aligned *						Aligned *	Aligned *	Aligned *	Aligned *	Aligned *	Aligned *	Aligned *
INFILL	Fill Density	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Fill Angle	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
SKIRT + BRIM	Loops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Min. Extrusion Length	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPEED	Parameters	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	Small Parameters	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	External Parameters	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	Infill	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	Solid Infill	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	Bridges	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	Travel	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	80 mm/s	80 mm/s	80 mm/s	80 mm/s	80 mm/s	80 mm/s	80 mm/s
	1st Layer Speed	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s	40 mm/s
	Max Print Speed	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	100 mm/s	100 mm/s	100 mm/s	100 mm/s	100 mm/s	100 mm/s	100 mm/s
ADVANCED	Default Ext. Width	7	7	7	7	7	7	7	7	7	14	14	7	7	7	7	7	7	7
	1st Layer	4	4	4	4	4	4	4	4	4	14	14	7	7	7	7	7	7	7
	Parameters	4	4	4	4	4	4	4	4	4	14	14	7	7	7	7	7	7	7
	External Parameters	4	4	4	4	4	4	4	4	4	14	14	7	7	7	7	7	7	7
	Infill	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	14	14	7	7	7	7	7	7	7
	Solid Infill	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	14	14	7	7	7	7	7	7	7
	Parameter Overlaps	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	Bridge Flow Ratio	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Threads	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
OBSERVATION	*On tower separate from shape																		
OUTCOME	Successful																		
	Unsuccessful																		
SNIPPET																			

Table 5 - Phase 1.2, test print data, geometric limits

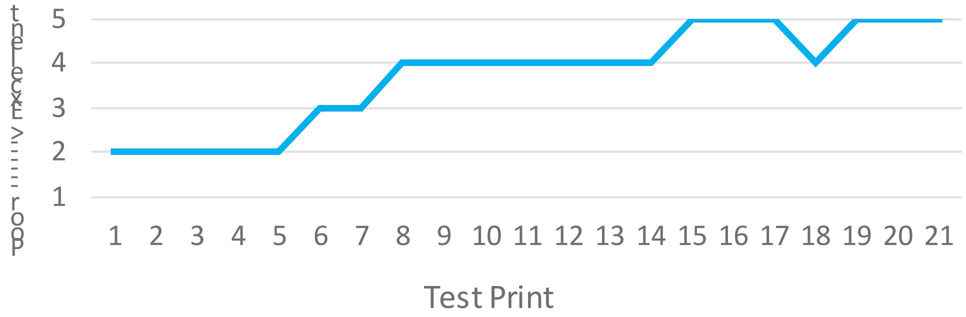
4.3.1 Artifacts Data Analysis

Collecting Data for analysis in design is challenging. The process of design and making is not linear and does not always yield the results expected. And in the case of Phase 1, the results that became significant where not always what was expected. To parse out how the variable of risk was influencing the making process, the data was analyzed through the following primary variables for failure: The *Digital Command* is the front-end process of digital modeling and post-digital processing into the g-code commands that control the tool. The *Tool* variable measures tool performance is relative to expectations. This includes both digital and mechanical performance. *Air and Material* regulation are measured as the craftsperson's skill and haptic knowledge of the tool and process. The *Geometry* variable is the risk involved in the production of shapes that tested the boundaries of the tool and material. Success was measured through observation for each defined variable. The Likert scale (Section 1-25) was used and is defined in the table (Table 6).

Table 6 - Likert Scale - Phase 1 Print Variables	
Digital Command	
Poor:	File setup faulty; print failed. (file set up incorrectly and does not print)
Fair:	The file set up barley allows for the shape to be printed
Good:	The file set up is able to print at a reasonably high resolution
Great:	The feeds and speeds are taken into account, as well as having a high resolution.
Excellent:	The file set up is working with the specific shape making subtle changes to allow for the best possible results.
Tool	
Poor:	The tool breaks and ruins a print completely
Fair:	The tool breaks but the prints are able to be salvaged
Good:	The tool doesn't break, but it is making the prints inconstant due to its inaccuracy.
Great:	The tool is working and constant.
Excellent:	The tool is set up to work with the known process.
User: Air Regulation	
Poor:	No air pressure control; failed print (The air pressure is so all over the place that the print doesn't work at all
Fair:	Some air pressure control; the shape can be printed. (The air pressure is good enough for the shape to be printed)
Good:	Air pressure control is mostly consistent. (The air pressure is mostly constant)

Great:	Air pressure control is consistent. (The air pressure is entirely consistent)
Excellent:	The proper manipulation of the air pressure is able to counteract problems with the material, such as air bubbles and dry spots.
User: Material	
Poor:	The clay's viscosity is ether to wet or to dry and does not work for the print
Fair:	The clay's viscosity allows for the clay to be printed.
Good:	The clay's viscosity is good but was not needed enough, and there is a lot of air bubbles.
Great:	The clay's viscosity is spot on, and the clay was needed correctly, so there are minimal air bubbles.
Excellent:	The clay's viscosity is spot on, and there are minimal air bubbles, and the clay was packed into the tube in the exact same way and amount every time.
Geometry	
Poor:	The shape cannot be printed with the limits of the material or tool
Fair:	The shape can be printed but barely and its integrity is lost
Good:	The shape can be printed, but final geometric integrity is inconsistent.
Great:	Geometry is printed to the limitations of the tool and material
Excellent:	Geometry is printed consistently using the tool and material limits.

Digital Command																					
Test Print	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Outcome	2	2	2	2	2	3	3	4	4	4	4	4	4	4	5	5	5	4	5	5	5

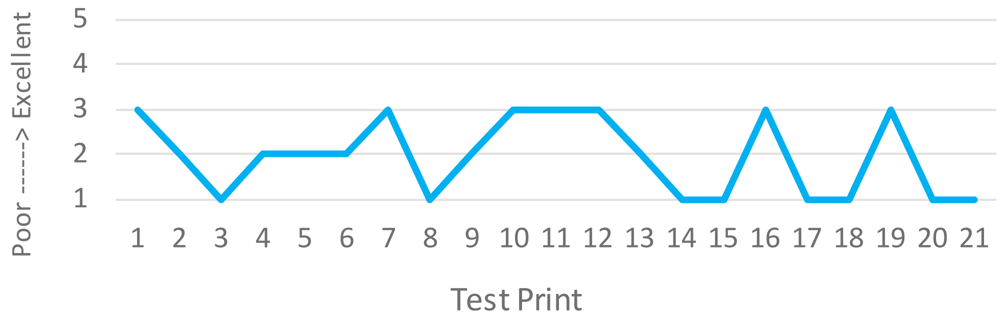


23.81%	Prints failed due to digital command
76.19%	Prints observed to be above good (3)
28.57%	Prints ranking Excellent (5)
100.00%	Prints following test print 10 was ranked great (4) or higher
Performance	Variable is not a significant risk factor once practiced

Table 7 - Digital Command

The data show that within 10 attempted prints all prints were considered good when only evaluated for digital command. This was expected due to the research conduced when altering the 3D printer's firmware (Figure 33 - Figure 34). When modifying the firmware reliable knowledge of the digital command was created. Once operational, the printer did not have digital command failures. The stability in this variable allowed for further isolation of more significant risk factors.

Tool																					
Test Print	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	3	2	1	2	2	2	3	1	2	3	3	3	2	1	1	3	1	1	3	1	1

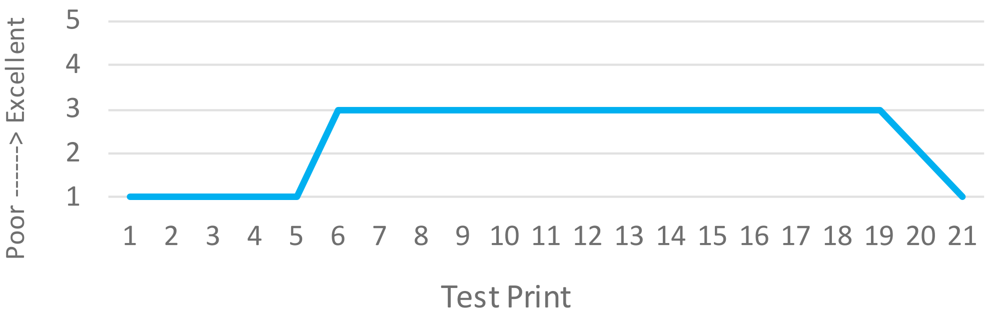


38.10%	Prints failed due to tool failure
33.33%	Prints observed to be above good (3)
0.00%	Prints ranking Excellent (5)
0.00%	Prints following test print 10 was ranked great (4) or higher
Performance	Variable is a significant and inconsistant risk factor.

Table 8 – Tool

The data show no significant improvement over the Phase 1 cycle. Errors persistently interrupted the printing process making the tool an unwanted and significant area of risk. This was significant because the errors where primary mechanical and were not variables that could be improved with practice. The tool limited the craftsperson's ability to improve skill and haptic knowledge of the process. Most troubling was the inconsistency of the tool's performance. Eight of the 21 prints were rated at '1' contrasted by seven prints rated at '3' the highest mark. The lowest and highest marks were evenly distributed along the phase 1 testing showing no sign of improvement. The tools performance initiated tool improvements in the Phase 1 'collection' test and an entire tool rebuild in Phase 2 (Section 4-96).

Geometry																					
Test Prints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	1

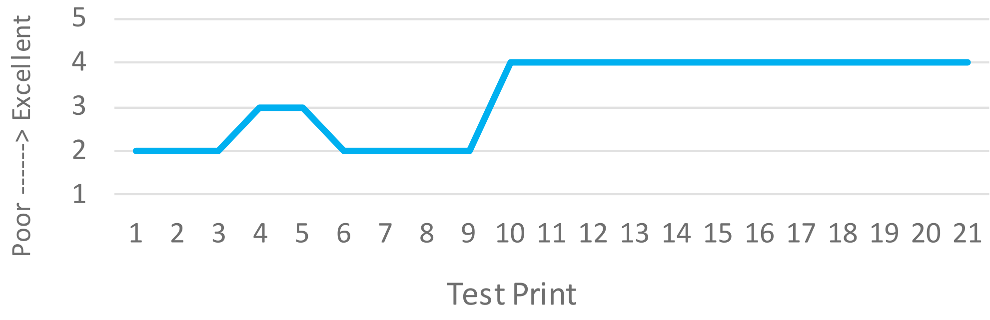


28.57%	Prints failed due to print geometry
66.67%	Prints observed to be above good (3)
0.00%	Prints ranking Excellent (5)
0.00%	Prints following test print 10 was ranked great (4) or higher
Performance	Variable is a risk factor contorled by complexity

Table 9 – Geometry

The data show a majority of the prints are rated ‘good’ (3) with a majority of the prints that did fail occurring in the first five prints. This was an expected outcome and the relative stability of the ratings from print five through twenty indicate a sustained period of success. However, the Likert scale is only partially affective in measuring risk as it relates to geometry due to the necessity of incremental difficulty. As an example, print five is less difficult to print than print six because new limitations were understood from the preceding prints. Therefore, although the graph remains steady at ‘good’ (3) this is when measured by increasing difficulty of print geometry.

User: Material																					
Test Prints	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	2	2	2	3	3	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4

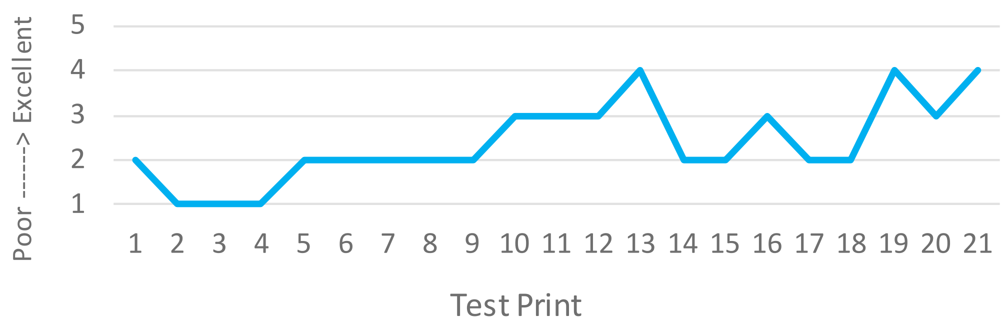


0.00%	Prints failed due to material
61.90%	Prints observed to be above good (3)
0.00%	Prints ranking Excellent (5)
100.00%	Prints following test print 10 was ranked great (4) or higher
Performance	Variable is a low risk factor once practiced

Table 9 - User: Material

User material is one of two risk variables measured that involve the haptic knowledge of the user. The data show an improvement overtime that reinforces that the material control can be learned and improved upon. The steady improvement to a good rating (4) was as expected.

User: Air Regulation																					
Test Print	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	2	1	1	1	2	2	2	2	2	3	3	3	4	2	2	3	2	2	4	3	4



14.29%	Prints failed due to air regulation by user
38.10%	Prints observed to be above good (3)
0.00%	Prints ranking Excellent (5)
27.27%	Prints following test print 10 was ranked great (4) or higher
Performance	Variable is a moderate risk factor that lowers with practice

Table 10 - User: Air Regulation

User air regulation was one of two risk variables measured that involve the haptic knowledge of the user. The data show an improvement overtime indicating learned control. However, the arc of improvement continues after print ten there are regular setbacks. Four of the prints after print 10 are rated as ‘fair’ (2) and correlate with tool failures seen in Table 8. Therefore, the air regulation did improve with experience but it was hindered by inconsistent mechanical response from the air control dial. This was addressed with improvements in the Phase 1 ‘collection’ test and an entire tool rebuild in Phase 2 (Section 4-96)

4.3.2 Phase I Tool Upgrade

Following the test prints in Phase 1, the observations, data, and experience all made explicit the need for the printer to be more reliable. Given the objective was to isolate distinct areas of risk and to leverage those risks to design possibilities, the areas could not be fully isolated without the total reliability of tool operation. To test improvements to the tool, several changes were made to the existing printer that increased lateral stability and accuracy of printing (Figure 37).

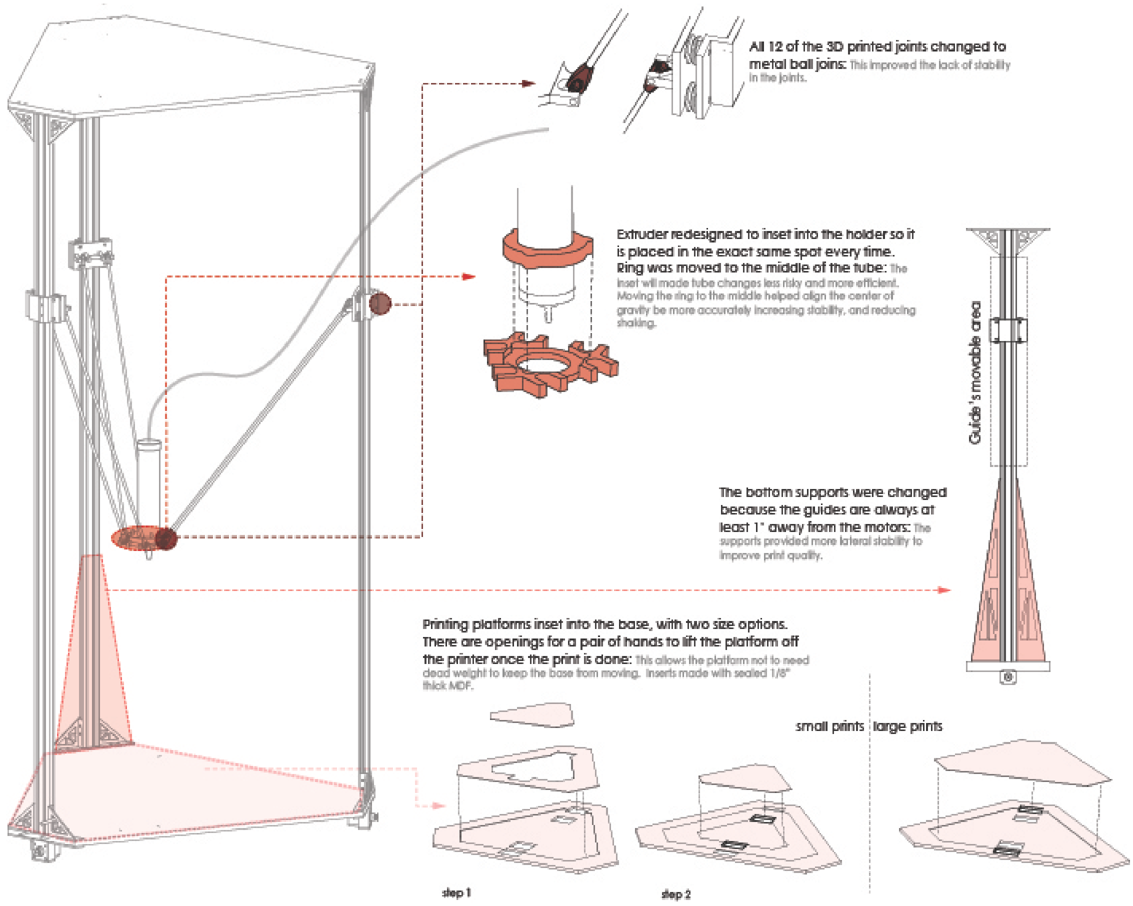


Figure 37 - Mechanical Changes to Printer in Phase 1

To maintain lateral stability, support braces were added to the bottom of the print rails. This did not impede the movements in the z-axis and prevented rocking of three vertical guides during directional changes in the x-y axis during printing. An inlaid print table was created that allowed prints of different sizes to be removed on the print surface for initial drying. This allowed for faster printing freeing the print space as soon as the tool completed the print. The clay extruder was upgraded to allow for seamless alignment when refilling with clay or when resuming a print that had been paused. The first ball joints that connected the three rails to the extruder were printed with a monofilament plastic 3D printer. The joints failed over time and led to inaccuracies in the prints. All twelve joints were replaced with metal ball joints.

4.3.3 Phase 1 Proposition: Collection

The collection was a two-part experiment that tested the craftsperson's control over the tool and material. Using what was learned in the initial tests, a "collection" of ceramic units was proposed that would provide an architectural outcome (Figure 38). The first, Part 1 test was designed to demonstrate the limits of the material through the morphology of allowable slope or angle of repose of the clay. The units also were printed to a maximum height, as

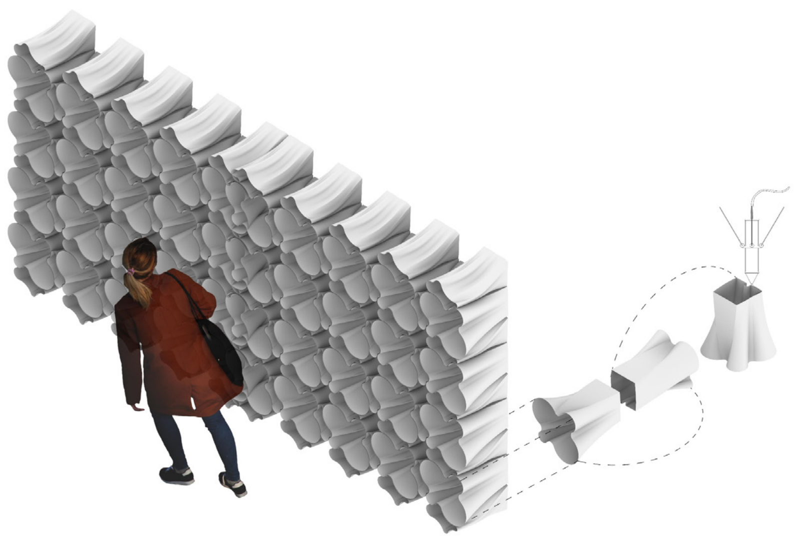


Figure 38 - Phase 1, Part 1 Collection

indicated in previous tests. Multiple units were conceived and printed that, when laid horizontally, stacked to create a perforated wall form. The curves produced by the maximum allowable angels in the previous tests would interlock, creating a stable stacking condition. The coordination between multiple units also required the craftsperson to maintain consistent material and air pressure flow throughout the collection printing. Significant deviations would result in physical differences that could not be reconciled when stacking.

Figure 39 - Phase 1, Part 1 Collection Prototype

Part 1 was successful in demonstrating that the craftsperson had control over the tool, material, and air controls. The prints were successful a majority of the time and with the minimal tool or user error. The forms also proved successful and demonstrated the tool and material's ability to build complex forms. The shape, however, did present an unexpected fit-and-finish problem. Given clay will shrink and various rates given water

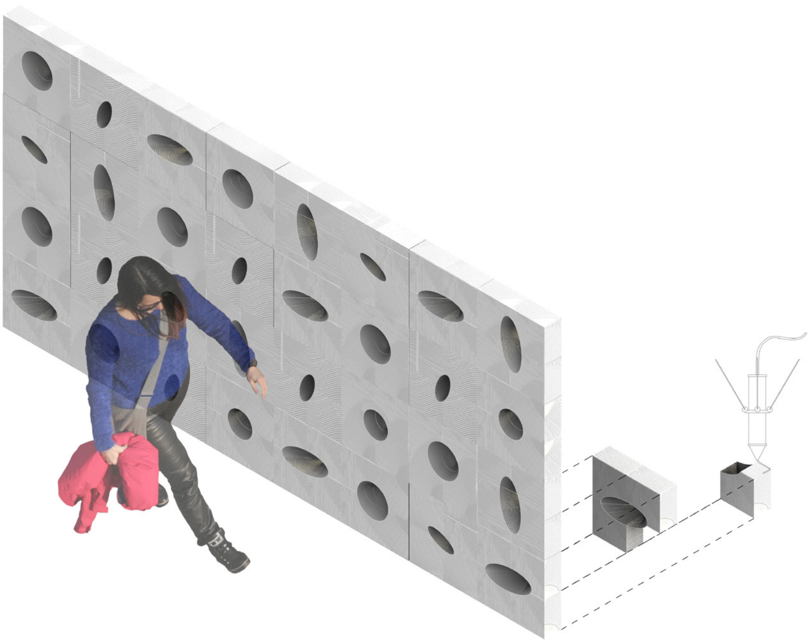


Figure 40 - Phase 1, Part 2 Collection

content of the clay and firing temperature, it made it nearly impossible for the collection to operate as fully stacking system as envisioned (Figure 39).

Figure 41 - Newly Printed Collection Unit

To rectify the difficulty in joining the units, Part 2 was conceived as an inversion of Part 1. In the Part 2 proposal, the maximum angle of repose was a subtraction rather than the silhouette of the form. This allowed for the unit to remain rectilinear while still providing the geometrical complexity that tested the limits of tool and material (Figure 40). The unit division was also considered by dividing each angled perforation into four parts. Therefore, each unit has one corner that is shaped to a maximum slope. This also provides the advantage of printing each unit with the modified corner in the positive z-axis (Figure 41). The rotation also provided the craftsperson to print all layers in the same direction once the units were stacked. The symmetry and consistency of the contour lines created are an example of the craftsperson's skill (Figure 42). The reconfiguration of the units also proved to be successful when stacked. When dry-stacked without mortar, the blocked are coordinated and aligned (Figure 43).

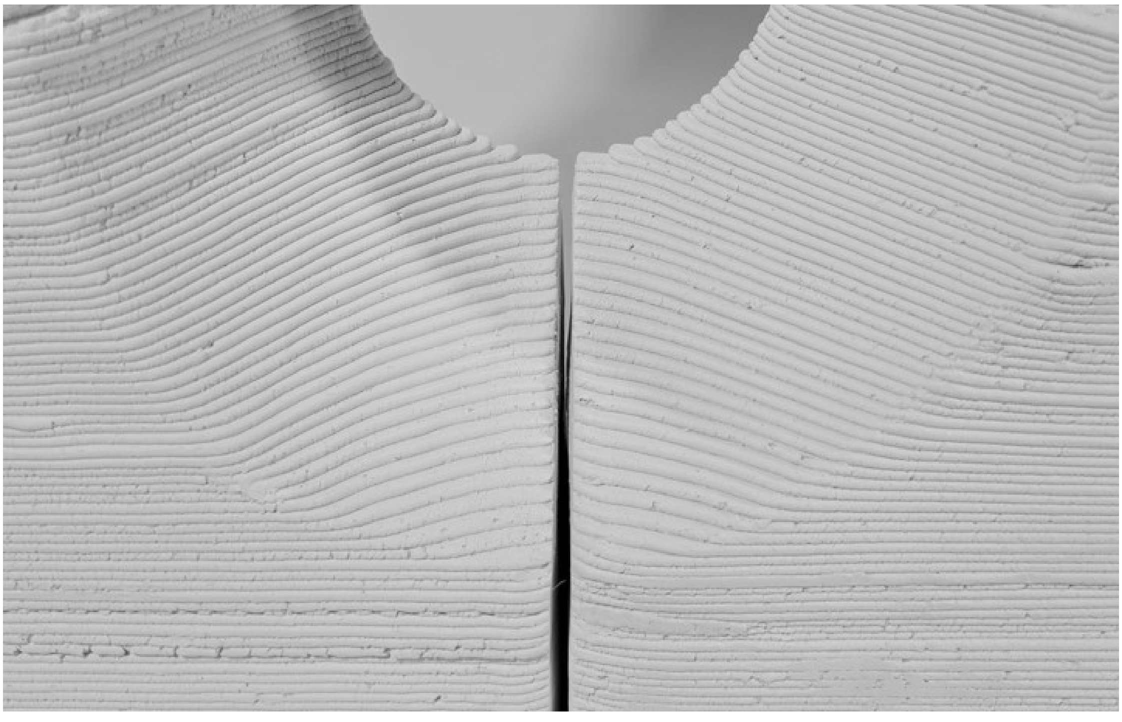


Figure 42 - Detail of Two Collection Units

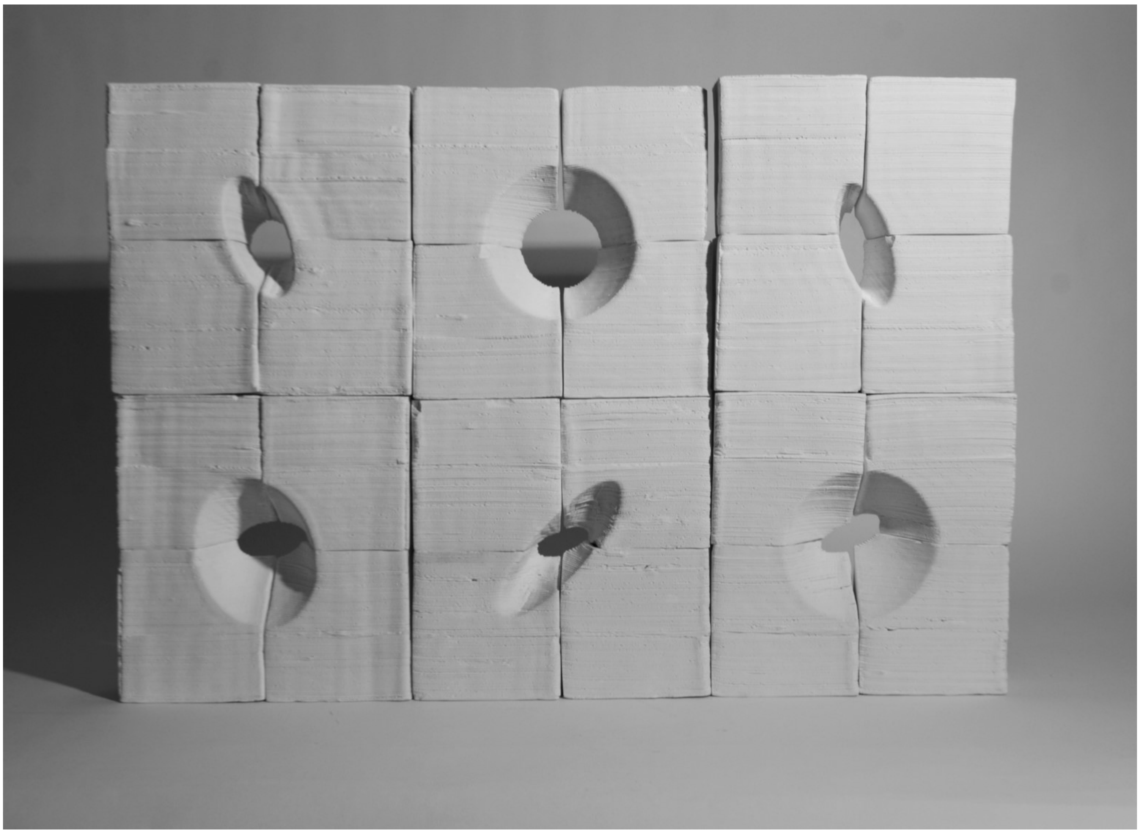


Figure 43 - Part 2 Collection Prototype

4.3.4 Phase 1 Conclusion

The findings of this study show that there is promise in the value of risk when aligning the human hand strategically with a digital tool. However, this study was only the first phase in understanding this complex phenomenon. During the research period of Phase1, the designated graduate student tasked with operating the printer (the craftsperson) made significant progress in learning the material and tool. The hybridization of digital and physical making is taxing on the maker, and the learning curve at times was steep. Phase 1 did demonstrate that the mixing of hand and digital skills can be learned by the craftsperson, much like other physical craftwork. Occasionally, an unexperienced student would attempt to print an object after observing the craftsperson at work. The failure rate of these prints was always a certainty showing the skill of the craftsperson was only something that could be acquired through concentration and practice.

Despite the outcome of the masonry unit collection and the improved skills of the craftsperson, the project struggled with tool consistency. Even following the tool upgrades, the tool only improved; it did not reach a level of consistency needed to conduct more refined tests. Tool inconsistency was the most significant outcome of Phase 1. Therefore it was concluded that the tool would need to be entirely rebuilt. This would allow for upgrades to provide further control by the craftsperson and to ensure consistency with all digital and mechanical operations.

4.4 Ceramic Risk, Phase 2: Application

The collection in Phase 1 demonstrated the craftsperson's skill to make geometrically consistent forms by controlling the material flow through air pressure and the material consistency through hand mixing. Phase 1 explored few variables due to the uncertainty of tool performance and the still-developing skills of the craftsperson. At the conclusion of phase 1, skill had been demonstrated that allowed for further testing in improvisation.

Many of the risks involved in making are abated to provide safe and error-free creation of artifacts. As this thesis argues, this is done at the expense of a craftsperson's ability to improvise and respond to the tool and material. It is the position of this research that when tacit knowledge is suppressed, design opportunities are lost, generating homogenous design outcomes. The Phase 2 objective is to further explore improvisation of the craftsperson. This was accomplished by manipulation of the g-code delivered to the tool that manipulated the vertical stepping of the extruder. Most 3D printing is accomplished by a set vertical step between stratified layers. Purposefully, the code was manipulated to allow for steps that increased in a pattern that the craftsperson could respond in real-time by adjusting the air pressure. Varying the layer height allowed the craftsperson to explore new ways of tapering vertical forms and how to create closed forms (Figure 44). Upgrading the tools air controls along with the improved skill of the craftsperson also allowed for an exploration of forms that include multiple vertical forms requiring the air to be closed and opened quickly to start and stop the flow of material in the extruder. Additionally, the clay could be mixed and loaded in the extruder using multiple material types. A single print could start with porcelain and transition to terracotta seamlessly enabled by the craftsperson's response to the density and viscosity that occur when the material differs.

Figure 44 - Varying Layer Height

The Likert scale used in Phase 1 was used to track and evaluate the success of prints. This was needed because when the first experiments were run, the likelihood of a print working was uncertain. Phase 1 did not test risk but the skill of the craftsperson and the reliability of the tool, both requirements to isolate and test risk. Phase 2 was tracked primarily through the use of a risk quadrant. Typically used in business and science to broadly evaluate risk, the quadrants define the level of risk associated with the print, and the potential these risks are to produce an artifact of quality that could not be made using normative 3D printing methodologies.

Prior to proceeding with Phase 2 tests, the 3D printer was rebuilt. This was done following the upgrades done in Phase 1. With the skill of the craftsperson continuing to improve, the tool needed to be stable and consistent, and the rebuild was able to provide this stability and add several features that enable greater control and comfort for the maker.

4.4.1 Phase 2: Tool Rebuild

It is important to note that the first tool used in Phase 1 was designed with human interaction intended but not fully understood. As the research evolved, the Phase 2 3D printer was designed and built to include more control by the user (Figure 45). Features such as a foot pedal that controls an air bleed valve give further control to the craftsperson. Stronger x, y, and z-axis construction reduced vibration and increased accuracy of the dimensional direction of the extruder. The printer was moved up onto a base where the craftsperson could sit with a line-of-sight at the extruder level. Using the foot pedal and the air valve, the material feed to the extruder could respond to custom changes in the digital g-code.

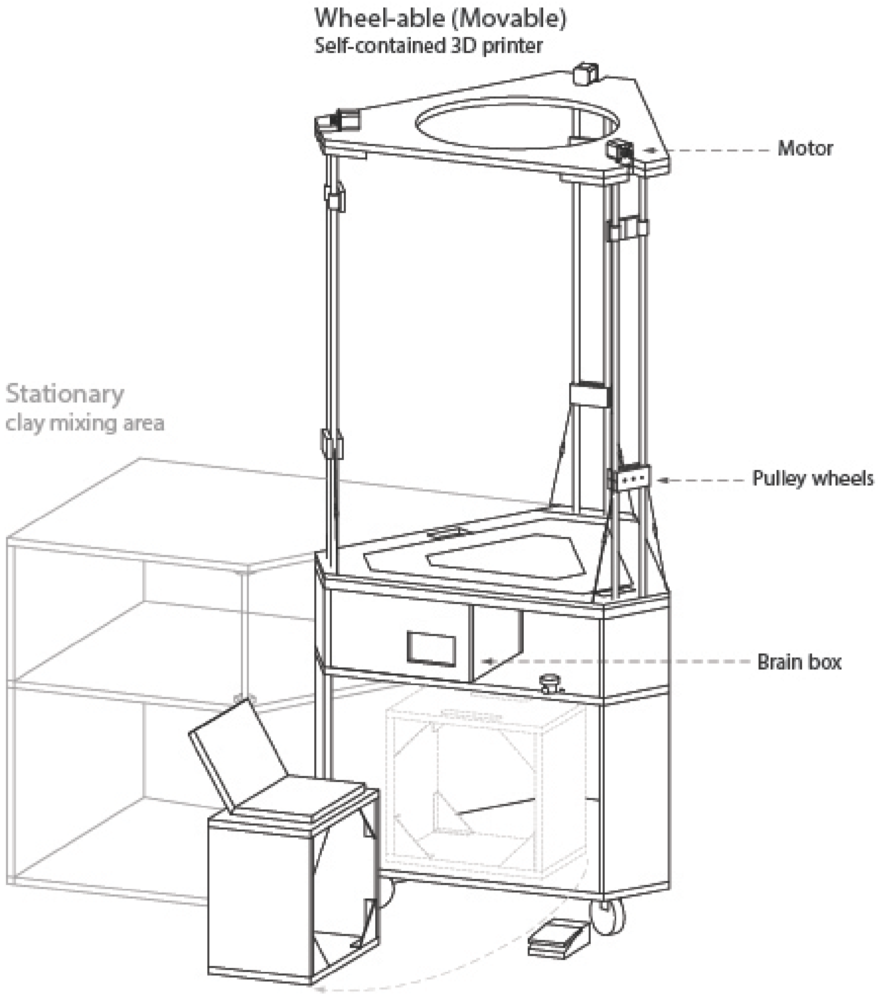


Figure 45 - Phase 2, 3D Printer Rebuild

4.4.2 Phase 2: Artifacts

Unlike Phase1, where the printing tests were prescribed, Phase 2 allowed the craftsperson to explore the potential of the tool and the improvisation that is possible. Therefore, each print conducted built upon the other, always seeking to take a measured risk but with the reasonable likelihood that the outcome will be successful. The process can be best understood with a simple risk quadrant diagram (Figure 46). When viewing the diagram, the bottom left quadrant represents improbable events that will bring low rewards and is named accurately as stupid. Similar is the quadrant described as a gamble. High rewards that are very improbable are inconsistent at best and a waste of time in general. Many of the early prints conducted in Phase 1 of this study could be classified in the gamble quadrant do to the tool inconsistency. The very likely to occur events that have low rewards are classified as a safe, daily decision. This research posits that many digital fabrication techniques used today have become daily decisions, void of risk, and generating outcomes that are of low reward. Therefore, the craftsperson sought to execute prints that fell within the high reward and likely probability quadrant of strategic risk. The craftsperson's agency and awareness of this are essential to the study. A keen understanding of the tool and the material would allow for many tacit decisions on what to print, how risky the operation will be, and what the potential outcome will result. This is not to say that intending to position a print in the strategic risk quadrant will position it as such if so, this would be a safe daily decision. The artifacts printed in phase 2 are located in the journal documentation in the Appendix at the end of this thesis.

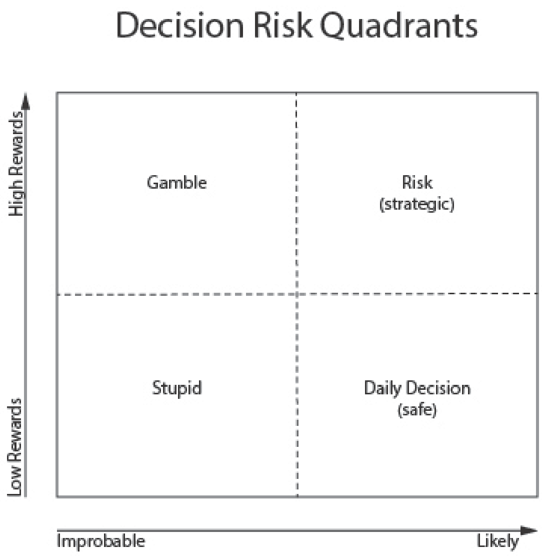


Figure 46 - Decision Risk Quadrants

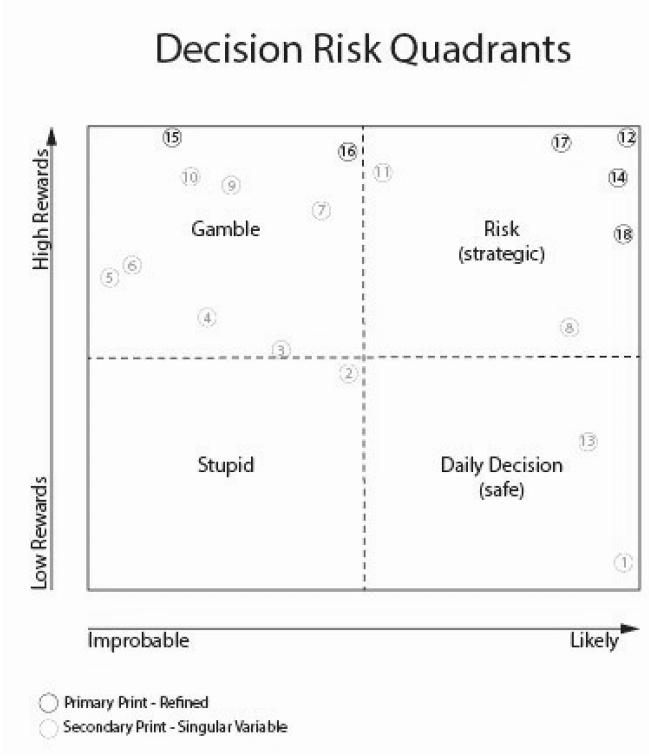


Figure 47 - Phase 2 Artifacts Risk Quadrants

Printing during Phase 2 was understood in two categories. The primary print was a refined print that was iterated multiple times by isolating a single variable for improvement. Following the secondary print, the craftsperson would attempt a primary print with the intention it would result in a strategic risk. If risk variables were not able to be as clearly defined as the craftsperson desired, the primary print would be classified as the less desirable gamble. The process of secondary to primary printing allowed the majority of the prints to move out of the gamble quadrant into the strategic risk column by minimizing the overall risks taken. As an example, shown in the Decision Risk Quadrants in Figure 47, prints 9, 10, and nearly 11 were all printed to test air pressure and z-axis step-up amounts to ultimately achieve print 12 located in the highest corner of the Strategic Risk quadrant. The final two prints of Phase 2 also built upon each other despite being primary prints. Both referred to in the lab notes

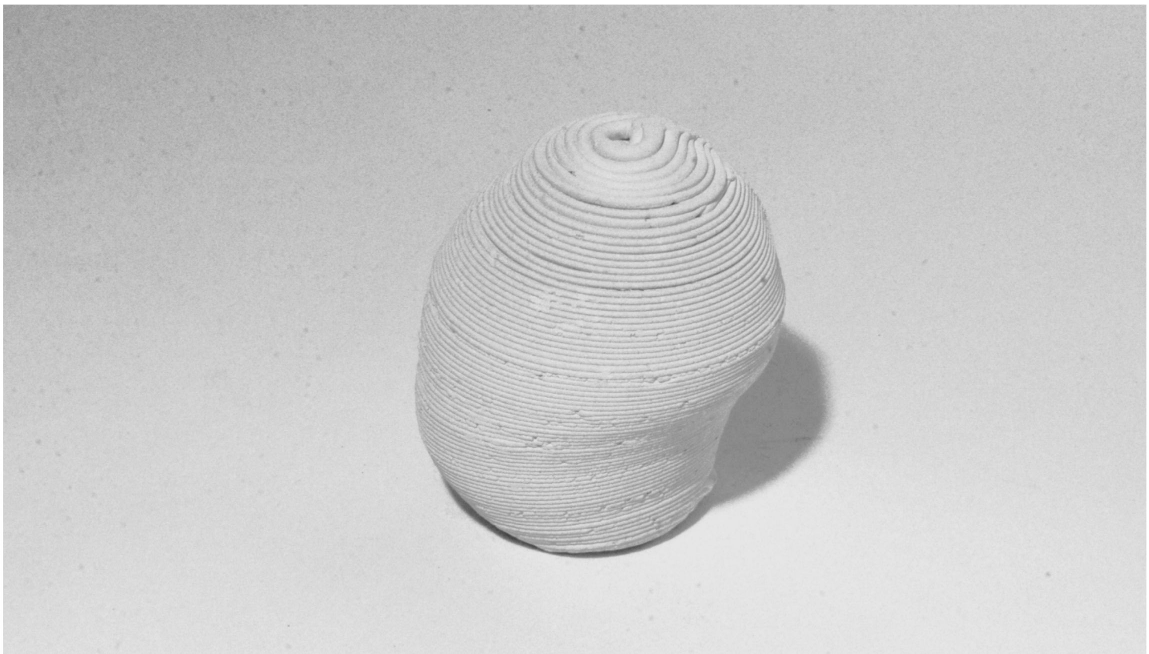


Figure 48 - Phase 2, Closed Form, Print 18

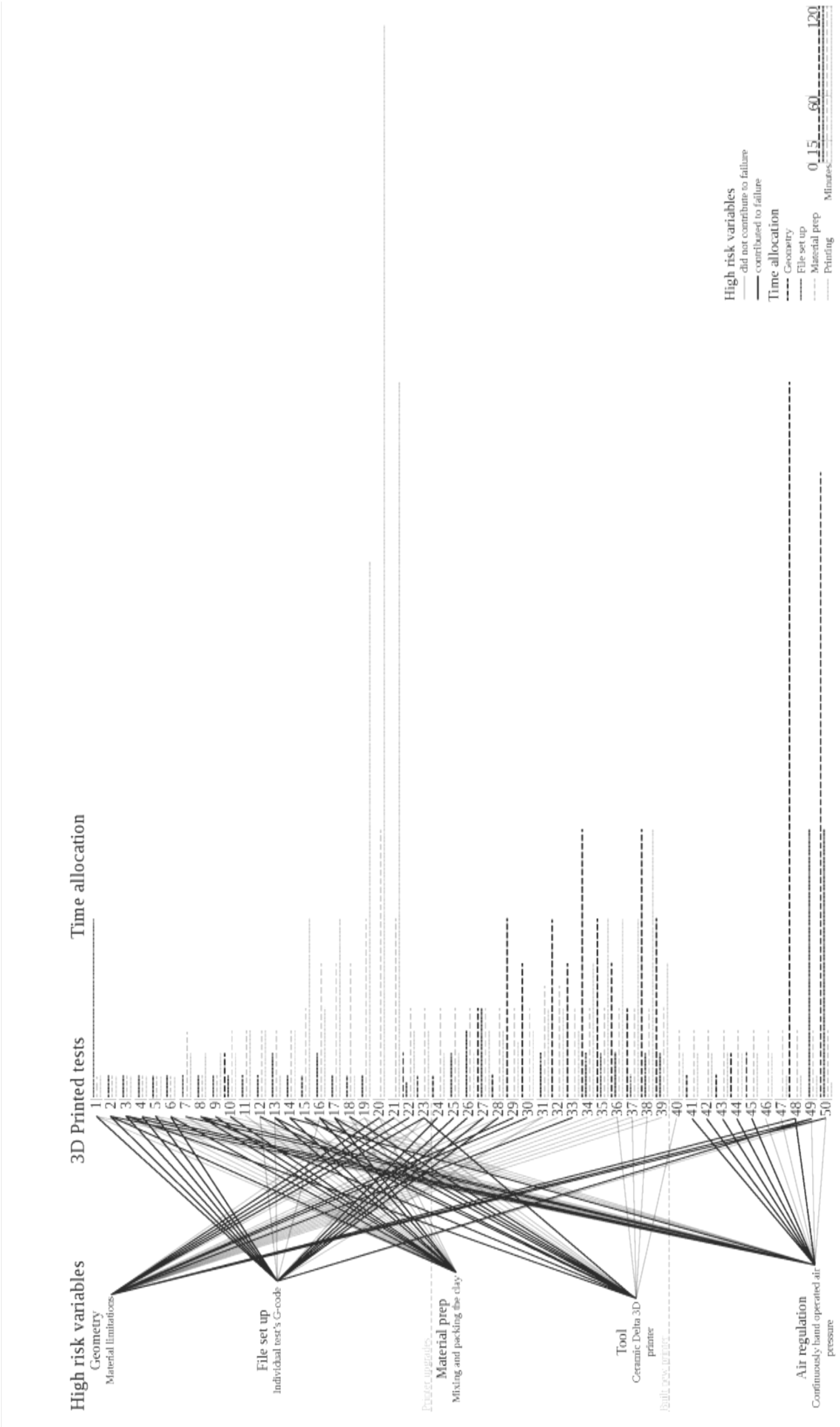
(Appendix) as the “egg” the print is closed from making the print layers and the air control of the craftsperson essential to success. Print 18 was a very successful print that balanced both the digital and hand commands (Figure 48).

4.4.3 Phase 2 Conclusion

By enhancing the tools consistency and the nuance of the human controls, the data show that failure is rare, and when it does occur, it is most likely human. Most significantly, the new printer and the craftsperson’s control over its performance is allowing for the design of unique objects and axial movements that allow for a fluid response by the craftsperson. This is allowing for the creation of outcomes that are unique and represent the synthesis of the digital and the human. The primary prints and the secondary prints that were used to understand significant variables demonstrate the potential for digital risk.

Figure 49 - Print detail

Table 11 - Print Risk Variables by Print



4.5 Ceramic Risk, Phase 3: Propagate

Phase one and two were understood as process-finding experiments. That is to say, they were not interested in form-finding or shape making. It was primarily an exercise in understanding digital risk and how to leverage the inherent benefits with a hybridized digital tool. The forms and shapes produced were mostly incidental and only served as a vehicle to test the process-based hypothesis. The goal of understanding the process of digital risk was to eventually seek new forms and discover new ways of working both digitally and manually with fluid improvisation. Phase 3 addresses these potentials through a further evolution of both the digital tool and the human craftsperson.[8]

Now with craftsperson's ability to take strategic risks, process Phase 3 added the additional variable of x-y axis modification. This ability now allows the craftsperson to have full morphological control over a digital print. Starting with a control shape output to the printer, the craftsperson was allowed to make subtle movements in the x-y axis by using an adjustable print surface and doing so produced prints in Phase 3 that did allow for new form and shape finding. For the first time the experimental process, the craftsperson was able to control the material, the airflow and material distribution, and the final shape and form within the limits of the print geometry. The shaping that occurred became more idiosyncratic to the craftsperson and less skill-based, as was seen in prior experiments. In phases one and two, the craftsperson improved improvisational skills, but this was primarily through reaction. In Phase 2, the craftsperson reacted with an improvisational action to a varying z-axis step-up by the tool. This, however, was codded into g-code, and the craftsperson would anticipate the step-up and respond with haptic skill. The addition of the x-y axis modification allowed the craftsperson for the first time to be proactive with their improvisations. This ability lead to outcomes that were shaped while printed, starting from a control form. The collection produced was a multitude of unique ceramic forms that were guided by a digital file but modified by the human craftsperson. Each print is unique and undigitized (Figure 53).

With the addition of the x,y-axis modifications, the tool, and the craftsperson's skill to control, it has evolved to full hybridization with options to override most of the primary control systems of a digital printer. The research tracked in Phase One, and Phase two of this thesis demonstrates that hybridization of the digital allows for craftspeople to maintain the

[8] Portions of Phase 3 was published in both the MD Journal and the Cubic Journal during the research period of this thesis.

inherent benefits embedded in risk while not fully forfeiting the virtues of digital production. Phase three investigates the possibilities of upgrading the craftsperson through the use of Artificial Intelligence (AI).

4.5.1 Phase 3: Human Upgrade (AI)

To extend human and machined hybridization, the research upgraded the human craftsperson through the introduction of AI. With the ability now to create numerous unique objects from a control digital geometry, the craftsperson began to create a collection of prints that represented their sensibilities as a designer. The prints, once re-digitized, served as a dataset of geometry that represented the improvisational and haptic creations of the craftsperson. This dataset can then be learned by an AI program to generate an infinite number of AI designed prints that have a direct parent-child relationship with the hybridized prints.

With the production of unique hybridized artifacts, the human craftsperson is limited by the time and effort required to attend to the printer. This has been an economic hindrance since the industrial revolution. Although industrial mechanization was able to produce a multitude of artifacts efficiently, it was not able to do so with mass-customization or with a large number of units of the same typology but not the same final dimensions and shape. A hand-made collection of designed artifacts does have this ability, but with the hardship of labor that limits the quantity, and for many, it makes it economically obsolescent. Phase 3 attempts to demonstrate how to teach a tool a designer’s sensibilities of a given collection of artifacts that can then be manufactured in an infinite number of units, all of unique dimensions and shapes. This then allows the opportunity for the craftsperson to move onto a new collection that the AI can be trained to produce at high quality. The craftsperson is no less engaged and can continuously work on improving craft yet with the freedom to do so on new and creative projects that become future datasets for AI. This leverages the human mind and allows for the pursuit of desired objects with full creative agency.

4.5.2 Phase 3: Tool Upgrade

The tool upgrade placed a manually controlled x, y-axis table below the print surface. The choreography thus allows for optional consistent digital control of the x, y-axis while also allowing for manual interruptions in the flow of the clay and the position of the x and y-axis by the craftsperson (Figure 50). Haptic control allows the craftsperson to work in tandem with the predictable and prescribed digital code to generate an improvised artifact. An artifact created in this way differs from the digital model that generated the g-code that directs the movements of the printer.

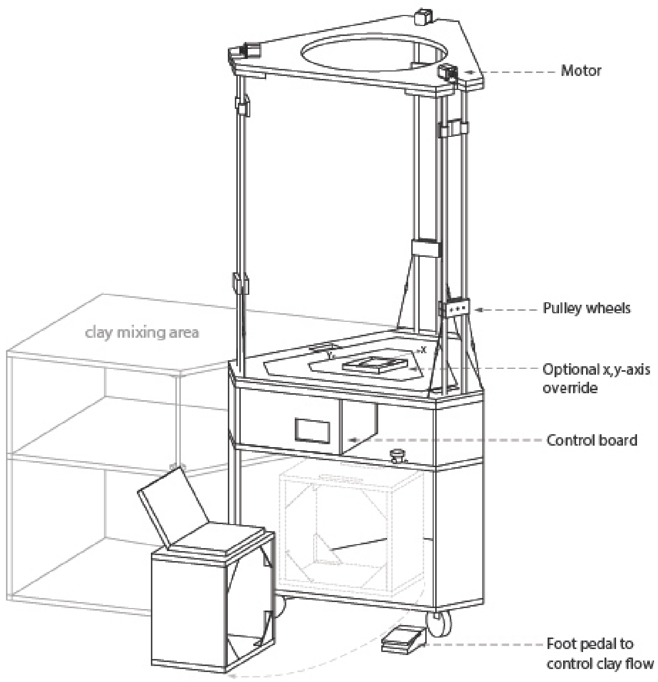


Figure 50 - Phase 3 Tool Upgrade

The following table describes the primary control systems of the printer and how predetermined digital files are mechanically controlled and what haptic interruptions can be made by the operator (Table 12).

Control System	Mechanical	Digital	Haptic
Material Extrusion	Compressed Air	N/A	Controlled and monitored by the operator
Digital code (G-code)	uploaded to control board	Post-processed from software	N/A
x, y-axis movement	Stepper motors	g-code defined positions	Secondary x,y-axis table controlled by the operator
z-axis movement	Stepper motors	g-code defined positions	N/A

Table 12 - Primary Control Systems

Most 3D clay printers have the four primary control systems listed in the table. However, unless customized, they do not allow for human or haptic control overrides. The table makes clear that the operator is in total control of the material with no digital monitoring, and the

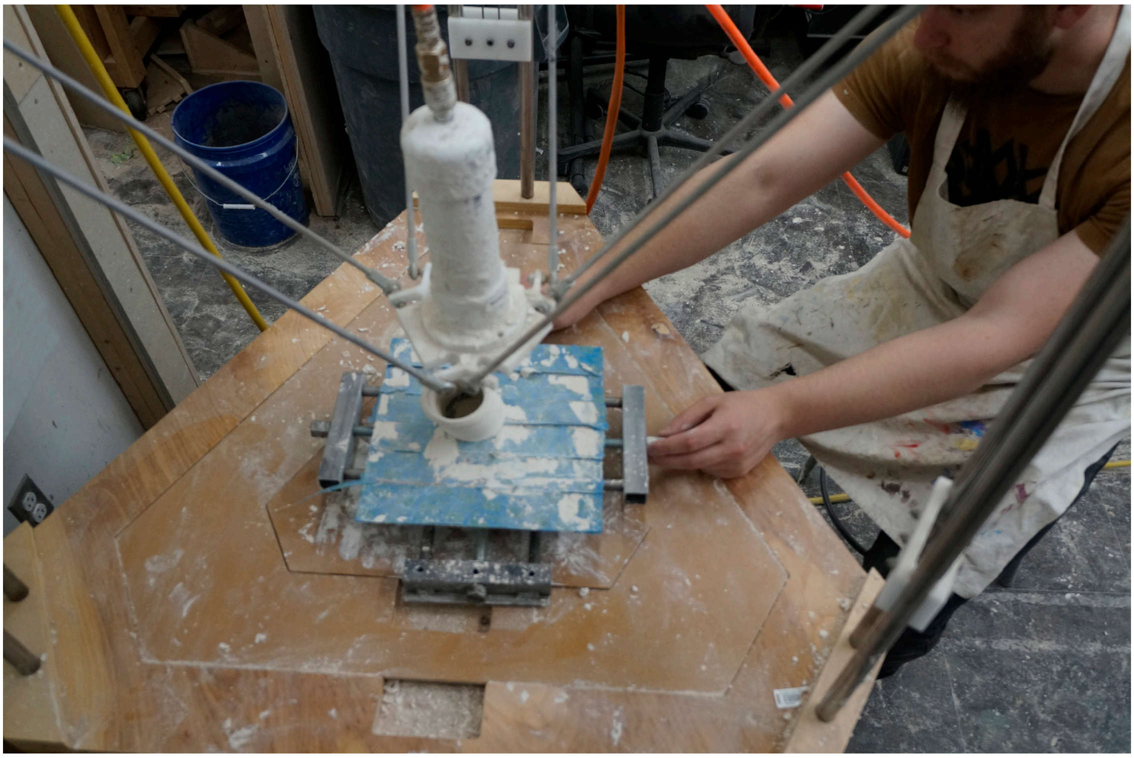


Figure 51 - Using the x, y-axis table

operator has no control over the digital g-code once it is uploaded and processed by the printer. Most dynamically, the operator is provided with a secondary x and y-axis that moves beneath the controlled x, y-axis movements dictated by the g-code. This allows the operator to "shape" or "craft," a new object from the source shape that the g-code is attempting to print (Figure 51). By allowing improvisations, the research team was able to produce a multitude of artifacts from the source shape, a cylinder that served as the control object made without alterations by the operator (Figure 52).

Figure 52 - Control Cylinder (left) with Altered Cylinder (right)

4.5.3 Phase 3: Measuring Improvisations

In describing the unique work of a craftsperson, historians and artisans have relied on comparing unique artifacts to each other to define styles and traditions and, more specifically, a collection or a work by an artesian that occurs over a designated period of time. The research team completed a broad set of unique improvised prints that defined a collection for the AI to learn (Figure 53).

Figure 53 - Improvised Collection of Prints

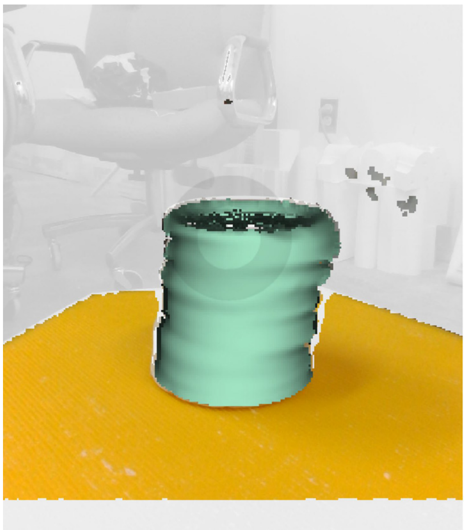


Figure 54 - Scanning Improvised Print

All improvised prints in the collection are unique hybridized digital and handmade artifacts that have a geometrical relationship to the control cylinder. To measure these modifications, all of the artifacts printed and improvised by the operator, where 3D scanned (

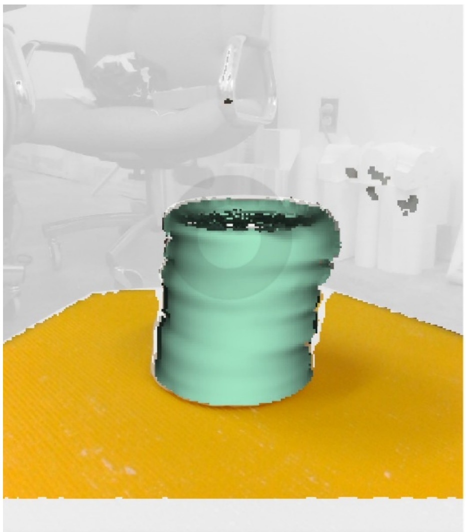


Figure 54). The re-digitization of the prints provided a digital 3D model to scale that was compared to the control cylinder. The AI database then could have the ability to measure the deviations for analysis. These improvised deviations built a morphological dataset that is unique to the operator who made the modifications and the output collection.

Methodologically, a Rhino Grasshopper script sliced the prints in equal measure to the number of z-axis print levels. The script produced hundreds of closed polylines for each print that were rendered as a .jpg file orthogonally in plan view. The single-slice orthogonal image is what distinguishes the improvised artifacts from each other. The control cylinder is made only of circles, while the improvised artifacts sectional slices mutated as the operator modified the prints by hand. The individual section cuts were then aggregated into one large data set. This dataset taught the AI what deviations from a circle were shared, how far from the centerline of x,y did the operator typically stray, and in what pattern was this common.

The AI Deep Learning database used the orthogonal sections to learn the deviation patterns. The AI then can be programmed to return an unlimited number of variations of the control cylinder in the “style” of the original collection created by the craftsperson. The AI output takes the form of a large quantity of pixilated orthographic section cuts resembling

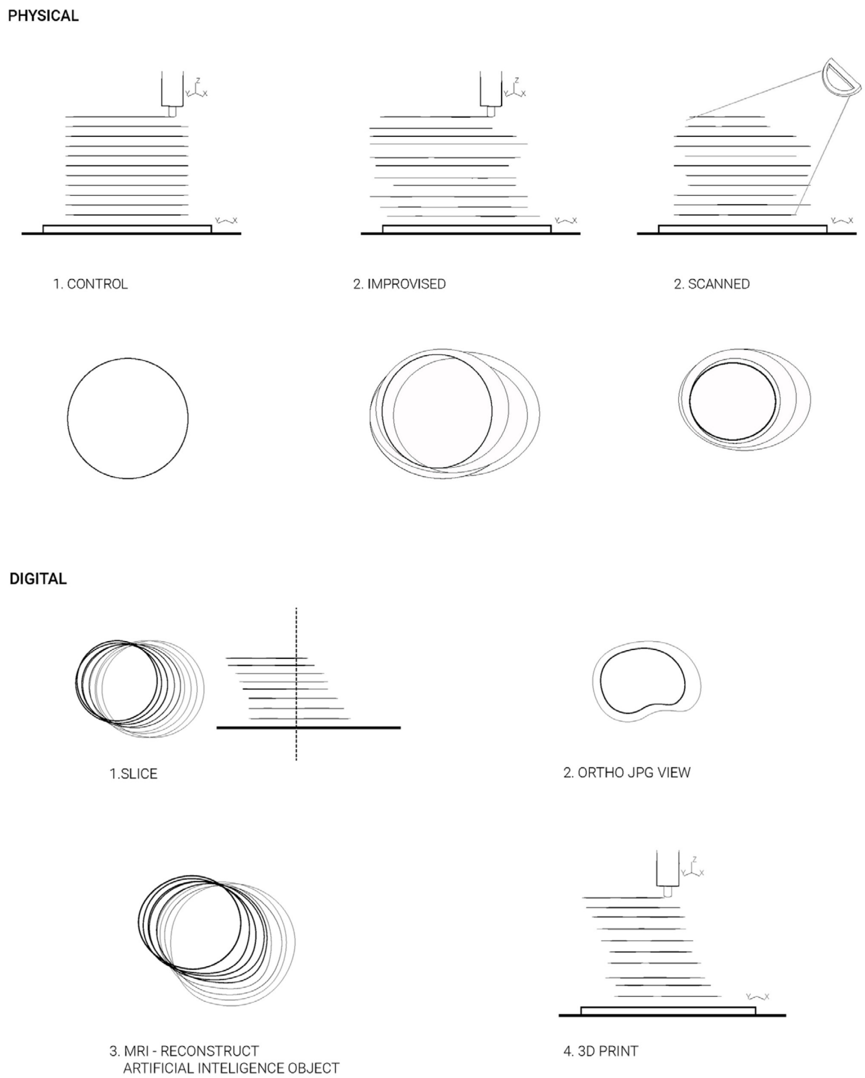


Figure 55 - Phase 3 Process

the original data provided. Using this dataset, new artifacts can be reassembled using medical MRI 3D reconstruction software that will reconstitute the orthographic sections into newly designed AI improvised one-of-a-kind artifacts (Figure 55). The new AI artifacts are then available to be printed using a standard 3D printer. Thus, the craftsperson’s tacit knowledge and tool dexterity is not degraded by AI but extended.

4.5.4 Phase 3: Artifacts

A key premise of Phase 3 is that AI can extend our sensibilities beyond our direct labor. This idea was tested in collaboration with a computer scientist.[9] To test the idea the computer scientist conducted the work in two primary steps. First, was testing feasibility. The system of printing, scanning, and slicing the scanned geometry into sections was tested with an initial run of prints. To do this, the data set needed to be "augmented" to replicate itself to produce virtual deviations that synthetically increased the sample set. Through

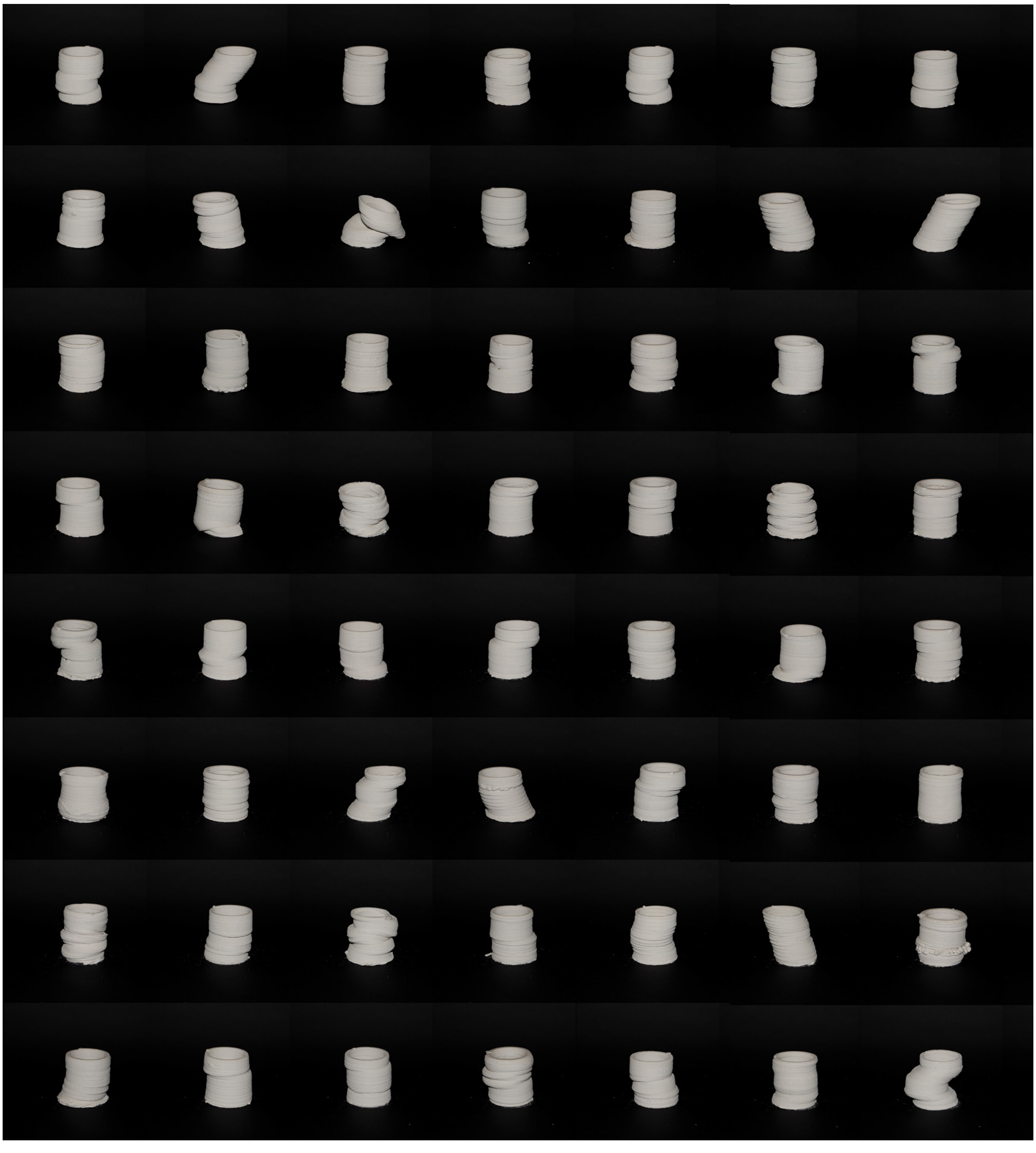


Figure 56 – Portion of Improvised Manual and Digital Prints Used for AI Data

[9] Ian Timmis, computer science graduate candidate at Lawrence Technological University provided AI coding and advising for Phase 3.

augmentation, it was concluded that the process was feasible. The outcomes from this step showed that it was computationally possible, but it was unknown how many original prints would be needed to remove the need for augmentation. Augmentation of the data set was necessary because it only proves the process will work, not that the prints will be to the liking of the craftsperson or that they will follow all the rules necessary to produce printable outcomes. For example, augmented data could return a set of sections that have a parent-child relationship with the original sections but not order them in a way vertically that responds to gravity or material performance. It can be described as the database has not recorded or learned enough prints to understand these limits (Figure 57).

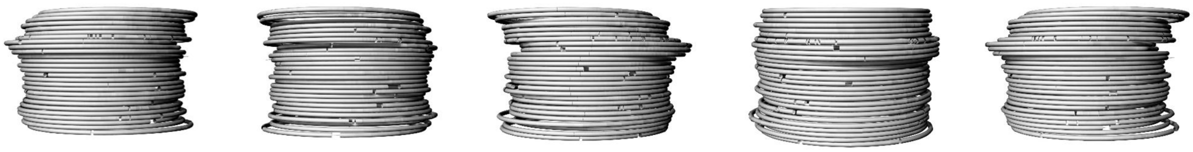


Figure 57 - Not Suitable for Printing, Augmented Artifact

In the second step, the computational process was to attempt to produce artifacts not augmented that could be directly printed. The research showed that the number of prints that could be produced in this research period was not sufficient to accomplish this outcome.

4.5.5 Phase 3: Conclusion

There is potential for artisans to teach AI the formal and morphological properties of a given collection. This then can be learned and replicated by the AI, allowing the craftsperson the freedom to move on to the development of new and inventive collections that the AI can later be trained to produce. This new division of labor removes laborious replication by the human hand and makes paramount the creative and couscous mind required to create a new artifact to serve as source data. The case study shows that AI was capable of learning how one human operator could improvise digitally fabricated objects and teach AI how to emulate their sensibilities. A shortcoming of this work, however, is the required volume necessary to train AI. This study provided a minimum number of original prints to test the design and computational process for feasibility but was unable to produce high-quality results capable of replication. However, the study did demonstrate feasibility if given more time and additional computer scientists to contribute to the study. The final step of Phase 3 that engaged AI was possibly outside the scope of this thesis, but in its attempt, it did push the boundaries of what the future of AI will bring to craft and how the disciplines can engage it productively. At the writing of this thesis, original prints are continuing to be added to further train the AI. Theoretically, this could continue until the craftsperson is satisfied that the AI is producing objects that suite their desire, or it could extend to record an artisan's life's work to produce a synthesis of artifacts.

Most significantly, the process, although in collaboration with AI, provides an extension of the human who made them originally; the artifacts produced are direct decedents of the craftsperson's hands and thus extend the productivity and economic impact of fluid improvisational making. AI allows higher productivity, but the human maker is essential in training, and if done in partnership, allows the human craftsperson to extend their influence and impact while still maintaining the necessity of handmade artifacts in the age of AI.

5 Principles and Reflection

The grounded research method applied in this thesis (Figure 7) prescribes a rhythm of journaling, observations, and reflection. Most of the experiments and theoretical positions are taken here produced peer-review publications that prompted a position of working principles. It is worth noting reoccurring principles that transcended each project and revealed themselves as explicit and transferable to any designer interested in testing this way of working.

5.1 Extracted Principles

The following are the listed principles for digital risk:

All digital risk projects require human error

However, this is not as simple as inducing mistakes; it is a measured risk that will lead to errors that can be measured and accounted for. The error is thus better understood and provides the designer with a boundary that can be tested. Improvisation was required for digital risk for the craftsperson's ability to react, anticipate, and apply their will on the artifact. Without improvisation, there is no risk.

Digital risk must include material resistance

In a safe digital environment, there is no material resistance. Once a craftsperson deploys their digital creations to a digital fabrication tool it is meet with material resistance. This can be accounted for when using standardized building materials but cannot be done with non-manufactured materials. Digital risk is most effective when the craftsperson uses material knowledge and resistance to provide productive feedback.

Digital risk requires measurable risk and reward

The craftsperson must understand the risk factors and the potential rewards to generate propositions that are strategic risks that produce high reward artifacts. Measuring and understanding risk factors allow the designer to convert these variables to data to train AI systems. This conversion of human sensibilities allows the craftsperson to extend haptic and material knowledge infinitely.

Digital risk must be understood as separate from chance

Chance is random and can be perceived as an interruption or interference in a process. Chance, however, only allows craftspeople to react, not anticipate. Digital risk requires earned dexterity, and chance does not.

The digital tools designed and built for digital risk must be reliable

To isolate risk factors, all other operations must run normally and as expect. If the digital tool is inconsistent, it is impossible to isolate strategic areas of risk associated with errors.

Digital risk requires the managing of risk factors

This often requires a process to be repeated to isolate a variable. Once all factors are understood, the isolated risk variable can be managed as a boundary to evoke innovation.

Digital risk requires accurate outcomes rather than precise outcomes

These descriptors are often used interchangeably, but it is important to separate them when measuring variables of risk (Winchester 2018 pg. 14-15) . With digital fabrication, the equipment can mill a circle within .00001 milometers of precision. This precise object can be milled multiple times with no variation in physical properties. Digital risk, however, does not require the outcomes to be precise, but they must be accurate with physical properties falling within an acceptable range judged by the craftsperson.

Digital risk requires tacit knowledge by the craftsperson

Tacit knowledge was shown only to emerge once the craftsperson has practiced extensively with the digital tool, materials, and improvisational movements in tandem with the printer.

Digital risk requires haptic knowledge

Haptic knowledge provides the feedback necessary for the craftsperson's interventions to be hybridized with a digital process.

Digital risk requires documentation

Documentation of the digital risk process is necessary to generate empirical data. This data aids in the management of strategic risk and builds foundational information. Empirical data provides the information necessary for thoughtful reflection and iterative propositions.

6 Conclusion

It is essential to reflect on the premise of this study and to reinforce that it is understood that there is an easier way to print ceramic vessels. The researcher has access to tools that could print a perfect ceramic unit every time without fail, given adequate preparation. Without fully understanding the study, one might offer suggestions of clay augers or other extrusion technology that would supplant the human hand and allow for greater control. This is understood, but purposely not used to create the experiment necessary to test the value of risk when using digital tools. To some this may seem a pointless task; after all you can manufacture similar objects at a low cost. This perspective is framed with industrialized logic and warrants attention. As digital tools continue to proliferate, so does the standardization and globalization of our design outcomes. It will become harder, if not impossible, for architects to design distinctly within our culture, our time, and our place. Digital modeling and simulation have given the digital designer freedom, one that can seduce our visual senses at the cost of all others that make us human.

The Digital Revolution brought numerous remarkable and productive virtues, but it has also introduced some potentially inhibiting deficiencies. Most profound is the increased abstraction and tendency toward loss of human touch introduced with digital tools. Because electronic digital tools are ultimately based on numeric control, they require specialized knowledge of an abstract set of commands and symbols. Digital tools do not yet emphasize intuitive and physical interaction and response. They require constant precision and inhibit most rough estimation. Digital tools can create a world unto themselves, with a tendency for an operator to lose themselves in a self-referential world of simulation and required procedures divorced from representing reality or intuitive process. The tools tend to guide the craftsman, not the craftsman guiding the tools. Outcomes often resemble abstract mathematical models more than haptic experiences defined by a craftsman through real material and specific historical lineage and context (Stevens 2015).

Nearing the end of the second decade of the twenty-first century, many craftspeople and makers are waking up to the inevitable reality that our next human evolution is very unlike those that came before. Klaus Schwab, Founder and Executive Chairman of the World Economic Forum refers to what we are beginning to experience as the Fourth Industrial Revolution. Schwab and his colleagues believe this revolution could be much more powerful and occur in a shorter period than the previous industrial and digital revolutions (Schwab 2016). This revolution will have a profound change in how we practice, labor, and orient ourselves in the world. Rapidly evolving technologies will proliferate the use of robotics and personalized robots (co-bots) that can sense our presence and safely work alongside us. Digital algorithms are already becoming more reliable predictors of complicated questions in medicine and economics than their human counterparts. Therefore, the gap between what a computer can learn and solve, and what a robot can do, will quickly close in on the craft traditions. It is easy to see how we may begin to ask what value a human-made object has outside of the sentimental imperfections. The anxiety in this is rooted in the reality that many of the inevitable technologies do have the ability to give the false impression that they can disembody craft, once the digital algorithm learns the craft from us, our presence is no longer necessary. This is a step into the unknown, and it is what makes this evolution, or devolution, depending on the perspective, so different.

The Industrial and Digital Revolution disrupted craft, but it never questioned human embodied skill and desire. This skill was legible to us as makers because our process drove input with outcomes dependent on our skill. Regardless of the tool, we provided the sole source of knowledge and skill, and it returned a product of our making – we practiced and learned, not the tool. This, however, is changing; our tools can now learn from us and continue to learn independently. The cycle of making is no longer only human input with an equivalent output but rather a post-human cycle of making whereby the tool has now entered the discourse of learning and making. However, AI participating in discourse does not imply consciousness; for now, the human remains the only sentient being in the dialogue. A craftsperson's haptic knowledge, skills, and intellect are embodied and are not algorithmic, positioning the human as the perpetual agent of craft (Hayles 1999). Void of the hallmarks of human embodiment, the shortcomings of digital technology and AI remain essential to all craft, design, and making.

Now with digital technology and fabrication, becoming ubiquitous craft is engaging new post-digital questions posed by the possible knowledge transfer to an AI database. This thesis interrogates the value of pairing digital control, manual dexterity, and AI iterations through the case studies and the three-phase, ceramic risk experiment. These examples provide insights into the role of digital tools in architecture and craft. The extracted principles that result are made explicit and transferable to future post-digital craftspeople engaged in acts of craft we have not yet conceived.

7 Postscript: A New Discourse for Craft, Design, and Architecture

Many of Katherine Hayles observations on the post-human condition in 1999 are now becoming a framework for the understanding of post-digital craft. The duality set up by the inscriptive and incorporated knowledge in Section 2.6.2 is not intended as a path that must be selected but as a place for humans to fluidly reside. In a striking statement to any craftsperson, Hayles states: "The recursivities that entangle inscription with incorporation, the body with embodiment, invite us to see these polarities not as static concepts but as mutating surfaces that transform one another, much like the Mobius strip... Starting from a model emphasizing polarities, then, we have moved toward a vision of interactions both pleasurable and dangerous, creatively dynamic and explosively transformative" (Hayles 1999 pg. 220). When discussing the future Hayles attempts to privilege materiality over information in the discussion of cybernetics by stating: "If my nightmare is a culture inhabited by post-humans who regard their bodies as fashion accessories rather than the ground of being, my dream is a version of the post-human that embraces the possibilities of information technologies without being seduced by fantasies of unlimited power and disembodied immortality, that recognizes and celebrates finitude as a condition of human being, and that understands human life is embedded in a material world of great complexity, one on which we depend for our continued survival" (Hayles 1999 pg. 05). Hayles' contribution rests in the area of cybernetics and literature. However, her definitions and defining characteristics of inscription and incorporation practices fall within the epitome of craft reconciling the encoded variable alongside the improvisational human. The discourse surrounding the post-human is still evolving since the publication of this text in 1999. Although engineers are no closer to developing a genuinely sentient machine, the debate continues around what post-human means and if it is a positive evolution or negative devolution. Questions of the validity of embodiment and if materiality (human form and action) are necessary for being human or if intellect, knowledge, and experience can be fully "downloaded" to a machine (cells to bits). Despite these intellectual debates, our understanding of how these technologies will impact the economy, society, and craft are still not understood, and given the rapid pace of their development, it may only be in hindsight.

The contemporary craftsperson must be aware of how new technological developments will impact social and economic systems. With the rise of AI and other disruptive technologies, both manufacturing and the service industry may no longer exist and therefore will not be outsourced to populations with low wage bases. Some reports indicate that up to 40% of current jobs may be eliminated over the next 30 years (Schwab 2016) . As with many of the past economic and social upheavals, these jobs will be replaced with new, but fewer high skilled jobs. Of course, these are only economic speculations, but they do carry with them an undeniable warning: our policymakers must engage in and understand technology so that they can lead their nations to a sustainable future. Developed economies like the United States and China are far from insulated from these changes. Many may argue that given the significant infrastructural obligations of these nations, their stability could unravel given the potential that AI and robotic automation may have. What these questions provoke is a possible third path, one that is not purely a technological utopia of digital making that excludes the human and minimizes labor but one that uses technology to extend human creativity and human potential. It is the nature of capitalism and liberal democracy to maximize profits and minimize labor obligations, so such a third proposal may seem idealistic and naïve. However, the leaders of our nations in the future may once again become vexed by even further social inequality. Marx identified the conditions of mass inequality in capitalism and predicted a revolution in industrialized nations where manufacturing degraded the worker and built wealth for the industrialists (Marx 2009 pg. 07). Although his predictions did not come to pass, the principles identified in his concerns were the impetus of the rise of the Communist Party and the Soviet Union that had their origins in protecting the worker from mechanization. Current populist movements in Western capitalist societies such as Brexit may be the first rumbles of the repercussions of the Fourth Industrial Revolution. These possible reactions are occurring even before capitalism has been tested by the possibility that AI and robotic automation could supplant many workers into a new useless class (Harari 2017 pg. 322).

This discourse is not nihilistic, nor does it dictate a bleak view of the future. In contrast, the debate probes ideas of what makes us human, more specifically, what makes us humans that are compelled to craft and make. Those engaged in studio-based practices that depend on traditional craft must be mindful of the inevitable disruptive technologies that this work recognizes. The contemporary craftsperson must acknowledge what is to come and begin to understand how to position craft into a new networked system not entirely under their control. The examples are given in this thesis only show a few of the infinite number of possibilities of how craft can productively enter the Fourth Industrial Revolution without sacrificing human agency. The contemporary craftsperson now has the opportunity to choreograph humans and machines to achieve artifacts not yet imagined.

Appendix

Bibliography

Adamson, Glenn. 2016. *The Craft Reader*. London: Blomsbury Academic.

———. 2013. *The Invention of Craft*. New York: Bloomsbury Academic.

———. 2007. *Thinking through Craft*. Oxford: Berg.

Allitt, Patrick N. 2017. *The Industrial Revolution.* Patrick N. Allitt. Smithsonian.

Beesley, Philip, Philip and Seebohm, and Thomas. 2000. *Digital Tectonic Design*.

Binkley, Timothy, Lucy Lippard, Gregory Battcock, and Terry Atkinson. 1974. "Six Years: The Dematerialization of the Art Object from 1966 to 1972." *The Journal of Aesthetics and Art Criticism* 33 (1): 109. doi:10.2307/428962. https://ltu.on.worldcat.org/oclc/7547598527.

Borden Peter, Gail and Michael Meredith. 2012. *Matter: Material Processes in Architectural Production*. New York: Rotledge.

Breanna Hielkema. 2017. *Experiences with Digital Craft and Digital Risk*.

Buchanan, 2015By P. "Empty Gestures: Starchitecture's Swan Song." Architectural Review., last modified February 27, accessed Jan 9, 2019, https://www.architectural-review.com/essays/viewpoints/empty-gestures-starchitectures-swan-song/8679010.article.

Coyne, Richard. 1999. *Technoromanticism : Digital Narrative, Holism, and the Romance of the Real*. Leonardo. Cambridge, Mass.: MIT Press. https://ltu.on.worldcat.org/oclc/45730589.

Crawford B, Matthew. 2009. *Shop Class as Soulcraft: An Inquiry into the Value of Work*. New York: Penguin Press.

Crawford, Matthew B. 2015. *The World Beyond Your Head: On Becoming an Individual in an Age of Distraction*. New York: Farrar, Straus and Giroux. http://www.netread.com/jcusers2/bk1388/980/9780374292980/image/lgcover.9780374292980.jpg.

Cross, Nigel. 2007. "From a Design Science to a Design Discipline: Understanding Designerly Ways of Knowing and Thinking." *Design Research Now*: 41-54.

Danto, Arthur Coleman. 2006. *The Abuse of Beauty: Aesthetics and the Concept of Art* Open Court.

Deamer, Peggy and Phillip Bernstein. 2010. *Building (in) the Future: Recasting Labor in Architecture*. New Haven: Yale School of Architecture.

Doyle, Shelby Elizabeth. 2015*. Fabricating Potentials: Constructing Social Engagement*.

Edwards, Owen. "Famous for His Rocking Chair, Sam Maloof made Furniture that had Soul." Smithsonian., accessed Jan 7, 2019, https://www.smithsonianmag.com/smithsonian-institution/famous-his-rocking-chair-sam-maloof-made-furniture-had-soul-180958943/.

Evans, Robin. 1995. *The Projective Cast: Architecture and its Three Geometries*. Cambridge: MIT Press.

———. 1997. *Translations from Drawing to Building*. Cambridge: MIT Press.

Findeli, A., D. Brouillet, S. Martin, C. Moineau, and R. Tarrago. 2008. "Research through Design and Transdisciplinarity: A Tentative Contribution to the Methodology of Design Research." *Swiss Design Network Symposium*: 67-88.

Frampton, Kenneth and John Cava. 1995. *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*. Cambridge: MIT Press.

Frayling, C. 1994. "Research in Art and Design." *Royal College of Art Research Papers* 1 (1).

Friedman, K. 2008. "Research into, by and for Design." *Journal of Visual Art Practice* 7 (2): 153-160.

———. 2003. "Theory Construction in Design Research: Criteria: Approaches, and Methods." *Design Studies* 24 (6): 507-522.

Gendzier J, Stephen. 2009. *Craft [Abridged]*.

Gershenfeild A, Neil. 2005. *Fab: The Coming Revolution on Your Desktop--from Personal Computers to Personal Fabrication*. New York: Basic Books.

Giedion, S. 1948. *Mechanization Takes Command, a Contribution to Anonymous History*. New York: Oxford University Press.

Groat, Linda N. and David Wang. 2002. *Architectural Research Methods* J.

Harari, Yuval N. 2017. *Homo Deus: A Brief History of Tomorrow* [Hisṭoryah shel ha-maḥar.]. First US ed. New York, NY: Harper, an imprint of HarperCollins Publishers. http://worldcat.org/oclc/951507538.

Hayles, Katherine. 1999. *How we Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago, Ill.: University of Chicago Press. http://www.loc.gov/catdir/description/uchi051/98036459.html; http://www.h-net.org/review/hrev-a0b7p8-aa; http://www.loc.gov/catdir/enhancements/fy0608/98036459-t.html.

Kolarevic, Branko. 2003. *Architecture in the Digital Age: Design and Manufacturing*. New York: Spon Press.

Leach, Neil. 2014. *Parametrics Explained*. doi:10.7480/ngb.1.1.1530.

Leach, Neil, David Tumbull, and Chris Williams. 2004. *Digital Tectonics*. Chichester: Wiley-Acadamy.

Link, Jeff. "5 Ways Architects are Redefining Craftsmanship for a Postdigital Age." ArchDaily., last modified -02-11T10:30:00+00:00, accessed Jan 7, 2019, http://www.archdaily.com/781960/5-ways-architects-are-redefining-craftsmanship-for-a-postdigital-age.

Llach Cardoso, Daniel. 2012. *Builders of the Vision: Technology and the Imagination of Design*. New York: Routledge.

Margolin, V. 2010. "Doctoral Education in Design: Problems and Prospects." *Design Issues* 26 (3).

Marx, Karl. 2009. "Economic and Philosophic Manuscripts of 1844." *Economica* 26 (104; 1; 3.).

McCullough, Malcolm. 1996. *Abstracting Craft: The Practiced Digital Hand*. Cambridge: MIT Press.

Moholy-Nagy, S. and C. Miles. 1971. "Experiment in Totality." *The Journal of Aesthetics and Art Criticism* 24 (4): 560.

Morris, William and May Morris. *Useful Work Versus Useless Toil [1884]* The Collected Works of William Morris.

Nilsson, F. 2013. "Architectural Assemblages and Materializations - Changing Notions of Tectonics and Materiality in Contemporary Architecture."Taylor and Francis Group, .

Pallasmaa, Juhani. 2009. *The Thinking Hand: Existential and Embodied Wisdom in Arthitecture*. Chichester, U.K.: Wiley.

Petroski, Henry. 1993. *The Evolution of Useful Things*. New York: Knopf.

Potanyi, M. and A. Sen K. 2013. *The Tacit Dimension*. Chicago: University of Chicago Press.

Princen, Thomas. 2005. *The Logic of Sufficiency*. Cambbridge: MIT Press.

Pye, David. 1952. "The Art of the Practical Engineer." *Proceedings of the Institution of Mechanical Engineers* 166 (1): 265-271. doi:10.1243/PIME_PROC_1952_166_027_02. https://doi.org/10.1243/PIME_PROC_1952_166_027_02.

———. 1978. *The Nature and Aesthetics of Design*. New York: Van Nostrand Reinhold.

———. 1968. *The Nature and Art of Workmanship*. Cambridge: Cambridge University Press.

Ruskin, John. 1849. *The Seven Lamps of Architecture*. New York: J. Wiley.

Sass, Lawrence. 2015. *Exploration of a Design Framework for Large-Scale Model Manufacturing* Cad'15.

Schwab, Klaus. 2016. *The Fourth Industrial Revolution*. First US ed. New York: Crown Business.

Sennett, Richard. 2009. *The Craftsman*. London: Penguin Books.

Smith, Ryan. 2016. "Prefabrication." *Journal of Architectural Education* 70 (01): 1-14. http://www.jaeonline.org/articles/exhibit-reviews/prefabrication#/page1/.

Stevens, James C. 2015. *Digital Vernacular: Architectural Principles, Tools, and Processes*. New York, NY: Routledge.

Stevens, James and Ralph Nelson. 2015. *Digital Vernacular: Architectural Principles, Tools, and Processes*. New York: Routledge.

Sullivan, Louis H. 1947. *Kindergarten Chats and Other Writings*. New York: Dover Publications. http://www.loc.gov/catdir/description/dover032/79052523.html.

Thwaites, Thomas. 2011. *The Toaster Project: Or A Heroic Attempt to Build a Simple Electric Appliance from Scratch*. New York: Princeton Architectural Press.

Till, Jeremy. 2007. *Architectural Research: Three Myths and One Model*.

Tsubaki, Kentaro. 2012. "Foldout Drawing: A Projective Drawing for Fabric Forming." *Journal of Architectural Education* 66 (1): 98-106. doi:10.1080/10464883.2012.719821. https://doi.org/10.1080/10464883.2012.719821.

Wilkinson-Weber, Clare M. and Alicia Ory DeNicola. 2016. *Critical Craft: Technology, Globalization, and Capitalism*. London ; New York: Bloomsbury Academic, an imprint of Bloomsbury Publishing Plc.

Winchester, Simon. 2018. *The Perfectionists* How Precision Engineers Created The Modern Wrold.

Zumthor, Peter. 1991. *Thinking Architecture*. Basel: Birkhäuser Architecture.

List of Figures and Graphics Credits

Literature Summaries

The literature summaries listed in the appendix were compiled in preparation for, and in concert with, the writing of this thesis. Although all summaries are listed in the bibliography, not all bibliography citations are given a summary. This was the outcome of journaling and notations during research, and many bibliography references did not require such summaries. These summaries can be viewed as the “field notes” from this thesis’ research and not a comprehensive list. Representing a wide range of topics, the summaries are intended to support the research contained in this document and to serve as a quick reference for readers of essential content of each reading. Together they are represented in Figure 3 Epistemological Framework.

Authors & Editors A-E	
Author	(Adamson), Glenn
Title	Thinking through Craft [Chapter 2, Material]
Date	2007
Content Summary	Adamson begins by asserting that craft is always an encounter with the material, furthermore material that is defined as “matter in space” (p. 39). The chapter’s theoretical framework is a comparison between the opticality and tactility both in art and in craft. The sculpture is examined because of its base in optics, which eventually shifted more to a tactile-based ceramic culture after Peter Voulkos demonstrated his work (p. 40-41). He shows how art likewise transitioned into “Process Art,” the closest fine art got to the craft horizon during the 20th century (p. 42). A similar movement occurred in the Japanese ceramic culture led by Isamu Noguchi (p. 55). One of his successors, Yagi Kazuo, opposed to pre-rationalized craft and continued the push for a more tactile ceramic process, shown in his work with mentally handicapped people where the material and the hands were the only instruments in the making process (p. 57).
Theoretical Contribution	Through these examples, Adamson shows how craftsmen sought to divide the optical meaning from the sensual performance of their work and how artists also questioned representation. The chapter examines if craft is capable of being “good” (which the author defines as being tactile-based) or if it should be considered another form of art if all else such as quality and skill is eliminated as variables and the only focus is material manipulation. Adamson posits this question, with “no simple answer” from himself, but adds that when one adds skill to the mix, it changes the working theory behind craft and art (see C026)

Academic Discourse	The stripping away of preconceived notions during the making process contributes to the value of experimentation in craft, and also reflects the many concerns surrounding the use of digital tools to manufacture craft items at a mass scale. The question becomes, how can a single material or craft process be affected through digital means. The theory emphasizes physical work and evidence of such in the making of crafts. Keywords: Base Materialism: only using or manipulating a single material (p. 56) Facture: "The way in which something has been produced shows itself in the finished product," which was a Process Art term (p. 59)
Epistemological Validity	Adamson seems to align art with optics and craft with tactility but generally tries to remain neutral when cross-referencing the many theoretical positions contained in the chapter.
Cross Reference	Peter Voulkos, destruction of traditional pottery (p. 43)

Author	(Adamson), Glenn
Title	The Invention of Craft [Chapter 3, Mechanical]
Date	2013
Content Summary	In the 1800s, there was a divide between artists and artisans where the artisan was generally considered to lack critical knowledge. Discussions often compared the artisan to the machine who toiled away monotonously at the same task each day. Activist groups formed in opposition to this social stigma, but their solution to making the craftsman knowledgeable was exposing him to the understanding of theory alone (p. 132). What happened when people got too caught up with theory essentially created a prejudice against those that were finely skilled by the hand but were not believed to have any intellectual value. Coupled with Western values and racism of the time, craft was painted by those with these beliefs as a barbaric activity (p. 138). Adamson looks into how craft is measured as a means to define it and notes that if craftsmen were asked to come up with an object to be judged, then only their design skills would be critiqued and not their skill in making as would happen if they were asked to imitate a preexisting object. This gives the fundamental definition of craft a non-generative character, but Adamson explains how craftsmen such as Richard Redgrave and David Pye have used imitation to understand methods of making and lead to branches of craft diversity (p. 143). Copying was the norm during the craft guilds, and during the 19th-century, machines often performed repetitive work, and humans did the hand-finishing (p. 145). This is one way that artisans found viable work during the Industrial Revolution, along with prototyping and mold casting during pre-machining processes, and also maintaining machine tools (p. 145-46). The author covers the indexicality of craft in the forms of photography, electroplating, sand mold casting, and describes analog craft in order to set up what craft means in a contemporary, digital setting (p. 165).

Theoretical Contribution	The chapter describes the early shift from an attitude where the artisan's mental powers were taken for granted to one that holds craft only in the hands and not in the intellect (p. 139). The author goes at length to explain the value of imitative craft and indexical craft, where the effect the artisan wishes to produce is one that causes the user or observer to become engaged with the fineness of the object and not have its characteristics quickly wash over him as just mere information. The embedded humanness and skill that crafted objects possess through the analog process is what sets them apart from the mass-produced (example of the PVC chair v. the Chinese ceramic chair).
Academic Discourse	On page 146, Glenn Adamson brings up the fact that the automotive designers have just recently abandoned the clay sculpting process that symbolized the pre-manufacturing artisanal craft. While he does not mention computer modeling, this effectively replaced the clay sculpting with a digital form, which many digital sympathizers would consider an equivalent craft. He then brings up Malcolm McCullough's optimism of a future craft that relied on virtual touch, saying that his hopes had not come to fruition and does not predict them to any time soon. Adamson sees the relationship between craft and computer-based design similar to the way artisans coexisted with the machine during the Industrial Revolution (p. 168). Keywords: Indexicality: "semiotic term that designates a sign with some direct physical relationship to its referent" (p. 0150) Faire: "does not mediate between the subject of the picture and the spectator, but tries to cancel itself" (p. 151) Surmoulage: "after-casting," a copy of a copy that was frowned upon in 19th-century work (p. 154).

Epistemological Validity	Adamson's status as a historian and head of research of traditional craft will understandably keep craft's history from a closer perspective than one who is involved with progressing digital machines or computerized making. That said, he is far from a Luddite point of view when talking about the computer; he just refers to most analog-digital relationships as "less than spectacular" (p. 168). Adamson questions the notion that craft needs improvement via the digital (p. 171).
Cross Reference	Ruskin, the savage craft (p. 141) Craftivists and wanting craft to remain slow and local (p. 165) McCullough, virtual crafting (p. 166) PostlerFerguson toys questionably crafted with digital tools and outsourcing (p. 169) Matthew Crawford, hating the corporate doublespeak, but whose "autonomy is entirely illusory"-Adamson (p. 170)

Author	(Adamson) , Glen
Title	Thinking Through Craft [Chapter 3, Skilled]
Date	2007
Content Summary	Adamson begins the chapter comparing David Pye and Michael Baxandall. While Baxandall believes that skill is culturally dependent (p. 71) and that it is a way of achieving authority in a given context, David Pye divorces manual skill from mental skill, saying that it is more in the ability to apply restraint and control (p. 72). The chapter then focuses on skill as it relates to vocational training and the studio pedagogy of Joseph Albers at the Black Mountain School. He describes how the Progressivists sought social reform through education and vocational training (p. 78). At the Black Mountain School, professors stressed the physical object during making and feeling when one draws instead of seeing (p. 81). Finally, Adamson concludes with an examination of skill in architecture using the theories of Charles Jencks (ad hoc design) and Kenneth Frampton (the tectonic) as main arguments (p. 87).
Theoretical Contribution	Chapter 3 tries to answer the question of the importance of skill in craft. Like the last chapter, it is a collection of various theories regarding skill from many design theorists: see "References." Adamson concludes that what Frampton showed to be profitable through craft skill is what Dewey and Albers were first to put into action at Black Mountain. He also shows how Frampton's theory on the skilled builder who works with the forces of material is similar to Baxandall's idea of skill becoming the cultural (p. 101). Adamson does an excellent job of pointing out the linkages between the theorists.

Academic Discourse	From the many arguments, it seems one thing is constant: that without skill, there is no further meaning in a craft or architecture outside of the possibility of an aesthetic appeal (Erik's assertion). The reason people like Josef Albers put a value on learning and experiential skill is to reinstate a value on intellect and design skills. When one experiments with materials, one understands how they can be manipulated in future design endeavors. Likewise, the reason people value objects that exhibit craftsmanship is that they can empathize with the human effort it took to achieve quality. This thinking prioritizes evidence of human touch in products that are made for human use; therefore, if digital tools are employed during the making process, one maybe considers that it does not take over the object's essence of humanness. Keywords: Slöjd: "craft" derived from the output at Swedish woodworking schools (p. 79) Bricoleur: "someone who works with his hands and uses devious means compared with those of a craftsman," someone who makes-do with only what is on hand (p. 90) Gut genug: German for "good enough," similar to ad-hoc and bricoleur (Erik's assertion) verbindung: "joint," Semper's basic building block of all architecture, shared by Frampton (p. 97).
Epistemological Validity	

Cross Reference	David Pye: divorce of manual skill from mental skill, opposed John Ruskin for being too seeking of a truth Michael Baxandall: skill is linked to culture by "not just knowing how to make something but rather knowing how to make something seem "just right" (p. 77). Levi Strauss: favored the ad-hoc and bricoleur (p. 90) John Dewey: taught experimentation and open endedness, not a perfected single task skill Josef Albers: transformed traditional Bauhaus teaching to an "unprofessional experience with materials" at BMC. Ad-hocism was anti-craft, with no skill required to succeed at it (p. 84) Charles Jencks: embraced pluralism and novelty in architecture, similar to Venturi and Scott Brown (p. 88). Gottfried Semper: all building elements had an internal logic based on their materiality (p. 96). *Verbindung*. Eduard Sekler: originally formulated the idea of tectonics (the way forces draw a building together through structure) in the manner in which Frampton uses it (p. 97). Kenneth Frampton: "championed a craft-based architecture that would dramatize the physical connections between a society and its locality" (p. 88) Martin Heidegger: "opposition to instrumental technology" and "to build is a spiritual activity." Marxist politics, associated with Nazism (p. 94), and also frequently used by Frampton. Hannah Arendt: *The Human Condition,* frequently referenced by Frampton Robert Venturi: craftsmanship became diluted when the economy and industrial standardization were prevalent in architecture, and therefore believed architecture could only be imagery

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 6, On the Economy of Machines and Manufactures, Charles Babbage]
Date	1832
Content Summary	Charles Babbage's two main points: 1. The identity of work when it is of the same kind of work versus its accuracy when of different kinds. This is what differentiates mass production from a skilled craftsman. Babbage says that a man can craft the tool that makes it in mass, but it is the machine that makes it in mass from that point on. 2. The division of labor: he describes the social phenomenon where one skill is preferable by the owner of a factory, which leads to parents raising their children to acquire this skill. As a result, the number of workers increases, and the wage decreases.
Theoretical Contribution	Babbage defends the efficiencies of making in mass by comparing a factory owner who keenly assembles many laborers of a single skill rather than trying to acquire and perfect the many skills necessary. His point is to use machines for what they are suitable for and to appreciate production as a skillfully planned system that is efficient increases worker dexterity and leads to the invention of more machines
Academic Discourse	This theory emphasizes the intellect it requires to assemble and run machinery, which can be thought of in itself as a craft. It requires planning, precision, and trial and error just as much as hand turning different wooden legs would require.
Epistemological Validity	Babbage placed more value on the machine than Marx or Wright. It could "function as a check against the inattention, idleness, and dishonesty of human labor" (p. 6). But his views still value craft skill due to his observations of the factory and promoted capitalist usage of skilled labor in a precise quantity. Keywords: manufacturing, evolution
Cross Reference	Petroski: the series of failures that lead to an object being perfected

Author	(Adamson) , Glenn, et.
Title	Abstracting Craft: The Practiced Digital Hand [Chapter 7, Medium, M. McCulough]
Date	2016
Content Summary	McCullough describes medium in two parts, first the traditional and then the electronic. A “medium is a substance that may be sensed or altered somehow by tools” (p. 2 of PDF…check corresponding book page). McCullough states that a richer medium will create interpretation from its observer and stir his attention (p.2-3). He acknowledges the fact that there is “considerable debate” as to whether or not a medium must take a material form or be abstract such as a generative algorithm (p. 2). In the chapter, he outlines a given digital medium and its corresponding continuous process that one must master to achieve continuity (Erik’s assertion: aka quality, but I think McCullough is really itching to call it craftsmanship). On electronic medium, the author describes how television allowed a medium that no longer carried just the message, but was the message, and the change in society towards a postmodern consumerist culture emphasized aesthetics, politics, and economics rather than simple functionalism beginning in the 1960s (p. 18). Then as bits and data became a new medium, the message could be housed in these and was redefined once again. He offers that modern-day consumption methods that humans are used almost to make it a necessity for craft to be electronically transmissible in order to gain exposure (p. 18).
Theoretical Contribution	“Acute knowledge of a medium's structure comes not by theory but through involvement” (p. 5). McCullough states that in reality, there is no ultimate medium and that there will always be constraints, but constraint leads to expression (p. 8). Later, he says that since industry, the craftsman had to adapt to a new way of using a medium, which is a more abstract matter than it used to be. He asserts that the craftsman can retain control of the working process through technological excellence (p. 11).

Academic Discourse	On the dematerialization of art from craft, McCullough traces the historical development to increasing differentiation of skills and a new respect for the original medium and freedom found in going from a functional object to non-literal representation as a new definition of beauty (p. 14). (Erik's assertion: very much aligned to the evolution of theory from the metaphysical to the intellectual). What the author here calls "cabinet arts vs. useful arts" is also discussed in further detail in C.025 where Glenn Adamson refers to it as "opticality vs. tactility" McCullough foresees the question that would come from Pye readers: "For example, in Pye's conception of workmanship we have a fundamental challenge from tradition to the proposition of electronic craft: must a true medium entail sufficient risk and irreversibility to demand the rigor and devotion that have always been necessary for great works? Can a computer with its undo and save as functions ever demand sufficient concentration on our part to enable serious, expressive works to come forth? Can these functions enable us to take greater risks and therefore express ourselves all the better? Or do they render us noncommital and our work superficial?" (p. 21) His answer to this question is that the digital medium is more advantageous because it has a continuum of states and can be edited and changed in real-time (p. 23). "Lastly, then, better human-computer interfaces, based on dense notations, provide increasing engagement in structural manipulations. In particular, they engage the hand in the modification of notation, and this begins to reunite skill and intellect."
Epistemological Validity	Similar to Pye, McCullough utilizes the term workmanship to relate to his medium argument: "Good workmanship is sympathetic to such potentials of a medium and uses any idiosyncrasies to its advantage" (p. 10). He also links it to Thorstein Veblen's The Instinct of Workmanship and the State of the Industrial Arts (1914).

Cross Reference	David Pye, the 2 workmanships Thorstein Veblen's, The Instinct of Workmanship and the State of the Industrial Arts Nicholas Negroponte, bits commingle, and bits exist to tell you how to use other bits

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 10, Capital, Karl Marx]
Date	1867
Content Summary	The Marxist understanding of industrialism and craft is that the craftsman makes use of the tool, but in the factory, the tool makes use of the man. To Karl Marx, the power of a tool is provided by a man, but the power of the machine is provided by something other than men, such as a donkey, the wind, or a steam engine. When the machine is given the power over people, the tender or laborer becomes reliant on his task for any life fulfillment, and when removed from the machine, cannot find meaning away from it.
Theoretical Contribution	He discusses the social ramifications of capitalist manufacturing and how it enslaves freedom. Marx, like Wright but unlike Morris and Ruskin, does not denounce outright mass production, but does not necessarily support it as an ethical endeavor either. Since people can't do other things for themselves, bought products aid them in doing so, which only feeds the dependent-consumerist cycle in society. "In the factory we have a lifeless mechanism independent of the workman, who becomes its mere living appendage" (p. 75).
Academic Discourse	The handcraft is validated when the worker is in control over the tool. The tool could be a machine, and therefore powered by something other than the human, but it must yield to the laborer's intellect in order to promote freedom for the worker.
Epistemological Validity	The position did not entirely reject manufacturing or totally support a peasant lifestyle like Morris. He is in the middle ground but believed in human control. Keywords: machine, energy, craft, control

Cross Reference	William Morris: fond of the feudal peasant life John Ruskin: the full rejection of the machine Frank Lloyd Wright: similar sentiments regarding the control of the machine Pye: the transformation of energy Princen: the physical adaptation of the human body to the ergonomics of a machine Ford, “any color so long as it’s black.”

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [The Craft Reader, Chapter 15, In the Cause of Architecture, Frank Lloyd Wright]
Date	1927
Content Summary	In this excerpt, Wright talks about the architect and his relationship to the machine in “Usonia.” He declares architects should either adapt to using machines in their work or risk becoming obsolete. The reason he does not outright shuns the manufacturing is because he believes that machines cannot control the creative ideas, but it is man that can determine whether or not mass production will be the engine of emancipation or enslavement to creativity. He goes on to describe the love of making is the architect’s life, and that quality in life is found in nature.
Theoretical Contribution	Wright was addressing his essay to the young architects of his succeeding generation, which puts him in an exciting position as a prognosticator. He admitted that there was little he could do as his contemporaries pushed architecture in search of a style of progress, but it seems to indicate that Wright feared the machine would take over “architecture for architecture’s sake.” Although the machine was there to stay, he hopes future architects could wrest control of its endless consumption and return design back to something less alienating from the spiritual essences found in handcraft and nature.
Academic Discourse	It is crucial when working with mechanized tools that the tool itself does not usurp the designer’s ability to produce generative, creative work. It is still up for discussion whether things like 3d modeling software can enslave the user by limiting one’s creativity to either the knowledge of the program or limits of the scripts.

Epistemological Validity	Wright saw nature as the spirit behind architecture, and the unnatural machine put in jeopardy that essence. He also understood the efficiencies and the value of what the machine could do in terms of material and fabrication, so he wanted to enforce a balance between a strict arts and crafts application of design and a solely automated one. Mass customization architect vs. manufacturing in mass. Keywords: machine
Cross Reference	Siegfried Bing: saw machine as a handmaiden to art and creativity

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 17, Building Materials, Adolph Loos]
Date	1898
Content Summary	Adolph Loos laments the use of materials in an untruthful manner. He describes how the artist must master his work so that the final output is of higher worth than the original value of the materials alone. When people see a granite wall, he argues that they are not in awe of it because of its materiality, but the time and skill in which it took the craftsperson to achieve its change of state. By this concept, Loos also points out that vernacular architecture is of no less important than that of grandiose stone columns or golden streets, but it is when the peasant starts using concrete for stone or paint for gold that it becomes problematic.
Theoretical Contribution	Loos was one to call for the energies of the craftsman not to be expended in the work of applying ornament but making a simple, high-quality craft where a value was found in its authenticity (Ornament and Crime). He furthers this premise in Building Materials while not arguing against craftsmanship, but arguing for authentic practices. He recognized that during his time, the artist was being pushed out by day laborers and the machine who made it quicker and easier to replicate the desired effect, and that was changing the social value of aesthetics in design
Academic Discourse	The behavior Loos is denouncing would be akin to an individual buying a counterfeit Rolex to heighten his perceived wealth, while only making a fool of oneself because those that possess the true timepiece can easily discern authenticity from imitative wealth. With the idea of authenticity of the tool, does leaving evidence mean poor craft?
Epistemological Validity	Loos is against the violation of materials, as well as the expenditure of extra energy to achieve an inauthentic aesthetic. Keywords: mastery, skill, material, imitation.

Cross Reference	Fischer von Erlach, the “king” of materials in Loos’ day (p. 116).

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 18, Handwerk/Kunsthandwerk, Stefan Muthesius]
Date	1998
Content Summary	Stefan Muthesius looks at the history of craft in Germany. The author describes how the term Handwerk changed as artisans found themselves going from making Kraft to merely doing repair work when Manufaktor changed the economic climate. The German craftspeople banded together in response to industry, forming social groups like Handwersverband that set up quality guidelines and kept the relationships of the guilds alive. The other route was emphasizing art in manufacturing (Kunsthandwerk). German manufacturing had the perception of cheapness, and in 1905 avant-garde Modernism challenged the idea of old fashioned craft and traditionalism. As a result, Handwerk was valued in terms of quality by the 1920s, while the Nazi regime carried a simplified style of quality with Classical influence.
Theoretical Contribution	The essay is an etymological study of the concept of craft in the 19th and 20th century. He uses the study of definitions to track the debates about design reform and how they relate to the English translations.
Academic Discourse	Some of the terms as defined by Muthesius' study: Handwerk: any trade job that plays down commercial involvement Kunsthandwerk: German equivalent to the Arts & Crafts movement applied to manufacture Werkbund: a close-knit group of traditional craft workers Handwerkliche Qualität: craftsman-like quality Gestaltung: giving something shape, a predecessor term to the word "design."
Epistemological Validity	Through the survey of definitions, the author presents the ranging views on the subject of craft and industry.

Cross Reference	George Friedrich Hartlaub: Handwerk is eternal Alois Riegl and Richard Riemerschmid: good ornamented products could be produced with less effort and cost using mechanical devices Herman Muthesius: Avantgarde designer Keywords: craft, kraft, Handwerk

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 39, What is Cybernetics? From The Human Use of Humans, Norbert Wiener]
Date	1950
Content Summary	The text explains how humans can be thought of as being different from machines because humans have sense organs and machines do not, but in reality, modern machines do use sensory devices to communicate conditions of the exterior environment to the actions it is required to compute. The things are thermocouples, photo-electric receptors, or tension-conductivity wires (p. 305). It also goes over the concept of input, which is introduced data, and output, or effect on the external world. Elements that indicate the performance of a machine from input to output are known as monitors that produce feedback. The feedback helps a human or machine to function more effectively when the external conditions change.
Theoretical Contribution	Wiener is against the use of the machine that minimizes the human element in life (p. 304). He argues for a world not of buying and selling but one that values the intellect of humans by not subjecting them to mindless tasks tending to machines. If machines can one day think for themselves, then it is better than having a human reduce his brain capacity in order to keep a machine running. Wiener approaches the idea of control; control is "the sending of messages which effectively change the behavior of the recipient" (p. 304).
Academic Discourse	His thesis is aligned with the goals of the pro-craft movements when understood from the concept of control. Wiener argues that the machine and technological advancements need to be controlled by those that value social reform and not the defamation of human intellect.
Epistemological Validity	In this essay, Wiener uses the theory of feedback to understand how a machine may think. His views on the first industrial revolution: "dark satanic mills." He sees the modern industrial revolution in a similar manner but which devalues the human brain rather than the body (p. 303). Keywords: control, feedback, sensory

Cross Reference	Frank Lloyd Wright: similar sentiments regarding the control of the machine

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 40, Abstracting Craft: The Practiced Digital Hand, Malcolm McCulough]
Date	1997
Content Summary	McCullough defines craft in many ways, stating what it is and what it is not. He provides the example of a graphic designer who uses computer tools to be considered an artisan due to the fact that he possesses unprecedented skillsets, including quickness, anticipation, has a feel for the program. He goes on elaborate that one needs to be an expert in order to get a crafted result from the use of technology, thus validating the digital process as a type of workmanship (p. 314). The second half of the essay describes the state of technological advancement in 1997 and laments the lack of integration of haptic communication in craft and design. The abstracted craft is made possible by computers and is a growing type of craft in the 1990s identified by McCullough.
Theoretical Contribution	The author proposes that digital toolsets enable craft to be relevant again in the face of mass production. He disregards the popular discussion of "what is considered handwork?" by asserting that computers offer a totally different type of tactility, and with the progress of haptic technology, it will only enable digital craft more (p. 313).
Academic Discourse	Three reasons are provided to the validity of digital craft and its future success: 1. tools are affordable, and that will crumble the stereotype that machine ownership is for capitalist gain or authoritarian regime 2. the input-output gap in computers and digital equipment is diversifying which allows talent to flourish as it naturally would in traditional craft 3. there is a growing appreciation of abstractions socially and culturally that digital craft will find success in

Epistemological Validity	McCullough still believes that "the most humane of ends" is craftsmanship. The bottom line from his perspective is that humans still control how technology impacts the social ramifications of work discussed by the likes of Babbage, Marx, Princen, and others. He is arguing for dematerialized craft. Keywords: technology (Greek)= the study of skill. Also, the order or apparatus imposed on skill (p. 311).
Cross Reference	Ruskin Babbage Marx Princen Diderot, description of craft assimilated to the graphic designer

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 41, The Digital Artisan's Manifesto, Richard Barbrook & Pit Schultz]
Date	2016
Content Summary	Barbrook and Schultz drafted a false manifesto in response to the dot-com boom of the 1990s. In it, they describe their faux craft guild with its corresponding set of values. Although it is written tongue in cheek, it exaggerates to make a case for workers' rights in the field of virtual media and comments on the intellectual suppression often associated with freelance/subcontracted digital artwork.
Theoretical Contribution	Being a digital artisan is a way for the independent worker to find meaning and success away from the typical division of labor style "job." The manifesto stresses the reestablishing of autonomy that was once the pre-industry norm. They call for things like public funding and educational programs to sustain their interests in order to touch on the political side of human rights issues that Ruskin, Marx, and others have previously written on.
Academic Discourse	The emphasis on creating intellectual communities to draw the full potential from digital tools is relevant to digital craft. On "Making the Future," they state, "Although they [information technologies] were originally developed to reinforce hierarchical power, the full potential of the Net and computing can only be realized through our autonomous and creative labor. We will transform the machines of domination into the technologies of liberation" (p. 317).
Epistemological Validity	The authors' point of view falls alongside the McCullough faith in the digital artisan and focuses mainly on the visual but not necessarily tangible work of graphic design. They argue for digital art in the 20th and 21st century to be recognized similarly to how handicrafts once were during the realization of guilds and labor associations. Keywords: autonomy

Cross Reference	McCullough, and the digital artisan Princen, autonomy Marx Ruskin Crawford, counterargument of the value of work Pye, everything

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 42, Craft Versus Design: Moving Beyond a Tired Dichotomy, Rafael Cardoso]
Date	2008
Content Summary	Rafael Cardoso presents the concept of craft, which at one time meant power, strength, and skill (p. 321). Like many authors on the subject, he too goes into an etymological study of the word. The debate on art, craft, and the industry is sequenced beginning in the 1850s where products became accessible to the lower class. The American and Ford style system of standardization changed industry and skill in 1913, which also lead to a new standard of quality as industrial products had previously been known for their rough finish. Designers also began guiding products produced by the machine at this point. The computer then shifted industry to be capable of mass customization and one-off production.
Theoretical Contribution	To Cardoso, the idea that "craft" transitioned to "design" when industry arose is a myth. He believes design and craft were always together, but its distribution varied based on the control of industry. He examines the relationship of imperfection and perfection in produced work (p. 327); The stigma of imperfection shifted from a machine-produced object in the 1800s to a valued characteristic of hand-produced objects in the 1900s due to the standardization of the machine.
Academic Discourse	Cardoso argues that today, we are far from the standardized, one-way system where manufacturers impose what is available on the market. Today consumers are deciding what is marketable because the designer has achieved control over the machine. He explains how the enemy of craft prior to the 21st century was industry, but now the enemy is individuation of experience. Craft has a specific appeal today, which is community and shared interaction (p. 330).

Epistemological Validity	Cardoso weighs in on how craft is defined, citing origami, surgery, music, athletics, and dentistry as examples covered under his definition of the term. He believes that Ruskin is often misinterpreted as a machine hater when really the focus was intended to be on the disapproval of the idea that “consuming pleasure of the few justified the dehumanization of the many” (p. 324). Extending Ruskin’s sentiments, Cardoso believes that to be art. It needs to be the “work of the heart” (also a Frampton assertion). Furthermore, craft is not an individual experience. Like Barbrook and Schultz, he stresses networking and knowledge sharing, not keeping expertise to oneself. Keywords: Artisant: French, 1546 translation to “handicraft.” Artesao: Portuguese 15th-century translation Metiers: French, translation to “manual trades.”
Cross Reference	Ruskin, Morris: art as craft, digital craft as not craft Babbage, Art as intellect, Renaissance Humanism Henry Ford, standardization: “you can have any color so long as it’s black.” Jeff Link, and the bespoke Malcolm McCullough, a case for digital media Sam Maloof, woodworker/furniture, “many things are made with perfection, but they don’t have a soul.”

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 52, The Case for the Tectonic, Kenneth Frampton]
Date	1990
Content Summary	Frampton describes how the only true path of architecture is to return the focus to the structural unit. For this reason, tectonic-based architecture is neither constructivist nor deconstructivist; it does not embody a style at all, and that is what makes it pure (p. 412). He reiterates his two modes of the tectonic: the structural-technical and the structural-symbolic, which correspond to his other two characteristics of the frame and the stereotomic. To him, culture is able to express itself through the joint and not style, citing the joint as a timeless element of truth. Frampton also covers the etymology of the word in the remainder of his essay.
Theoretical Contribution	Frampton argues for an architecture that manifests itself in the tectonic and opposes technology that makes placeless architecture such as the prefabricated home. Regarding craft, craft involves a vernacular, something that must be connected to local customs and traditions.
Academic Discourse	According to Frampton, if the digital craftsman is looking for the truth of craft in their work, then it can be found in the way objects are brought together. It does not deal with the debate around style or of the manipulation of forms, or even the modernist notion of space. It is physical, it locates the work, and it brings continuity to the designed outcome.
Epistemological Validity	The critical perspective is one that orients architecture to its constructional logic. Other modes or styles of finding meaning away from the joint are inauthentic. Context is the 1990s. Keywords: Mauer, or frame anchored to the site Want: the light frame and infill wall which means “weaving,” or in other translations, is “the essence of building tectonically”

Cross Reference	Gottfried Semper & Martin Heidegger: poetics of construction, the “thing rather than the sign.” Venturi, and the decorated shed as antagonist viewpoint Hans Sedlmayr, man’s shift from organic to inorganic, “rapes the earth” (p. 410).

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 54, Art & Work, Harold Rosenberg]
Date	1965
Content Summary	The essay talks about the degradation of the worker when life consists of tending buttons that keep machines from breaking down. One of the arguments is that if we have so much ability to have machines produce goods for us, then why are we not using our ample time to progress intellectually rather than continuing the cycle of produce and consume?
Theoretical Contribution	Rosenberg's theory reverses the adage "art for art's sake" as art being self-referential, to "art for the artist's sake," where non-alienated labor is the ideal. This is still an issue at his time, but has been a topic of theory since 1850 was when Kant and Hegel attributed great meaning to the intellectualization of the arts, which alienated the artisan who was not considered "genius." Rosenberg breaks it down as such: man in nature is a maker when man is not maker, man is no longer man.
Academic Discourse	"art as an experiment [and craft] can function under any social system" (p. 429). This means to further the craft is to do it for the intellect gathered through the making process, not solely for the critique of the aesthetic or self-referential object.
Epistemological Validity	Although Rosenberg's knowledge of craft history and theory was limited as it was out of his domain, his arguments are very similar to those in opposition to the alienation of the artist. Commentary on the essay also provides he is pro postwar avant-garde. Keywords: Mauer, or frame anchored to the site Want the light frame and infill wall which means "weaving," or in other translations, is "the essence of building tectonically"

Cross Reference	Kant Hegel Princen, work done when the worker wants to Crawford, Shop class as Soulcraft Malcolm McCullough, art shifting from being functional to being intellectualized David Pye, “useless work.”

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 68, Manifesto of the Bauhaus and Education and the Bauhaus, Walter Gropius and Laszlo Moholy-Nagy]
Date	1919
Content Summary	Walter Gropius calls to action architects, painters, and sculptors to return to the crafts because separately, their value was diluted to “salon art.” Nagy comments on the education system of his time, which had shifted to emphasize specialized fields rather than a diverse knowledge of crafts. The shift occurred when industrial expansion created a demand for specialized workers and single-task jobs in the factories. Nagy also relinquishes the idea that the modern man can thrive without the machine, so he proposes to “exploit it for the benefit of all” (p. 558).
Theoretical Contribution	The Bauhaus pedagogy centered around learning a handcraft in order to preserve the taught skills of the artisan in order to develop a well-rounded designer. Nagy speaks out against the specialist (see logic_prin_T019.pdf, box 5.3) who finds his motivation in material gain rather than respect for the environment around him or intellectual development. (p. 536). In order to liberate these creative energies of the non-specialist, Nagy believes man shall avoid being intimidated by industry, the machine, and its rushed pace, and use it to his advantage (p. 558).
Academic Discourse	“Sterile hordes of textbook information” can only go so far, and making new knowledge through practice is necessary when one is trying to innovate using new tools.
Epistemological Validity	Gropius and Nagy share that craft is essential to architecture and the biological man, but that the machine is not an outright vulture to creative energy if utilized correctly. Keywords: Creative energy

Cross Reference	Gottfried Semper, Ruskin, Morris: in response to these views, it is not practical to run a horse of goods parallel to the railway (Nagy, p. 557).

Author	(Adamson) , Glenn, et.
Title	The Craft Reader [Chapter 70, Asilomar Conference Proceedings, Marguerite Wildenhain, and Charles Eames]
Date	1957
Content Summary	Wildenhain explains the cause of the craft-design split, which occurred when competition with the machine arose and "time became money"; the design process was shed in favor of rapid production. She encourages the craftsman to explore all the possibilities that handwork provides first through design and redesign, and then figure out a way to mass-produce it, if necessary. She values the teaching of fundamentals in an apprenticeship style but acknowledges the fact that the mode is becoming outdated due to the length of time it takes to master handcraft. Eames discusses society in his portion of the text and how it would be better if everyone gathered their satisfaction from their own intellectual autonomy through the production of high-quality craft rather than low-quality capital gain.
Theoretical Contribution	Wildenhain believes that the use of machines creatively is the modern craftsman's aim. The use of technology has its foundation in creative ingenuity, which can translate outputs between modes and tools. She also says that not everyone can be a good designer because it is the few craftsmen that understand the design process well enough to make something good. Eames expresses similar sentiments quoting Mies: "I don't want to be interesting, I want to be good" (p. 576).
Academic Discourse	The excerpt from Asilomar brings up the question, how do you know what is possible with a digital tool if you always go by the method of exhausting handwork first? The answer may be that by mastering the fundamentals of craft and design, then introducing new tools and experimenting with their limits will enable the craftsman to discover all of its capabilities instead of settling for one's knowledge of the tool alone to be the limit.

Epistemological Validity	The authors stress the importance of the design process and how teaching is a requisite for good design to flourish in the shop. By focusing on “good design,” the goal is to change the consumer’s acceptance of quality and thus improve lifestyles through craft.
Cross Reference	Mies Crawford

Author	(Adamson), Glenn, et.
Title	The Craft Reader [Chapter 75, Craft Hard, Die Free: Radical Curatorial Strategies for Craftivism in Unruly Contexts, Anthea Black and Nicole Burisch]
Date	2010
Content Summary	Black and Burisch present craft as an outlet for political/cultural activism. They describe how it's not about the end product as much as it is about the communal activity. The knitting circle and craft groups aim to non-violently oppose corporate production models. The use of the internet to spread the word about group projects is a significant resource for craftivism. They detail various projects that use arts and crafts in a public space to make a statement
Theoretical Contribution	Core entities to craftivism: a democratic process, the use of diversified media, and a commitment to political issues. Since the craftivist movement is a political standpoint, the critical opposition is not the machine or mass production itself, but the mass production of a similar aesthetic to the craftivists which does not participate in a political conversation. Many have spoken out about the social injustices related to craft and labor, but the craftivists see themselves as actually putting into action the theory and taking the message beyond text or spoken word through physical objects in a public realm.
Academic Discourse	Our current culture is one that favors the consumable and sharable content, which means it is also easier to get a message out than it used to be should one choose to use one's knowledge of craft to establish a political platform.
Epistemological Validity	The point of view is not one of pre-industrial sentiment but rather situated within the contemporary issues of urbanity, globalization, and capitalism.
Cross Reference	Indie craft Craftivism Anti-colonial craft

Author	(Beesley, and Seebohm, and Thomas)
Title	Digital Tectonic Design
Date	2000
Content Summary	Though not explicitly labeled "parametric design," Beesley and Seebohm describe the digital design process they teach at the University of Waterloo that uses generative form making combined with a set of parameters for developing actual construction details on the digital model. This is probably one of the earlier articles on parametric design. The authors studied Mies and Wright to establish sound tectonic precedents that could then be applied to newly-generated digital models.
Theoretical Contribution	"We see digital tectonic design as a systematic use of geometric and spatial ordinance, used in combination with the details and components directly related to contemporary construction" (p. 1).
Academic Discourse	This theory is representational of the larger scale method of digital tectonic design, while some others may utilize the CNC machine as a smaller scale method. Its focus is on building form prior to the joint being inserted into the geometry.
Epistemological Validity	Kenneth Frampton, Studies in Tectonic Culture, Gottfried Semper's four tectonic elements.

Cross Reference	Seagram Building (p. 2) 860 and 880 Lakeshore Drive (p. 2)

Author	(Deamer and Bernstein), et.
Title	Building (in) the Future [Imagining Risk, Scott Marble]
Date	2010
Content Summary	Marble's definition of craft puts architects far from the term, as he asserts they rely on the skill of the contractors to achieve their ideas rather than being involved with the construction process first-hand. He breaks digital processes into three categories: 1. Geometry replaced with scripts that generate complex form 2. Vast amounts of data organized and attributed to different building components 3. Direct linkage of architects to tools that make their designs (digital fabrication). Marble writes about how cognitive science has factored into how humans think; in terms of data, input translated to computer language. Experiential knowledge is difficult to translate to code, which makes it the area most likely to be lost in computational design, as observed by the author.
Theoretical Contribution	Craft in architecture has long been associated with detail, and today's detail is in managing information and data. With no mediation between design and product (how factory labor is conceptualized), there is an opportunity for today's drawings and models to communicate precise information. Continuing the argument that architects are far removed from craft, Marble asserts modern design avoids risk at all costs through simulations, load calculations, prescribed egress routes, etc. This is fundamentally against David Pye's definition of "the workmanship of risk."
Academic Discourse	Fundamental to working with digital tools, according to Scott Marble is processing information and deciding which bits are relevant simultaneously; this is the mental agility of a craftsman as described by David Pye.

Epistemological Validity	Scott Marble seems to advocate a back-and-forth relationship between human cognition and the computer. "It is the risk associated with interpreting and imagining alternative outcomes that need to be maintained to give craft a new role in mediating between humans and technology" (p. 043). Keywords: workmanship, craft, risk
Cross Reference	David Pye, the workmanship of risk

Author	(Deamer and Bernstein), et.
Title	Building (in) the Future [Intention, Craft, and Rationality, Kenneth Frampton]
Date	2010
Content Summary	Frampton begins by using Hannah Arendt's definition of labor as the biological and work being unnatural to show that the computer is now able to do the labor for humans through things like scripting and parametric modeling. He also comments on the notion of the specialist in architecture being the division of labor in an architectural office, where no one person holds the majority amount of creative authority.
Theoretical Contribution	When it comes to digital craft, Frampton believes that regardless of standardization, it cannot be generic or myopic in production, as different cultures and regions still do impart restrictions based on cost, time, and cultural biases. Frampton calls for proximity between design and construction; architecture is not at a point where it is best for them to be separated. He also believes digital technology should not be devoid of testing and redesign, or where designers create and then wash their hands of any liability post-installation (see Kieran in Design Theory Folder).
Academic Discourse	Digital tools/the computer, can make it more feasible for design and construction to come together, but it cannot be like the automotive factories where American doors are manufactured and expected to be compatible with an Italian vehicle. Standardization is the antithesis of creative craft with digital tools.
Epistemological Validity	For Frampton, architects should act like craftsmen, regardless of the tools involved. It does not mean dividing labor into specialized work Keywords: Homo Faber: the builder of the human cosmos in opposition to the chaos of nature

Cross Reference	Gottfried Semper, Ruskin, Morris: in response to these views, it is not practical to run a horse of goods parallel to the railway (Nagy, p. 557).

Author	(Deamer and Bernstein) , et.
Title	Building (in) the Future [Parametric Profligacy, Radical Economy, Mark Goulthorpe]
Date	2016
Content Summary	The chapter begins by introducing Heidi Gilpin, a client of Hi-D Haus by dECOi studio and former ballet aficionado whose house was a subject of a design project at MIT. The top group developed a script that automatically designed her house using a calligraphic form generating an applet called Springy Thingy that produced forms in a dance-like manner based on a set of parameters. Prototypes could be 3d-printed right from the program for quick review. The author describes a similar project that utilized repetitive geometric generation on the Borromean knot as well as a project adjacent to the Tate Modern in London that was created with a set of parametric guidelines for glazing, window frames, and discharge vents. A final example describes a digital musician who writes ballads via sound-abstracting applets.
Theoretical Contribution	The examples given by Goulthorpe illustrate the creative shift from the human intellect to the obedience of artificial intelligence. In architecture, scripts and applets can be used as tools for form generating, which the author says they could not have imagined on their own.
Academic Discourse	It brings up a discussion regarding the definition of design. It could be argued that designing consists of setting up the guidelines by which the program produces the result, or as Pye puts it, the manipulation of energy flow from one system to the next. Alternative arguments may offer that the computer performed all of the critical thinking while the human was merely the one who keeps the machine running akin to the industrial factory model described by Princen.
Epistemological Validity	Goulthorpe argues that because everything can be modeled informationally in a computer, its construction can be much radically efficient compared to traditional methods. Keywords: parametric

Cross Reference	Pye, T020 Princen, T019

Author	(Buchanan), Peter
Title	Empty Gestures: Starchitecture's Swan Song
Date	2015
Content Summary	The author's purpose is to condemn the starchitectural notion of the building as a jewel, or symbol of a theoretical position (p 2). He assimilates the modernist "paper architecture" to parametrically manifested architecture of today, such as Hadid, Gehry, Koolhaas. He questions the relevancy of computer-generated forms and calls into interrogation the social values of a style that exacerbates what modernism had already instituted (p. 4). Buchanan sites Aalto and Niemeyer as positive examples of socially responsible architecture but qualifies his criticism with the belief that parametricism is not to be altogether abandoned as its powerful tools can help improve the sustainable design and socially responsible architecture (p. 4,6).
Theoretical Contribution	The article takes a stand for architecture that is designed for the human, its needs, and for the environment rather than architecture built for fame, fortune, and form alone. Although digital tools have caused this to be so, Buchanan believes the power of digital parametricism is too valuable to throw out altogether for architecture's future.
Academic Discourse	Critique of contemporary critical practice.
Epistemological Validity	As Mr. Buchanan's piece is almost entirely point-of-view assertions, the value of the article lies in the discussion of how parametric tools are applied to design in today's context.
Cross Reference	The Old Way of Seeing by Jonathan Hale The Nature of the Order by Christopher Alexander

Author	(Crawford B), Matthew
Title	Shop Class as Soul Craft [Chapters 1-2,7]
Date	2009
Content Summary	Chapter 1: A Brief Case for the Useful Arts Crawford describes the trend of budget cuts in high schools that have eliminated many vocational courses in favor of computer literacy. He justifies craft as a psychological element of satisfaction in one's life: "craftsmanship has been said to consist simply in the desire to do something well, for its own sake" (p. 14). Craftsmanship also challenges the ethics of consumerism, which is why it will be challenging to implement shop class back into schools when parents are seeking "knowledge" work for their children versus "manual work" (p. 20). Chapter 2: The Separation of Thinking from Doing Crawford entirely attributes the degradation of work to the separation of thinking from doing (p. 37). He shows how blue-collared workers are degraded by the implantation of abstracted intellect, which in his example is Ford's assembly line. He also highlights the degradation of white-collared workers who are subject to routinization and standardized paper-pushing (p. 44). Crawford is skeptical of the idea that everyone is an Einstein in their own way, regardless of their domain, and argues that creativity is only gained via the mastery of a craft through long practice (p. 51). Chapter 7: Thinking as Doing He uses examples to compare book knowledge with experiential knowledge. One can try to use Ohm's law to fix a voltage problem on a vehicle or, more practically, scrounge around looking for moisture infestations or sand blockages.

Theoretical Contribution	The purpose of Crawford is to highlight the importance of human contact with physical work. The author describes the idea of intellectualization, or the "Albertian split" but uses Henry Ford's assembly line as an example of when it occurred in American economics (p. 31). "The assembly line's severing of the cognitive aspects of manual work from its physical execution. Such a partition of thinking from doing has bequeathed us the dichotomy of white-collar versus blue-collar, corresponding to mental versus manual." He also alludes to the human's natural tendency to just do enough work to get by, and how with the transformation in global economics to encourage debt accretion, workers no longer have options for free will in terms of labor schedules (p. 43). (See also: Logic of Sufficiency, T.019)
Academic Discourse	In the example of HyperGami, a computer program that takes 3d objects and uses mathematics to translate them into foldable paper templates, Crawford explains how experiments with certain types of digital tools cannot be constrained to simple algorithms or rule-following. Origami folding still requires experience to best use the computer, because tolerances of constraint and material are evident in real life that is not in the computer yet. He also shows how the use of technological protocols or self-diagnosing onboard computers on cars will require someone with tacit knowledge at some point in time to address the problems it has detected.

Epistemological Validity	It is interesting to compare Crawford's reasoning for working in the trades with William Morris' theory on skilled labor. It is safe to say that both would be for the proliferation of skilled physical labor, and both use the term "hope," but the hope is portrayed differently. Crawford says, "freedom from hope (in this case, the contemporary hopes of the economic society such as attaining wealth) and fear is the Stoic ideal (p. 53). While Morris described three hopes that the tradesman possessed that the factory worker did not. Keywords: Sophia: Greek for wisdom, used as a skill by Homer (p. 21). Labor sausage: when all of the intellectual activities are split up into ingredients for individuals to complete, and then stuffed back into the final product (p. 40).
Cross Reference	Hannah Arendt, durable objects made by humans, give familiarity to the world (p. 16). Cardoso Llach, the Albertian split as it relates to the assembly line (Erik's assertion) (p. 31). William Morris, hope Marx, alienated labor (p. 38) Martin Heidegger, handing things, leads to knowledge (p. 161).

Author	(Crawford), Matthew
Title	The World Beyond Your Head [Chapter 10 The Erotics of Attention]
Date	2015
Content Summary	Crawford goes into more detail about the phenomenon of isolation of the self that Robin Evans discusses in Figures and Doors (p. 178). Both authors describe a shifted mindset from being socially apt with a preference for connecting emotionally with others to self-centeredness driven by esteem and increased sensitivity to inconvenience. Crawford describes a third shift attributed to the digital age, where our communication is preferred to be highly edited and succinct, while at the same time increasing public; a threat to personal privacy. In the chapter, he critiques techniques for dealing with frustration through imagination, focusing one's attention on less offensive objects, and subliminal rituals people engage in to ground their lives. He compares juvenile development during the 1960s to the 2010s discovering that childhood learning through conflict is not socially desirable today as it was decades ago.
Theoretical Contribution	The author brings into perspective what it means to be aware of the self today. It is not the same as it was 50 years ago, and it changes how people now communicate, how knowledge is shared, how the youth matures, and how individuals assume identities.
Academic Discourse	All of these changes, no doubt, are reflected in design priorities. Just as dwellings separated the individual from outside interference with the corridor, the design is responding to and will change to respond to the demand for unlimited choices for expression, or personal anonymity, as examples. Personal expression is at an all-time high (see Link, P002), but Crawford notes that what is being expressed is usually a re-representation of something in the past (example: hipsters) as a safety barrier against being held responsible for holding an identity.

Epistemological Validity	The chapter critiques points of view on the psychological subject and makes comparisons with past events in order to generate considerations of contemporary affairs.
Cross Reference	David Foster Wallace, This is Water

Author	(Crawford), Matthew
Title	The World Beyond Your Head [Chapter 13 The Organ Makers' Shop]
Date	2015
Content Summary	The organ shop is an excellent example of a Renaissance-era craft still in practice and in demand for its hand-made quality. The organ is something not effectively or efficiently mass-produced, and probably will never be because musical tones are meant for ears, not machines. Crawford introduces another layer that shares similarities with the longing for the "uniqueness of craft" movement in that people are "yearning for their roots" (p. 217). Through his visits with organ makers, the author learns that organ making is about building the best product; if technology helps to achieve the best, then it will be utilized to do so. If traditional materials and tools are the only means by which to achieve quality and guarantee longevity, then the organ makers will stick with tradition. In terms of a lineage of craft, original materials allow a survived language of making and repair between generations—a key point Crawford observes throughout the chapter.
Theoretical Contribution	Stating what he and others have been hinting at, Crawford believes "that we are on a cusp of a new renaissance of small-batch, specialty manufacturing in the United States, and probably in other places too" (p. 211). He also shares Petroski's point of view that using craft as a progressive exercise connects designers to ones in the past-- preferable over the modern mindset of "big bang" creativity which does not allow us to connect to others, our work to be communicative, or methods to be teachable.
Academic Discourse	The point of working in a traditional craft in a modern context is not to replicate historic findings but to act on the same issues the ancients had and improve them with today's materials and methods while still remaining true to the work (p. 244).

Epistemological Validity	The chapter uses an investigative approach to expose firsthand knowledge and rationale based on the human senses of hearing for continuing historical traditions.
Cross Reference	Kant, rational being (p. 209)

Author	(Danto) Arthur C.
Title	The Abuse of Beauty, Aesthetics and the Concept of Art [Chapter 4]
Date	2003
Content Summary	Danto critically examines philosophers and artistic works that deal with the concept of beauty. For a complete analysis, see Knauss, Journal 11. He discusses the issue of creating art which is transparent and directly represents the beauty of a natural object with art that adds its own beauty artificially, as Kant declared (p. 83). Danto also compares internal beauty, "where the beauty of the object is internal to the meaning of the work" (such as Maya Lin's Vietnam Memorial) to external beauty, which is the idea of the natural object alone separate from any thought (Danto gives the example of Duchamp's Fountain, but I find this could be argued either way.)
Theoretical Contribution	The matter at hand is beheld in Danto's book title, The Abuse of Beauty. It is a question of whether or not the creative object is beautiful in itself, or the concept behind it is what is beautiful, but both are used by Danto to show that art and beauty are indeed important to human life. This is in contrast to Hegel's belief that society has moved beyond the point where finding beauty from the senses satisfies the soul, and that only philosophy remains a relevant source for enrichment.
Academic Discourse	This piece is useful simply for the theoretical support to any argument that may need to be made regarding the importance of craft. The reason one crafts, or pursues the arts may be taken for granted or often left unsaid, but Danto connects art and beauty with making and "the deepest interests of mankind and the most comprehensive truths of the spirit" (p. 102).
Epistemological Validity	The chapter is a comprehensive survey of both philosophy and art critique from the Renaissance to Modern Art. Danto presents both the case for art and the case against it (Hegel). His aim is to "show how to use the concept of beauty with a clearer sense of art-critical responsibility than has thus far been the case" due to its hotly debated definition through product and philosophy.

Cross Reference	Kant, beautification, natural beauty, imitation (p. 81). Hegel, death of the arts, artistic beauty is higher than natural Ruskin, the rejection of beautification, in favor of representing stern facts (p. 85) Robert Mapplethorpe, photography that is transparent but not beautiful (p. 82) Charles Caffin, the utilitarian, and the aesthetic (p. 82). Matisse, shift from the beauty of the imitated to work itself David Hume, aesthetics as morality (p. 91)

Author	(Doyle), Shelby Elizabeth
Title	Fabricating Potentials: Constructing Social Engagement
Date	2016
Content Summary	Doyle makes a case for digital craft as being a new tool and method for architects to engage more closely with the social aspects of architecture. As contemporary architecture struggles to rationalize parametric design, she shows how digitally fabricated projects have attempted to enter this dialogue between architecture and social issues, with "no void between them" (p. 8).
Theoretical Contribution	The essay presents a good diagnosis of architectural autonomy. Doyle states that "the search for architectural autonomy is a symptom of lost confidence in the possibility of a truly buildable and simultaneously culturally valid architecture" (p. 4). The problem of architecture being out of touch with social conditions is that it is frequently viewed as a critique within itself, a utopian mindset. Doyle's theory involves realigning architecture with craft-based principles. Because craft encourages imagination, imagination allows the architect to enter into all experiences of life (p. 6).
Academic Discourse	According to Doyle, the ability to craft is to think through making (p. 5). Digital craft is seen as an extension of this agency because it is capable of reaching into social and political realms of architecture. She also states that while digital worlds should not be thought to be replacements for our physical world, they can today be thought of as additional dimensions that give the architect more freedom (p. 13).
Epistemological Validity	Doyle argues that it is a myth that architecture can remove itself from ethics through autonomous practices such as parametric scripting. The way she presents digital tools is more akin to craft ideologies of the Bauhaus, where the designer is more directly engaged with the design, fabrication, and cultural context of the architecture. She emphasizes construction rather than image-making in order to achieve a stronger discourse for digital design.

Cross Reference	80-35 Pavilion (p. 10). Matthew McCullough, “challenges hand making as a prerequisite for craft” (p. 2). Nicolas Negroponte, “interface has become an architectural problem” (p. 3). John Ruskin, master-builder-craftsman relationship (p. 6).

Author	(Edwards), Owens
Title	Famous for His Rocking Chair, Sam Maloof Made Furniture That Had Soul
Date	2016
Content Summary	Sam Maloof learned woodworking at Chafee High School in Ontario and began his career working with scrap wood and palettes to make ends meet for him and his wife. He hand-produced over 5,000 pieces of furniture over his career and intended each one to have both beauty and utility. He saw craft as the ability to work with a piece of wood that contribute to everyday life, and in doing so, he was able to connect with people he made the furniture for. The Smithsonian American Art Museum recently held a symposium on Sep. 16, 2016 "to examine furniture design and production in light of changes brought about by the digital age" (p. 1).
Theoretical Contribution	Maloof believes in learning by doing and embraces not knowing how a specific area is worked so that one is forced to pick up a chisel or tool and allow it to inform. The author defines Maloofs work as "pre-modernist" as it is close to nature, focused on material properties, and displays excellent workmanship.
Academic Discourse	When one speaks of an item "having soul," the root of that particular characteristic is something made by a human's touch. It also relies on the use of materials that are naturally derived, and that have a legacy, or meaning behind them rather than being seen as cheap or mass-produced. These sentiments remain intact even with the use of digital tools rather than rasps or planes, as David Pye would argue.
Epistemological Validity	Although the author, Owen Edwards, describes Maloof as "pre-modernist," it would not be a surprise if Maloof supported the use of digital tools, as he is quoted in saying "whatever tool is needed for a particular job" (p. 1). As his career progressed, he upgraded his materials and his tools, but the spirit behind the work always stayed the same.

Cross Reference	Matthew Crawford, Shop Class, and Soul Craft

Author	(Evans) , Robin
Title	Figures, Doors, and Passages, pg. 55-91
Date	1978
Content Summary	Evans gives the reader a look into the social relationships in the 1500s and 1600s through the study of the floorplan, specifically portals and corridors, used for organizing circulation. What he found is supported by paintings of the time, and shows that the early model for laying out a dwelling space was based on the Classical precedents of open circulation, repetition, and symmetry. It was not until the 1650's that privacy became a design force, where central corridors were then desired to keep the servants separate from the ladies and gentlemen of the dwelling, as well as separating interference from each other (p. 73). These changes in architecture represent changes in social values: one of beauty alone and one of preservation of self; the latter continues today.
Theoretical Contribution	The author approaches the larger conversation in his conclusion, saying that architecture goes hand in hand with art and literature in describing society and its changes, but mainly when reflected upon with symbolism stripped away (p. 88).
Academic Discourse	The use of drawings as a historical tool of record is of particular interest to Evans, who has looked only at floorplans in this chapter. It poses the question of what else can be revealed through the many other types of architectural drawing and increases the value of precedents.
Epistemological Validity	Evans arrives at his insights from first-hand experience and historical interpretations, often finding new ways to redraw what has been done in order to illustrate his thought process.
Cross Reference	

Author	(Evans), Robin
Title	The Projective Cast [Introduction]
Date	2000
Content Summary	Evans sets out to write about the shift from the object to the image, explained by geometry in two types. First geometry: Euclidean geometry used for measuring proportions. Second geometry: projective geometry not concerned with measuring properties of objects, geometry in a plastic state. Evans' focus is on the relationship between projection and architecture between the 15th and 20th centuries.
Theoretical Contribution	The topic of architectural projection was rather undiscussed during the time Evans was investigating it, and he challenges the transparent view of projection with historical narrative.
Academic Discourse	What Evans wishes to show is that architecture can be broken down into principles such as projection, geometry, and mathematics and studied from a historical point of view in order to gain insight into the condition of toady's architectural practices.
Epistemological Validity	Use of first source material from the likes of Philibert de'Lorme, Guarino Guarini, and surveys of historical works between the 1400s and 1900s. A constant tool employed by the author is a cross-reference of the domain of art and the domain of architecture.
Cross Reference	Guarino Guarini, on art and math (p. xxix)

Author	(Evans), Robin
Title	The Projective Cast [Chapter 3, Seeing through Paper]
Date	2000
Content Summary	In this chapter, the author uses a similar approach as Translations from Drawings to compare and contrast drawing projection techniques in painting and architecture in the 15th-18th centuries. The orthogonal & economic ground plan, axial section, and front elevation are compared to the perspective. The latter using light to simulate depth was already in use by Renaissance painters but had not become a necessity until architecture shifted away from Classical order. Light, being the "ultimate geometric instrument" facilitates architectural projection through the use of the parallel line, derived from the ray (p. 108). Using the parallel line, theorists in the 1700s constructed orthographic projective space on a 2d plane using proportion and shadow.
Theoretical Contribution	Evans provides the principles of orthographic projection while explaining the schools of thought in its use. In architecture, the three "flat drawings" could adequately describe a symmetrical building in its entirety, but the perspective was needed to reveal asymmetries and curves. All methods are in use today, while modern artists have shunned perspective as a standard convention because it was believed that vision itself was not perspectival.
Academic Discourse	Modes of drawing remains a viable tool for construction that has not changed in principle since at least the 1400s.
Epistemological Validity	The insights into drawing and orthography provide the possibility of links to making as the possible equivalent to drawing.

Cross Reference	Villa Madam, Rome (p. 112). Philharmonie, Berlin (p. 120). Wolfgang Lots, “The Rendering of the Interior in Architectural Drawings of the Renaissance (p. 107). Alberti Raphael Bramante

Author	(Evans), Robin
Title	The Projective Cast [Chapter 4, Piero's Heads]
Date	2000
Content Summary	Perspective for architecture and a perspective for heads…Evans begins by discussing the differing points of view regarding the truth of the perspective: commenting on light from the last chapter, Evans explains why the perspective is difficult to justify as a truthful representation of sight: because light rays are actually not perfectly straight, (only the concept of their geometry is perfect, something that has been in theory as far back as Platonic dualistic metaphysics) perspective does not take into account the focus of the eye, and have therefore been seen as an untruthful art form, although very similar to vision. He questions whether perspective should be given an unfavorable agency in the arts, and illustrates its breakthroughs. When people came into perspective drawings, it loosened the grip of the grid and the vanishing point and required a new technique for documenting organic forms (p. 136). Piero's Other Method, which uses a field of points to align linear perspective projection, is described as being ahead of its time during the Renaissance to do so (p. 154). The Other Method represents the first technique of recording a complex organic form in perspectival drawing from a 2d source (plan and elevation).
Theoretical Contribution	Piero's Other Method demonstrates that Renaissance perspective can be examined in ways other than necessitated by the vanishing point, light rays, or that Alberti's perspective is representational of Renaissance technique. It shows up in studies by Piero, paintings of Uccello, and architectural drawings of Brunelleschi (p. 176).
Academic Discourse	The Renaissance drawing methods discussed in this chapter are contextual foundations for how physical objects were described on paper. These serve as the precursor to stereotomic drawing, another method used to model the complex three-dimensional object in 2d space.

Epistemological Validity	It is through the comparison of studies between painting, architectural drawings, and critiques by others that Evans develops his justified opinion on the value of the projected perspectival technique.
Cross Reference	Piazza della Signoria, oblique view (p. 176). Alberti Brunelleschi, (p. 176). Piero Uccello
Author	(Evans), Robin
Title	The Projective Cast [Chapter 6, The Trouble With Numbers]
Date	2000
Content Summary	In a similar way in which Evans compares and contrasts painting and architecture to search for themes in truth and theory regarding geometry, he uses this chapter to look into music. Musical harmony has long been associated with architecture's proportions (p. 247). Evans asks if there were such a pure form that regulated both harmony and proportion, then why is it usually not presented as such, and furthermore, when historians find evidence of it, why does it seem intentionally hidden? From Evans' research, it seems as though there is no singular defining proportion that unified architecture, art, and music, rather an assortment of different values that were used to generate work (p. 267). Although visual proportion was usually the final effect in music and architecture, it was not always the first cause (p. 268).
Theoretical Contribution	The underlying concept for this chapter is a search to define consistencies in beauty. Since architects, composers, and artists during the Renaissance were all involved with their craft from design to completion, they did exhibit supreme control out of their final outcome. Some used laws of proportions, some applied mathematics, some used projective drawing, etc. but all relied on some type of rationalism to generate.

Academic Discourse	The ability to structure the physical work as well as the conceptual work is one possible characteristic of an architect that makes or crafts the final outcome of their work.
Epistemological Validity	Validation of the architecture and intrinsic links to the allied arts.
Cross Reference	Pye, David, Esthetics

Author	(Evans), Robin
Title	Translations from Drawing to Building
Date	1986
Content Summary	Evans examines the second of two main routes a drawing, which he calls the "one unfailing communicant," can take an artistic or representational route, or a disembodied approach to communicating information (p. 160). In the example of Turrell's light rooms, the author says that not everything architectural can be arrived at through drawing alone and that if a drawing can't plan out a design, then another way of working is required. He investigates how Philibert de l'Orme's dome drawings at Anet made thought possible, and even obscured truth through misrepresentation (p. 180). Evans longs for history to be written on this deceit instead of the standard approach to analyzing drawings for how they get ideas to construction workers.
Theoretical Contribution	The drawing, in some cases, is not necessary for the final outcome. Sometimes physical experiments are favored when a drawing cannot describe what is being generated physically. Since this is so, drawings have the capacity to fill in the gap between drawing and building in any sort of manner; the architect deems excitable or symbolic.
Academic Discourse	The drawing will always be a tool for design, but the context under which it is generated or the point of view from which it is drawn will vary. It is possible for drawings to be generative as well as post-rationalizations of ideas, but either way, they both translate information between the cognitive and the physical.
Epistemological Validity	Evans arrives at his insights from first-hand experience and historical interpretations, often finding new ways to redraw what has been done in order to illustrate his thought process.

Cross Reference	Royal Chapel, Anet (p. 174). Turrell, illuminated spaces (p. 159). Premier Tome de l'Architecture sterotomic diagrams (p. 177)

Authors & Editors F-J	
Author	(Frampton and Cava), Kenneth
Title	Studies in Tectonic Culture [Introduction]
Date	1995
Content Summary	Unlike Evans, Frampton does not directly associate architecture to art, stating that architecture is an object to experience with the body, not just a sign. His definition of tectonics is derived from an investigation of the Greek etymology: a craftsman working with all hard materials, and he also provides examples of atectonics (p. 4). According to Frampton, there are two fundamental building crafts: the tectonics of the frame, and the stereotomics of mass (5). He covers meaning through cultural values, acknowledging that the power of craft is often found in cultural truth; the ultimate truth of a building is its durability and duration (p. 27). Thus the importance of tectonic craft from multiple levels is the subject for his book.
Theoretical Contribution	There is much evidence to suggest that Frampton approaches architecture with an anti-metaphysical point of view. He references many monist influencers in philosophy to describe tectonics and craft as a physical, rather than symbolic practice. He does not say, however, that the metaphorical aspect of tectonics is not essential, but anchors his theoretical position in Manfredo Tafui & Francesco Dal Co's statement: "what needs to be done, instead, is to trace the entire course of modern architecture with an eye to whatever cracks and gaps break up its compactness, and then to make a fresh start, without, however, elevating to the status of myth either the continuity of history or those separate discontinuities" (1).

Academic Discourse	The author does speak about the use of technology and its tendency to devoid an object's material properties from its natural existence. Again with Heidegger as an example, Frampton believes that tectonics should help show how an object was constructed, held together, formed, etc. (p. 23). On the topic of tradition in craft, he explains how innovation for the sake of radicalism holds no weight compared to the progression of craft rooted in a legacy of cultural origin (p. 24). This concept may, however, include the use of technology to continue tradition (evident in the organ maker's shop [Crawford]).
Epistemological Validity	The introduction to Studies in Tectonic Culture is heavily grounded in architectural theory and philosophical arguments from first source authors. These concepts are used to illustrate the different points of view throughout history on tectonic culture.
Cross Reference	Casa Vicens, vaulting (p. 6). Gogo houses of Tanzania, infill wall detail (p. 7) Town Hall, Alvar Aalto (p. 12) Stoclet House, (p. 20) AEG turbine factory (p. 21) Manfredo Tafui & Francesco Dal Co's (p.1) Viollet-le-Duc (p. 1) Gottfried Semper (p. 1) Le Corbusier (p. 2) Giorgio Grassi (p. 2) Vittorio Gregotti (p. 8) Merleau-Ponty, experiencing through the senses (p. 11). Martin Heidegger, letting things be (21)

Author	(Frampton and Cava), Kenneth
Title	Studies in Tectonic Culture [Chapter 9 Carlos Scarpa and the Adoration of the Joint]
Date	1995
Content Summary	Carlos Scarpa's works are examined in depth in this chapter with an emphasis on the way he strings together building components with the crafted joint. Scarpa, who works symbolically as well as performatively, drew influence from Chinese craft as well as Giambattista Vilo and Carlo Lodoli. His architecture is described by the author as cinematic and the epitome of tectonic authenticity (p. 332).
Theoretical Contribution	It is evident that Carlos Scarpa was pursuing truth through making. His involvement from drawing to fabrication was highlighted by his planning of drilled saw stops at an angled metal connection. Scarpa was not concerned with following the trend of creating a corporate identity in style. Instead, he celebrated materials through the craftsmanship of tectonics and fine-tuning the sensory responses to them.
Academic Discourse	The author covers a bit of Scarpa's process, which is described as a gestural impulse from drafting to making (p. 307). He used a three-step drawing process (308): 1. initial cartoon concepts on stiff ochre 2. details overlaid on trace 3. colored pen and crayon overlaid to indicated materials and layers Scarpa was also fond of archaic building elements but found new ways to interpret them (p. 309), such as the delayed loading of the columns' moment support.
Epistemological Validity	Frampton's chapter is a tectonic analysis drawing from plans, sections, sketches, and studies from other architectural critics.

Cross Reference	Fondazione Querini Stampalia (p. 299). Banca Popolare di Verona, column detail (p. 310) AEG turbine factory, column detail (p. 311) Neue Nationalgalerie, column detail (p. 312). Olivetti shop (p. 312) Museo di Castelvecchio (p. 313) Gavina store (p. 315) Banca Popolare di Verona (p. 315) Brion Cemetery (p. 316)

Author	(Frampton and Cava), Kenneth
Title	Studies in Tectonic Culture [Chapter 10 Postscriptum: The Tectonic Trajectory 1903-1994]
Date	1995
Content Summary	Chapter 10 covers the many forms of tectonic expression during the 20th century: It begins with Berlange & Otto Wagner and the beginning of cladding over the frame (p. 336). Le Corbusier and his use of vernacular architecture that bleeds into modern techniques and materials (p. 345). The work of Wright, Hertzberger, and Kahn that articulates space and circulation through a structure (p. 350). Aalto's use of wood, truss, and frame (p. 356). The rise of New Brutalism (p. 360), tectonic minimalism (p. 363), and high tech architecture (p. 367). Re-interpretation of Classical stadia in modern venue design (368).
Theoretical Contribution	The tectonic is the means by which cultural tradition is captured and shared with the users (375). Frampton makes another case for Truth in architecture to be found in tectonics, stating, "one can argue that the tectonic resists and has always resisted the fungibility of the world" (p. 375). The author's last question asks how does tectonic trajectory continue, and what will be its form in a postindustrial society that sees the world as a singular commodity (p. 376.)
Academic Discourse	The scope of Frampton's research ends before the prevalence of digital craft, but principles from the myriad of precedents provided in his work are of value: -tectonics manifest regional expression & culture -tectonics adapt and evolve through technological innovation -tectonics is the syntax for the larger building -tectonics promotes homogeny between architect/designer + the engineer/fabricator
Epistemological Validity	see T003

Cross Reference	Project for Gentil Bridge, Calatrava, 1988 (p. 336) Boots pharmaceutical plant, Williams, 1932 (p. 336) Stock Exchange, Berlage, 1903 (p. 339) Diamond Workers' Union, Berlage, 1903 (p. 339) List of engineers (p. 335)

Author	(Gershenfeild A), Neil
Title	Fab: The Coming Revolution on Your Desktop—from Personal Computers to Personal Fabrication
Date	2007
Content Summary	Fab describes machines developed and researched by MIT called personal fabricators that changed the way knowledge was shared and distributed in a class setting (p. 7), and put creation control through technology into the hand of the individual, rather than the manufacturer (p. 8). He also explores how personal fabricators could be used in different areas of the world, not as fortunate as MIT, to eventually self-produce a "fab-lab" out self-replicating parts and machines (p. 12). According to the author, the restriction to PF is currently the lack of knowledge of the possibilities of the technology. The latter part of the chapter is a brief overview of a series of projects produced in his MIT course.
Theoretical Contribution	Gershenfeld's discoveries in his course at MIT resonate with other conclusions about digital craft: the individual desire for personal value is a key catalyst for the increasing demand for digital tools. He makes the case that some of the world's least developed regions can benefit the most from advanced technologies (p. 14) and that commercialism will evolve into individual services with PFs (p. 15).
Academic Discourse	Gershenfeld's research shows that we are on the verge of a digital fabrication revolution. We will soon be able to print parts that assemble conductors, semiconductors, and insulators to make machines that make machines, empowering the designer-producer.
Epistemological Validity	The author justifies his claims with comparisons to the development of the PC, but most of his research is new and unadvertised.

Cross Reference	

Author	(Hayles)(Hayles), Katherine N.
Title	How we Became Post-human: Virtual Bodies in Cybernetics, Literature, and Informatics.
Date	1999
Content Summary	This text searches for answers to the boundaries between humans and machines and how we are evolving or devolving with technology. It probes the question of what might be preserved that makes us "human" and will we continue to value the "liberal subject" or alienate it. Provided is an outline of discursive understanding of cybernetics, or the science of communication and automatic control systems. These critical moments of understanding resulted from what has been become know as the Macy Conferences held between 1945-1954 and help define the epistemological foundation of cybernetics. Hayles explains this in three plateaus of understanding (page 10-11): The first model of cybernetics grew out of an understanding of the biological systems of homeostasis. The concept is founded on the idea that living organisms have the ability to maintain steady states regardless of environmental changes. Therefore, information was seen as a quantifiable choice in a feedback loop with the organism regardless of environmental conditions. The programmer feeds input data, and the machine returns output in a binary loop. From dialogue and debate came the understanding that cybernetics may also emulate the biological system of autopoiesis or a self-encoded system that develops not but what it observes but how it is encoded to respond to its unique needs. The ideas presented the possibility that systems construct reality rather than observe it and that system components could work together to replicate themselves. Autopoiesis leads to a larger understanding of emergence. This is to say that the system has the ability to evolve on its own. This is seen in contemporary systems of virtual reality, augmented reality (AR) and Virtual reality (AI). Emergence uses the feedback loop of information understood by homeostasis but

	adds both an input and output of information, thus collecting, processing and evolving independently. Hayles provides the following "suggestive" rather than a prescriptive list of what post-human view is (page 3): The post-human view privileges informational pattern over material instantiation, so that embodiment in a biological substrate is seen as an accident of history rather than an inevitability of life. The post-human view considers consciousness, regarded as the seat of human identity I the Western tradition of long before Descartes thought he was a mind thinking, as an epiphenomenon, as an evolutionary upstart trying to claim that it is the whole show when thin actuality it is only a minor slideshow. The post-human view thinks of the body as the original prosthesis we all learn to manipulate so that extending or replacing the body with other prostheses becomes a continuation of the process that began before we were born. The post-human view configures human being so that it can be seamlessly articulated with intelligent machines. In the post-human, there are no essential differences or absolute demarcations between bodily existence and computer simulation, cybernetic mechanism and biosocial organism, robot teleology, and human goals. Hayles divides human practice and knowledge into two dualities: first, an incorporating practice that is encoded into bodily memory by repeated performances until it is habitual. Apposing is inscribing practices that can be cognitively mapped and encoded (page 199). The implications of the post-human are explained by Hayles through a semiotic square diagram framed by evolving and devolving incorporation and inscription. The diagrams describe the possibilities of our symbiotic relationship with technology. One scenario is that human's incorporation devolves along with the devolution of inscription; this will result in only information. Alternatively, both incorporation and inscription can evolve and converge to achieve materiality.

	Evolved incorporation (action) and evolved inscription (levels of coding) can achieve materiality (embodiment). Hayles continues by providing five distinguishing the characteristics of knowledge gained through incorporative practices (page 205). Incorporated knowledge retains improvisational elements that make it contextual rather than abstract that keep it tied to the circumstances of its instantiation. It is deeply sedimented into the body and is highly resistant to change. It is incorporated knowledge is partly screened from conscious view because it is habitual. Because it is contextual resistant to change and obscure to the cogitating mind, it has the power to define the boundaries within which conscious thought takes place. When changes in incorporation practices take place, they are often linked with new technologies that affect how people use their bodies and experience space and time. Hayles continues to summarize by stating: Formed by technology at the same time that it creates technology, embodiment mediates between technology and discourse by creating new experiential frameworks that serve as boundary markers for the creation of corresponding discursive systems. In the feedback loop between technological innovations and discursive practices, incorporation is a critical link.
Theoretical Contribution	Hayles contribution clearly rests in the area of cybernetics and literature. However, her definitions and defined characteristics of inscription and incorporation practices fall within the epitome of post-digital craft. The encoded mapped variable alongside the improvisational human.
Academic Discourse	The discourse surrounding the post-human is still evolving since the publication of this text in 1999. Although engineers are no closer to developing a truly sentient machine, the discourse continues around what post-human means and if it is a positive evolution or negative devolution. Questions of the validity of embodiment and if materiality (human form and action) are

	necessary for being human or an intellect, knowledge, and experience be fully "downloaded" to a machine (cells to bits).
Epistemological Validity	The inclusion of this text is an epistemological transfer of domain that could be seen as invalid. Therefore, the validity of architecture is narrow in scope to include the primary chrematistics of inscription and incorporated knowledge. This boundary provides a framework to speculate on scenarios whereby technology and human are intertwined. This framework allows for valuable discourse around what is essential to humanness and what is not. It allows the research to ask the question: are we extending our abilities or devolving into information.
Cross Reference	Daugherty, Human + Machine Harari, Homo Deus Schwab, The Fourth Industrial Revolution

Authors & Editors K-O	
Author	(Kolarevic), Branko
Title	Digital Production
Date	2011
Content Summary	Details various techniques of digital production including NURBS, point clouds, laser scanning, CNC machinery, milling, additive fab, stereolithography, selective laser sintering, 3d printing, laminated manufacture process, fused deposition modeling, multi-jet manufacture, contour crafting, formative fabrication, digital assembly, monocoque structures, construction robots, production strategies, rationalizing curves, Gaussian analysis, composites, intelligent materials, and mass customization. Kolarevic asserts that fully automated construction is possible, and the industry will slowly evolve over the next several decades in the direction of autonomously erected architecture (p.39). He discusses the empowerment from the architect, limiting design to what could be built to the architect that could fabricate anything made possible by digitally represented design. The author projects that digitizing design will achieve buildings that are alive (p. 51).
Theoretical Contribution	Kolarevic provides examples of digital production as evidence of architecture's next era of autonomous design and custom craft.
Academic Discourse	Survey and overview
Epistemological Validity	An objective catalog of the tools is provided to support the position.

Cross Reference	William Mitchell (p. 32) Skidmore, Owings, and Merrill (p. 32) Cathedral of St. John the Divine stones, NY (p. 35) Sagrada Familia Church columns, Barcelona (p. 35) Walt Disney Concert Hall stone skin, LA (p. 35) Conde Nast Cafeteria laminated glass panels, NY (p. 35) Bernard Franken's "Bubble" BMW pavilion (p. 35) Zollhof Towers, Dusseldorf load-bearing panels (p. 36) Rose Center for Earth and Sciences truss elements, NY (p. 37) LeCuyer, using digital assembly in the aerospace industry (p. 39) NatWest Media Centre monocoque structure, London (p. 40) Jakob+ MacFalane Georges Restaurant monocoque (p. 40) Statue of Liberty frame and contoured skin (p. 42) Sydney Opera House roof tessellation (p. 45) DG Bank glass roof tessellation, Berlin (p. 45) Great Court in British Museum glass roof tessellation, London (p. 45) Peter Zellner, custom manufacturing (p. 53)

Author	(Leach), Neil
Title	Parametrics Explained
Date	2014
Content Summary	Leach examines the difference between the term "parametric" and "algorithmic" as it pertains to design, and its use in and influence on contemporary architectural practice. While the term "parametricism" is often confused as the combining of both terms, parametric means to work within parameters of a defined range (BIM, CATIA, Digital Project), and algorithmic means to use procedural techniques (scripting) in solving design problems. Leach also points out that both tools have allowed for more efficient computation of curvilinear forms, and it is because of this efficiency that the parametrically curved buildings became popular, as well as the view that parametricism is the new global style. Another critical distinction is that parametric techniques are based on form manipulation, and algorithmic is based on code. When code is visualized into icons or diagrams, such as Grasshopper, Leach argues it becomes less of a potent tool because the user relies on his knowledge of simplified scripting rather than true coding.
Theoretical Contribution	There are many designers and architects that consider scripting through things like Grasshopper to be innovative, but according to Leach's argument, users are limiting technology's potential by not learning true code. It is a similar condition to the machine controlling the user rather than the user controlling the machine, as illustrated by the parallel drawing boards of decades ago that encouraged rectilinear designs over curvilinear.

Academic Discourse	Leach argues that today, architectural ideas are being disseminated more effectively before and in a greater amount, so in theory it should become more accessible for the architect to pick up on new coding abilities and, thus, new design abilities through the computer. Parametric design still mainly remains in the diagramming stage, as most significant firms use CATIA or Digital Project for construction documentation. Leach asks what happens when new codes are bred, and the diagram becomes a reality, and reality is in the diagram simultaneously.
Epistemological Validity	This article seems to push for some solutions to Vidler's critique on architectural diagramming (see Design Theory folder), but also illustrates Robin Evans' argument on the "disadvantaged architect": "As the late Robin Evans noted, this is "the peculiar disadvantage under which architects labor; never working directly with the object of their thought, always working at it through some intervening medium, almost always the drawing, while painters and sculptors, who might spend some time working on preliminary sketches and maquettes, all ended up working on the thing itself." (Translation from Drawing to Building and Other Essays p. 156). Keywords: Parametric, Algorithmic
Cross Reference	

Author	(Link), Jeff
Title	5 Ways Architects Are Redefining Craftsmanship For a Post-digital Age
Date	2016
Content Summary	The link describes how top fabricators are: 1.Engaging with materials in a way that hasn't happened since industrialization (p. 2) 2.Replicating old building methods with today's technology because the traditional style is of value but the methods are inefficient by today's standards (p. 3) 3.Using parametric modeling to jump up in scale (p. 4) 4.Reversing the process of design and fabrication to confront the process in which a machine will interpret the designer's inputs first before fabrication even begins (p. 5) 5.Realizing that in today's society, value is shifting towards more individualism and, thus custom, or bespoke, products rather than mass production.
Theoretical Contribution	While he does not provide his own definition of digital craft, Jeff Link explores five key characteristics of digital craftsmen that are shared with craftspeople of centuries ago.
Academic Discourse	Comparisons between epochs such as comparing contemporary craft to traditional craft, social values of design of the present to those of the industrial age, and methods of efficiencies between now and then are used as a discourse in Link's article.
Epistemological Validity	Link acquires professional knowledge from three principals in the field who hold dear the importance of their work.

Cross Reference	Wes Mcgee and Brandon Clifford (p. 1) Periscope: Foam Tower (p. 2) La Voute de LeFevre stereotomy (p. 2) Guy Martin (p. 3) Trois Mec milled barstools (p. 3) Cypriere milled table (p. 3) Alvin Huang (p. 5) Chelsea Workspace CNC desk (p. 5)

Author	(Binkley et al.)
Title	Six Years, The Dematerialization of Art
Date	1997
Content Summary	The authors' area of study is between 1966 and 1972, where ultra-conceptual art attempted to highlight the thinking process behind art rather than the making of any kind of physical object. The summary includes a brief timeline of five zones of art: 1. pre-aesthetic, biological mimicry 2. traditional aesthetic, magic, and ritual related art 3. emotional-aesthetic, self-expressing art, "art for art's sake." 4. rational-aesthetic, empiricist, experimental, and novel art 5. post-aesthetic, the scientifically-based abstraction, and liberation of the idea from medium
Theoretical Contribution	They propose that one reason art may have dematerialized is that it creates less and less for someone to comment on, which allows for more and more interpretation. They also predict that the "dematerialization of the object might eventually lead to the disintegration of criticism as it is known today" (p. 49).
Academic Discourse	Conceptual art need not be materialized.
Epistemological Validity	They are not entirely talking about art or craft within the computer yet, as McCullough does, but the common theme that dematerialization creates "multiple realisms" can be said to be behind both art in the '60s and digital art.
Cross Reference	Malcolm McCullough, the medium being the message vs. the medium carrying the message

Author	(Llach Cardoso), Daniel
Title	Builders of the Vision: Software and the Imagination of Design
Date	2015
Content Summary	Chapter 1: Introduction: Seeing Software as a Cultural Infrastructure Daniel Cardoso Llach was an MIT researcher who also worked for Gehry Technologies in the UAE, so most of his experience is either first hand, or gleaned from records at MIT, the birthplace of Computer-Aided Design. The book frequently refers back to the idea of the "Albertian split," which was when design became intellectualized by privileged designers, and fabrication was considered to be a passive task. Through his experience and research, Cardoso Llach views CAD as a cultural infrastructure critical to how the world has arrived at its point in architecture today. In the introduction, he briefs the reader on his methods, points of view, and sites worked in. Chapter 2: Codification before Software The author begins in 15th century Italy, where wealthy patrons employed craftsmen over other skilled tradesmen in order to achieve extensive designs. It was also during this time that drawings emerged as intellectual property of the designer in authority (p. 12) (as opposed to the ownership of the trait by the stone cutters, See: Knauss TechJournal2). Designers developed what the author defines as codification, where materials and ideas of physical worlds are inscribed in a drawing form (p. 13). This eventually enabled architects to see themselves as a higher power than craftsmen but became a paradox when this gap diluted their knowledge of building practices, contradicting the goal of authority. This paradox has developed the Western value of architects viewing themselves as "crafters of abstraction," a fundamentally Cartesian concept (p. 15). In the 1850's United States, the Beaux-Arts schooling model facilitated another divide between the theorists of design and the technically oriented groups, which were exasperated by a militarized society that relied on machine production and corporate models of doing business (p. 22). Llach illustrates this

	divide through the mind of Frank Gehry, who saw that the client could too easily approach the builder in order to usurp the architect's chief authority, which was devaluing the architect. For Gehry, the computer makes sure that everything the architect designs is pre-solved and leaves no room for the builder to compromise on the architect's intellectual assertions. Chapter 3: Software Comes to Matter Physical coding is the "matter," which Cardoso Llach references in the title, as the first successful method of controlling a machine was Joseph Sacquard's loom, which used perforated paper sheets to automate needle patterns (p. 34). This strategy was employed on milling machines at MIT that was controlled by punched tape, and eventually led to developing a language for toolsets, and software. Although it was MIT credited for developing numerically controlled machines, it was John T Parsons of Parsons Corp in Traverse City, MI that had the first vision for numerical control while working on an Air Force sponsored project (p. 38). The author talks about how CAD's development owes itself to the Cold War government efforts that pushed technology research (p. 40). The other meaning of "matter" occurred when the software for CAD was finally worked out, and designers using it saw themselves as "freed" by the computer and no longer shackled to working with physical materials. Cardoso Llach relates this to the contemporary view on 3d printing and parametric design. Chapter 4: Perfect Slaves and Cooperation Partners Steve Coons, the inventor of CAD and professor at MIT, saw the computer as the human slave (p. 57). Coons view on creative authorship when the computer is used by a human is akin to making music with an instrument; the result is still owned by the human (p. 62). Originally, CAD's intent was to allow human ingenuity to prevail over computer automated design work, similar to the idea behind the Albertian split (p. 65). The CAD inventors envisioned CAD not only drawing a design but building it along with its inherent information and properties within the computer (p. 67). The author aligns this to the Renaissance-era

	development of perspectival drawing (p. 67) (see also: T.016, The Projective Cast). Larry G. Roberts is credited with the first 3d program (p. 68). Chapter 5: Computer-Aided Revolutions Nicholas Negroponte was first to link CAD with architectural projects during his time at MIT, looking at urban applications in 1967. His works Urban 5, Arc Mac, and The Architecture Machine portrayed CAD not as a slave, but as a neutral party capable of liberating society from design middlemen and solving social strife. This twisted the theory regarding CAD into a more "humanizing" the machine and its ethics (p. 79). The author described how "Arc Mac's work anticipates a desire—and a market—for digitally produced mass-customized goods" (p. 82), which echoes loud and clear today (see P.002). Today, "the algorithmic conception of the natural" drives contemporary computational design today (p. 83). Chapter 6: Visions of Design When CAD technologies became more prevalent, it created a questioning of what design meant when utilizing the software. Was it to draw something in the computer design enough? Or was using the computer to run scripts the new avant-garde? Cardoso Llach showed how conflict arose between the inventors of Rhino, who saw their software more like physical clay modeling, with developers of BIM, who's definition of the design lay in the coded information of digital models. The author again uses Gehry to illustrate a design process that begins analog with physical modeling, and then digital tools that reinterpret forms through laser scanning and rationalizing. Chapter 7: The Architect's Bargain Chapter 7 begins part 2 of the book, where Daniel Cardoso Llach discusses some of the uses and difficulties of CAD from his experience in Dubai. He illustrates how the workforce in Dubai is made up of many different nationalities, and that the working conditions are borderline slavery since the workers are not allowed driver's licenses. The architect's bargain is using these workers for the lucrative gains that designing in an oil-rich

	area offers. Cardoso Llach comments that most of the starchitects see themselves as global actors, but don't worry about the local problems (see T.001, Empty Gestures). Concerning CAD and BIM implementation on this project, it can either be used as a universal language as a utopian value or can be received as just another struggle with the many languages and skills present at the job site. Chapter 8: Contesting the Infrastructure The author uses this chapter to expound upon what he brought up in the previous one regarding BIM implantation. It is a mandate that all government-sponsored projects be produced with a building information model, but as Cardoso Llach shows, this is not always received well. Many architects see it as a formality, and in his case, the BIM team was actually updating the model off of 2d drawings as redundancy in order to fulfill the mandate. This was not what the inventors of CAD intended for BIM, as it completely reversed the idea of the friendly slave and made the unskilled humans working on the model a slave to technology. Chapter 9: Rethinking Redundancy A final spin is put on redundancies in practice. He describes how inefficiencies and shortcomings with digital modeling are a part of a large sum of wasted capital in the architectural industry, but he extracts a positive out of redundancy. As he states in his chapter summary, "In the struggle to use the software as a way to bridge the gap that separates design from technique, I reveal 'redundancies' not as problems to solve but as the fundamental dynamic of design and building practices" (p. 11). He argues that redundancy is crucial to the architect-fabricator gap in developing trust and understanding. A healing measure to the Albertian split.
Theoretical Contribution	The central theoretical position on display in Builders of the Vision is the notion of separation between a designer and a builder. People like Coons show a very different view regarding materials to that of Frampton or Voulkos that arose in the design industry upon the adoption of CAD technologies. People saw

	the computer as a means to free themselves from the messiness of working with materials, but it all stems from the Cartesian idea of intellectual control.
Academic Discourse	The book brings perspective to the original intention of CAD, which was to be an aid to the human's design process, but not to become the sole tool for architecture. That use sprouted from military models of fabrication and was adopted by a commercial design sector in order to improve efficiency and explicitly dictate design specifics to the fabricator.
Epistemological Validity	Cardoso Llach views CAD as a cultural infrastructure critical to how the world has arrived at its point in architecture today. He admits that he does not care for the fetishization of autonomous digital tools, which is curious given his proximity to the development of CAD technology. The author also expresses concern that design has become watered down because of the frequent use of CAD and digital modeling (p. 013). Keywords: Codification Design authority Albertian split
Cross Reference	Malcolm McCullough, "exploring digital design practices as both embodied and expressive" (p. 5) Robin Evans, trait (p. 16) Charles Babbage, conception v. making (p. 41). Frank Gehry, designing with models than with computers (p. 25)

Author	(Moholy-Nagy and Miles)
Title	Experiment in Totality
Date	1971
Content Summary	The excerpt provides clarity of comparison between Laszlo Moholy-Nagy, and his spouse Sibyl Moholy-Nagy (See: Native Genius in Anonymous Architecture, V.002)
Theoretical Contribution	“And this reality of our century is technology: the invention, construction, and maintenance of machines. To be a user of machines is to be of the spirit of this century. It has replaced the transcendental spiritualism of past errors. Before the machine, everyone is equal: I can use it, so can you. It can crush me, and the same can happen to you. There is no tradition in technology, no consciousness of class, or standard. Everyone can be the machine’s master, or it’s a slave. This is the root of Socialism.” (p. 20-21).
Academic Discourse	This is the opposite view of William Morris, which finds more relevance today than in the 19th century. Although (Erik’s Assertion): I argue that not everybody is equal sitting behind a computer whether it be for the knowledge of software, or the possession of unequal design skills, and experience.
Epistemological Validity	While Sibyl speaks to the natural (1957), pre-Palladio, and pre-religious condition as the great equalizer of the anonymous builder, Laszlo (1922) speaks to the machine as the great equalizer. Both seem to take two different but similar routes from the Ruskinian and Morris theoretical position regarding social working conditions.
Cross Reference	John Ruskin, Socialism and the three hopes, the elevation of the natural (D.003).

Author	(Morris and May Morris), William
Title	Useful Work Versus Useless Toil
Date	1986 (original:1884)
Content Summary	Morris points out that because of nature, all men are required to work. The difference between work that is enriching to the laborer (useful work) and work that slowly kills him (useless toil) is hope (p. 28). Three hopes specifically set apart work, which is good from work, which is bad: the hope of rest, the hope of product, and the hope of pleasure in the work. Morris says that because of the upper-class oppression on the working class, there is no hope for labor and is the same as slave work. His solution is a Socialist approach that requires each man to work "as well as he can for his own livelihood" (p. 30).
Theoretical Contribution	Although a utopian Socialist mindset, Morris' three hopes is a valid assessment of what makes labor an enriching act and not a dreaded task. The hope of rest allows the worker to be aware that he will have time to physically and mentally restore at some point each day, which improves the quality of the work. The hope of the product brings a sense of accomplishment, and hope of pleasure is manifested through the use of creative skill, which Morris alludes to setting humans apart from the beasts (p. 28).
Academic Discourse	Contrary to 1884, today, the question of whether or not to use the machine in work is not a revolutionary one. Mechanization and technology are here to stay and has shown evidence of how it can be used both as a slave for human work and as a generator of creative intellect. It can be argued Morris' three hopes are still attainable through the use of digital tools as facilitators to complete work, and it is also apparent that digital tools as a social infrastructure can re-enslave the human (See: Builders of the Vision, T.022).

Epistemological Validity	With influence from John Ruskin's theories on the moral and social implications of craft, Morris continues the argument for the hand made and the creative authority of the human over the machine. According to him, if the social balancing of labor is affected, humans would be better than machines. There are many who misunderstand Morris for being in direct opposition to machines, and while he does not fully support them as substitutes for creative authority, he does not outright condemn them in this lecture either. (Erik's Assertion): I would be inclined to think that he would share the same idea as Steve Coons, viewing the machine as a "friendly slave" in order to replace the useless toil as part of his socialist solution.
Cross Reference	John Ruskin, emphasis on handcraft and natural material Steve Coons, machine as a slave

Author	(Nilsson), F.
Title	Architectural Assemblages and Materializations-Changing Notions of Tectonics and Materiality in Contemporary Architecture
Date	2013
Content Summary	The paper looks at a few approaches of materials and tectonics being employed by architects and theorists: Bruno Latour: buildings have been thought of as static things but are never in the same state of construction or repair; therefore, the matter is too complex to be represented on a CAD screen (p. 410). Manuel DeLanda: assemblage theory states that the more abundant form cannot exist separately without aggregated components. Jesse Reiser & Nanako Umemoto: materiality today has to do with how something performs (p. 411), but something should be both structural and atmospheric (p. 412). Kas Oosterhuis: all building elements can act as intelligent actors that inform the building and change the building even after initial construction. "They are not bricks and mortar, neither are they exclusively bits and bytes" (p. 413). He seeks to merge the virtual and the real. Lars Spuybroek: uses the computer as a constructional tool, not as a representational one, and argues that "experience counts as the main form of involvement" (p. 413).
Theoretical Contribution	"Information technologies not only influence the conception of the design and the production processes but also are embedded in the materials and components, influencing our experience of and interaction with the built" (p. 413).
Academic Discourse	The author talks more about the larger purpose and methods of tectonics and materials than specific examples of practice. Many writers on the topic of digital tectonics tend to center around the design actions and production tactics and stop there. Nilsson focuses on theory but also touches on digital tectonics applications within a completed building and beyond just the design stage.

Epistemological Validity	There are similarities to other authors such as Anne Schmidt when it comes to representing architecture versus constructing it with digital tools. Keywords: Assemblage, Semperian reversal
Cross Reference	

Authors & Editors P-T	
Author	(Pallasmaa), Juhani
Title	The Thinking Hand: Existential and Embodied Wisdom in Architecture
Date	2009
Content Summary	Introduction: Embodied Existence and Sensory Thought Our bodies are subjects of what Pallasmaa calls commercial manipulation. Although the Cartesian concept of mind-body separation still rules education, culture, and capitalism, he asserts that we are connected to the natural world with our senses: "I believe now that even one's sense of beauty and ethical judgment are firmly grounded in the early experiences of the integrated nature of the human lifeworld" (p. 012). He references Martin Heidegger's concept of the hand directly connected to thinking, claims the hand as the "executor of intentions of the brain" (p. 021). Juhani sets out a clear case for the natural and for handwork. Chapter 1: The Mysterious Hand The chapter covers the basics of the body part, including its essences, its definition, relation to the eye, brain, and language, symbolic meaning, gestures, and sign language. Scientists attribute tool use, which began 3 million years ago, with the hand as a proponent of evolution and the development of the brain, and led directly to language development. (Erik's assertion): With this in mind, tool use is natural to the development of the human brain and helps to explain why we today have an affinity towards the natural and the hand-tool made. Chapter 2: The Working Hand Pallasmaa provides a definition of the tool: "an extension and specialization of the hand that alters the hand's natural powers and capacities" (p. 047). He describes how the tool evolves gradually, similar to how Henry Petroski describes the evolution of useful things. The tool is something that merges with the body to achieve a result, but a computer mouse is not interchangeable with a pencil or ink pen (p. 050). (Erik's assertion): I am not

	convinced that Pallasmaa means that the computer mouse cannot become one with the body, I read it as he sees an obvious set of differences in how the computer mouse can be used compared to a charcoal pencil compared to a pen. Each has its own limits that the user must acknowledge before use. In this chapter the author also states that craft is imagination with the hand (p. 052), being a craftsman implies collaboration with his material (p. 055), and really makes a case for drawing by hand (p. 059). On the relationship between the architect and the fabricator, he believes challenging designs are good because they foster a commitment to the work and pride for the contractor (p. 063). (Erik's Assertion): He probably is not thinking about collaborative design at this point at the business level that Building in the Future is, but he does mention collaborative craftsmanship which describes the mature architect understanding the unspoken languages and material knowledge of the master craftsmen he works with (p. 063). Chapter 3: Eye-Hand-Mind Fusion Pallasmaa directly references David Pye and his concept of "workmanship of risk" and "workmanship of certainty and applies it to architectural processes today where the firms willing to take the creative risk often come out with better designs. He extends this idea to fishing, as Finnish architect Reima Pietila compared design to casting the line never certain on what you'll catch. Fellow Finn Alvar Aalto is admirable for his ability to hand draw from instinct, and Mark West's making processes have both evolved from this spirit of experimentation. Pallasmaa also attributes creativity to having "the art of solitude" or time to ponder (p. 081). Chapter 4: The Drawing Hand Hand drawing does three things: it puts visual residue on actual paper, it makes a historical record of an image, and it develops muscle memory for the self. He compares the memory of sketching a holiday scene with the act of photographing one where he barely remembers ever being at the photographed site (p. 092). The comparison between the hand and the digital is a

	theme in this chapter. While he believes computers have been good for efficiency and accuracy, he does not condone the use of computer drawing at the schematic design stage (p. 095). He explains this with Anton Ehrenzweig's study of the creative process, where it was discovered that too much precision causes less vagueness in design that is essential to creativity (p. 096). With his belief that architecture should be about sensory experience, Pallasmaa defends drawing and imagining through sensations as a means to generate it (Merleau-Ponty theoretical position) Chapter 5: Embodied Thinking Pallasmaa expands on uncertainty as a source of motivation to find the right fit for a problem, and his experience in collecting it helps question ideas (p. 109). The tectonic language of architecture is described by him as the inner logic and the expression of gravity and structure (p. 113). For him, architecture is space making before aesthetics and uses Sigurd Lewerentz, Albert Kahn, Peter Zumthor, and Aldo Van Eyck as support. Embodied thinking is like building a cabinet (referencing a Martin Heidegger thought) in that where the hand has an essential role in informing the brain on the steps it takes to make the cabinet fit tight, which only a being who can speak and think can do well. The author also believes teaching existential wisdom is more complicated than learning; it requires the teacher to have a "to let learn" attitude (p. 120). Chapter 6: Body, Self, and Mind This chapter describes the mode of thinking during the design process that puts the architect on the boundary of his self, thoughts, and imagination, and on the other side, the actual experiences and effects of the real world. Pallasmaa finds it useful to create the ideal client for his building rather than not aspiring to a high enough meaning, merely meeting clientele demands (p. 125). Meaning in architecture develops from the revealing effect that architecture has on the "flesh of the world" (p. 128). Chapter 7: Emotion and Imagination

	The reality of imagination is used to describe how art and architecture that are experientially true (physical life) register in the same area of the brain as our imaginations (p. 132). (Erik's assertion): Pallasmaa is saying that architecture is experienced both in our emotions and our physical senses, i.e., the separation of thought and touch is not accurate. The gift of imagination is something that television, fictitious architecture proposals, and images of entertainment attempt to weaken (p. 134). The author errs on the side that art and architecture should not be created for their symbolism but for their physical experience. Chapter 8: Theory and Life Pallasmaa finds it essential to include a little chapter on the pursuit of theory. Too much critique and theorizing can lead to work that is a "caged-in exposition of conceptions evolved in terms of logic and words" (original quote: Henry Moore, p. 141). Pallasmaa doesn't find a need for theory but believes architects must have a guiding aspiration as to not walk in two directions at the same time. He wraps up with reemphasizing his position on experiential architecture.
Theoretical Contribution	The Thinking Hand covers a fair number of concepts beginning with the hand as a tool for creativity and continually reinforces the value of a working design process that refers to physical touch as much as possible. Imagination to Pallasmaa is something that is sparked by physical existence, and the mind carries ideas to new heights through questioning and experimentation.
Academic Discourse	Theory from this book focuses on the digital in terms of the Latin digitus that refers to the fingers and hand rather than the computer. It is also valuable to the case that drawings matter for any type of making: digital or handcraft, as the experiential design process is shown by Juhani Pallasmaa to be at minimum advantageous to the goal of a physical end product, if not essential.

Epistemological Validity	Pallasmaa grew up in Finland during World War II on his grandfather's farm and attributed that lifestyle to his natural perspective in architecture. Additionally, architects from his region, such as Alvar Aalto, Reima Pietila, and Sigurd Lewerentz, were significant influencers on his theory. Keywords: Mastersvo, the Russian term for craftsman (p. 052) Material prima: "state of mind that sees everything in nothing" as the eye of the mind uses the hand to materialize ideas (p. 084)
Cross Reference	Martin Heidegger, brain connected to the hand (p. 017) Albert Einstein, the importance of a visual thinking process (p. 017) Alvar Aalto Sigurd Lewerenz (p. 061) Renzo Piano, way of working: tireless repetition (p. 068) David Pye, the art of workmanship (p. 071). Merleau-Ponty, hapticity of human life (p. 100) Matisse cut off your tongue and get out your paintbrush (p. 142)

Author	(Petroski), Henry
Title	The Evolution of Useful Things
Date	1994
Content Summary	Petroski begins with a discussion about the origins of progressive design, stating that luxury is the mother of progress and describing how social conditions change to develop different levels of need, which are really wanted (p. 22). Design, therefore, responds to these new wants by ever so slightly improving upon an already existing state of form and function, but never reaches perfection; a sentiment gleaned from David Pye (p. 26). He uses Christopher Alexander's argument to declare that good design need not be perfect, but reach a level of quality where its perceivable flaws are outweighed by its perceivable strengths, much like matching a button or using spell heck (p. 29). In closing, he provides the example of the industrial designer and how the role in that domain is to anticipate future shortcomings of design in order to balance the strengths and flaws more quickly.
Theoretical Contribution	the text seeks to develop an understanding of why some designs exist among the realm of ones that do. The focus is on the evolution of design and the importance of object-making in a changing social context.
Academic Discourse	The objective of Petroski's chapter is to celebrate the cleverness through iteration of day to day objects if we think of the world today as an environment in opposition to design perfection.
Epistemological Validity	The author references other thinkers discussing design such as Pye and Alexander while also providing a counterargument to the topic of form and function. This text falls under justified belief more than opinion.

Cross Reference	David Pye (p. 26) Notes on the Synthesis of Form by Christopher Alexander (p. 28).

Author	(Petroski), Henry
Title	The Evolution of Useful Things [Chapter 4, From Pins to Paper Clips]
Date	1994
Content Summary	Pushing materials discovers new machines, as the pin helped develop steel extruding and bending technology (p. 68). Advances in tools imply disadvantages in the ones they replace (p. 73). Even though the Gem Clip (today's ordinary paperclip) was seen by almost everyone as the perfected design of the paperclip, it still did not function correctly for every paper binding scenario and thus developed into relatives of the Gem Clip that could handle more precisely different demands of function. The same is true regarding aesthetics, but the point in history where the aesthetic value of a paperclip was evident did not occur until the functionality was flushed out through technology (p. 74).
Theoretical Contribution	Improvements to tools are a constant evolution in parallel with what technology allows to be possible. In the same way, as a Gem Clip paperclip improved the pin, a CNC router improved the accuracy and efficiency of the hand-guided chisel.
Academic Discourse	The investigation of the evolution of the paper binding mechanism allows one to make valid historical comparisons between tools currently used in craft and those first invented. It reinforces the idea that an object's function (holding papers together) remains constant through time, while its capabilities, aesthetics, and specializations follow a path that is dictated by technological capacity.
Epistemological Validity	The study references patents for the paperclip as well as entries in the Merriam-Webster Dictionary and encyclopedias of various time periods to understand how the tool was valued in its context.

Cross Reference	Owen Edwards, (p. 70).

Author	(Petroski), Henry
Title	The Evolution of Useful Things [Chapter 6, Stick Before Zip]
Date	1994
Content Summary	The invention process behind the zipper could make a case for the necessity of drawings in design. The inventor, Gideon Sundback, drew up his first patent for what would be known as the zipper, but production fell flat due to difficulties in production and faulty final object. He toiled for years, no doubt working through drawing and making until the zipper was improved, but what is fascinating is that his first patent drawing and final patent drawing are not that much different, suggesting that between 1896 and 1917, something factored into his process that made the zipper successful. It seems that this factor was the shift in social values that created the demand for the product: "The demand may be said to have existed for a long time in the unconscious minds of people who were tired of buttons that came off and snaps that wore out and buckles that rattled. But it lay buried under a deadweight of custom and inertia. Manufacturers were positively hostile. They didn't want to face the many challenges of redesign, of drastic changes in methods of manufacture and, most particularly, of additional cost." (p. 108).
Theoretical Contribution	In closing, Petroski states that the zipper is an example of a form that did not follow function directly. It, in fact, was a series of failures that lead to the form through iteration. Additionally, the timeliness of a product or the variables of its context will influence whether or not it will be consumable.
Academic Discourse	In the same way that the saw and the paperclip evolved through trial, there is also an error to account for, as exhibited in the zipper. The difference between the paperclip and the zipper was that the clip was progressed by multiple inventors while the zipper one or two. This could be due to complexity and lack of demand, but eventually, those conditions shifted to enable the zipper to become successful.

Epistemological Validity	Petroski's historical point of view highlights different outcomes in text than say, for example, Louis Sullivan's more theoretical based point of view on design.
Cross Reference	Gideon Sundback Whitcomb Judson

Author	(Petroski), Henry
Title	Tools Make Tools [Chapter 7, The Evolution of Useful Things]
Date	1994
Content Summary	Tools have evolved to build other tools and improve efficiencies and comfort, but still, many mysteries exist about the use of some (p. 117). The evolutionary path of the wood saw is examined. (p. 119-124) as is the ax, (p. 125-126) and the hammer (p. 127-129). When economic and social change challenges the use of hand tools, it responds by remaining competitive in its market, or it develops another function for specialty use. This is why the hand saw has not died, per say, because even though there are tools available that can cut in mass (turbine powered mills), or cut with extreme precision (laser, CNC), there is still a specialty market where the means to achieve such efficiencies or accuracy is unattainable to the user. The power of the hand saw lies in the skill of its user
Theoretical Contribution	. "That a single hammer could have so many divergent specialized users does suggest that there is a limit to diversity and that the limit represents a balance rather than a conflict between utilitarian and economic means and ends." (p. 129).
Academic Discourse	Petroski highlights the ax as "a prime example of form not following function" (p. 125).
Epistemological Validity	This chapter is based on historical findings.
Cross Reference	David Pye, (p. 125).

Author	(Petroski), Henry
Title	The Evolution of Useful Things [Chapter 10, The Power of Precedent]
Date	1994
Content Summary	According to Petroski, the puzzle jug, motorcycle, tractor, circuit breaker, airplane, architecture competitions, and bridge design illustrates that there are multiples forms to a given function. In each case, the designer was directly involved in the making process, but rarely did he ever come up with anything brand new. Thus the power of precedents in improving an already existing product, but not infringing upon patented ideas.
Theoretical Contribution	The closing words for this chapter read, "it is the serious choices among forms and details that make the difference between ultimate success and failure" (p. 184).
Academic Discourse	Perhaps architecture takes aim at changing the way it uses the division of knowledge from staying ahead to improving the flaws of the design we already have on record. Is this happening, and if not, why isn't it?
Epistemological Validity	All new ideas are rooted in precedent; all good design has a lineage.
Cross Reference	Crystal Palace (p. 181).

Author	(Petroski), Henry
Title	The Evolution of Useful Things [Chapter 13, When Good is Better than Best]
Date	1994
Content Summary	Petroski has established in previous chapters that since we know, objects change to improve on their ancestral designs. In this chapter, he looks at how a good designer will anticipate the future shortcomings of a product (p. 236). These can include avoiding gimmicky outcomes, unsustainable practices, or unintended uses.
Theoretical Contribution	Petroski states the best designs routinely exhibit substance over style, things that are not a gimmick (p. 231). A redesigned object may be perceived as better from one point of view, while in an alternate view is actually a detriment (Styrofoam food packaging). Understanding the problems of the past is just as important as having a holistic view of the future.
Academic Discourse	"Design problems arise out of the failure of some existing thing, system, or process to function as well as might be hoped, and they also arise out of anticipated situations wherein the failure is envisioned" (p. 231). It could be argued that digital craft is a solution to the problem of the substantial craft of the Renaissance, failing to be functionally economical in today's market.
Epistemological Validity	Demonstrates the need to separate substantive content in design and making over empty gestures
Cross Reference	Matthew Crawford, Shop Class as Soulcraft Peter Buchanan, Empty Gestures: Starchitecture's Swan Song

Author	(Princen), Thomas
Title	The Logic of Sufficiency
Date	2005
Content Summary	When the Parliamentary government seized agricultural land to rent back to tenants, they had no choice but to seek work in the manufactories. As a result, the presence of skilled labor dropped; social life and economic life were once the same livelihoods, but the Industrial Revolution split the two into labor and freedom. The author discusses how materialization is putting stress on the environment as well as members of society in which the norm is to spend, consume, and produce endlessly (p. 131). For solutions, he looks into the natural way in which humans once worked: hunted and gathered, paused for meals, cared for children, planned the next day's route. It has been understood by psychologists that a balance of varied, stimulating tasks is more healthful than an endless cycle of work and leisure (p. 136). This rational working type is marginalized by three factors of mass production jobs: specialization, scale, and the sovereignty of the consumer (p. 141).
Theoretical Contribution	One argument brought up is that humans have an innate ability to self-govern work and productivity, something that mass production disturbs. This is a work rooted in the satisfaction of quality, not a produce-and consume cycle (p. 129). The logic of efficiency and capital gain is examined versus the logic of sufficiency, which is described as a threshold between monetary gain and expended effort. The author proposes that more self-directed work will lead to better welfare as well as cut down on excessive consumption (p. 142). He attributes the failure of the "producerist" system to a lack of central organization but does not provide a solution.

Academic Discourse	The producerist (populist) core value really boils down to a mindset that will trade away wealth for a feeling of meaningful impact in one's community through production, opposite to today's value on consumerism. It centers on producing with a net neutral stance on economics and natural resources. Contemporary political and economic conditions render this ideal more utopian than realistic at large scale, but there is evidence in this chapter that shows independent craftsmanship is feasible and sustainable if the mindset is not clouded by consumerism.
Epistemological Validity	Princen does an adequate job investigating the relationships between culture, technology, and politics throughout significant shifts in the producer-consumer climate. His perspective seems to be more in favor of producerist ideals than the expansionist.
Cross Reference	Cradle to Cradle, Michael Braungart, and William McDonough

Author	(Pye), David
Title	The Art of the Practical Engineer, Presidential Address of Sir David Pye
Date	1952
Content Summary	The address is an account of David Pye's experience with studying and teaching engineering from the 1930s to the 1950s. As a student, he gained much of his experience from practical work, such as his time during World War II with the Royal Flying Corps. He also talks about the difficulties of establishing an engineering program at a university like Cambridge. From a professor's perspective it may be easier to grade students based on standard examinations, which during the time was chiefly mathematical, but as a teacher, Pye believes in taking the extra time to assess students individually, as not all great engineers are mathematicians and not all mathematicians lead to great design instincts. Design skills are what is most important for Pye, which he remarks is not adequately focused on during the first two years of general studies for engineering students.
Theoretical Contribution	Pye states that all levels of technical careers (draftsmen, engineers, skilled craftsmen, designers, researchers) will have certain people who excel, and it is up to leadership to find them out an help them develop. Good leaders are vital to a design office because it is trial and error based, and those with experience can help push or drawback on a creative idea. Pye also says that a prerequisite for creativity is a thorough understanding of the materials one is working with. He goes so far as to say that it is a universal truth (p. 271).
Academic Discourse	David Pye speaks of math in a way that can be applied to how Cardoso Llach examines computer programs in architecture and design. Pye actually speaks of higher arithmetic as "a friendly tool" to those that math comes easily, rather than how Steve Coon's CAD, the "perfect slave" treated technology (See T022). For Pye, math is helpful when applied in the right way but does not usurp design skills as a method. "An ounce of instinct is worth a pound of information" (Pye, 270).

Epistemological Validity	The author is speaking from his own experience as a student and as an instructor of engineering who has observed the evolution of the curriculum, which allows him the critique of a standardized pedagogy.
Cross Reference	See Daniel Cardoso Llach (T022) Pye, Workmanship (C001) Pye, skill (T018) Pye, Nature of design (T020)

Author	(Pye), David
Title	The Nature & Aesthetics of Design [Chapter 5, Techniques. Skill]
Date	1978
Content Summary	Pye identifies four techniques for processing any given material: 1. wasting: carving out/ removing/ planing / milling 2. constructing: joining/ weaving / attaching with other parts 3. forming: bending/ molding/ flexing 4. casting: filling a pattern with from a liquid state and allowing it to harden into the pattern He also looks at handcraft and the skill required to process materials by hand, and its value compared to the skill needed to employ a machine to affect an outcome. Much is distilled down to the economy. He says making a surface flat to fit against another flat object is just as much work with the hand as it is to make irregular surfaces mate together (p. 47). The machine is economical because it takes control of constraints, unlike the hand (p. 51). Thus, he differentiates a skilled system of skilled constraint from a determining system of mechanical constraint. His summarizing argument is that a machine does not make something by itself, but requires a person with skill to design its actions or set of constraints that will make the desired object.
Theoretical Contribution	There is a compelling theoretical argument Pye brings up regarding the standardization of materials. People take for granted the squareness of building components, but naturally, very few objects exhibit right angles. A wide flange beam does not necessarily need to be a continuous depth either because forces are rarely evenly distributed according to mathematical models of man. Man is fond of convenience, and therefore economy plays a much more significant role in design than most are conscious of (p. 53).

Academic Discourse	Using the assertions above, it sets up an interesting position for digital production and its ability to approach mass production while still providing a high level of skill. Objects no longer need to be square, which challenges aesthetic and tectonic norms. Instead of approximating with standard components, a free form is achievable without compromising the integrity of a material.
Epistemological Validity	Pye's point of view is undoubtedly justifiable given his material examples and awareness of Classical theory to compare and contrast his arguments.
Cross Reference	John Ruskin Matthew Crawford

Author	(Pye), David
Title	The Nature and Art of Workmanship
Date	1968
Content Summary	Design is in drawing and words; workmanship is not (p. 5). The problem with products, in Pye's mind, is that mass production has caused them to be one-dimensional (p. 6). Pye's definition of craftsmanship is as follows: "workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends on the judgment, dexterity, and care which the maker exercises as he works" (p. 7). He contrasts workmanship of risk, present throughout all human making until the last 3-4 generations with the workmanship of certainty, availed by full automation (p. 7). Risk in workmanship is reduced through the use of jigs or apparatus. Pye seeks to answer the question, "what is the value of the workmanship of risk, and how can it be continued?" He uses a distillation exercise to explore the meaning of the phrase hand-made and settles on the fact that by defining handicrafts in a technical context, it is almost irrelevant, noting the different technical ages. He provides William Morris' counterargument that handicraft was work without division of labor (p. 12).
Theoretical Contribution	Pye brings to question the definition of handicraft, risk, and the maker.
Academic Discourse	Pye Marks the recurring theme of workmanship of risk corresponding to the increasing social value of individualism/uniqueness (p. 9). Architects today design in drawings and words, which, according to David Pye, is not true workmanship or craftsmanship. If one accepts this notion, where is there a risk for the architect, because certainly risk is involved? It could be argued that if a design process is extremely automated (through the use of parametric design, prescriptive programming, etc), then workmanship of certainty would prevail, while design that is "without division of labor" may prove to exhibit more workmanship of risk.

Epistemological Validity	The text, although philosophical, does provide concrete examples from publicly accepted truths in the making and design domain to establish the reason.
Cross Reference	Building (p. X). William Morris (p. 12)

Author	(Ruskin), John
Title	The Seven Lamps of Architecture
Date	1849
Content Summary	Lamp 1: Sacrifice, putting religious duties before design decisions, like having a place for the inhabitants to pray. Lamp 2: Truth, making an “honest” building that does not veil artificialness under ornament. Lamp 3: Power, buildings should be viewed from multiple perspectives, power in the edges and boundary lines Lamp 4: Beauty, using the highest quality of materials derived from nature Lamp 5: Life, that great architecture is assembled by human hands of skilled craftsmen and architects together, not the machine Lamp 6: Memory, we cannot remember without architecture, and built spaces that shape our experiences Lamp 7: Obedience, neither originality or change are to be sought with respect to themselves, and calls for a unifying style
Theoretical Contribution	During the 1800s, everyone was trying to figure out what style represented their way of life. Pugin’s belief was that ornament should enrich the function of the building, and he was one who came from the Christian ideal that connected the Gothic style to purity. So, this was one of many other reasons for style. What first started as a moral issue in society shifted to an ethical issue when Ruskin (who also based his theory on Christian principles) was writing, The Seven Lamps of Architecture. We have seen this shift before, though, when regulating guidelines of humanity (and architecture) were stripped from the idea of a higher power of the cosmos and attributed to the individual, or in this case the morality of man. This provided a platform for those speaking out about social issues of the time on ethical grounds. As Harries writes, people then were questioning what their way of life for that period was to be, especially with the growth of the machine as context. Most of what Ruskin wrote about was concerned with injustices of the worker, which at the time of industrial expansion was very bleak. Because of Ruskin’s association

	with the Arts and Crafts Movement, he and fellow Pre-Raphaelites still found value in work that was tied to the natural; therefore, the machine was a direct opponent to this stance. Ornamentation that was made via the machine would show that the state of society was losing its honesty towards the individual craftsman and God who created nature, while ornamentation made via the hand embraced the value of human work and in Ruskin's eyes, portrayed a healthier, more ethical society rooted in faith. (Adapted from Design Theory Journal)
Academic Discourse	The Seven Lamps have become synonymous with conversations surrounding nonindustrial artifacts.
Epistemological Validity	Address uniquely human qualities of making: memory, obedience, and principles.
Cross Reference	Pye, David Mies, material honesty

Author	(Sullivan), Louis
Title	Kindergarten Chats and Other Writings
Date	1947
Content Summary	Asserting that there is form in every function, and function in every form for only that form, Sullivan asks why then, is there such deception in architecture? (p. 44). He says what brings them together for humans, who are the only spectators of form and function, is rhythm (p.45). A building shall, therefore, be able to be read through for its function as displayed in its form regardless of art or style choice, and this includes its details (p. 46). In closing, he makes a case that architecture's form has become abnormal and is decrepit due to the people who focus on creating architecture not for its realities, but for the construction of words and ideas.
Theoretical Contribution	What matters for digital craft is the idea of wariness about the abnormal form and function for the sake of interpreting ideas and words. One should be careful that digital tools do not become an even more destructive crutch than has already been used by architects in Sullivan's day.
Academic Discourse	Sullivan's thoughts likely represent one school of thought on the state of architecture and should be examined within its context of modern architecture.
Epistemological Validity	A philosophical approach that roots itself in nature, but also exposes the author's subjective values towards architecture
Cross Reference	Henry Petroski, function follows desire

Author	(Smith), Ryan
Title	Prefabrication, Journal of Architectural Education
Date	2016
Content Summary	General history of the prefabricated dwelling. The term “modular” is contrasted with the term “prefabrication,” and it is explained that modular is used outside architecture as a term that connotes flexibility.
Theoretical Contribution	The article claims that architecture today uses an old definition of Le Corbusier’s modular to connote standardization rather than flexibility, but we have the tools necessary for modular construction to be both flexible and as efficient as a Fordist assembly line. It introduces a spectrum of customizability that architects who wish to design with prefab should implement. These include MTS, ATO, MTO, and ETO elements in various ways to maximize the budget (See Keywords below
Academic Discourse	From the article’s argument, standardization is one extreme of prefabrication, and mass customization is another. There is a range in between that offers a designer option to select. If these can also be optimized in a digital tool such as parametric software, then prefabrication will undoubtedly have a more diversified connotation within the industry.
Epistemological Validity	The article is recommending the architectural industry to borrow knowledge from the manufacturing domain that has already been developed. This new perspective is referred to as manufactured construction, and is intended to “provide a more nuanced and intelligent way in which to study, understand, and discuss the extent and breadth of prefab as a growing domain of the architecture discipline” (p. 8). Keywords: MTS/ Made-to-Stock: lumber, steel, aluminum sections, ceiling panels, ATO/ Assembled-to-Order: shipping containers, mobile homes, dorms, hospitality housing modules, MTO/ Make-to-Order: custom windows, doors, modernist prefab systems, ETO/ Engineered-to-Order: unique facades, custom sections, carbon fiber stairwells

Cross Reference	Ford assembly line (p. 5)

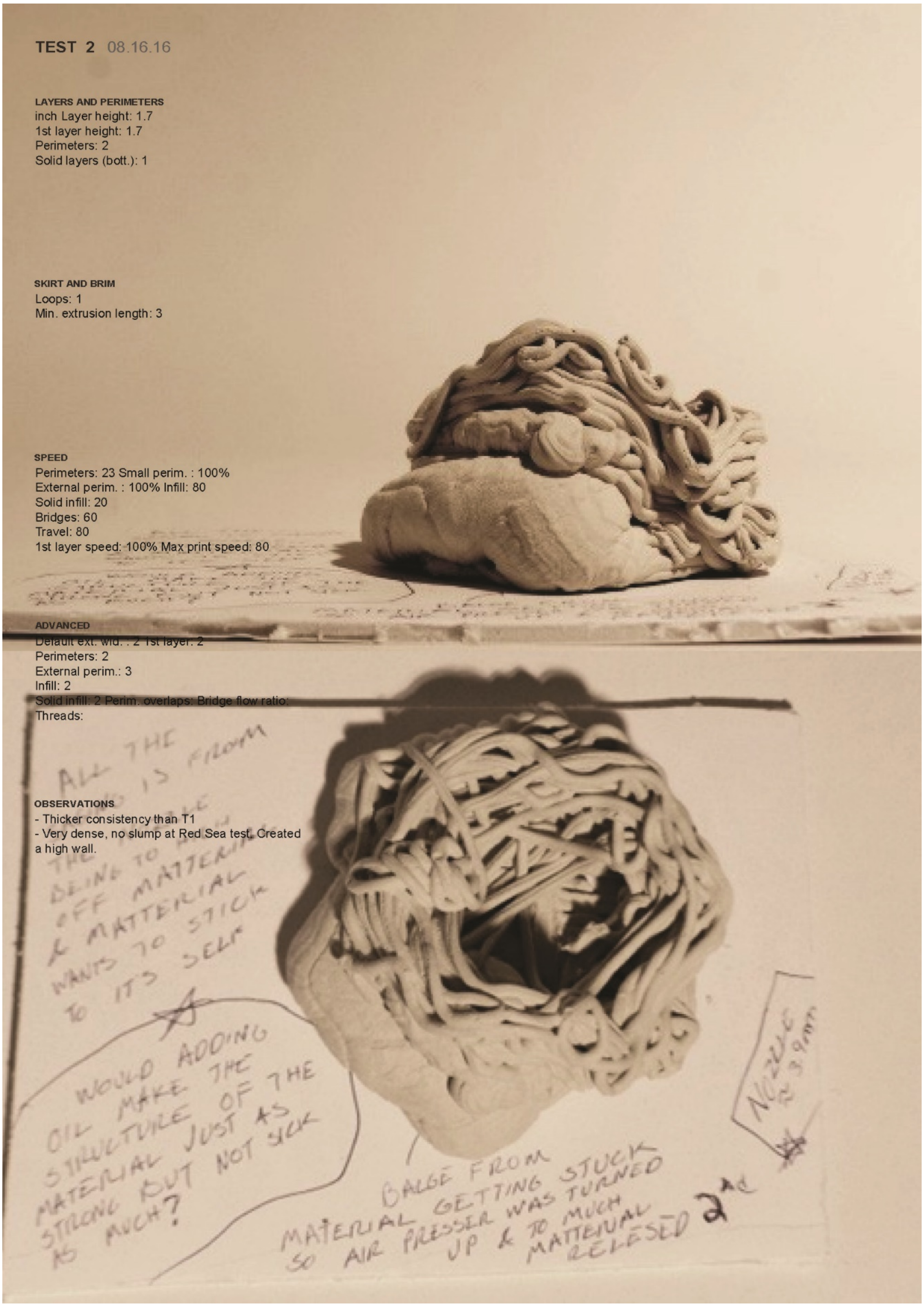
Author	(Thwaites), Thomas
Title	The Toaster Project – [Chapter 1, Deconstruction & Chapter 7, Construction]
Date	2011
Content Summary	As a master's project, Thomas Thwaites sets out to build a modern toaster from scratch, demonstrating the enormous amount of resources required to produce what is today seen as a common household commodity. Working under a set of self-imposed rules, he tries to answer his question, "how the hell do some rocks become a toaster?" (p. 015). Although he does end up with a functioning toaster at the end, what the exercise really did was expose the consumer-producer cycle and bring into question the ethics of a modern society that "divorces people from practical ability" and facilitates such a disposable lifestyle (p. 036)
Theoretical Contribution	There are two main topics the author discusses. The first is the dilemma of defining what it means to "build from scratch", which he argues at one end only God could build from scratch because you would need to invent the universe, but on the other end he defines scratch as the working conditions before technology made it easier to "cheat" materials into form. Secondly, he discusses ownership as it applies to environmental consumerism and how the objects we make with our hands differ in value than those mass-produced.
Academic Discourse	Both points are salient to the subject of digital craft. Can the process of making be both a highly valued activity because it interfaces closely with material manipulation, but also find solace in the fact that the designer built the tool that built the object? What is the ratio of consumption to production in this making process?
Epistemological Validity	The academic discourse established by stepping back in context allows Thwaites a unique perspective to discuss the future of making

Cross Reference	Matthew Crawford, Shop Class as Soulcraft

Author	(Till), Jeremy
Title	Architectural Research: Three Myths and One Model
Date	2017
Content Summary	The three myths of architecture and research are: 1. That architecture is just architecture, and scientific methods can't be applied. 2. That architecture is not architecture, it is a result of creative genius, or turn to other disciplines for authority 3. That is merely building a building is research. The author then discusses how architecture is a tool for knowledge dissemination, and what is lacking today is excellent communication between those who are primarily practice-based and those who are predominantly research-based. His new model avoids breaking down architecture into categories of practice, science, or history, but focussing on researching architectural process, products, and performance with input from many disciplines.
Theoretical Contribution	The theory Till writes about encourages domain transfer as the core of architectural research. He wants to avoid architecture being researched for the sake of itself and the concealing of tacit knowledge.
Academic Discourse	Till's argument as it relates to digital fabrication could encompass things like making scripts open-source so that others can learn from research projects and start experimental offshoots of their own in order to progress the craft. There is also a stress on the communication between academic societies and professional societies because more progress will result in the categories of processes, products, and performance if there is feedback.
Epistemological Validity	Similar to Crawford's view on tacit knowledge, but considered from a more holistic approach where more than just the craftsman is involved with the knowledge transfer. The paper was initially written for the RIBA but republished to a broader audience.

Cross Reference	Frayling, Research in art and design (p. 6).

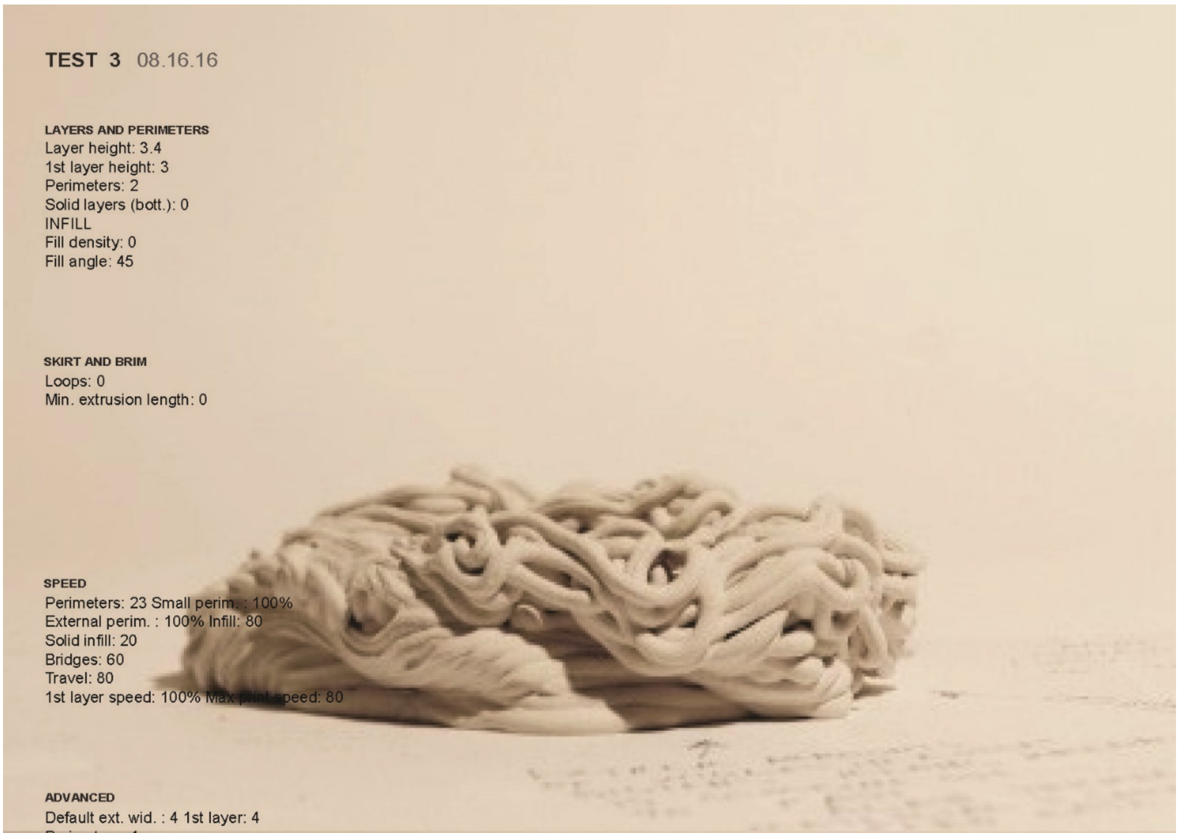
Author	**(Zumthor), Peter**
Title	**Thinking Architecture [The Hard Core of Beauty]**
Date	**1991**
Content Summary	Zumthor walks through different ways in which creatives have defined beauty in their work: Italo Calvino's use of vagueness in his literature, composer John Cage who forces music until it sounds right, and Herzog and de Meuron's theory of the artificial building concept. Peter Zumthor compares and contrasts these techniques to his method of designing to extract beauty. The "obvious but difficult solution," which is to focus architecture on the basis of structure, material, and space as it relates to the body and "just being" (p. 32). No symbolism necessary, no building that talks theory at the user, just "living among things" as he quotes Heidegger (p. 34).
Theoretical Contribution	Almost an anti-theoretical piece, but if one were, to sum up, Zumthor's philosophy it would be describing his emphasis on quality and allowing the design to speak for itself.
Academic Discourse	How does one "let something be" with the digital process? Zumthor speaks about the superficial pursuit of merely inventing forms. Letting the processed material speak to how it was cut, extruded, or milled would, to him be more important than how it was showcased as a final object.
Epistemological Validity	Zumthor's theory is in opposition to the intellectualized design principles universal amongst his contemporaries. He believes the materials of a specific place can create enough meaning if that is the focus of the built work.
Cross Reference	Heidegger, living among things (p. 34). Herzog de Meuron, intellectually heavy materiality theory (p. 29)


TEST 2 08.16.16
LAYERS AND PERIMETERS
inch Layer height: 1.7
1st layer height: 1.7
Perimeters: 2
Solid layers (bott.): 1
SKIRT AND BRIM
Loops: 1
Min. extrusion length: 3
SPEED
Perimeters: 23 Small perim. : 100%
External perim. : 100% Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100% Max print speed: 80
ADVANCED
Default ext. wid. : 2 1st layer: 2
Perimeters: 2
External perim.: 3
Infill: 2
Solid infill: 2 Perim. overlaps: Bridge flow ratio:
Threads:
OBSERVATIONS
- Thicker consistency than T1
- Very dense, no slump at Red Sea test. Created a high wall.
ALL THE
IS FROM
BEING TO
OFF MATTERIAL
& MATTERIAL
WANTS TO STICK
TO ITS SELF
WOULD ADDING OIL MAKE THE STRUCTURE OF THE MATERIAL JUST AS STRONG BUT NOT STICK AS MUCH?
BALGE FROM MATERIAL GETTING STUCK SO AIR PRESSER WAS TURNED UP & TO MUCH MATTERIAL RELESED
NOZZLE

TEST 3 08.16.16

LAYERS AND PERIMETERS
Layer height: 3.4
1st layer height: 3
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

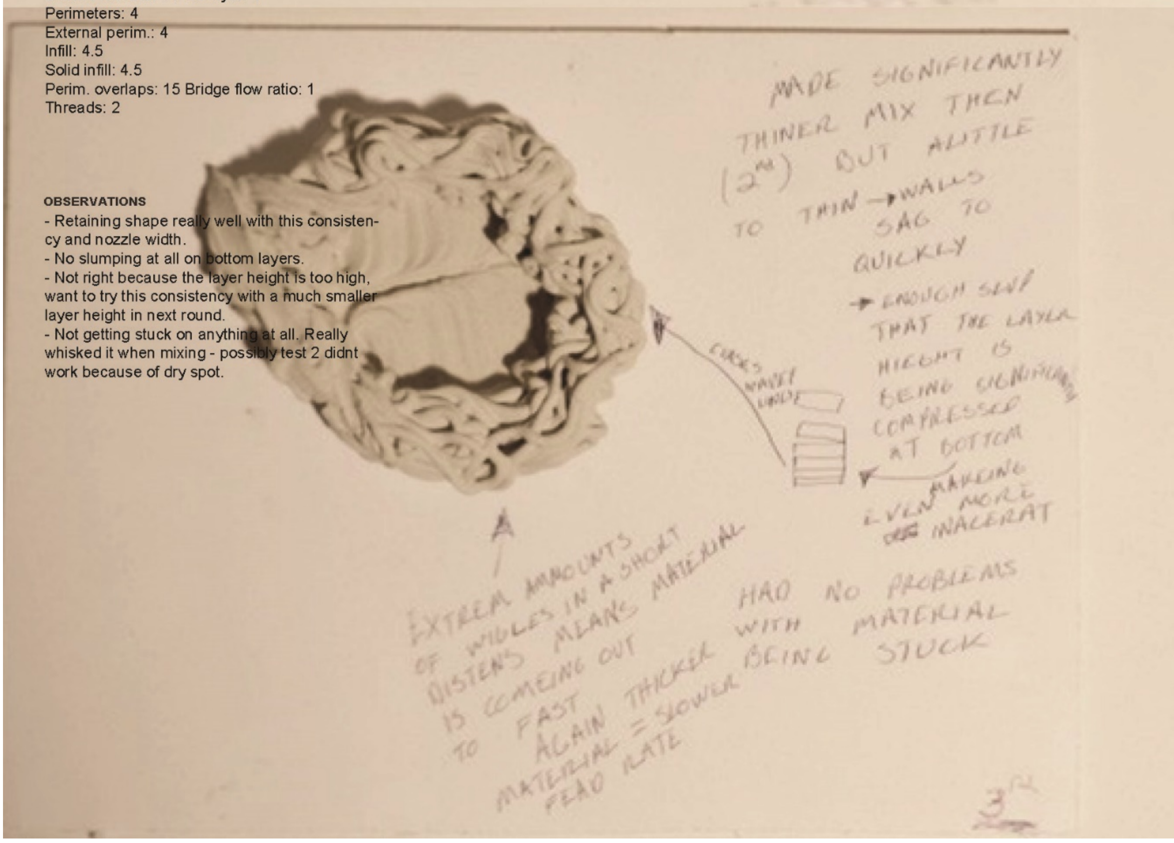
SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0



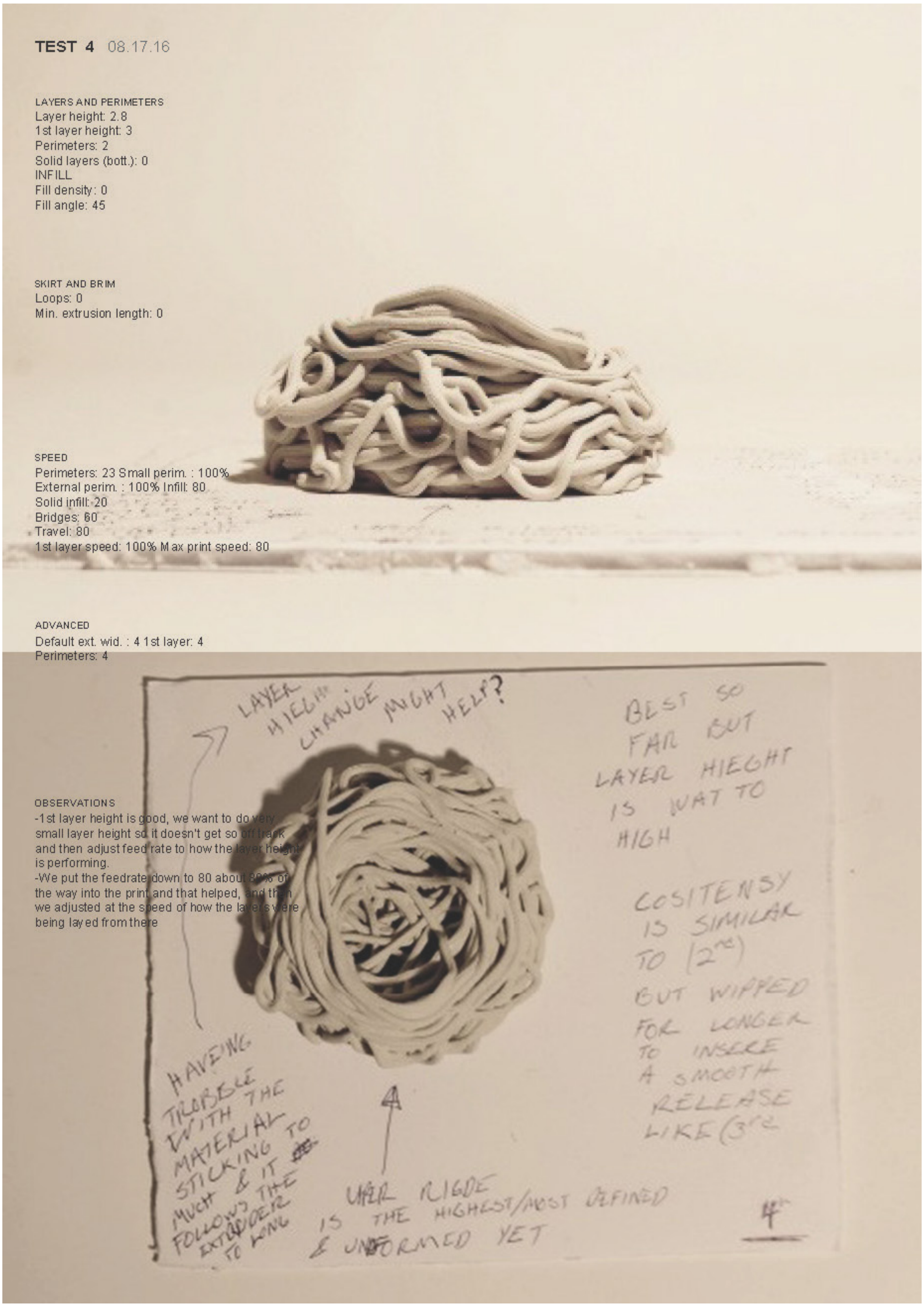
SPEED
Perimeters: 23 Small perim. : 100%
External perim. : 100% Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100% Max print speed: 80

ADVANCED
Default ext. wid. : 4 1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15 Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
- Retaining shape really well with this consistency and nozzle width.
- No slumping at all on bottom layers.
- Not right because the layer height is too high, want to try this consistency with a much smaller layer height in next round.
- Not getting stuck on anything at all. Really whisked it when mixing - possibly test 2 didnt work because of dry spot.



TEST 4 08.17.16



LAYERS AND PERIMETERS
Layer height: 2.8
1st layer height: 3
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23 Small perim. : 100%
External perim. : 100% Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100% Max print speed: 80

ADVANCED
Default ext. wid. : 4 1st layer: 4
Perimeters: 4

OBSERVATIONS
-1st layer height is good, we want to do very small layer height so it doesn't get so off track and then adjust feed rate to how the layer height is performing.
-We put the feedrate down to 80 about 80% of the way into the print and that helped, and then we adjusted at the speed of how the layers were being layed from there

TEST 5 08.17.16

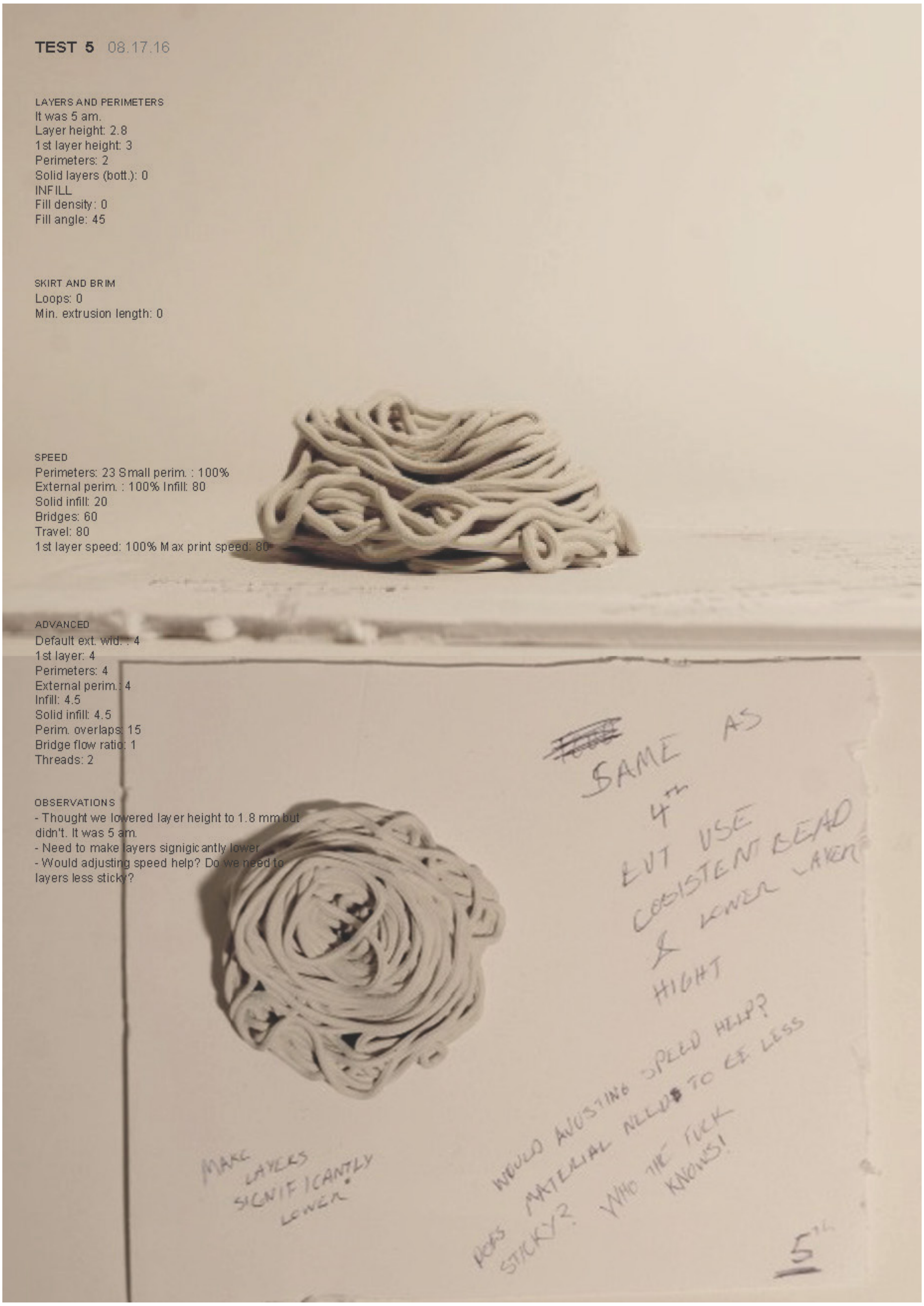
LAYERS AND PERIMETERS
It was 5 am.
Layer height: 2.8
1st layer height: 3
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23 Small perim. : 100%
External perim. : 100% Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100% Max print speed: 80

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
- Thought we lowered layer height to 1.8 mm but didn't. It was 5 am.
- Need to make layers signigicantly lower
- Would adjusting speed help? Do we need to layers less sticky?



TEST 6 08.17.16

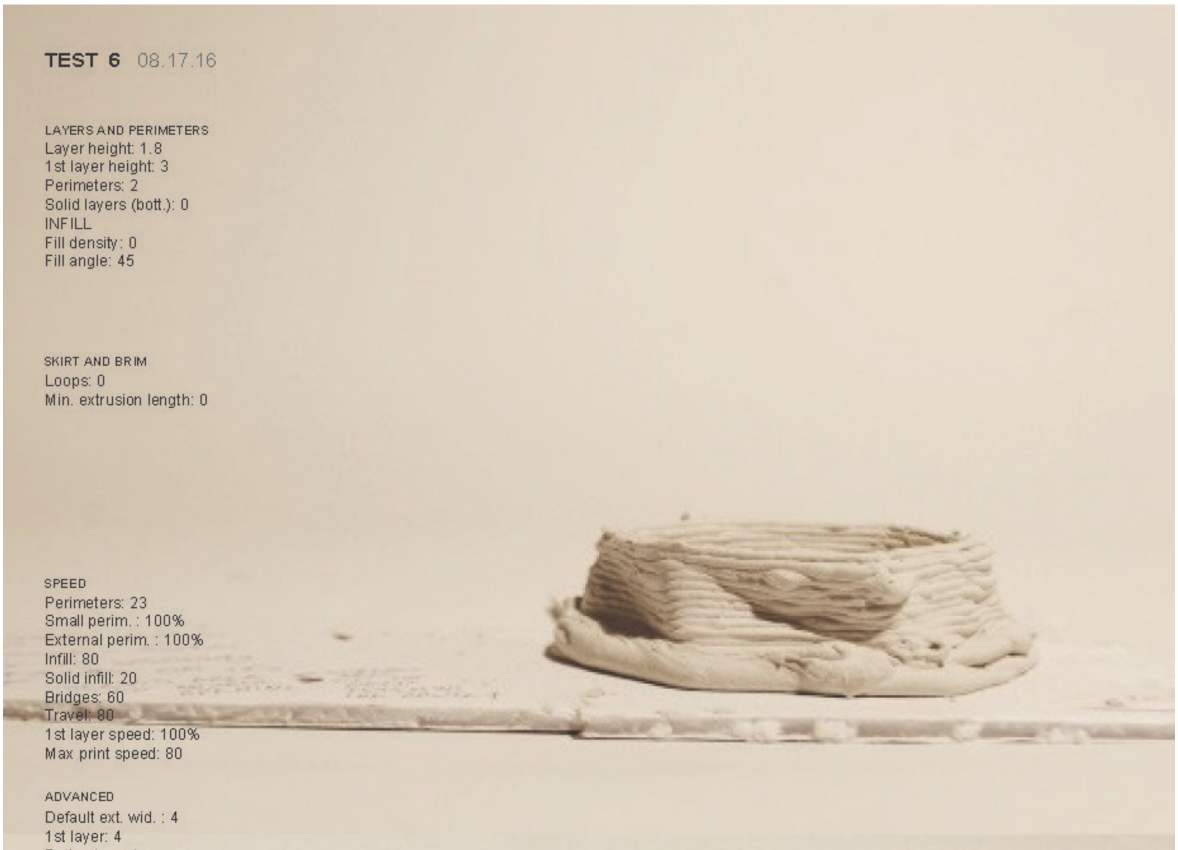
LAYERS AND PERIMETERS
Layer height: 1.8
1st layer height: 3
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

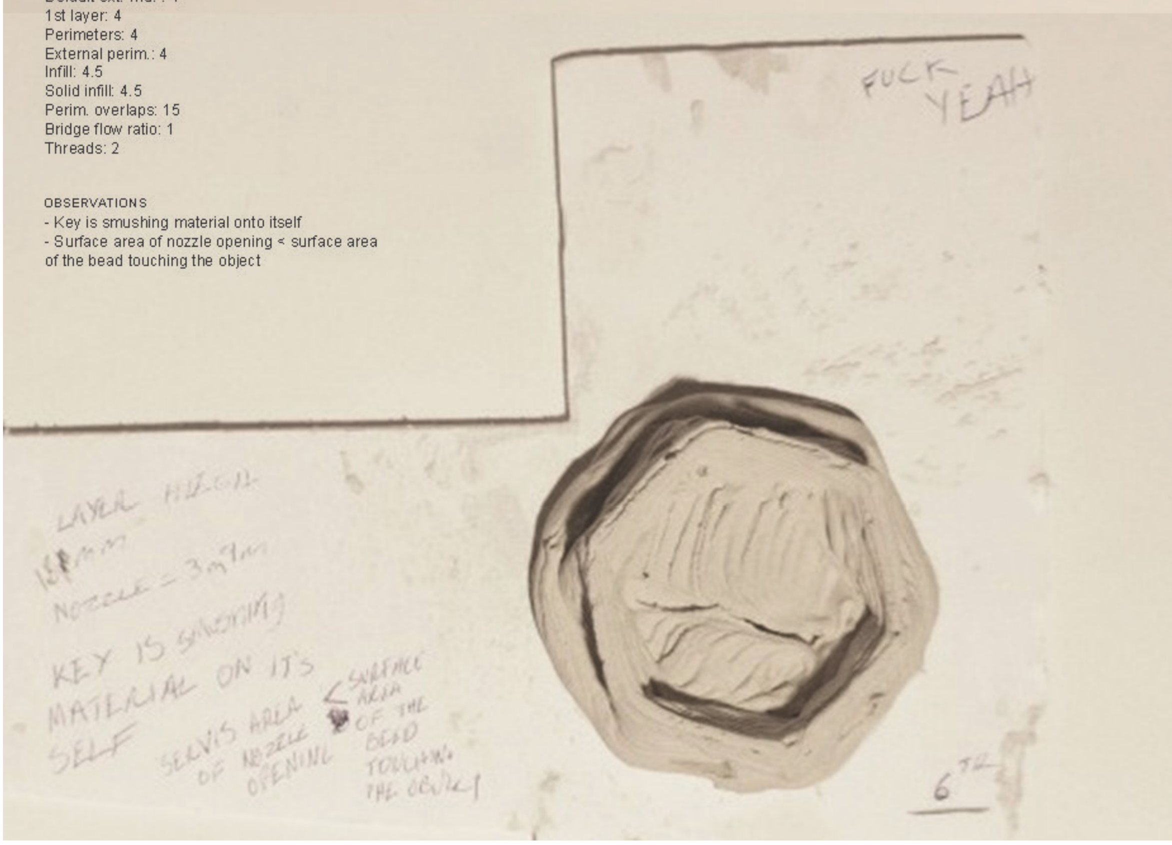
SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
- Key is smushing material onto itself
- Surface area of nozzle opening < surface area of the bead touching the object





TEST 7 08.17.16

LAYERS AND PERIMETERS
Layer height: 1.8
1st layer height: 3
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

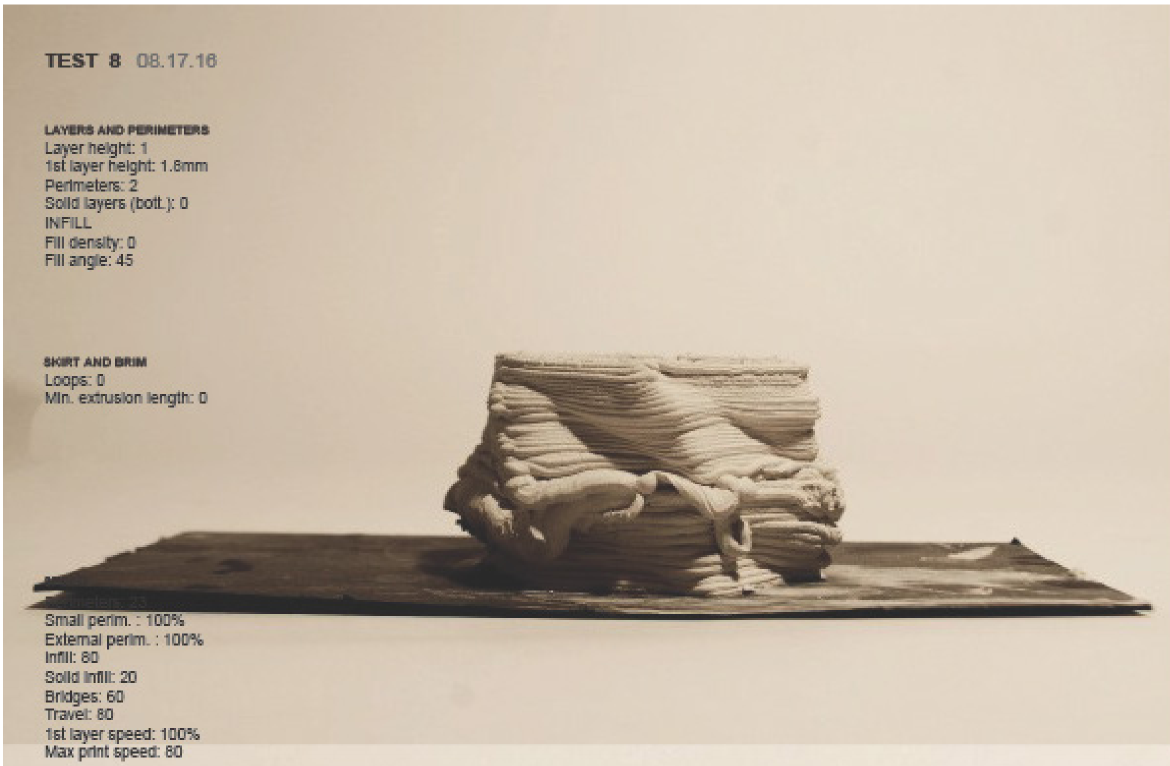
ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
- Mix had red sea effect
- Need to find better way to get air bubbles out - Air pressure has to be turned way up the more time goes on because it dries. This is why the top is messed up - too many hand adjustments needed to be made.
- Do we stop at the point of solidarity in elevation, let object dry, make new mix, perform cold joint?

TEST 8 08.17.16

LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 1.6mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

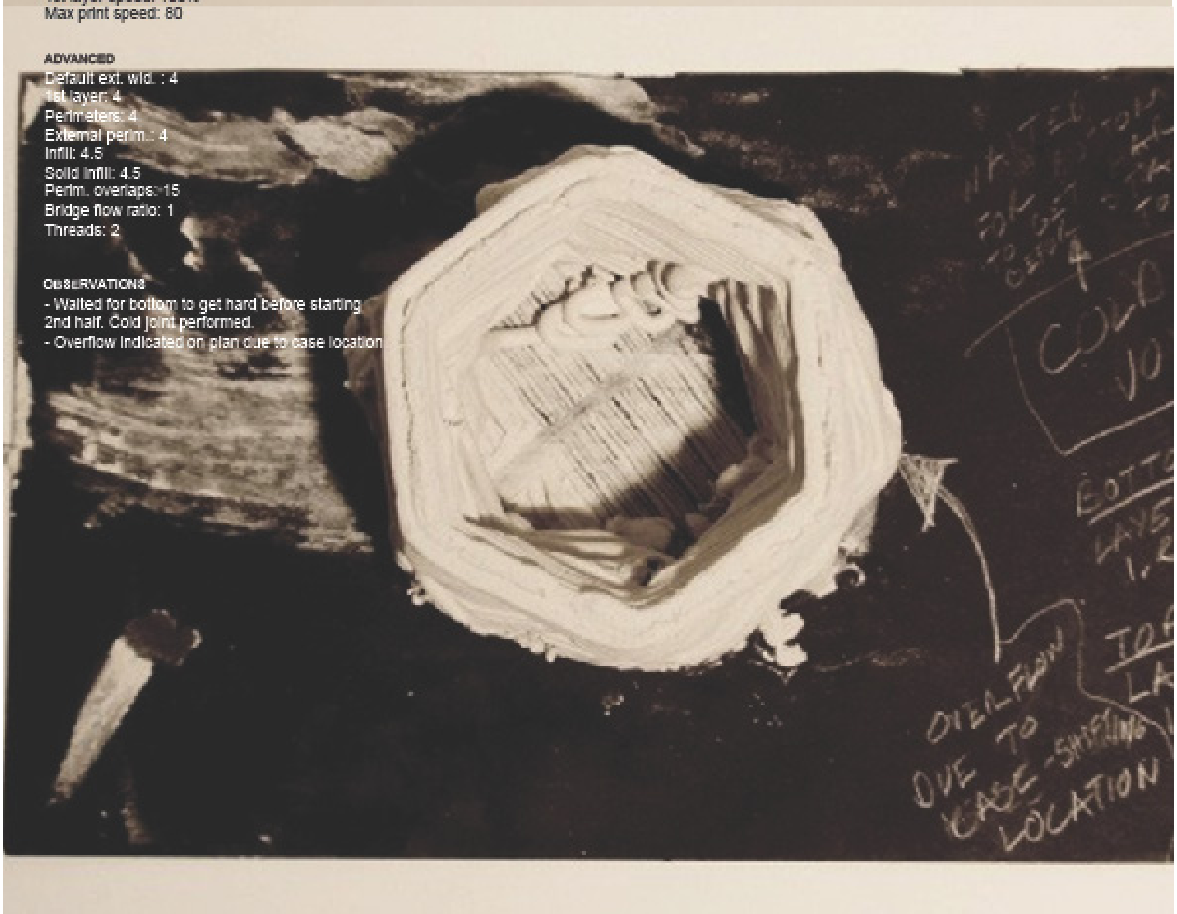
SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0



Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 60
Solid infill: 20
Bridges: 60
Travel: 60
1st layer speed: 100%
Max print speed: 60

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
- Waited for bottom to get hard before starting 2nd half. Cold joint performed.
- Overflow indicated on plan due to case location



TEST 9 08.17.16

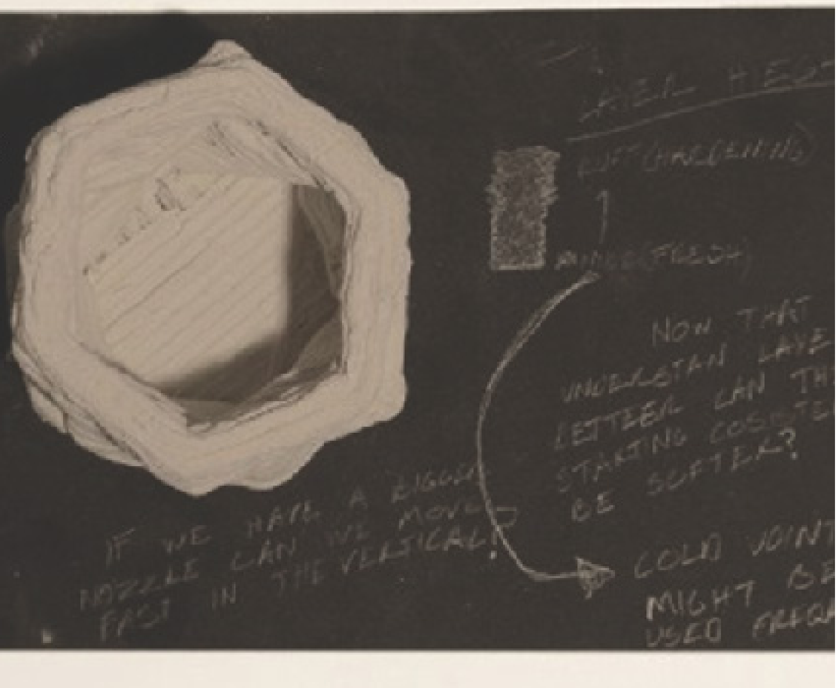
LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 1.6mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

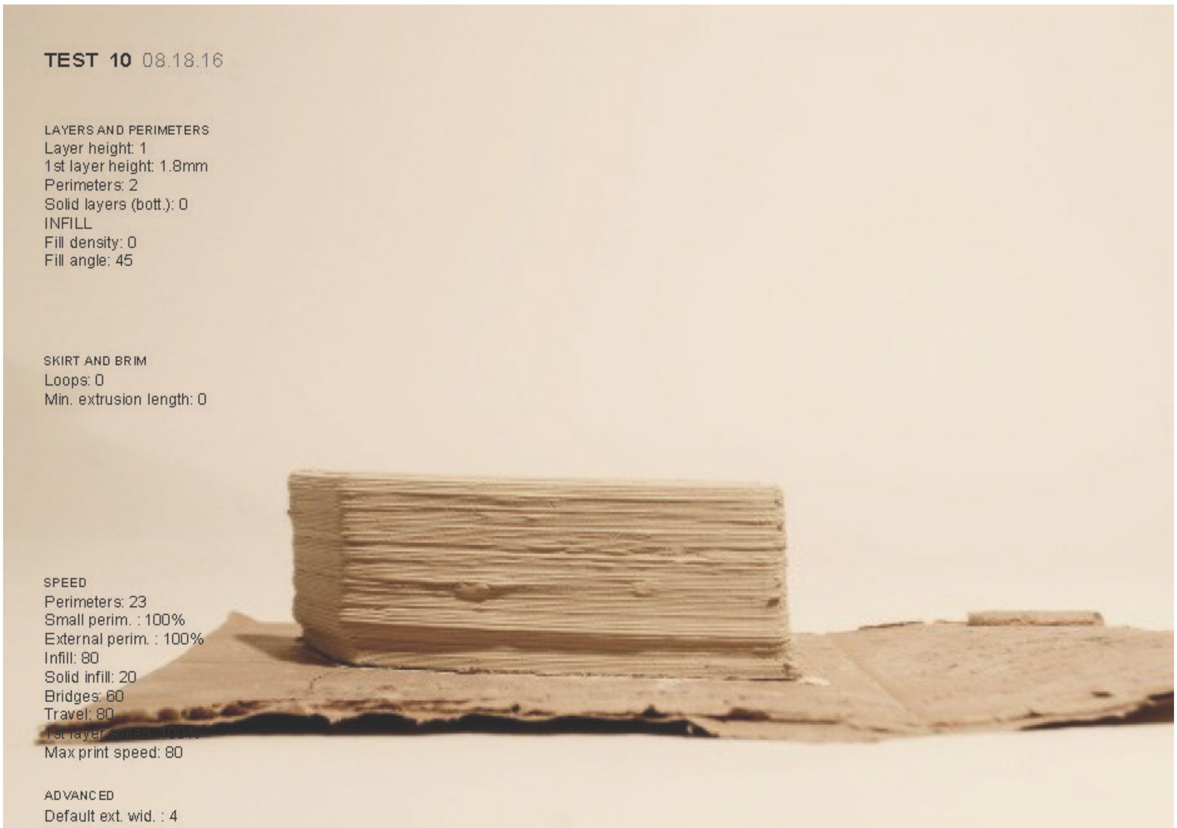
SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads:

OBSERVATIONS
- Constant hand adjustment of air is crucial. Needle stayed between 0-1 in first half of print. 2nd half of needle stayed between 1-2.
- If we have a bigger nozzle can we move fast in the vertical?
- Layer height is understood, so can starting consistency start to be softer?
- Cold joint might become a consistent



TEST 10 08.18.16

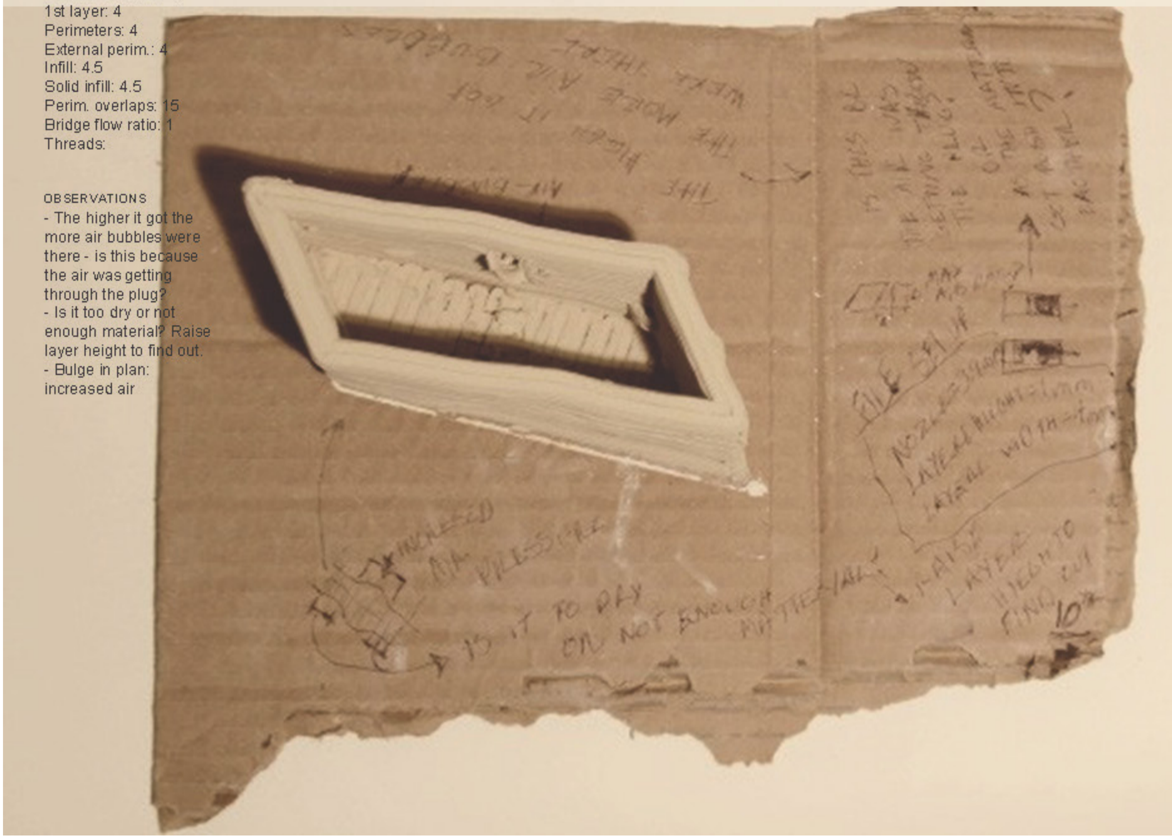


LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 1.8mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads:



OBSERVATIONS
- The higher it got the more air bubbles were there - is this because the air was getting through the plug?
- Is it too dry or not enough material? Raise layer height to find out.
- Bulge in plan: increased air

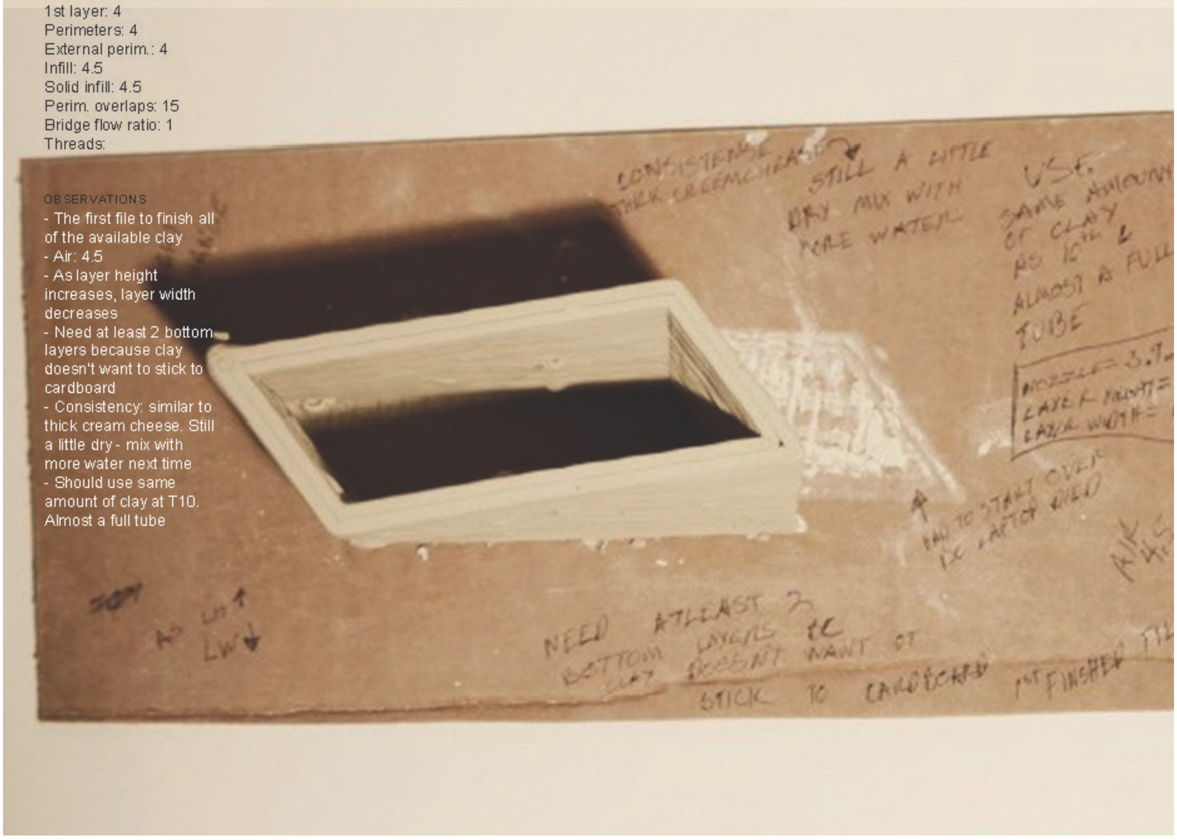
TEST 11 08.18.16

LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 1.8mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads:



OBSERVATIONS
- The first file to finish all of the available clay
- Air: 4.5
- As layer height increases, layer width decreases
- Need at least 2 bottom layers because clay doesn't want to stick to cardboard
- Consistency: similar to thick cream cheese. Still a little dry - mix with more water next time
- Should use same amount of clay at T10. Almost a full tube

TEST 12 08.19.16

LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 1.5mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 4
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads:

OBSERVATIONS
- It's good for layers to be a little thicker.

TEST 13 who knows

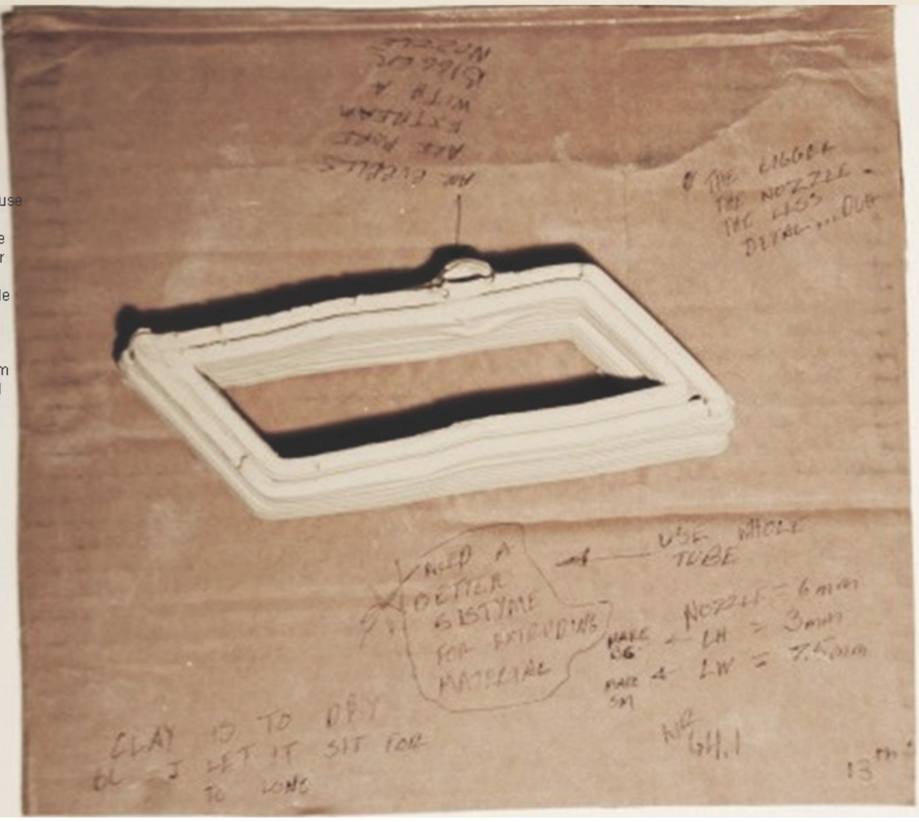
LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 1.5mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm
Air: 4.1

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80

ADVANCED
Default ext. wid. : 7.5 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-Clay is too dry because it sat for too long
-Air bubbles are more extreme with a bigger nozzle
-The bigger the nozzle the less detail
-Used whole tube of clay
-Need a better system for extruding material with this nozzle diameter



TEST 14 who knows

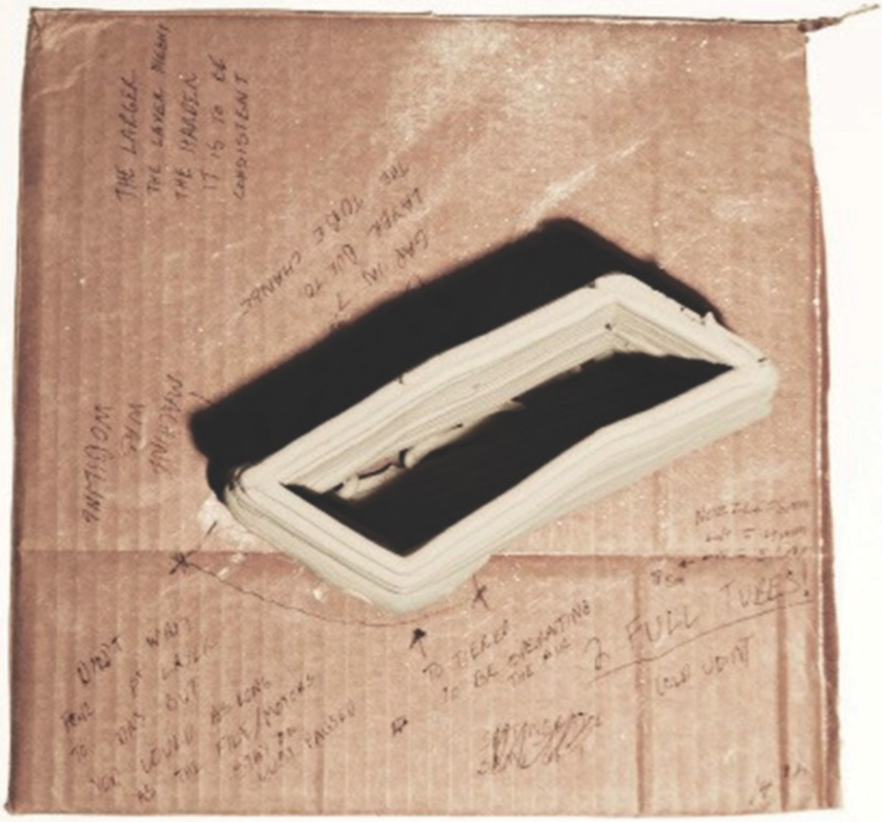
LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 4mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm
Air: 4.1

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 7.5 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-Machine was wobbling
-The larger the layer height the harder it is to be consistent
-Gap in the 7th layer due to the tube change
-Didn't wait for the 1st layer to dry out but you could as long as the file/motors stay on just paused
-2 full tubes of clay were used with a cold joint



TEST 15 who knows

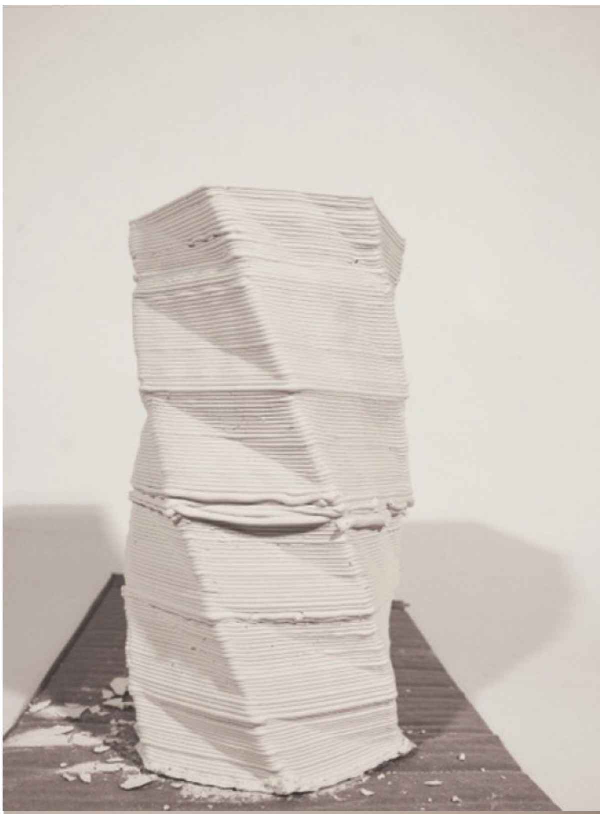
LAYERS AND PERIMETERS
Layer height: 1
1st layer height: 4mm
Perimeters: 2
Solid layers (bott.): 0
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm
Air: 4.1

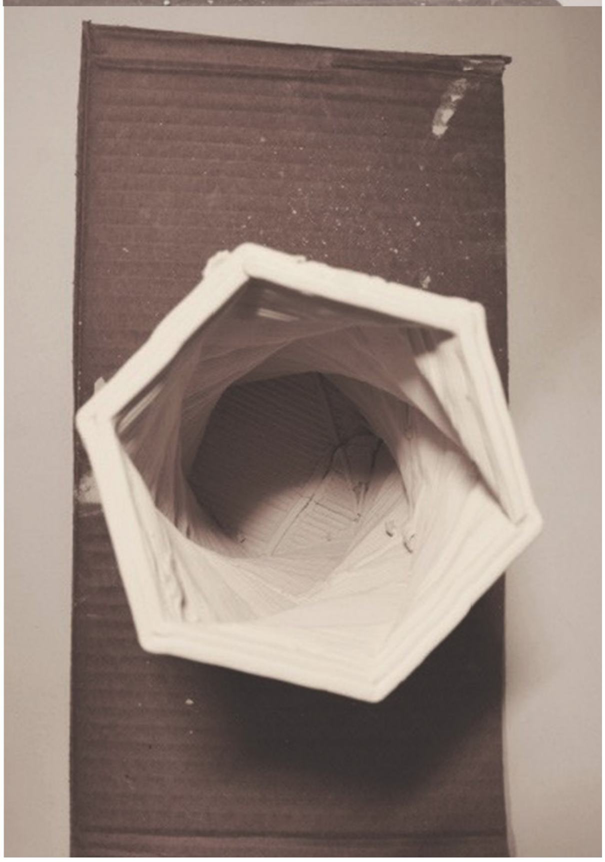
SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 7.5 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-Machine was wobbling
-The larger the layer height the harder it is to be consistent
-Gap in the 7th layer due to the tube change
-Didn't wait for the 1st layer to dry out but you could as long as the file/motors stay on just paused
-2 full tubes of clay were used with a cold joint





TEST 16 09.09.16

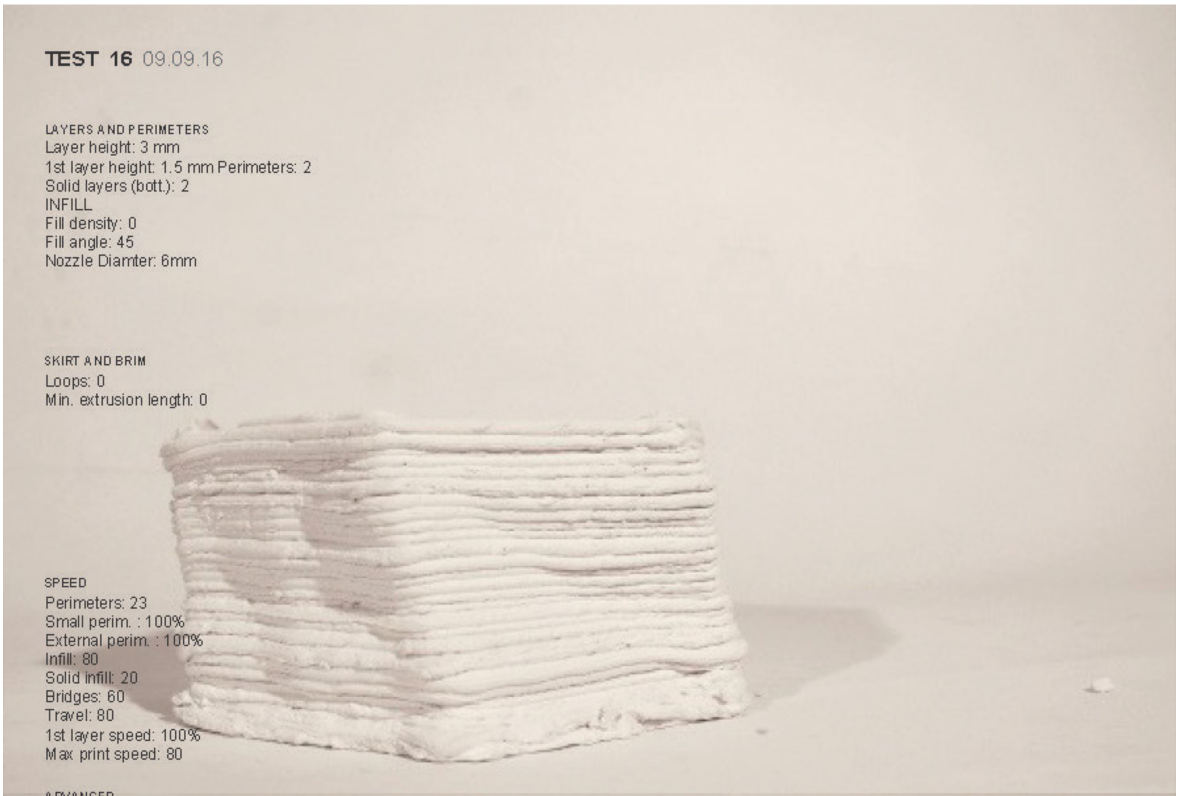
LAYERS AND PERIMETERS
Layer height: 3 mm
1st layer height: 1.5 mm Perimeters: 2
Solid layers (bott.): 2
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm

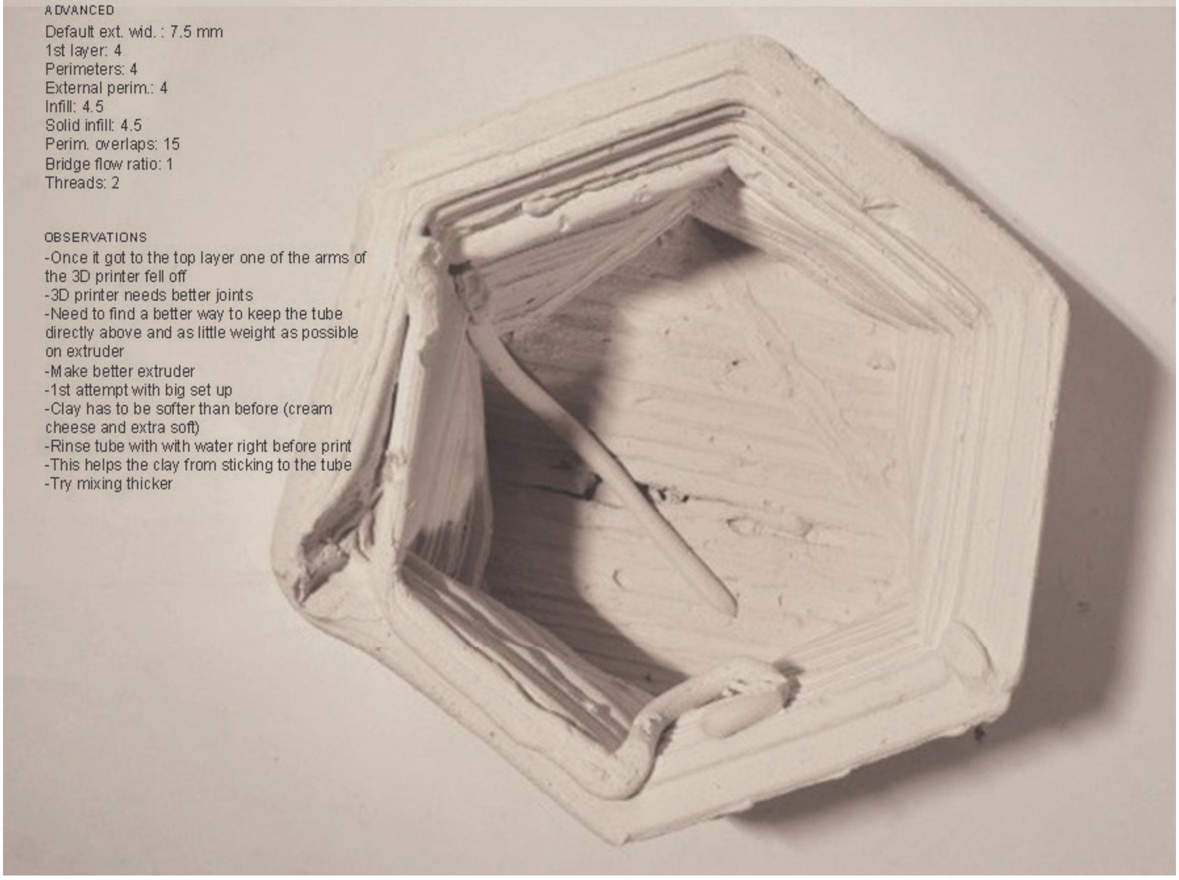
SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 7.5 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-Once it got to the top layer one of the arms of the 3D printer fell off
-3D printer needs better joints
-Need to find a better way to keep the tube directly above and as little weight as possible on extruder
-Make better extruder
-1st attempt with big set up
-Clay has to be softer than before (cream cheese and extra soft)
-Rinse tube with with water right before print
-This helps the clay from sticking to the tube
-Try mixing thicker





TEST 17 09.23.16

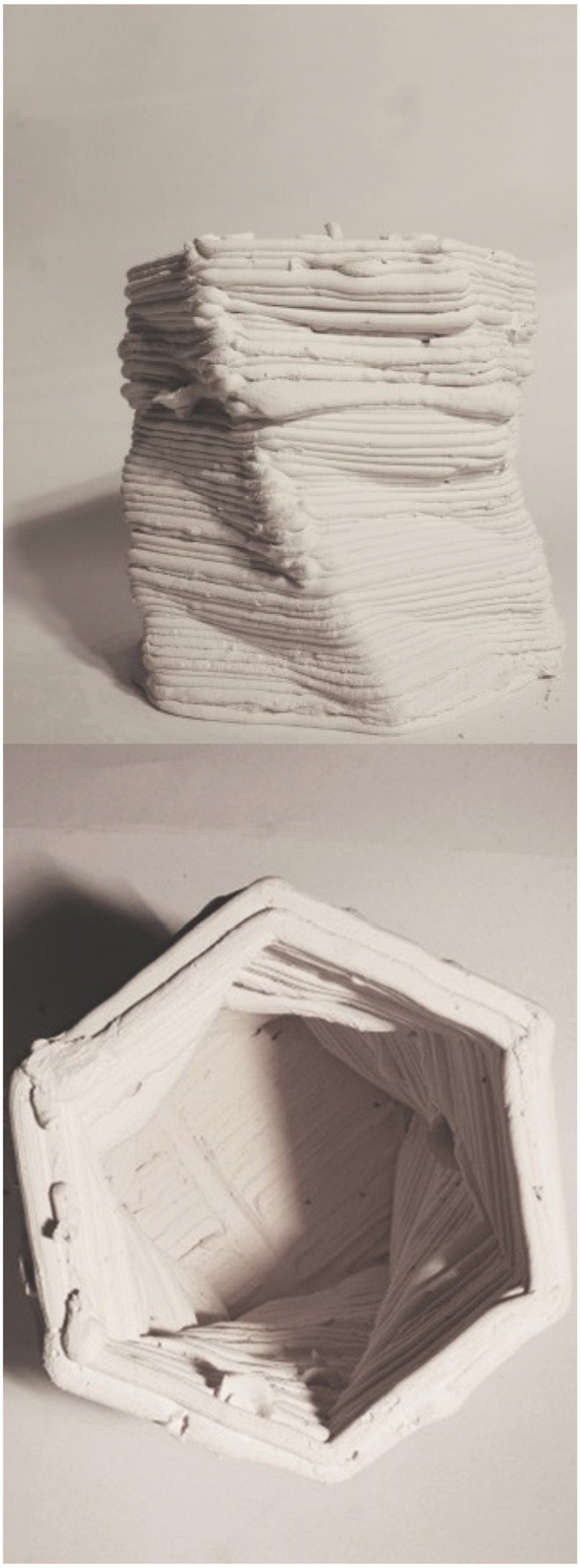
LAYERS AND PERIMETERS
Layer height: 3 mm
1st layer height: 1.5 mm
Perimeters: 2
Solid layers (bott.): 2
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 7.5 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-Try just a little thicker consistency
-Make base layer height bigger
-Try filling tube next time - might help with air bubbles
-Bulges from inconsistency (air jump from 3 to 1.8)



TEST 18 09.29.18

LAYERS AND PERIMETERS
Layer height: 3.8 mm
1st layer height: 1.5 mm
Perimeters: 2
Solid layers (bott.): 2

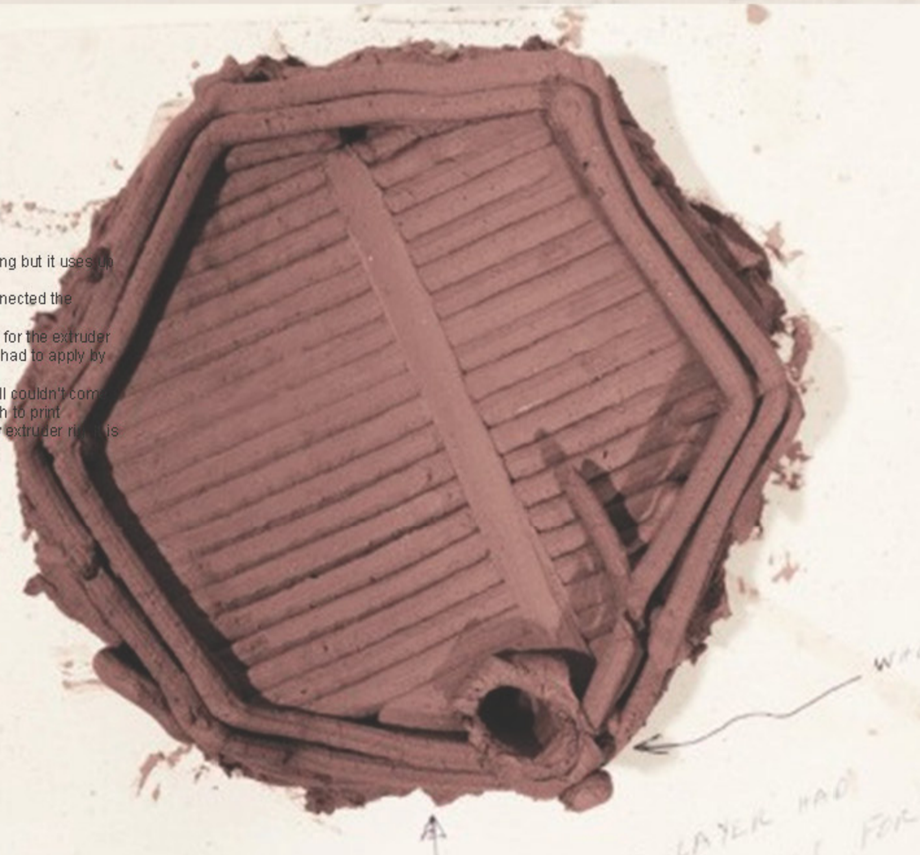
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 23
Small perim. : 100%
External perim. : 100%
Infill: 80
Solid infill: 20
Bridges: 60
Travel: 80
1st layer speed: 100%
Max print speed: 80

ADVANCED
Default ext. wid. : 7.5 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-3 bottom layers
- This would be good for casting but it uses up a lot of clay
-There's a hole when I disconnected the compter and the nozzle fell
-1st bottom layer was too fast for the extruder so hardly any came out and I had to apply by hand
-Mixed clay too thick and it still couldn't come out of the extruder fast enough to print
-This is the first print with new extruder ri[illegible] is much better without air leaks



TEST 19 09.29.18

LAYERS AND PERIMETERS
Layer height: 3.8 mm
1st layer height: 1.5 mm
Perimeters: 2
Solid layers (bott.): 2

INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 25 mm/s
Small perim. : 25 mm/s
External perim. : 25 mm/s
Infill: 25 mm/s
Solid infill: 25 mm/s
Bridges: 25 mm/s
Travel: 25 mm/s
1st layer speed: 25 mm/s
Max print speed: 25 mm/s

ADVANCED
Default ext. wid. : 7 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-Bottom layer had about 3 hours to dry
-Model finished before something failed
-Ist layer came out way too fast
-With new set up, not air escapes so turn air on until it is to the correct spot then immediately turn it off

TEST 20 10.03.16

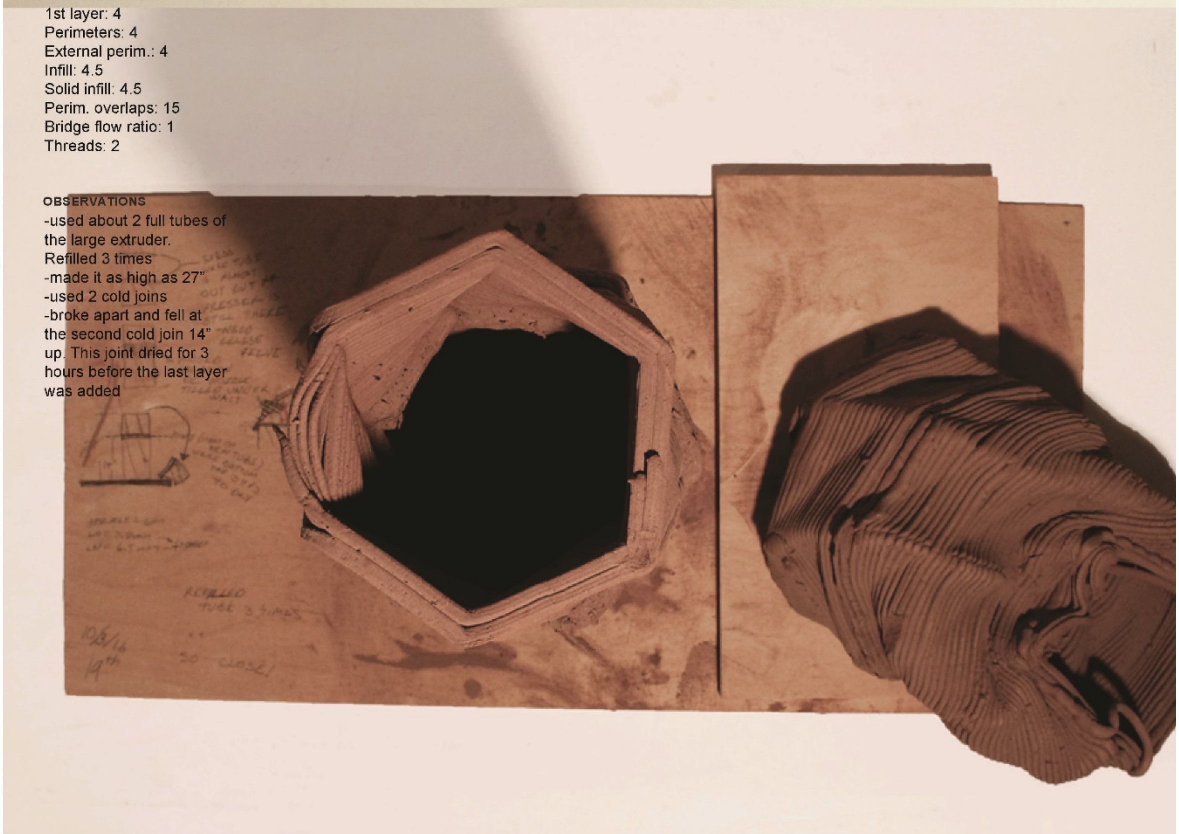
LAYERS AND PERIMETERS
Layer height: 3.8 mm
1st layer height: 1.5 mm
Perimeters: 2
Solid layers (bott.): 2

INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 25 mm/s
Small perim. : 25 mm/s
External perim. : 25 mm/s
Infill: 25 mm/s
Solid infill: 25 mm/s
Bridges: 25 mm/s
Travel: 25 mm/s
1st layer speed: 25 mm/s
Max print speed: 25 mm/s

ADVANCED
Default ext. wid. : 7 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2



OBSERVATIONS
-used about 2 full tubes of the large extruder. Refilled 3 times
-made it as high as 27"
-used 2 cold joins
-broke apart and fell at the second cold join 14" up. This joint dried for 3 hours before the last layer was added

TEST 21 10.06.16

LAYERS AND PERIMETERS
Layer height: 3.8 mm
1st layer height: 1.5 mm
Perimeters: 2
Solid layers (bott.): 2

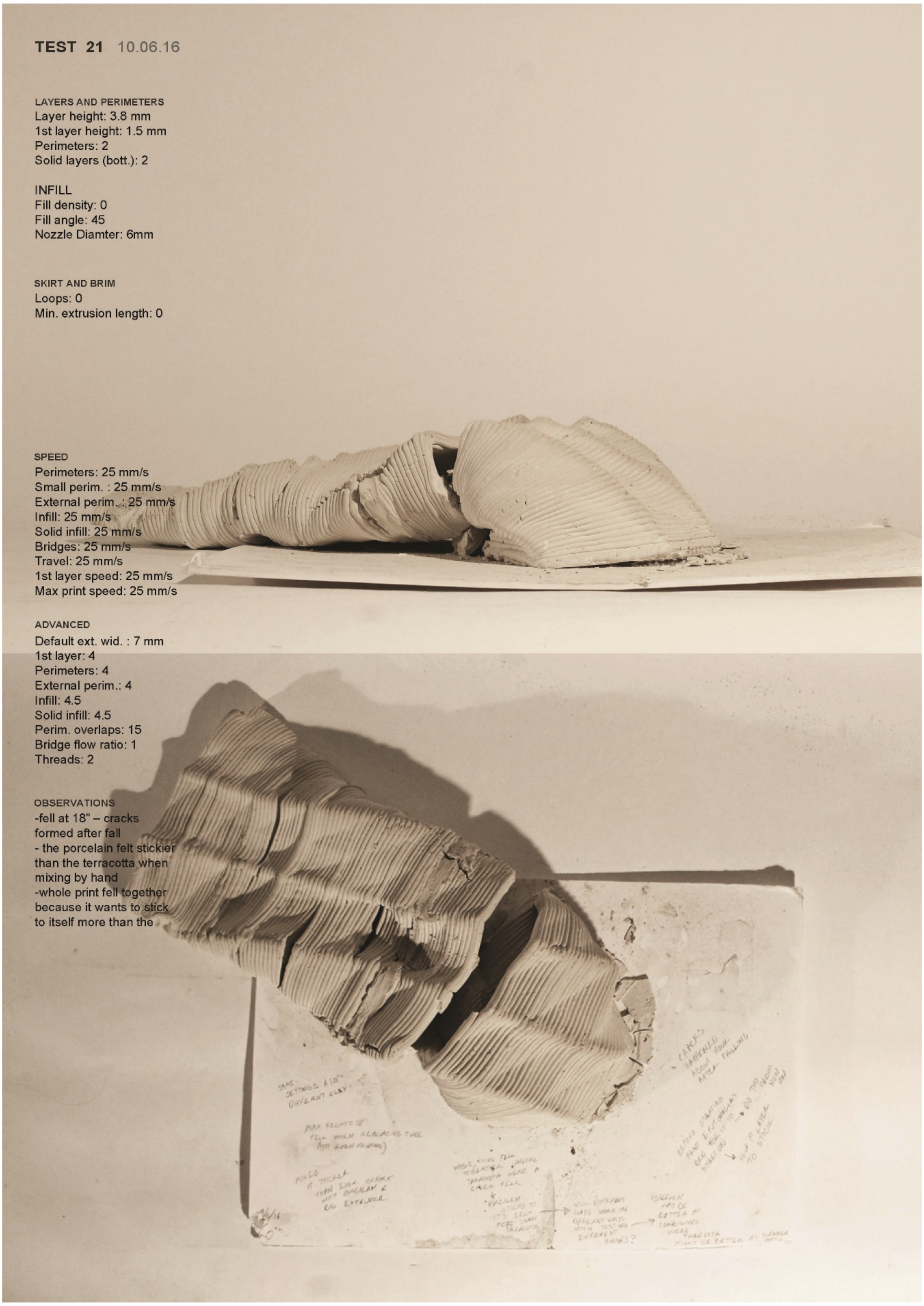
INFILL
Fill density: 0
Fill angle: 45
Nozzle Diamter: 6mm

SKIRT AND BRIM
Loops: 0
Min. extrusion length: 0

SPEED
Perimeters: 25 mm/s
Small perim. : 25 mm/s
External perim. : 25 mm/s
Infill: 25 mm/s
Solid infill: 25 mm/s
Bridges: 25 mm/s
Travel: 25 mm/s
1st layer speed: 25 mm/s
Max print speed: 25 mm/s

ADVANCED
Default ext. wid. : 7 mm
1st layer: 4
Perimeters: 4
External perim.: 4
Infill: 4.5
Solid infill: 4.5
Perim. overlaps: 15
Bridge flow ratio: 1
Threads: 2

OBSERVATIONS
-fell at 18" – cracks formed after fall
- the porcelain felt stickier than the terracotta when mixing by hand
-whole print fell together because it wants to stick to itself more than the

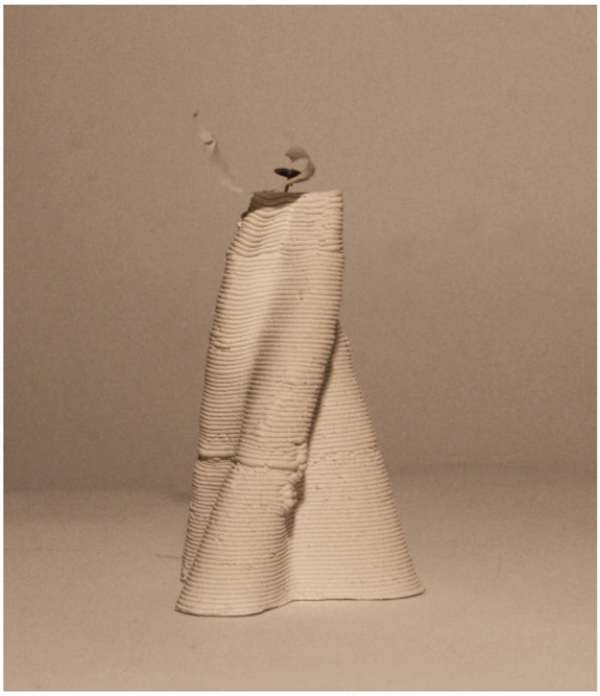


Test Print Journal Data Phase 2

PRINT 1

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Outcome: Final test of tool rebuild (Phase 2)
Risk Quadrant: Safe, Daily Decision



PRINT NOTES/OBSERVATIONS:

- This print was to make sure printer is working fine
- Everything went well; printer running smoothly
- Didn't have to adjust anything
- Could have left the room while printing, no need watch

PRINT 2

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Test print
Risk Quadrant: Stupid/Daily Decision

PRINT NOTES/OBSERVATIONS:

- This print is to learn how to use the foot pedal which controls air regulation
- Turned the air to High setting so the foot pedal needed to be used constantly as a way to learn using it
- Maintaining consistency on the print the entire time was difficult - practice needed to maintain consistency

PRINT 3

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Test print
Risk Quadrant: Gamble

PRINT NOTES/OBSERVATIONS:

- This print is also to learn how to use the foot pedal, which controls air regulation
- Consistency was much better than first time (print 2), already adjusting to foot pedal
- Tried to make a consistent gap around 3/4 up the print
    - Stopping the print (air) at the same spot each layer was much easier that starting it again - it takes a second for the printer to begin printing once it has been stopped completely (to create the gap)
    - If there's any clay hanging off the nozzle once it starts printing again, it hangs off the print like little tails - must wipe any excess clay before turning on air pressure again
- Print direction is counterclockwise

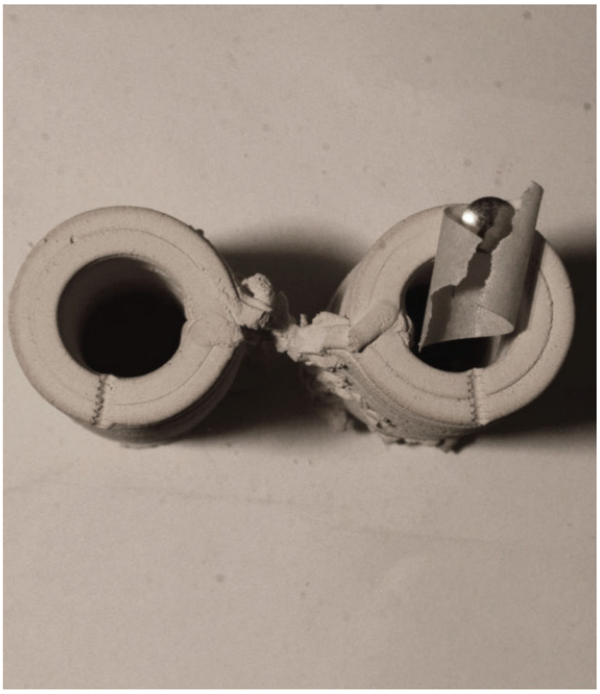
PRINT 4

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Test print
Risk Quadrant: Gamble

PRINT NOTES/OBSERVATIONS:

- This print is still to learn how to use the foot pedal, which controls air regulation
- Learning to use the foot pedal to print multiple shapes simultaneously - cut air while nozzle moved between the two shapes
- The two prints would be completely connected if foot pedal not used
- Didn't adjust anything or use the foot pedal for the last inch of the print (1")
- If printed inside first, the little nubs wouldn't be as visible
- Try with one shape
- I can see little clay pieces on the seams between the prints
    - I think the pieces would go away if set the printer to print the outside ring first and the inside ring second
- Print direction is counterclockwise



PRINT 5

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Risk Quadrant: Gamble

PRINT NOTES/OBSERVATIONS:

- Trying to make a hole using foot pedal
- Print direction is counterclockwise
- Left side of opening is cleaner because the air can be shut off right away
- Right side not as clean finish because air takes a second to start again; hard to tell when to turn air on
- Air is cut off at tangent point in order to create opening
- Added a solid cylinder where I wanted the hole to be as a visual cue for when to start/stop the air via foot pedal in order to make the hole

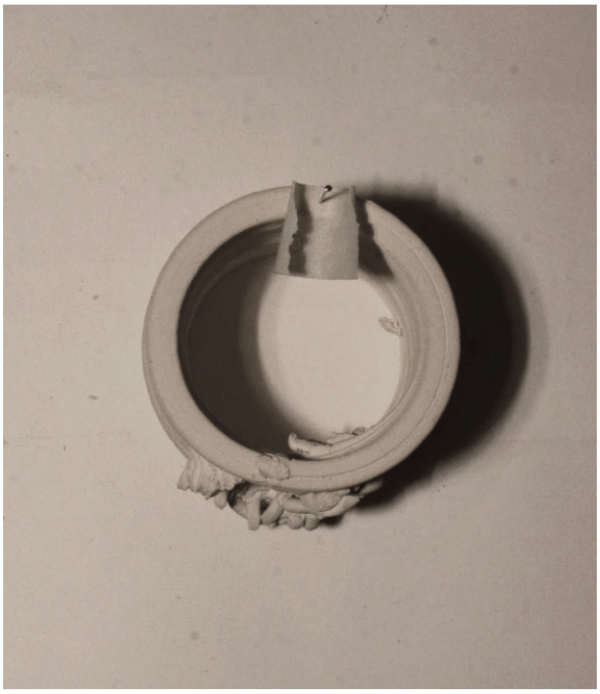
PRINT 6

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Geometry Test
Risk Quadrant: Gamble

PRINT NOTES/OBSERVATIONS:

- Same as Print 5 but made geometry a little different
- Right side of opening still worse because the excess clay sticking off the nozzle
- Used much longer/exaggerated cylinder in order to have more time to turn air on again and avoid nozzle excess clay for a cleaner finish
    - This definitely helped, but for it to actually work and produce a clean finish, the visual cue would have to show exactly when to start the air again, which would be easier and more exact to alter the print after it was finished



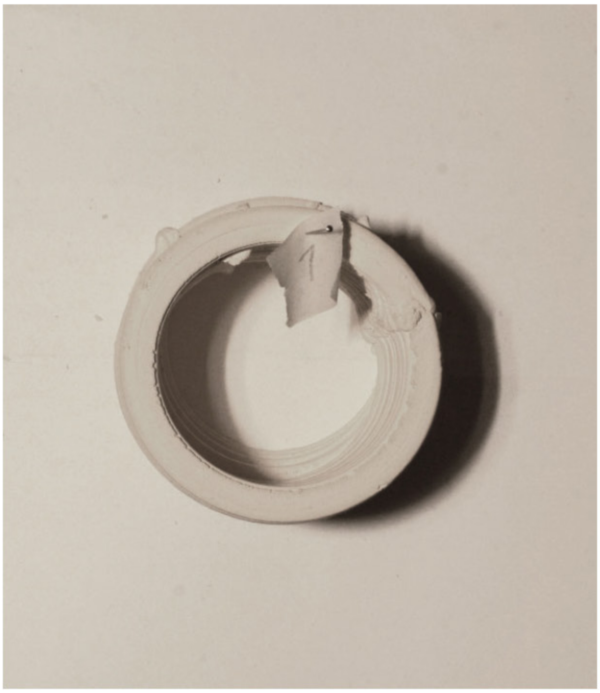
PRINT 7

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Layer Test
Risk Quadrant: Gamble

PRINT NOTES/OBSERVATIONS:

- The purpose of this print is to control layer height (resolution of the print) using the air - different layer heights throughout the print
- Process:
  1. Deliberately set air to High
  2. Use foot pedal to release a small consistent amount of air to keep constant pressure for the 1.5 mm layers
  3. Use the foot pedal to completely release all air by pressing it down completely for 2 layers of the 1.5 mm height, before changing to a new height.
  4. Release the foot pedal completely so there is enough air to fill a 4.5 mm gap for one layer
  5. Repeat steps 3 + 4 one more 4.5 mm layer
  6. Return to step 2



PRINT 8

PRINT SPECIFICATIONS:

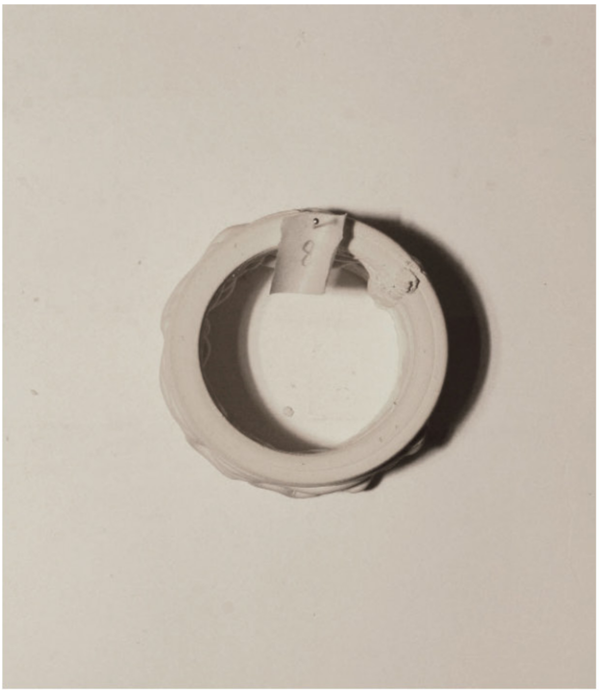
Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Air Pressure Test
Risk Quadrant: Strategic Risk

PRINT NOTES/OBSERVATIONS:

- This print is similar to Print 7, but this print cut the air pressure off for more layer to get a cleaner print

- Process:
    1. Set air for 1.5 mm (the smallest height and beginning height)
    2. Allow print to run for 9 layers without interfering
    3. Use foot pedal to completely cut air off for 10 layers - 15 mm (1.5 mm x 10 layers). Air will begin again at 16.5 mm
    4. Use the air regulator to turn up the pressure very high while the air is cut off to the print. This will allow the clay to begin printing again once the foot pedal is released.
    5. Allow the air pressure to remain high until the print layers reach 1.5 mm
    6. Lower the air pressure once it is able to consistently print at 1.5 mm

    -It took 6 layers of high pressure clay for the material height to reach the printing height.



PRINT 9

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Outcome:
Status: Test Print
Risk Quadrant: Gamble

PRINT NOTES/OBSERVATIONS:

- Test and practice for print 12

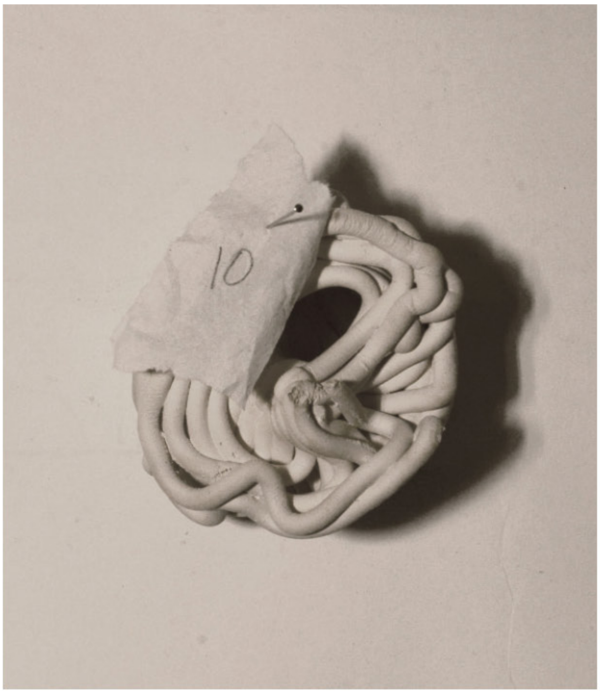
PRINT 10

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Status: Test print
Risk Quadrant: Gamble

PRINT OBSERVATIONS:

- Test and practice for print 12



PRINT 11

PRINT SPECIFICATIONS:

Computer Geometry Modeling: N/A
Code/File Setup: N/A
Material Preparation: N/A
Print Time: N/A
Outcome:
Status: Test Print
Risk Quadrant: Strategic Risk

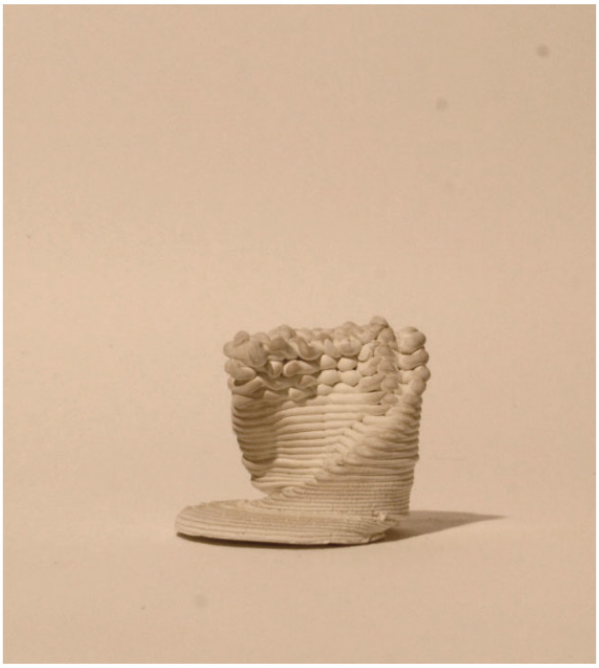
PRINT OBSERVATIONS:

- Test and practice for print 12

PRINT 12

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 8 Hrs
Code/File Setup: 2 Hrs
Material Preparation: 45 Min
Print Time: 30 Min
Status: Final print (of prints 9, 10, 11)
Priority of this print: File Setup
Risk Quadrant: Strategic Risk



PRINT NOTES/OBSERVATIONS:

- Tool (printer) no longer factor because it works without issues
- Designed geometry to coordinate with file set up to achieve maximum slope the particular layer height would allow without failure.
  - Printed using 3 different layer heights with maximum slope:
    - 1.5 mm max (bottom section)
    - 3 mm max (mid section)
    - 6 mm max (top section)

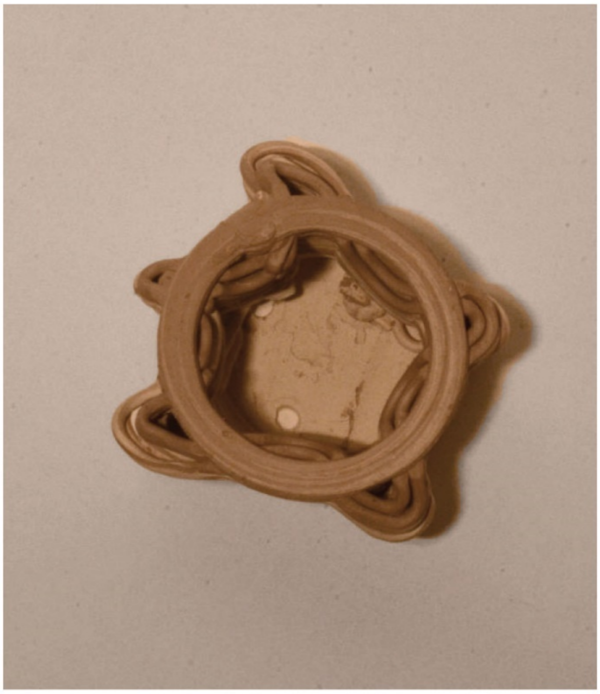
PRINT 13

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 2 Hrs
Code/File Setup: 5 Min (used existing standard template)
Material Preparation: 2 Hrs
Print Time: Not recorded
Status: Test/Final print
Risk Quadrant: Daily Decision

PRINT OBSERVATIONS:

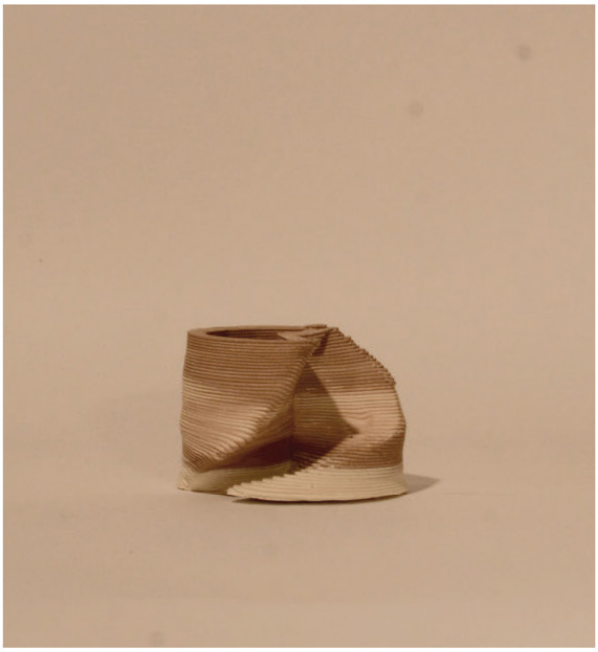
- Took longer than normal because it was testing the difference in material - Porcelain and Terracotta.
- Testing the switching of both back and forth, and also to see which material would break (if it did)more easily when it folds over (see print).
    - They all seemed to be about the same, except for the Terracotta – cannot handle larger slopes, broke a certain points.
    - Porcelain can handle larger slopes is gist of this test.
- Also learned timing for how full to fill tube with material, and when to transition between the two materials
- Also figured out time and slope for each material
- This test falls in the Daily Decision category of the graph.
- Only Test for Print 14.



PRINT 14

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 6 Hrs
Code/File Setup: 5 Min (used existing standard template)
Material Preparation: ?
Print Time: Not recorded
Status: Test/Final print
Risk Quadrant: Strategic Risk



PRINT NOTES/OBSERVATIONS:

- 1.5 mm existing standard height
- Does not coordinate with layer height, but coordinates with material: lower slope areas are porcelain, higher are terracotta.
    - Porcelain 'sticks' to itself more, therefore it can achieve shallower (lower) slopes as opposed to terracotta, which needs higher slopes to achieve clean print, otherwise it fails.
- This print prioritized material prep
- Only print, not test prints

PRINT 15 (Sphere)

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 10 Hrs
Code/File Setup: 5 Min (used existing standard template)
Material Preparation: 45 Min
Print Time: 20 Min
Status: Test print - No photo
Risk Quadrant: Gamble

NO PHOTO

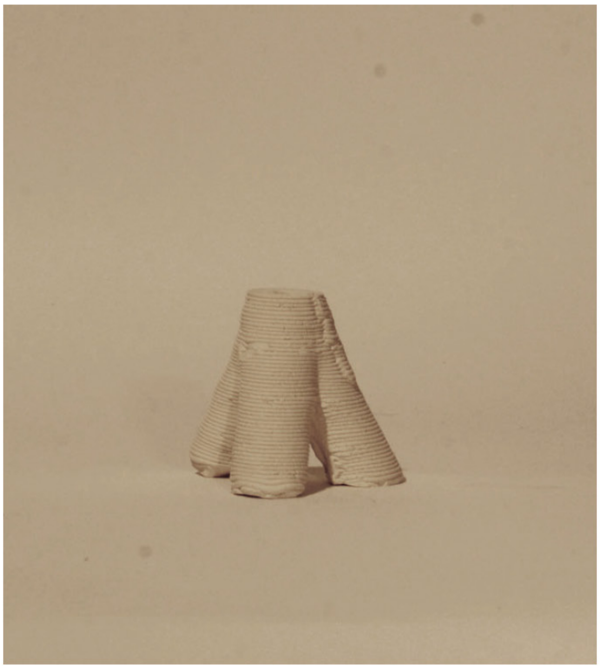
PRINT NOTES/OBSERVATIONS:

- Didn't Work, print broke
- Don't have print, broke – almost perfect sphere.
- Failed due to geometry: geometry was to bowed, therefore printing width doesn't overlap every time, so printer was printing too far out, and as a result it was falling over itself.
- It was predicted it would not work, therefore this print falls in the Improbable category of the graph, but it would have fallen in High Reward category of the graph if it succeeded because it "would've been great".
- This print prioritized geometry
    - Test to see if geometry would work

PRINT 16 (Tripod)

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 1.5 Hrs
Code/File Setup: 5 Min
Material Preparation:
Print Time: ~20 Min each (8-10 tries)
Status: Final print of Print 4
Tripod
Priority of this print: User: Air Regulation
Risk Quadrant: Gamble / Strategic Risk



PRINT OBSERVATIONS:

- Skipped geometry because didn't know where to go.
- This print prioritizes user: air regulation.
- Took 8-12 tried because of 3 towers - every time tower changed, air must be cut off, which has to be timed, and allow air to start up again because it takes a second for clay to come out of nozzle, "so to get it this crisp and clean took so many tries."
- Air must be cut off for a second and then released so it can have time to print again before getting to next tower:
    - If too soon, clay dollops will hang
    - If too late, clay will be missing from print
    - Air had to be cut every time it moved from one tower to the next so it wouldn't print (excess material)
    - "This was so hard." B. Scranton.
        - Closer to Improbable category of graph, but High Reward.

PRINT 17 (Egg)

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 5 Hrs
Code/File Setup: 1 Hr (see notes below)
Material Preparation:
Print Time: ?
Print Status: Test print
Terracotta/Porcelain Mix Egg
Risk Quadrant: Strategic Risk

PRINT NOTES/OBSERVATIONS:

- Didn't transition well
- Based off of Print 15 (Sphere) previous semester prints to create shape – subtly not an egg.
- Began with egg but manipulated to something more printable.
- Used porcelain on base and terracotta on top to help build up structure, but failed. Shape outcome is dissimilar to computer modeled shape; Did not transition well.
- Did not use a standard file because it shifted based on lower/upper half of egg - whether to print inside or outside ring first
    - Inside ring first, outside ring last for lower half of egg
    - Outside ring first, inside ring last for upper half of egg
- This print prioritized geometry

PRINT 18 (Egg)

PRINT SPECIFICATIONS:

Computer Geometry Modeling: 2 Hrs (tweaking Print 17)
Code/File Setup: 5 Min (same as Print 17)
Material Preparation: 45 Min
Print Time: 30 - 45 Min
Status: Final print (of Print 18)
Egg: Porcelain only
Risk Quadrant: Strategic Risk

PRINT OBSERVATIONS:

- Tweaked 17, spent 2 hours tweaking.
- Printed with porcelain only because of the way porcelain behaves, this would produce better print because porcelain sticks to itself more so than terracotta.

Index

3

A

C

D

E

F

G

H

I

J

L

M

N

O

P

Q

R

S

T

U

V

W