MAKING MISTAKES

Error as Emergent Property in Craft Practice

Author: Mary Tsai | Advisors: Jonathan Chapman & Mark Baskinger

Making Mistakes: Error as Emergent Property in Craft Practice

How might one find a more human connection into computational forms of making?

Mary Tsai (author) ______________________________

Jonathan Chapman (advisor) ______________________________

Mark Baskinger (advisor) ______________________________

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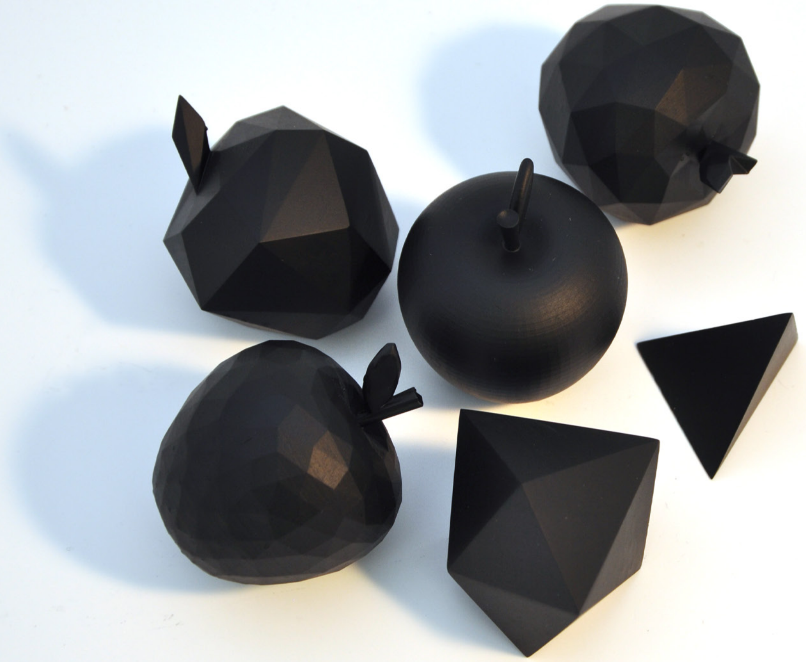

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ABSTRACT

This thesis reframes error as a collaborator to develop form in analog and digital craft practices. When evaluating David Pye's Maker Theory regarding the Workmanship of Risk and Certainty, makers and designers can have a very specific perspective of the role of digital technology in craft. With the use of Computer Numerically Controlled machining becoming more prevalent in today's creative fields, it is important to understand the relationship that designers have with the tools they are using to produce their objects. When utilizing computational technology, a designer can create conditions for emergent properties to occur through error, which ultimately lead to developing a mindset that views the potential in giving agency to the machine. This evaluation of error is set against the trajectory in which design and technology are situated – a future that aims to eliminate failure or imperfection through technology, as well as a concentration on increasing levels of accuracy.

This framework of utilizing error as a collaborator can be a potential way to accelerate the discovery and exploratory process of a design. The projects conducted in this thesis establish several key findings about error and its creative capability. First, in order to be aware of the potential that mistakes can bring, one must adopt a mindset to not prematurely judge error as something negative. Next, there will be an aspect of vulnerability and letting go of control that many designers have a difficult time doing. Additionally, it is important to differentiate from the "happy accident" — projects conducted in this framework are an intentional effort to cause an error in order to see what unpredictable things might happen. Finally, in the realm of digital craft, the machine must be given agency or have its "personality" shine through error. The result of this collaboration between the designer and the machine is a record of the interaction that occurred.

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PREFACE

This thesis is a personal reflection on how I relate to the tools that I use. I began my career working as a professional architect for 4 years before moving into studying interaction design. I have often felt like my interests and design intents are a result of the two creative fields that make up my background.

When moving from architecture to interaction design, I relished in the capabilities and benefits of working with digital and physical products that are tangible and are able to be modified due the smaller scale and more personal connection. When working as an architect, the design process would often be to produce schematic and technical drawings before handing them off to the contractor and ultimately seeing the final result a few months (or years) later. I disliked this feeling of not being able to have a “hand” in or even see the process of something that I created being made. I felt this same disconnect when working with digital technology, even on a smaller scale. Although I see the benefits and conveniences of utilizing machines such as CNC technology, it felt unnatural and less personal due to my lack of control and even the amount of hours spent working on crafting the final product. Using a machine to create something physical felt almost like cheating, despite my actual interest and fondness in learning about technological advancements in today’s world. Moving from architecture to interaction design was something that I valued immensely due to my ability to affect and actually create products, and designating a machine to do everything for me felt too similar to my previous career.

Despite my hesitance to use machines, my background is based in CAD modeling and digital skills. I have never had any problems learning new 3D modeling software quickly and my initial way of thinking through an idea usually starts on the computer. For this thesis, I wanted to bridge that gap between my natural inclination to work with technology to design and my hesitance to use those actual machines that I have access to. I started out the year knowing vaguely the area that I wanted to focus on — the role of craft in physical and digital technologies; however, as I made more things and delved deeper into product creation, I knew I wanted to focus on bringing a “human” voice to machines — something that allowed a more personal connection.

I eventually discovered that the component of error played an important role in all my past projects and it embodied that element of agency that I value in objects in which I feel more connected to. In my thesis, I wanted to see if there was a way to create that similar sort of connection with digitally produced objects.

Although this endeavour embodies my own personal reflection on my approach to design, it also addresses a mindset in the design field in which craftspeople or makers should consider the role of error or imperfection when approaching a project. There is a certain importance and necessity to redeveloping one’s mindset to not immediately dismiss error. The term error has consistently had negative connotations associated with it, since it tends to mean that the designer’s intended vision has failed; however, I believe that it is within this area that innovative and experimental projects are formed. The ability to see the potential of in an error is particularly significant in that it requires an understanding as to why the error occurred and how that it may be utilized or exploited for something else.

It is important to set this thesis work against the current intersection between design and technology. As a society, we are designing towards a future that aims to eliminate failure or imperfection through technology, as well as a concentration on increasing levels of accuracy. The process of how we navigate creativity can lead to a certain type of output that’s usually predetermined before we even begin, and this is partially encouraged by the convenience of the technology that we use. So, even if a designer does not work with physical objects, what is really important is the mindset or willingness to let go of control and move towards an unpredictable and speculative area where innovative and unexpected things can happen.

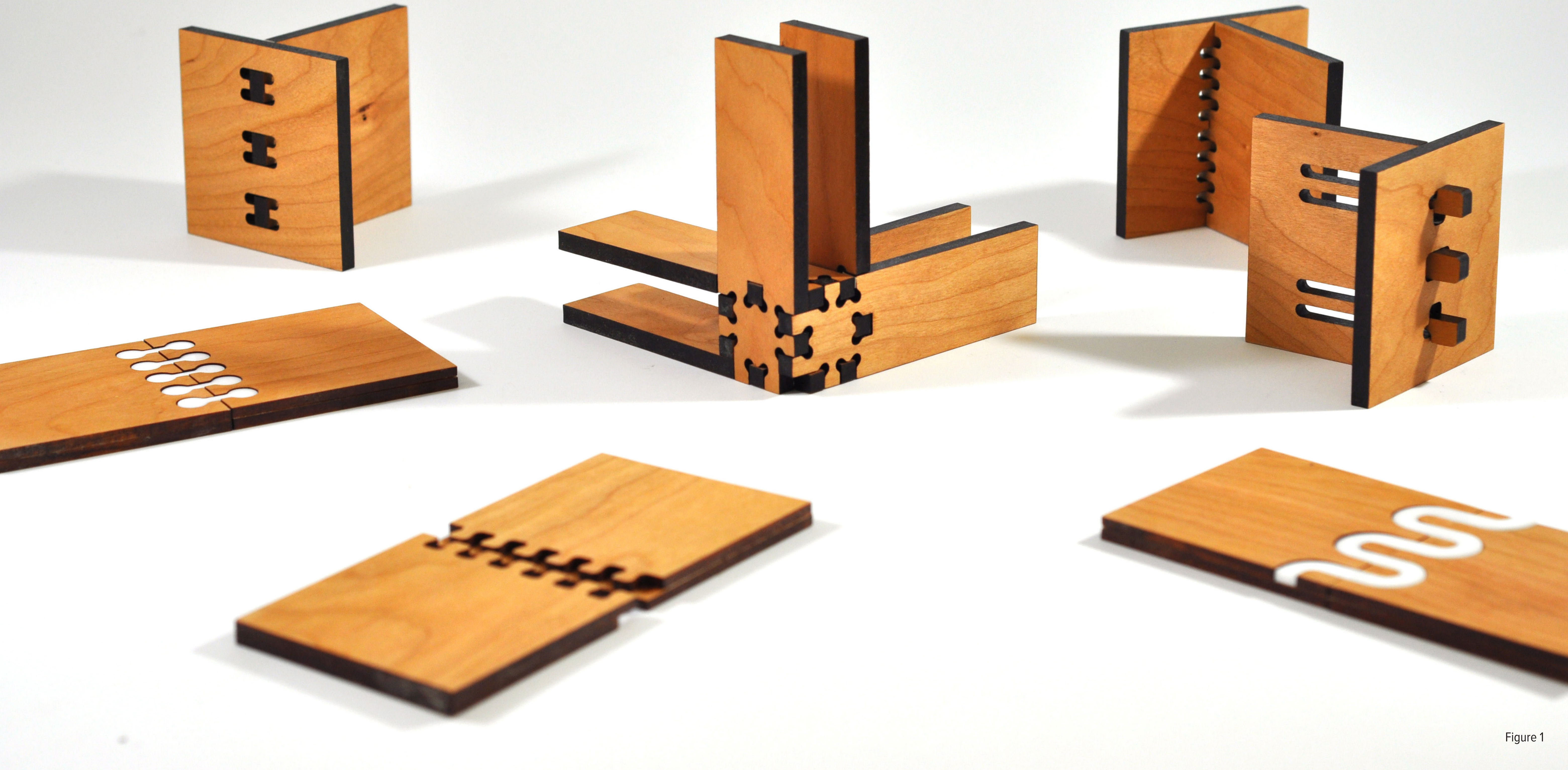
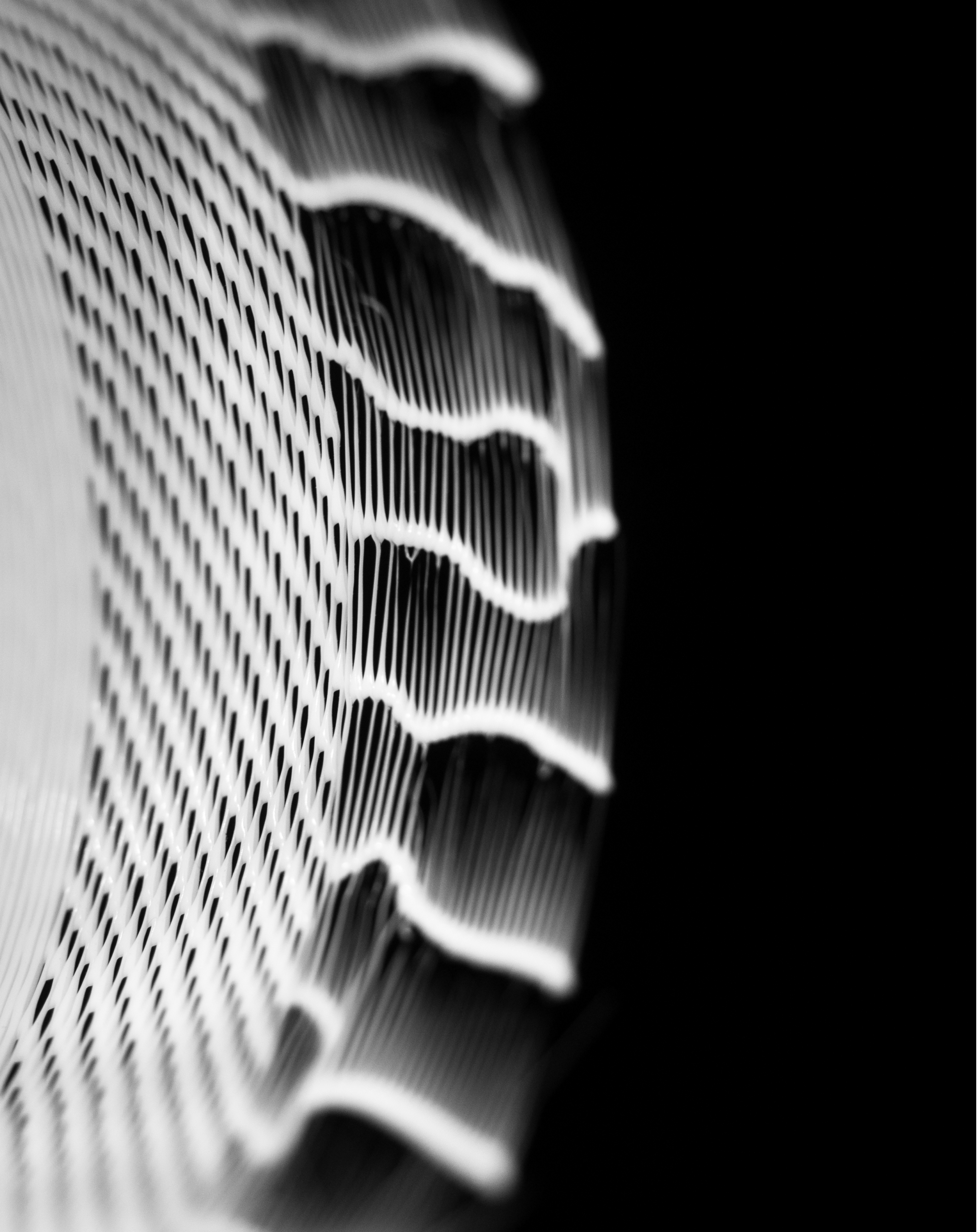


Figure 1

RESEARCH CONTEXT 01

LITERATURE REVIEW
EXPERT INTERVIEWS
INTRODUCTORY PROJECTS



BACKGROUND

In order to understand the potential of studying craft in the design field, it was necessary to look at existing work in this area of study. This thesis changed the way I approach making and made me more sensitive to materiality, manufacturing, and fabrication processes. The first step was to evaluate where I stood in comparison to other designers and practitioners with similar interests. This was essential because by understanding the views of other makers, it allowed me to be influenced by their work but also let me forge my own separate path. With my background in architecture and interaction design, this thesis became a journey of how I play a role in facilitating my work as an active maker.

I conducted a literature review and multiple expert interviews in order to deepen my understanding of relevant and existing work in this area of study. In addition to secondary research, I created a few exploratory making projects in order to immerse my work in digital craft practices.

LITERATURE REVIEW

The literature review I conducted analyzed the role of workmanship and the craftsperson, the making and design process (in both analog and digital), the integration of technology to craft, and the concept of error in non-design related areas.

David Pye's maker theory is particularly resonant to my area of study because his idea of risk directly correlates to errors that are made. He describes handcrafted techniques to involve more potential for risk but also assumes that computer and machines will output products of certainty, which I would argue is not always the case. Machines are typically built for perfection, and aim to eliminate any of the natural variables that increase risk in traditional craft; however, when those variables are unintentionally included and affect the final output, they are defined as errors or "risk". This thesis was founded in Pye's theory and extrapolates on how digital techniques are included into his workmanship of risk framework.

"Is the result predetermined and unalterable once production begins?" [1]

THE NATURE AND ART OF WORKMANSHIP

By David Pye

David Pye was a professor of Furniture Design at the Royal College of Art and in his book, ***The Nature and Art of Workmanship***, he proposed his best known concept—the workmanship of risk. Pye defines the workmanship of risk as "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".[2] He compares this against the workmanship of certainty, which can always be found in mass production; the quality of the product is always predetermined before anything is actually made. Pye discusses the pros and cons of each type of workmanship and also points out that he is not arguing that the workmanship is always or necessarily valuable. His concern is the following:

"The danger is not that the workmanship of risk will die out altogether but rather that, from want of theory, and lack of standards, its possibilities will be neglected and infer forms of it will be taken for granted and accepted".[3]

Pye discusses the quality of workmanship and considers the quality to be on a sliding scale, from good to bad workmanship. Good workmanship carries out or improves upon the intended design and bad workmanship fails to do that by being farther removed from the design intent. Pye argues that goodness or badness is dependent on two different criteria—soundness and comeliness. Soundness is the ability to "transmit and resist forces as designer intended" without any hidden flaws or weaknesses. Comeliness, according to Pye, is the ability to "give or add to the aesthetic expression which the designer intended".[4] The Intended Design is considered the ideally perfect design that the designer has in his mind's eye—it is essentially an unattainable embodiment of his intention.

David Pye describes the workmanship of risk, a concept that most people would associate with craft.

The workmanship of risk can be applied to two different purposes—preparatory and productive. The preparatory stage includes making the jigs, tools, and other devices in order to make the workmanship of certainty possible. The productive stage turns out products for sale. Both these stages can slide in between the workmanship of risk and certainty and often, when an artifact is created, it moves in and out of the two types of workmanship.

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[1] Pye, David, The Nature and Art of Workmanship (University Press, 1968), 22.
[2] Ibid., 20.
[3] Ibid., 7.
[4] Ibid., 13.

"To the absolutist in every craftsman, each imperfection is a failure; to the practitioner, obsession with perfection seems a perception for failure." [5]

THE CRAFTSMAN

By Richard Sennett

Richard Sennett argues that "making is thinking" in his book, ***The Craftsman***. He explores the effects of craft as "an enduring, basic human impulse, the desire to do a job well for its own sake".[6] Because of this "impulse", he argues that good craftsmanship is a quality that every person has and that "there is an intelligent craftsman in most of us".[7]

Sennett divides the book into 3 sections—the first looks at the historical context of craft from medieval goldsmiths to industrial machines. In the second section, he examines the development of skill and argues that knowledge in the hand is gained through touch and movement. In the final third of his book, Sennett argues that motivation matters more than talent due to the craftsman's desire for quality, which "poses a motivational danger: the obsession with getting things perfectly right may deform the work itself". [8] The book then concludes by considering how the craftspersons way of working can give people an "anchor in material reality".[9] He does this through an examination of the "craft of experience", stating that "the craft of making physical things provides insight into the techniques of experience that can shape our dealings with others".[10]

Sennett discusses why physical making can be so satisfying and how that satisfaction is a necessary part of being human. There is a relationship between mental and manual labor that is necessary for humans to feel content and if there is an imbalance, it creates a less motivated individual.

As humans, we are surrounded in material reality, so we need to create things as a way to maintain a relationship with our environment.

Sennett then brings the idea of craftsman into a more contemporary setting by looking at the implications of machines for craftwork. He supports the use of machines to reduce "unskilled, noisome tasks" but considers it an inadequate substitute for "high-cost skilled labor".[11] After discussing the role of machinery, Sennett goes into the role of tools. A tool, unlike a machine, is not able to produce a final product without the help of the craftsperson. The purpose of tools is not to be a final 'end', but to help the craftsperson in the process of creating and exploring.

Ultimately, Sennett finishes up by summarizing how craft is the ability to do and produce good work, and it is something that each individual is capable of doing. It is inherent to humans and commonly practiced as long as relationship, community, and working together remains possible.

[5] Sennett, Richard, The Craftsman (Penguin Press, 2009), 7.
[6] Ibid., 7.
[7] Ibid., 11.
[8] Ibid., 11.
[9] Ibid., 11.
[10] Ibid., 289.
[11] Ibid., 106.

"We must understand what matters in traditional notions of practical, form-giving work." [12]

ABSTRACTING CRAFT: THE PRACTICED DIGITAL HAND

By Malcolm McCullough

In his book ***Abstracting Craft***, designer and technologist McCullough investigates the role of craft in the emerging digital realm. He explores the "fundamental humanity of handicraft" and tool usage, specifically computing technology. [13] McCullough then goes into the emergence of computation as a medium, rather than a set of tools by looking at symbols, interfaces, and constructions, and then moves onto exploring the experience of craft in the world of digital media through investigating medium, play, and practice. A main argument that McCullough makes is how digital work can collaborate with physical human agency and to develop a critical understanding of the ways in which the computer works (as a medium, not a tool) requires a new set of creative skills.

Throughout the book, McCullough discusses how CAD practice is an "abstracting craft" that is not ruled by automation but by inventive, playful artistry. This abstraction is closer to the ideal of pre-modern craft instead of industrial factory work; however, the author claims that with the rise of such tools as Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) systems, along with a number of other software such as paint programs, a new technology is born with old roots by regaining what McCullough calls indirect manipulation. Despite his optimism for computational design, McCullough still considers computers as devices that fragment our way of thinking, which is normally unified and refined. He states that computers are "a bit too

The most important aspect is not "how to use a computer" but "how to be when using a computer." [16]

rewarding to the short reflexive response" and they supply "instantaneous reward".[14]

A major point that McCullough discusses is the engagement of a medium. He states that a medium "must have sufficient effect on the senses in order to command our attention".[15] Skills are evolved from a meeting point between tools and mediums. There must be a range of possibilities for the medium and ultimately, it is up to the craftsperson to gauge how to choose the right medium and push it as far as it will go. Understanding affordances well is what designers and craftspeople do due to their deep familiarity with the possibilities and practicalities of a particular media.

McCullough concludes his book by discussing mental models and really leaving the answer up to the user. He also discusses how in craft, to reach a satisfying level of engagement, one must acquire and maintain an expertise: anything really worth doing takes practice.

[12] McCullough, Malcolm, Abstracting Craft: The Practiced Digital Hand (MIT Press, 1998), 310.
[13] Ibid., xvii.
[14] Ibid., 53.
[15] Ibid., 194.
[16] Ibid., 271.

> *“Error suggests a way of investigating the control of highly practiced actions.”* [17]

As a professor of psychology and an expert in human error and safety, James Reason succinctly describes the various types of mistakes and errors that one encounters in everyday life in his book, ***A Life in Error***.

Reason starts off his book with the event that triggered his analysis of human error — accidentally putting cat food in the teapot absentmindedly. He discusses the ways that failure can occur when one has a desired objective. The first way is that the planning of an action may be correct but the action itself does not work properly. The second way is that the actions perform accurately but the initial planning was inadequate and not thought out enough to achieve the desired outcome. [18]

A LIFE IN ERROR: FROM LITTLE SLIPS TO BIG DISASTERS

By James Reason

The main takeaway that one can take away from Reason’s book is his classification of error typologies. He creates these typologies with reference to Jens Rasmussen’s categorization of human performance. Rasmussen was a safety systems and accident research expert based in Denmark. His model of human performance is divided into skill-based, rule-based, and knowledge-based errors.

Reason discusses the differences between slips, lapses, mistakes and violations before moving into ways in which planning can go wrong, specifically with examples from the engineering field.

> *“I felt very strongly that these naturalistic observations [of human error] could reveal the stuff of which human thought and action were truly made.”* [19]

Overall, Reason’s book focuses on more factual and organizational models to classify error typologies and looks at the reasoning behind each of these categories. It is clear that his background is based in safety research and accident prevention due to its focus on avoiding failures that can cause serious damage to people, organizations, and the environment.

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[17] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 10.
[18] Ibid., 7.
[19] Ibid., 3.

LITERATURE REVIEW OVERVIEW

Over the course of the year, I read a plethora of articles and books about craft. I chose these specific writings due to their wide coverage of risk and working with technology. Despite their different specialities and timelines, the authors tend to agree on the role of machines as a positive component that must be carefully and thoughtfully incorporated into craft in order to enhance skills, rather than replace them. The authors diverge on how specific machines can be used, mostly due to the different times of publication, as well as the capabilities of the technology they had access to.

EXPERT INTERVIEWS

In the initial phase of exploring craft, I interviewed 5 local designers and fabricators in the Pittsburgh area. When talking to the makers, I wanted to learn about their areas of expertise and examine their views on craft in a developing digital world. Each person had differing opinions on how and if technology can contribute to their own field of work and to the overall world of design making. The main reason for these interviews was compare my findings against the literature review that I conducted. Although literature review can provide context and guidance in certain areas, they may be written by authors who are not designers (i.e. Richard Sennett) or may even be outdated (i.e. David Pye). I was hoping that the expert interviews would be able to provide different points of views on the role of error in craft. Because of this hypothesis, I chose a few participants who work solely in design, and the others are design-adjacent but provide a more technical and engineering-heavy perspective. These fabricators ranged from primarily analog work to digital design. I interviewed two woodworkers, one metalworker, one architectural robotic researcher, and a machine learning and algorithmic fabricator.

The expert interviews provided me with perspectives that the literature review was unable to do.

The most insightful and interesting interview I conducted was with the mechanical engineer, who steadfastly did not consider himself part of the design world, despite producing objects and programming software that designers utilize. In our discussion, he remarked that the programs and algorithms that he generates help technology reduce the human error factor and that with machine learning, the work that designers do would eventually become obsolete because the AI would be able to accurately produce objects that humans would take longer to create. It was this remark that made me evaluate how his definition of error differs from my own.

Throughout our conversation, I realized that most of his entire job requires thinking about ways that machines can eliminate the human factor, which in this case was error; however, when I thought back to my own experiences using machines to create something that I might have done by hand, the process was not as easy as I had expected and the outcome often produced something that looked obviously mechanized, which I would then bring back to a more bespoke level through more handwork. It was in this realization that I knew that the component of error was something that I wanted to focus on, since it seems to be the connection between a designer and their object.

When I interviewed each participant, I asked them to define what craft meant to them. I received the following definitions:

Participant 1: "Craft is functional things — it could be an accessory — and has a strong relation to society. I make things for other people, artists make things for themselves."

Participant 2: "Craft is the relationship between designing and making. Craft is designing the process by which you bring something to realization. It also has to do with how you reconcile your design intent with external constraints."

Participant 3: "Craft is what defines us. It means that there is skill in whatever is made and really brings it to a level that machines strive to achieve."

Participant 4: "Craft suggests that it's a high skill domain, what we're doing takes the very best of our skill and robotic/machine skill to pull it off; unlike manufacturing, that's the lowest common denominator of human skill, picked apart into discrete tasks."

Participant 5: "Craft is scale models and hobbies, it's not engineering and professional. Craft is something that doesn't pay the bills, maybe there's not a huge demand for what you do but there's a personal satisfaction associated with it."

The definition that I related most with was the one stated by Participant 2. Learning to work with external variables becomes deceiving with the inclusion of technology, since the design of machines obscures the idea that anything could go wrong. Computers are a black box where information goes in and an output is produced, but when an error occurs, there is very little explanation or understanding as to what happened. I knew that studying the "external constraints" could help me further develop this hypothesis I had of utilizing error as an agent of discovery.

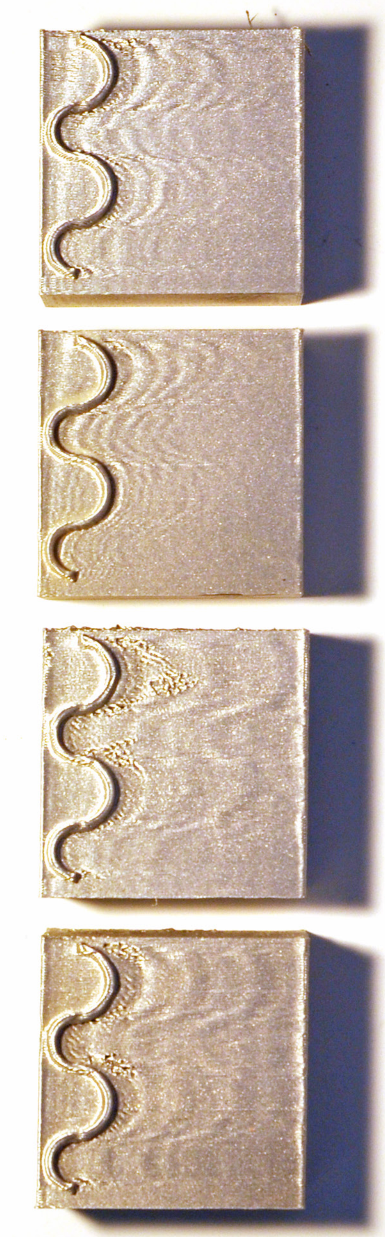


Figure 2

EXPLORATORY PROJECTS

Besides doing literature review and interviews, I created physical artifacts as a means of exploring craft first hand. I had created objects previously, but not specifically for the purpose of simply making something and evaluating the creative process. Additionally, I had to familiarize myself with the fabrication capabilities offered to me at Carnegie Mellon University so that I could formulate my next steps clearly. My hope for these projects was to come across a component that would be interesting to follow down a path — this suspicion ended up being correct, I would eventually recognize that error became the main connective thread amongst all the conducted projects.

Figure 3

SCOPING

For the first project, I looked at creating a simple and recognizable form — a spoon — with different techniques. The fabrication techniques ranged from using handheld tools, to power tools, to the CNC Machine, and finally to 3D printing (Figure 3). Ultimately, I realized how much more intimate I felt to the ones that I had spent time carving and understanding how to create the form. This was not solely isolated to the hand-carved versions, it also included my process with the CNC machine — since I was unsure if it was possible to create a curved double sided form successfully, I had to spend a good amount of time experimenting and failing with the machine before finally producing an accurate representation of my digital file.

After producing my spoons, I decided to analyze them on a scale relevant to David Pye's Workmanship of Risk and Certainty (Diagram 1). I mapped the amount of risk that was present in each stage of the making and was able to break down the differences between each technology. As predicted, the largest stage of risk were in the ones containing hand tools and less computer technology; however, an important thing to note is the high amount of risk still present at certain areas in the digitally created spoons — these were due to my lack of knowledge of how the material and software worked, which increased the potential for error and failure.

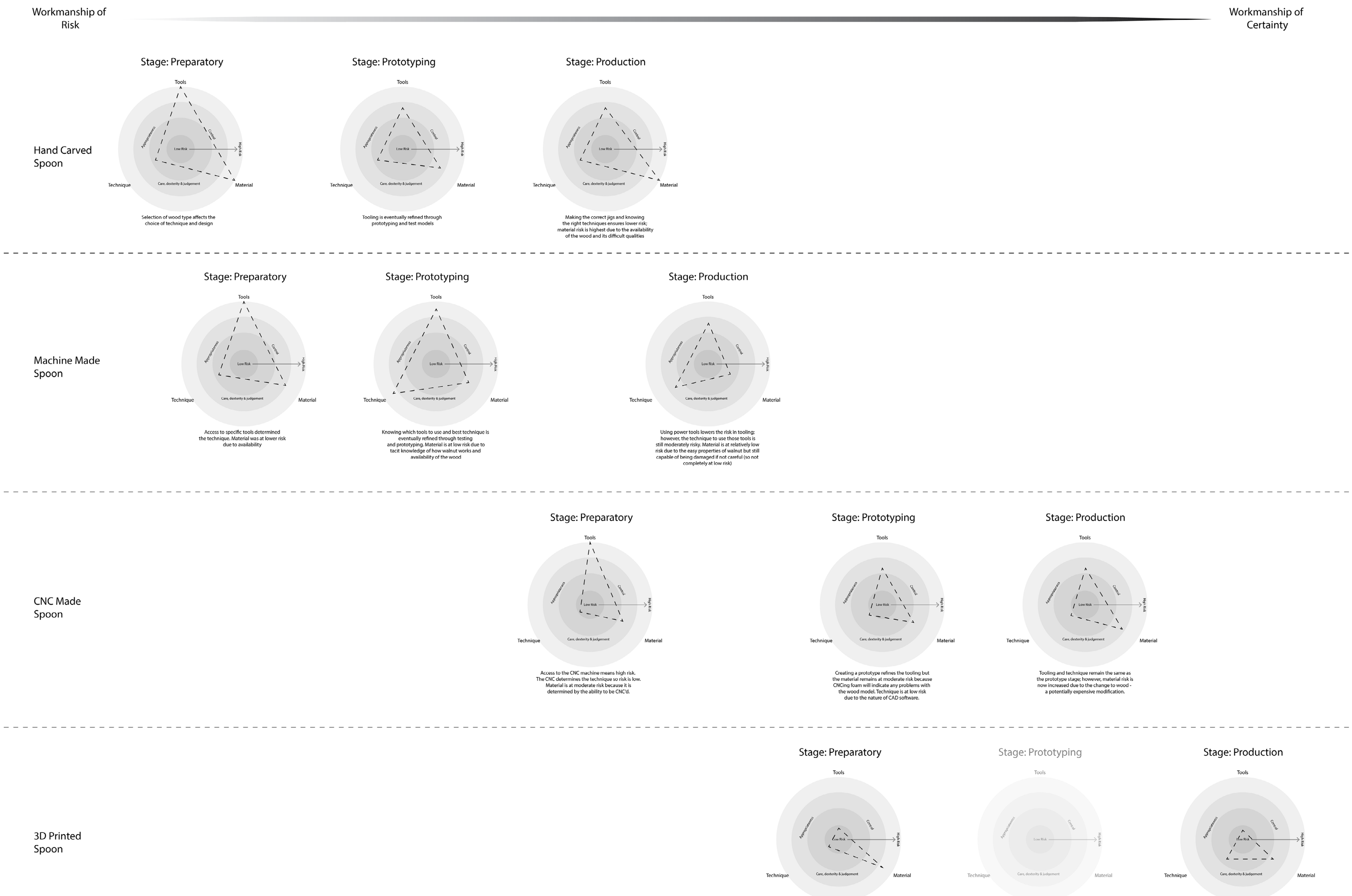


Diagram 1: Using David Pye's Workmanship of Risk vs. Certainty to Analyze My Spoons

Figure 4

DIGITAL JOINTS

I also wanted to create joints with Computer Numerically Controlled (CNC) technology (Figure 1). Since wood joints are usually created by hours of practice with a hand chisel and require extremely careful attention, the CNC seems like an “easy way out” to create joints that are just as strong and potentially even more creative. I decided to try using the CNC machine to route out wood and assumed that the final output would be a perfect replica of the digital file but failed to take into account all the different variables that could cause error. I ended up with joints that had a fair amount of tear out and were not perfect fits due to the bowing of the CNC bed.

Only after this failed experiment did I think about the process. I had always presumed that machines make things more convenient since I can spend less time using my hands to create the object, but they actually require much deeper understanding of the technology in order to perform successfully and I spend just as much time experimenting and thinking through the digital file as I do with hand tools. This project highly reflected the opinion of Participant 2 in my interviews. Working with technology can still be considered craft — it depends on how well I am able to take into account the external variables that do not necessarily exist in the digital world and work around or with them.

My assumption when using machines was that they always make life easier.

Ultimately, I ended up using laser cutting technology (Figure 4) to produce the digital joints (again, not a perfect output) but it was with this realization that I decided to focus on analyzing my perceptions of error in both analog craft and digital technology.

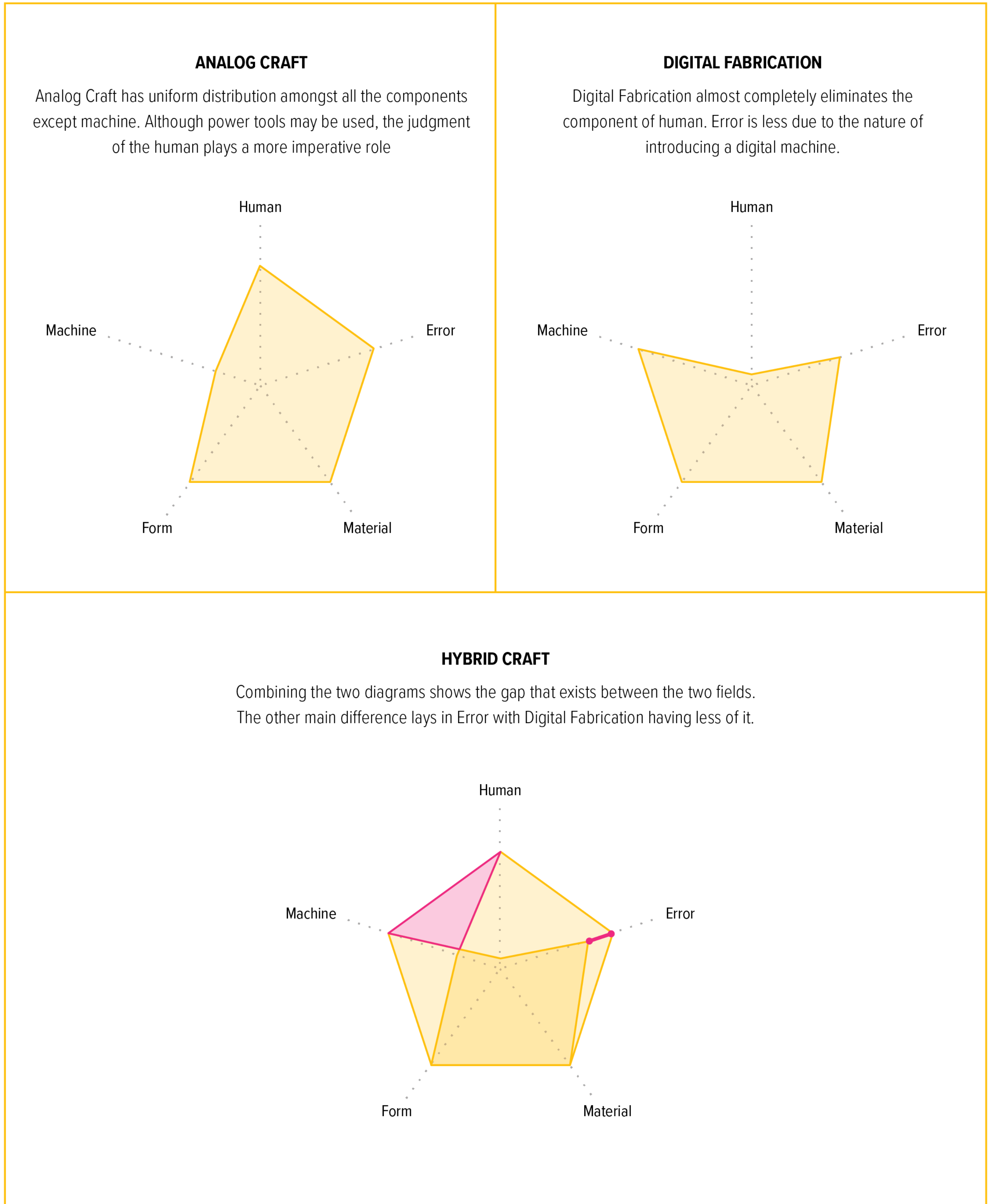


Diagram 2: Mapping Hybrid Craft

FINDING THE GAPS

In Diagram 2, the web layout shows the relationship between five components — human, machine, form, material, and error factor. In analog craft, each element is spaced out equally, except for machine. This is the equivalent to David Pye's Workmanship of Risk theory. In digital fabrication, the human is eliminated and the chance for error is slightly reduced. By comparing the two diagrams, one can see that the area for exploration lays in the missing gap between human and machine. The error factor is the only other component that changes, which can lead to consideration about how it affects the missing area highlighted in pink.

Moving forward, it was essential to understand the role of error, both in a maker setting as well as in an environment outside of design.

ERROR TYPOLOGIES 02

ERROR AS LAPSES
ERROR AS SLIPS
ERROR AS MISTAKES
ERROR AS VIOLATIONS

ERROR TYPOLOGIES

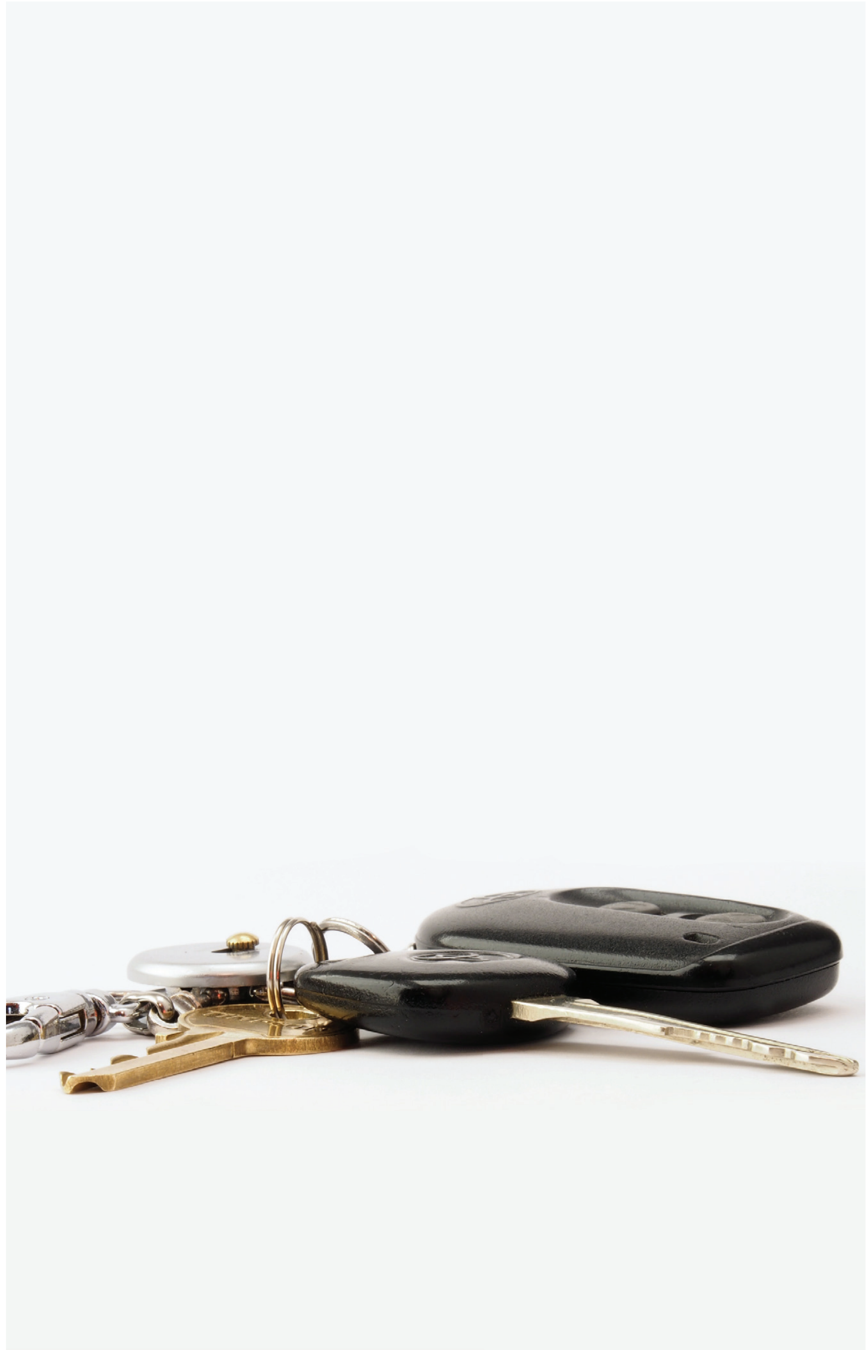
Before exploring error in the context of making and design, I researched its role in everyday life. I looked at the existing framework proposed by James Reason, a professor of psychology at the University of Manchester and an expert in human error and safety. Reason is able to organize the different typologies and succinctly explain how human error can be dealt with on both a personal and organizational level. Understanding this framework is necessary in order to filter through mistakes in design and making. By focusing on certain aspects of human error, designers can then experiment with the individual variables that make up a type of mistake.

Reason defines error as "a term applied to all those occasions in which a planned sequence of mental or physical activities fail to achieve its desired goal without the intervention of some chance agency." [20]

Before delving into errors and mistakes in design, it was important to first analyze them in the context of everyday life. Based off of James Reason's typologies of mistakes (which were derived from Rasmussen), I decided to further study the particular instances in which these errors would occur. Reason discusses three main different kinds of absent minded errors — lapses, slips, and mistakes. These errors are correlated to Rasmussen's three performance levels (skill based, rule based, and knowledge based) and can coexist at the same time. [21]

Inadvertent errors can be divided into action errors and thinking errors. [22] Reason discusses this further when he describes how action errors indicate that the planning was thought out but the ultimate action did not function as planned. The action errors contain lapses and slips.

[20] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 10.
[21] Ibid., 14.
[22] Ibid., 7.



Lapse Example: Forgetting to lock your car

ERROR AS LAPSES

Lapses are a failure of memory. They are typically caused by oversight and are not directly observable. [23] Tasks that are often performed without much attention are the most susceptible to lapses since even the slightest distraction can cause the actor's concentration to shift. Because lapses are internal events, they are not noticeable to an external viewer. With lapses, the involved party often loses their place midway through a task due to distraction.

Lapses are often grouped together with slips due to the situation in which they take place. Normally these errors occur in routines that are frequently performed by the same person. Because of their short attention spans, most people can become distracted by something else and rely on their muscle memory to perform the action; however, it is not always successful, which results in a lapse.

Examples of lapses can be forgetting to lock a car or failing to pay for a subscription because the system did not notify the user of that their credit card had expired.

[23] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 19.

Slip Example: Not turning the kettle on when making tea

ERROR AS SLIPS

Slips are failures of execution. Slips differ from lapses because they concern the level of skill required to complete the action. [24] It is directly observable at the action stage, such as moving a light switch up rather than down. When comparing slips to lapses, it would be possible for a third party viewer to carefully observe and prevent the slip from happening; in the case of lapses, the failure occurs internally so there is significantly less chance of correcting the error. Slips occur when the actor does not perform what he or she meant to do — they occur in familiar situations, similarly to lapses. Examples of slips may include turning the car wheel the wrong way, forgetting to switch the kettle on when making a cup of tea, or creating a typo due to larger fingers using a small keyboard on a cell phone.

Often slips and lapses are brought up in the medical field due to the dire consequences that would happen because of negligence. By being human, it is almost impossible to be completely alert 100% of the time. Slips are attentional actions that are may occur when losing concentration and lapses are memory-based errors.

[24] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 13.

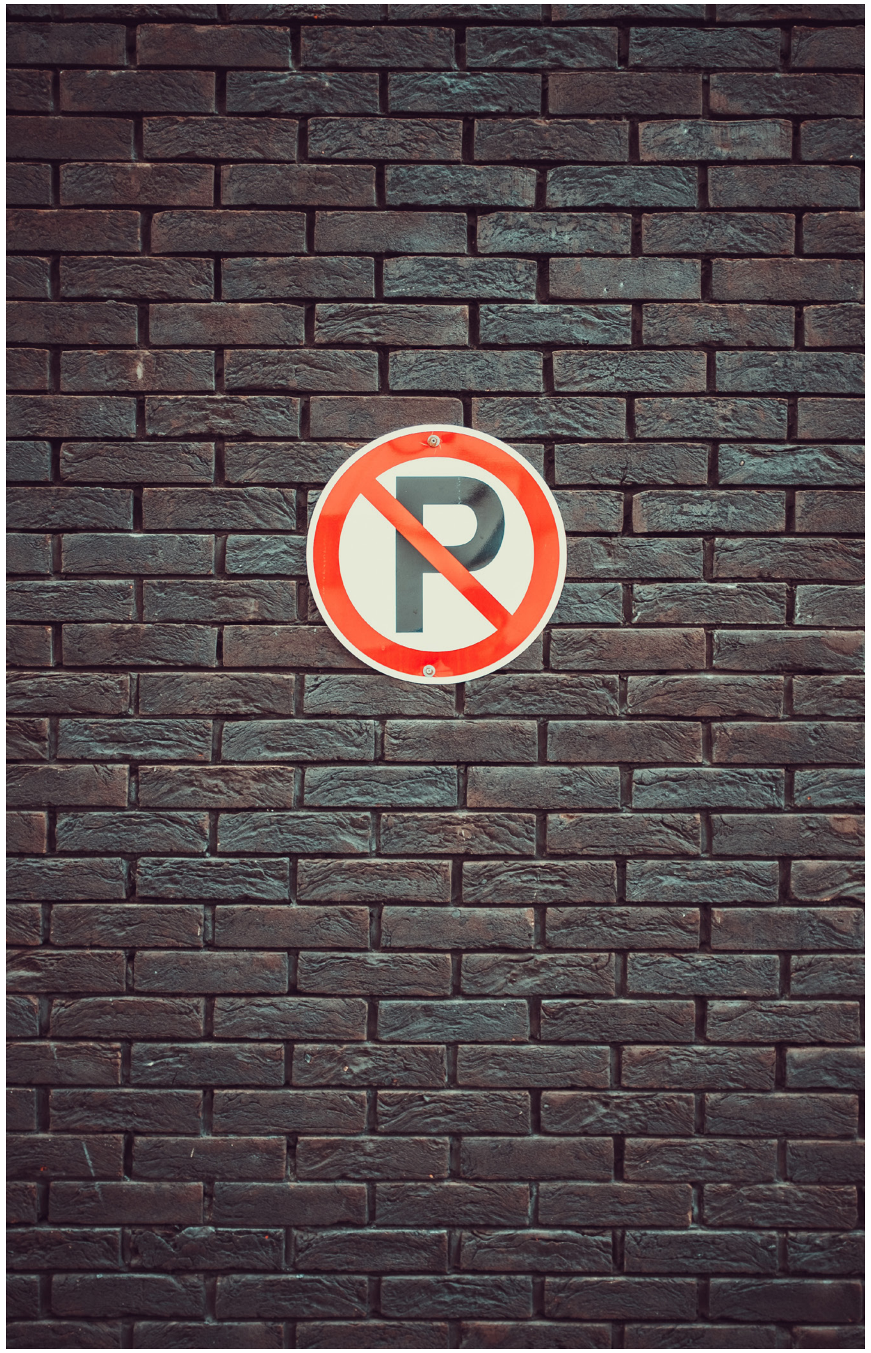
Knowledge-based Mistake Example: Relying on an outdated map

ERROR AS MISTAKES

Thinking errors refer to when the action is performed accurately but the planning was poorly thought out and not developed properly. [25] Mistakes would be considered thinking errors because they are failures of planning, where the initial strategy should achieve the desired outcome, however due to inexperience or poor information, it fails. [26] These kinds of errors occur more frequently when people with less knowledge of experience are involved.

Within mistakes, there are rule-based and knowledge-based mistakes. Rule-based mistakes are situations where the use or disregard of a particular rule results in an undesired outcome. [27] An example of this would be ignoring an alarm after a history of false alarms. Knowledge-based mistakes are due to the lack of understanding or a trial-and-error application, essentially doing the wrong thing believing it to be correct. [28] In these situations, other external variables are important. Humans do not perform well in high-stress situations and often convince themselves to become overconfident, resulting in an error. An example of a knowledge-based mistake would be to rely on an out of date map to plan an unfamiliar route. Although one may be confident that the map is correct, the lack of accurate knowledge or information will cause them to become lost.

[25] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 7.
[26] Ibid., 11.
[27] Ibid., 15.
[28] Ibid., 15.



Violation Example: Parking in an incorrect spot during an emergency

ERROR AS VIOLATIONS

After discussing the absent minded errors, Reason discusses planned errors, which he would consider to be called violations. [29] These are intentional failures, where the actor is deliberately doing the wrong thing.

There are four types of violations: routine, optimizing, necessary, and exceptional. Routine violations occur when the majority of the actors are breaking the prescribed rules and procedures, like most cars driving at 80 mph in a 70mph zone. Optimizing violations occur when the actors try to create more excitement or thrilling activity in order to impress others or relieve boredom. Reason uses speeding as an example of this violation and also states how there seems to be a correlation to gender in this category. Necessary violations occur when circumstances in the environment require a breaking of rules or regulations. An example of this would be a delivery man having to speed in order to complete the day's deliveries. Reasons states that in this instance, the problem occurs within the system, not the individual actor. Finally, an exceptional violation happens in situations of crisis and might be inevitable. The violation may be necessary, such as a partner speeding to the hospital because his or her wife goes into labor. [30]

The author stresses that those who commit the violations may not necessarily intend for the bad outcome that occurs from deviating from the rule. Because of this, Reason talks about the "mental economics of violations", an interesting concept that partially serves as a base point for my exploration into error in making. When Reason mentions the economics of violations, he is discussing something that is not completely understood in full and because of this, is often dealt with incorrectly. [31] The example that he uses is when organizations utilize harsher penalties and control rather than increasing the benefits of compliance.

[29] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 64.
[30] Ibid., 65.
[31] Ibid., 67.

I was drawn to Reason's discussion of violations because of this particular line:

"I mentioned earlier that violations do not always have bad outcomes. In many cases, significant innovations and improved practices can only be achieved by those prepared to push the boundaries, and in some cases to exceed them." [32]

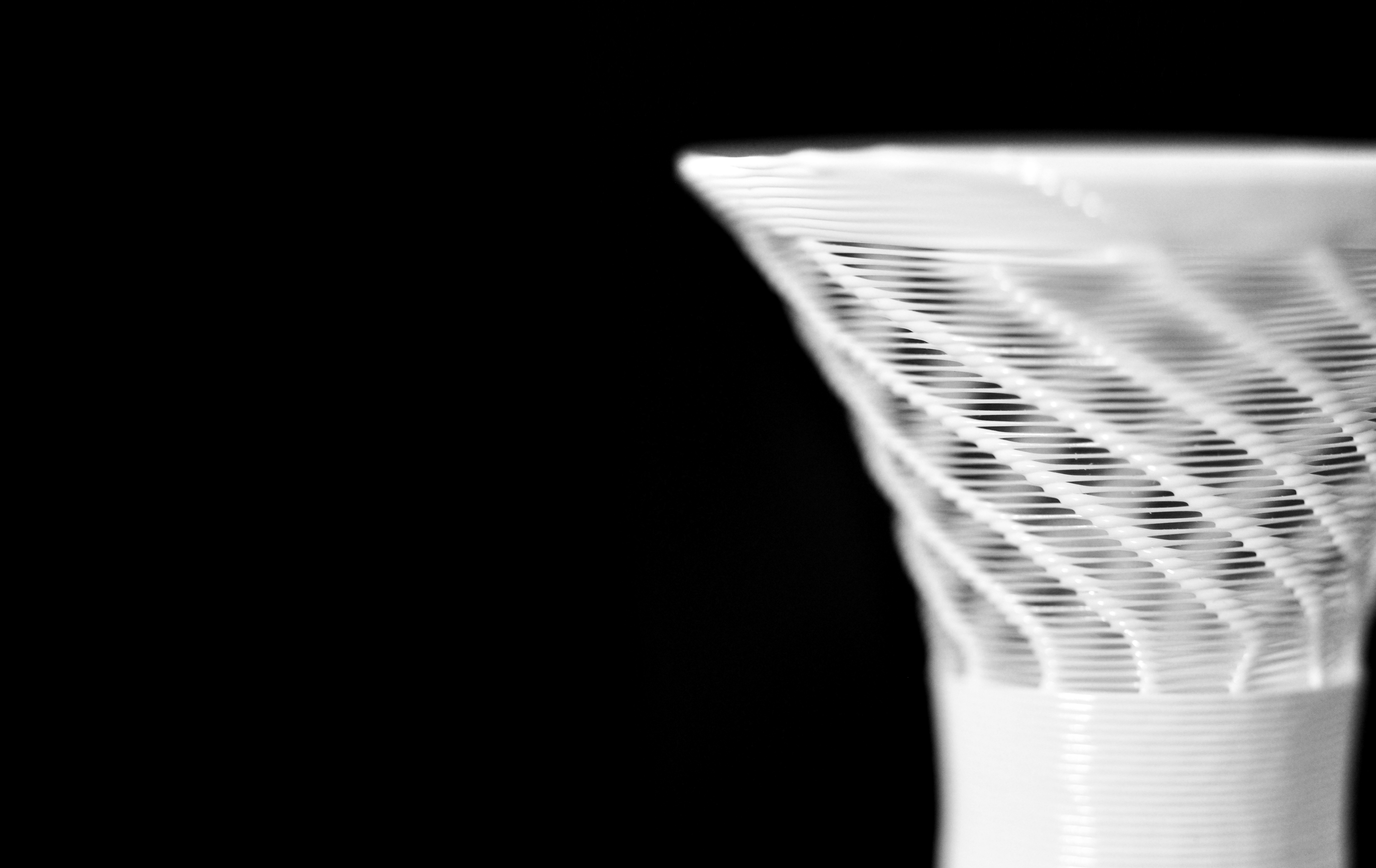
This application and way of thinking is something that I found to be relatable to innovation in design and making, particularly when looking at designers who are able to push the line of creativity by questioning their failures and prescribing an explicit research agenda that is embedded within their creative practice. Reason's economics of violations are crucial to making a successful and positive structure because it has to delve deeply into understanding how the system works and creates beneficial opportunities or touch points out of the problem areas. When creating a product in design, the expected methodology is to provide a solution-based approach for the problem; however, when the solution is unsuccessful, the usual inclination is to start over or readapt to ensure that the solution can be attained. It is from this point that I think that an additional mentality switch could be beneficial — instead of fixating on the one solution that must be achieved, is it possible to adapt and figure out another solution using the groundwork already in place?

Laying out the groundwork of absent-minded and intentional errors is important in order to understand where a possible explorational entry point could be for making with error in mind. In my next chapter, I look at several designers and artists who commit "violations" (which may have been unintentional at first) in order to create something innovative and unique.

[32] Reason, James, A Life in Error: From Little Slips to Big Disasters (CRC Press, 2017), 68.

ERROR IN MAKING 03

THEORY
CASE STUDIES



ERROR IN MAKING

After analyzing error in everyday life in the last chapter, it is essential to understand how it relates to the design world, and specifically in product creation. Error can vary depending on what kind of technique or tool you are using and it is conducive to know the situations in which it can be utilized. Previously, I looked at the different typologies of error defined by James Reason — these categories can be translated into design making as well. Lapses and slips are the typical errors that occur when the designer does not have the adequate knowledge or expertise to perform a task. Mistakes, on the other hand, can be learned from and it can be up to the designer to realize the potential in the error created. These can lead to committing violations, or deliberate explorations with error. In order to recover from mistakes, the designer has to fully understand what went wrong — it is in within this discovery where an exploitation of error can occur.

Designing unpredictable encounters with machines is something that can create space for the tool to behave in ways that would normally be discounted or engineered out, but now can act as an agent of discovery.

As a maker and designer, I have often been quite calculating and systemic when approaching a new project. This stems from my architectural background, but I also know that it is essential to reach beyond my comfort zone in order to create unique products that are particularly meaningful to me. The notion of utilizing error is particularly compelling because it forces me to deeply immerse myself in the craft and understand how I can experiment with qualities that might go unnoticed at a more surface-level analysis.

When looking at manipulating error as a driving inspiration, the situation becomes more about creating conditions for emergent properties to occur. When I decided to focus on 3D printing, there was a shift to create mental conditions where I noticed errors occurring but I did not prematurely judge them as failure, but instead as additional conditions that were happening. By doing this, I had to allow some of the ownership of the creativity to be displaced from my control — instead, the material, machine, and natural variables had more of a say. We utilize 3D printers as obedient and highly skilled machines, but they are often only utilized as a final output device. By allowing the printer to have agency, the relationship between maker and machine becomes more of a conversation — there is input from both sides, rather than one-way didactic design. Ultimately, the product that emerges is the result of the interaction. It is a record of the negotiation that happened between human and machine.

David Pye served as my starting point because of his concepts that revolve around the relationship of tool, human, and material. 3D printing is a technology that is very subject to failure despite its reputation as an output device that produces final pieces. If I could turn 3D printing into a manipulatable tool, it would bring the relationship between tool, human, and material back into something more unique and bespoke. The printer is not usually subject to modification or experimentation but by introducing natural error as an agent, it allows the machine to have a little more agency and input its own voice into the final product.

There are certain terms that I found myself often using when describing my process. The role of error came into play because of my inability to relinquish control in some of the projects that I have done in the past. This idea of control is tied directly to planning and predictability. The part that I am not completely in control of — the unpredictable element — is the main focal point where the emergent properties appear. With error in mind as the focal point of discovery, it opens up new opportunities to view machines and tools and allows for designers to think in a different and less methodical way.

CASE STUDIES

There are several existing projects that address the idea of craft and error in an innovative manner. In order to formulate my own explorations, I created case studies about these artists to evaluate how they have embraced, confronted, and avoided error in their projects. Almost all of these case studies worked with digital technology — this was important because the computer/machine is a tool that is expected to produce a perfect output but as we can see in most of our creations, that is not necessarily the case. I was interested in seeing how other artists reacted to this "imperfection" of technology and how they could utilize it to their own benefit.

When we input information into the computer, we assume that the machine is built to eliminate all variables that would exist in the traditional craft world, elements such as gravity, temperature, etc. I found that with the machine eliminating these variables that would be normally be considered "problems to tackle", the relationship between maker and object becomes distanced due to the assumption that the technology can output something equal or better than something handmade. The error that a machine makes is the computer's inability to make up for the variables that should have been dealt with. The following artists were able to study that error and utilize the failure in a way that makes the project revolve around celebrating it.

Figure 5: Wilson, Mark. “Kanagawa Blade.” [34]

Figure 6: Keret, Shira. “Monolith.” [34]

‘KANAGAWA BLADE’ | Mark Wilson
‘MONOLITH’ | Shira Keret

Designer Mark Wilson created a unique steel knife by taking advantage of the properties of water jet cutting (Figure 5). Waterjet cutting is a CNC machining process that uses a high-pressure stream of water to cut material; however, as the water cuts into the material, it loses pressure and precision. As the streams of water carve into the steel, a trail back is created. A trail back is a raised pattern that is created from the loss of pressure and precision and ultimately causes the uneven serrations along the blade. Wilson described the knife as the following: “Although the Kanagawa Blade is formed through mathematical precision and machine creation, it reveals its mechanical creator’s serendipitous faults”. [34]

Inspired by water erosion, Shira Keret took a similar trailback approach in creating her Carrera marble plates and vessels that showcases the industrial waterjet cutting process (Figure 6). When using the water jet cutter, Keret was able to mimic the natural process and morphology of erosion in a few seconds and on a smaller scale. She points out that, “although the technical drawing for the machine is 2D and extremely basic, this process makes the final shapes unpredictable, organic, and one of a kind”. [34] In the final pieces, one end of the form remained true to the original drawing that went into the machine and the other end emphasized that natural and random erosion carving.

These two projects were most relevant my area of exploration because Wilson and Keret were able to exploit these technical errors into something new. By emphasizing a quality that is usually avoided in water jet cutting, these pieces give a voice to the machine.

[33] Tucker, Emma. “Mark Wilson’s Kanagawa Blade has a serrated edge carved by jets of water.” Dezeen, 25 June 2016, https://www.dezeen.com/2016/06/25/kanagawa-blade-mark-wilson knife-design-serrated-edge-steel-water-jet-cutter. Accessed 7 Feb 2019.

[34] Howarth, Dan. “Monolith eroded marble tableware by Shira Keret.” Dezeen, 12 Nov 2013, https://www.dezeen.com/2013/11/12/monolith-eroded-marble-tableware-by-shira-keret/. Accessed 7 Feb 2019.

When looking at traditional analog craft, our connection to the piece is increased due to its unique features — one can usually tell when something is crafted by hand due to the artist's chosen characteristics to impart into the piece. In the cases of Wilson and Keret, the machine almost starts to replicate a human way of making — it takes something predictable (the CAD file) and showcases its own way of creating through the cutting process. Ultimately, the end product is still a piece created in a controlled environment, but the texture is completely random and showcases the machine's ability to create something unique. It is essential that the water jet has a say in creating the final details — although the overall structure is determined by the designer, the end product is formed by the unpredictable nature of the machine.

Figure 7: Plummer Fernandez, Matthew. “Digital Natives.” [35]

‘DIGITAL NATIVES’ | M. Plummer Fernandez

In ‘Digital Natives’, designer Matthew Plummer Fernandez creates colorful and faceted 3D printed versions of everyday items (Figure 7). He first 3D scans each object and then subjects the files to algorithmic distortion. These algorithms stretch and morph the data into new forms, which are obviously mutated but the original object is still apparent underneath. He then 3D prints these new forms with colorless sand particles and tinted resin. [35]

I was drawn to Digital Natives because I wanted to explore that side of computational error — the process that happens before anything physical becomes output. The progression of our current use of digital technology usually is, CAD file ➜ computer ➜ machine ➜ output. I thought this collection really embodied how things can go wrong even before any sort of material is produced. In the previous example (Kanagawa Blade and Monolith), the artists allowed the material process to be what affects the final output but in Digital Natives, Fernandez places the emphasis on the transformed computation with a flawless 3D printed output. Unlike the waterjet projects, Digital Natives allows the voice of the computer to come out more than the designer’s since the objects are already created. By choosing to use existing everyday objects, there is less form design for Plummer Fernandez to do, but he instead focuses his intent on building the algorithmic distortion software.

[35] Chalcraft, Emilie. “Digital Natives by Matthew Plummer Fernandez.” Dezeen, 12 Oct 2012. Web. Accessed 7 Feb 2019. https://www.dezeen.com/2012/10/12/digital-natives-by-matthew-plummer-fernandez/.

Figure 8: "Topo Glasses." Pittsburgh. Personal photographs by author. 26 Mar. 2019.

'TOPO GLASSES' | Caroline Landau

By using a technique that would normally be discouraged in caneworking, glassworker Caroline Landau was able to create a unique pattern that was representative of landscape topography. She was first experimenting with making cane and was encountering numerous failures — the lines would bleed, bubbles were trapped, or it looked messy (Figure 8). These errors inspired her to embrace those flaws and she developed a technique of pushing and pulling on a textured surface to create an organic looking pattern reminiscent to topography.

Landau discusses how her consistent failure in caning fueled her desire to understand and embrace the mistakes that were showing up in her objects. The ability to turn the cane process around and give agency and priority to the actual threads that were "misbehaving" was a pivotal point in her design mindset of approaching obstacles in her work.

I am drawn to this project due to Landau's ability to reset her mindset in approaching caneworking. When she describes that certain glass thread acted as if they had a mind of their own, she decided to let them do exactly that and even exaggerate those features. By realizing that her ability to create conventional caneworking was less than ideal, she was able to embrace the features that would be considered failures and turn them into something aesthetically beautiful and unique. Glassblowing is extremely procedural, which allows for experimentation and discovery within each step. This is the only precedent that does not include a mechanical component — I believe her vessels are an excellent example of utilizing error as inspiration in traditional analog craft.

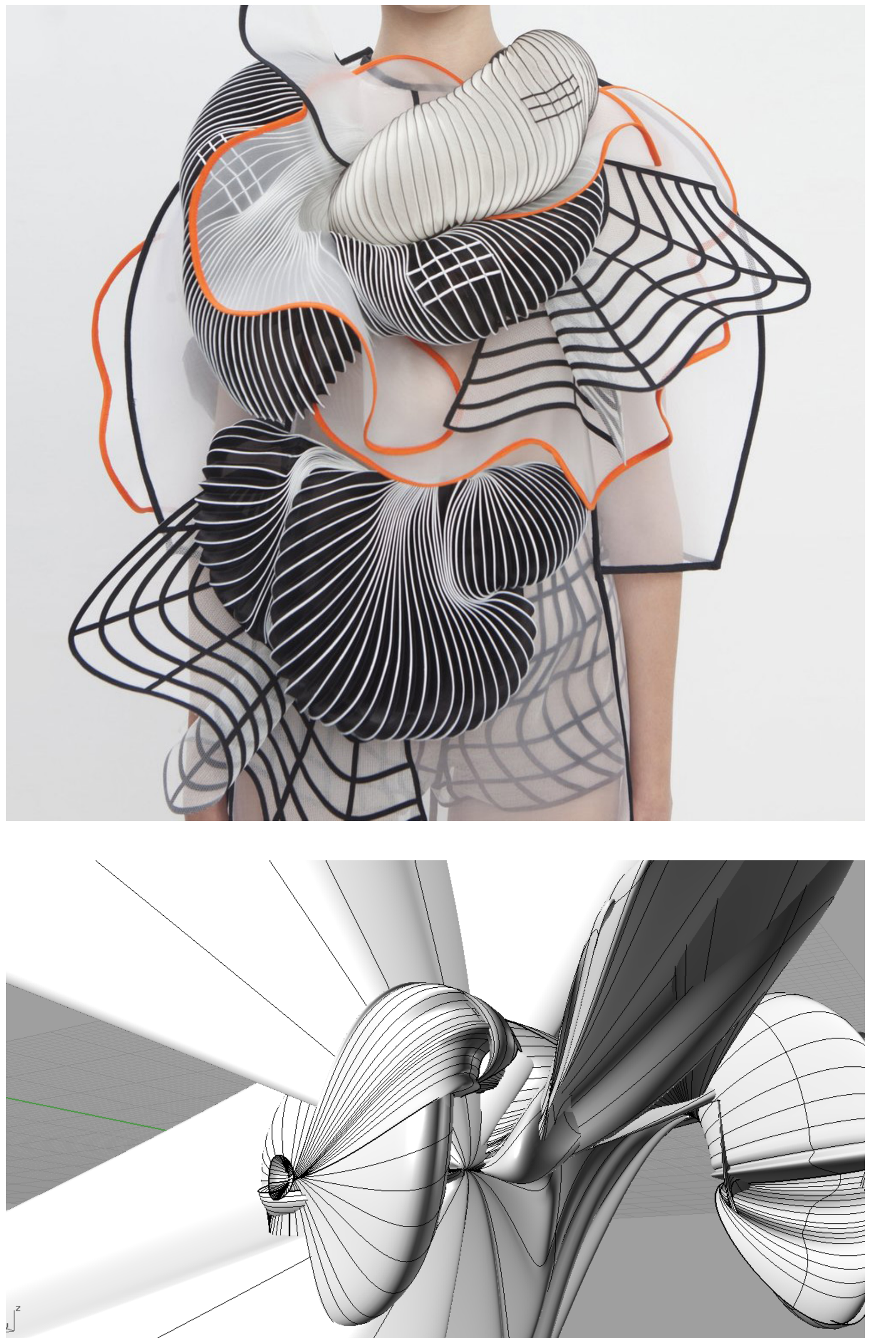


Figure 9: Raviv, Noa. "Hard Copy Collection." [36]

'HARD COPY COLLECTION' | Noa Raviv

Noa Raviv is an Italian fashion designer who was inspired by distorted digital elements and incorporated these images of corrupted computational drawings into her garments through 3D printing. During her concept phase, Raviv would encounter errors within CAD modeling software (Figure 9). These corrupted elements could not actually be printed since they only were temporarily visualized in virtual space. Using these distorted images as inspiration, she brought the errors to reality, forming morphed grids and shapes. According to Raviv, 'Hard Copy Collection' is an "exploration into the unseen mechanisms of the world, allowing spectators a glimpse at what humans can grasp, but perhaps never fully understand". [36]

Raviv's work was particularly interesting to me due to her ability to view corrupted errors as an inspiration point for her fashion. The two fields have had some overlap in the last decade with examples such as 3D printed clothes, and parametrically designed prints, but utilizing the side of computation where things can go wrong and errors existing virtually is an interesting take on this crossover between fashion and technology. In 'Hard Copy Collection', I appreciate Raviv's ability to recognize an interesting problem that occurred and be able to explore more in depth as to why it happened and then utilize it to her advantage. As an architect who previously encountered some of these same errors, I am impressed by her ability to not be immediately frustrated with the software. This lack of pre-judgment is something that should be considered by each designer since it can lead to innovative projects such as this Raviv's.

[36] Brink, Nick. "Noa Raviv Visualizes Immaterial Computer Errors with Grid Installation." designboom, 08 April 2015, https://www.designboom.com/art/noa-raviv-grid-istallation-oops-hansen-house-jerusalem-04-08-2015. Accessed 9 Feb 2019.

Figure 10: Castignola, Pierre. “Moca.” [37]

‘MOCA’ | Studio Joachim - Morineau

Designers Carla Joachim and Jordan Morineau created a “drip” machine that consist of two parts — a computer controlled rotating platform and a dripping system (Figure 10). The machine attempts to replicate human error in the way that each piece created is unique and is subject to different variables such as nozzle diameter, clay viscosity, and gravity. The designers described the machine as capable of “producing the same object at almost an industrial level, however each piece is unique”. [37] Their goal was to combine the precision of computational technology with “glitches” in order to create objects that are overall quite similar but not identical. The diameter of the nozzle can be modified depending on the desired drip size; however, not everything is controlled. The designers allow variables such as flow and viscosity to be determined by the machine and material — for example, the vibration of the machine may change on a certain piece and would ultimately influence the final outcome. [38]

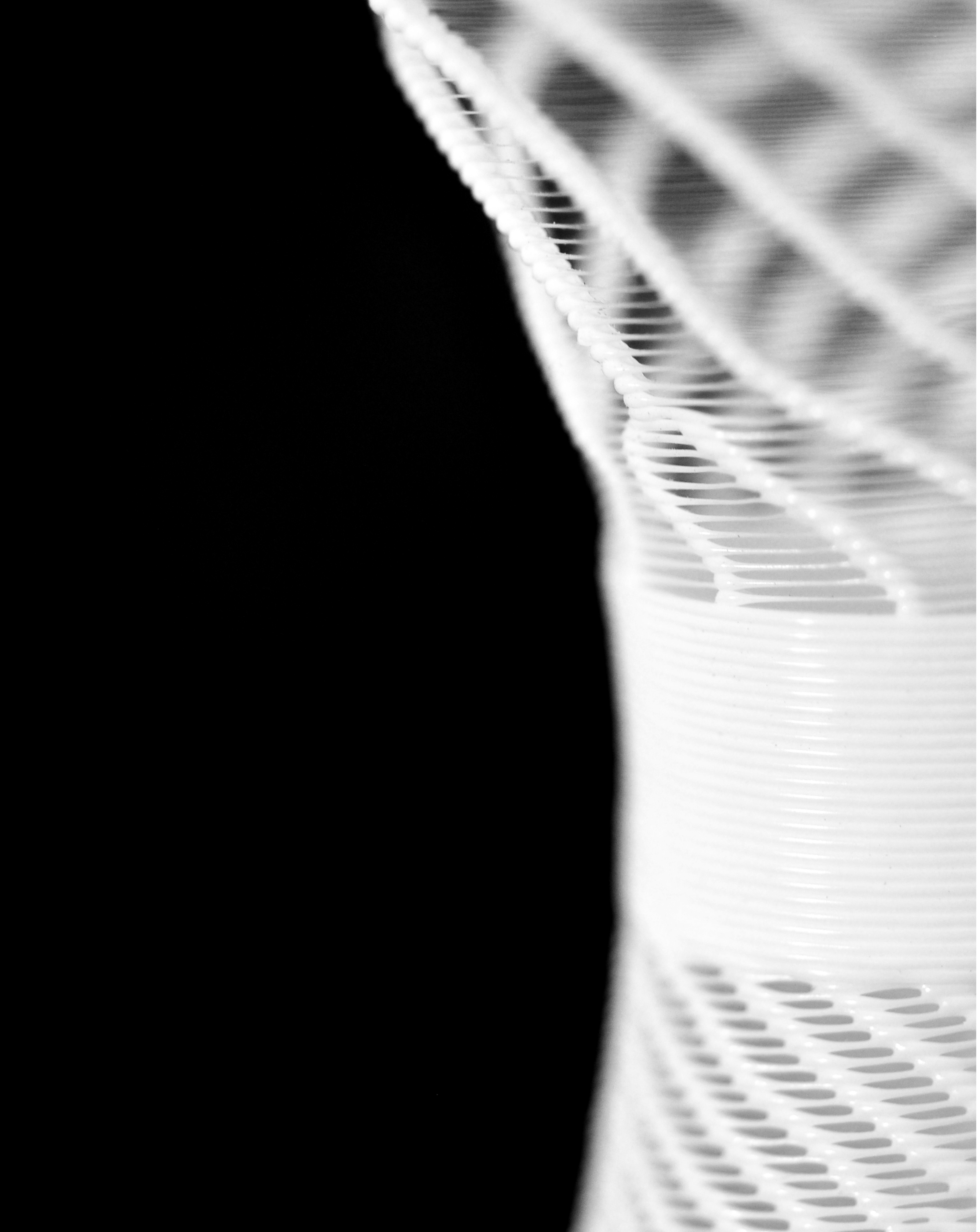
This project resonated with me greatly due to the designer’s intention to allow the machine do most of the controlling of the object’s final aesthetic. By only manipulating a few elements, the designers give a voice to the drip machine — it reacts to different elements and produces unpredictable pieces each time. As humans, we are easily affected by variables in our environment and it is interesting to see how we can relate to objects that endure the same elements and actually show the effect of that interaction. Normally, machine-made products are meant to withstand any sort of external forces and are considered failures if there is any record of being affected by anything other than the programmed technology. By allowing these characteristics to come out and be the driver of the design, Joachim and Morineau have given voice to the machine and created objects that are still beautiful and unique enough to cherish, but also celebrate the fact that technology can be affected just as much as humans can be.

[37] Hitti, Natashah. “Dripping machine creates ceramics that marry technological precision with handmade details.” Dezeen, 18 Oct. 2018, https://www.dezeen.com/2018/10/18/studio-joachim-morineau-dripping-machine-ceramic-design. Accessed 7 Feb 2019.

[38] Ibid., par. 6.

SUPPORTING PROJECTS 04

EXPERIMENT 01
EXPERIMENT 02
EXPERIMENT 03



PROJECT INTRODUCTION

After understanding the theory behind error in making and looking at several case studies, I conducted a few experiments to explore different ways to utilize error. I was mostly driven by the concept of violations and utilizing error as a way to inform and then exploit to create emergent properties.

The following experiments ranged from using error as a basic tool for information to becoming the focal point of a design aesthetic.

EXPERIMENT 01

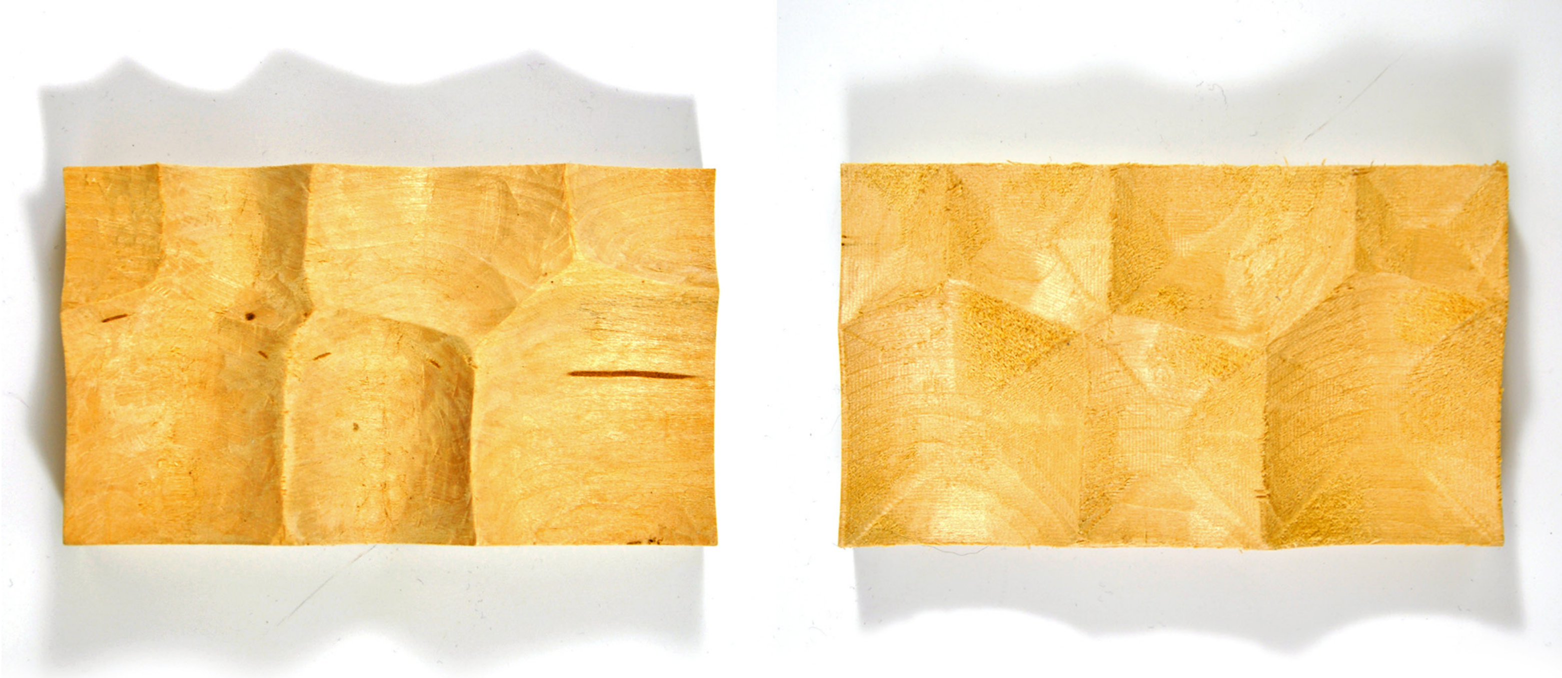
Unplanned Error to Inform

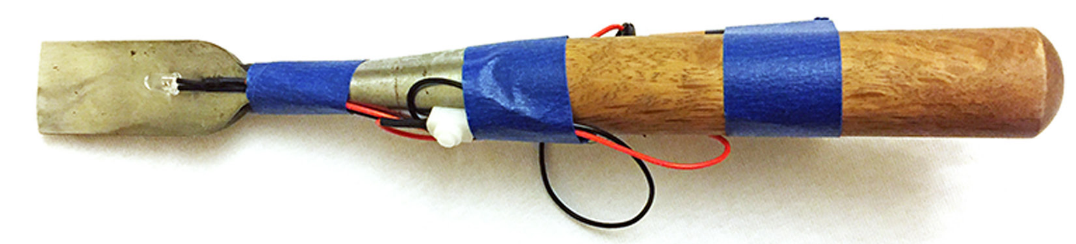
Procedural Tooling Processes

This first project was a look into the way that error can inform and teach the maker in real time. This sort of error is the simplest form — learning from your mistakes. When hand carving this piece, I allowed the depth and visual cues of the wood to guide me in judging what looked correct. When I carved too far down or in an incorrect area, I would be forced to re-evaluate my technique. This project was meant to compare the processes of hand carving and using a computationally controlled machine to affect the final outcome.

I took long-exposure photos (Figure 11) of the tool paths for both of the carvings because I wanted to see if it was apparent how unplanned error was my informant and driver for where to go next. Using trial and error, I quickly learned the best technique to create what I wanted after realizing that I was carving too much. The point of the experiment was to see what it looks like when the carver is responding to the material compared to what it looks like when the tool is not responding to the material — the bit moves and the wood happens to be in the way. The results of the long-exposure photos clearly capture the qualities that each of the carvings possessed — the CNC path was mechanical and technical while the hard carved path was organic and animated. Additionally, due to the programming of the digital file into the CNC machine, it created a very geometric and angular surface instead of the curved craters that were in the original CAD model.

Ultimately, this experiment was an introductory step into utilizing error as a main component when designing and crafting a project.





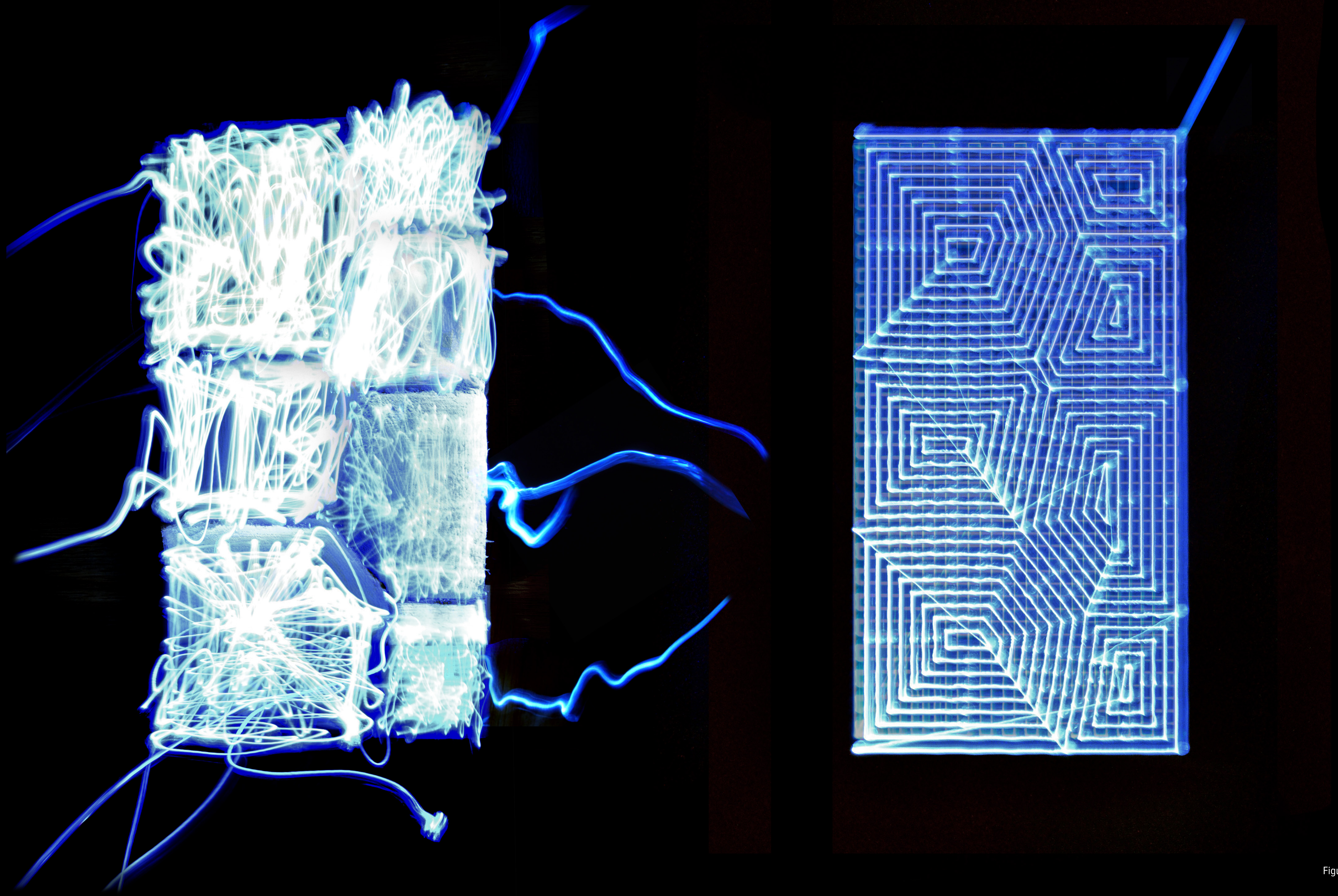


Figure 11

EXPERIMENT 02

Planned Error as a Visual Translation

Utilizing Computational Defects as Informative Transformations

This second experiment looked at the pre-production stage, error that happens in the computer software, so before anything has been actually printed. As an architect, I was trained to model using Rhino 3D, a parametric modeling program that can transform objects between surfaces and meshes; however, its output into physical curved forms is often discontinuous because of how it converts meshes using polygons.

In the photograph of the 3D printed cup (Figure 12), the form of the vessel is supposed to be a continuous curve but the facets that make up the surface are clearly visible. Since I was unaware of how Rhino simplifies meshes, this project looked to create a visual representation of the breakdown that occurs.

I wanted to show the visual translation of a simple form — in this case, an apple (Figure 13). By reducing the amount of polygons by a factor of 50%, I could start to grasp how an object is simplified in Rhino. Ultimately, this comprehension of meshes could help the maker understand and take advantage of these properties when designing.

In order to create these apple forms, I created an apple form in Rhino 3D, transformed it into a mesh, and analyzed the number of polygons that made up the surface. I then created multiple iterations, each reducing the number of polygons by 50%, and printed the form in SLA. Overall, the visual translation is apparent and although each individual form may not be recognizable on its own, it is easy to understand them as a whole collection.

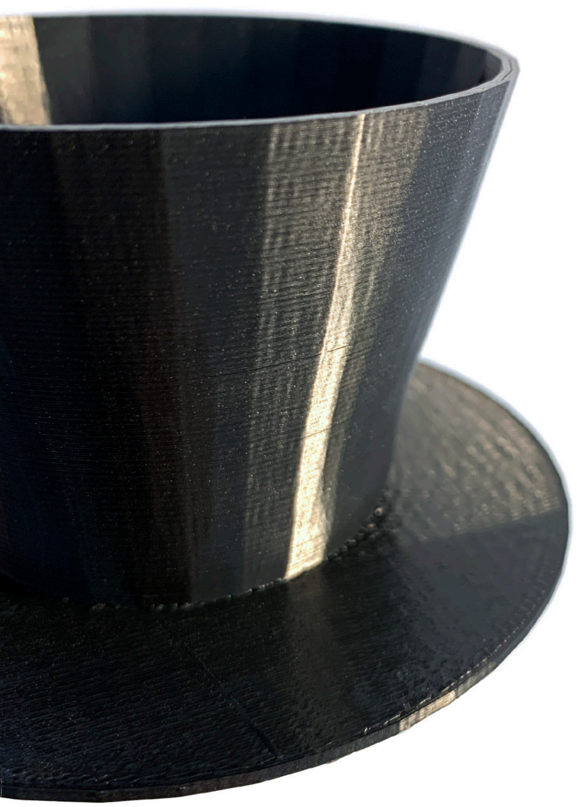
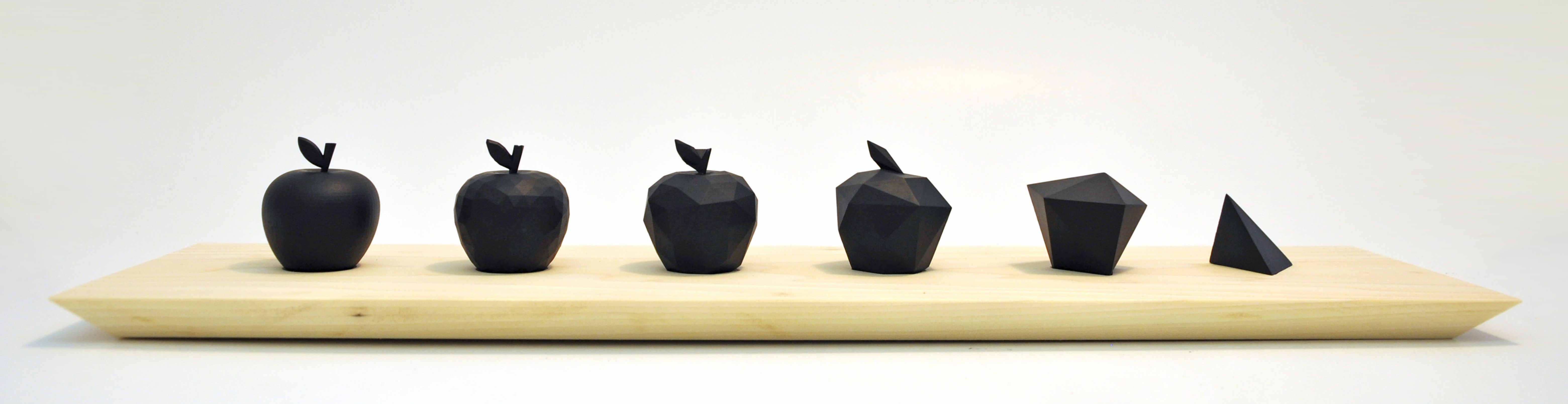


Figure 12

Figure 13



If taken further, a collaborative project (like in Figure 14) between a designer and machine could produce a form that is initially established by the human, but ultimately have the final arrangement created by the computational mesh algorithms that emphasize the polygonal error. Instead of a regular low-poly art piece where the design is decided by aesthetics alone, the software has a say and purpose in the way the angles are created.

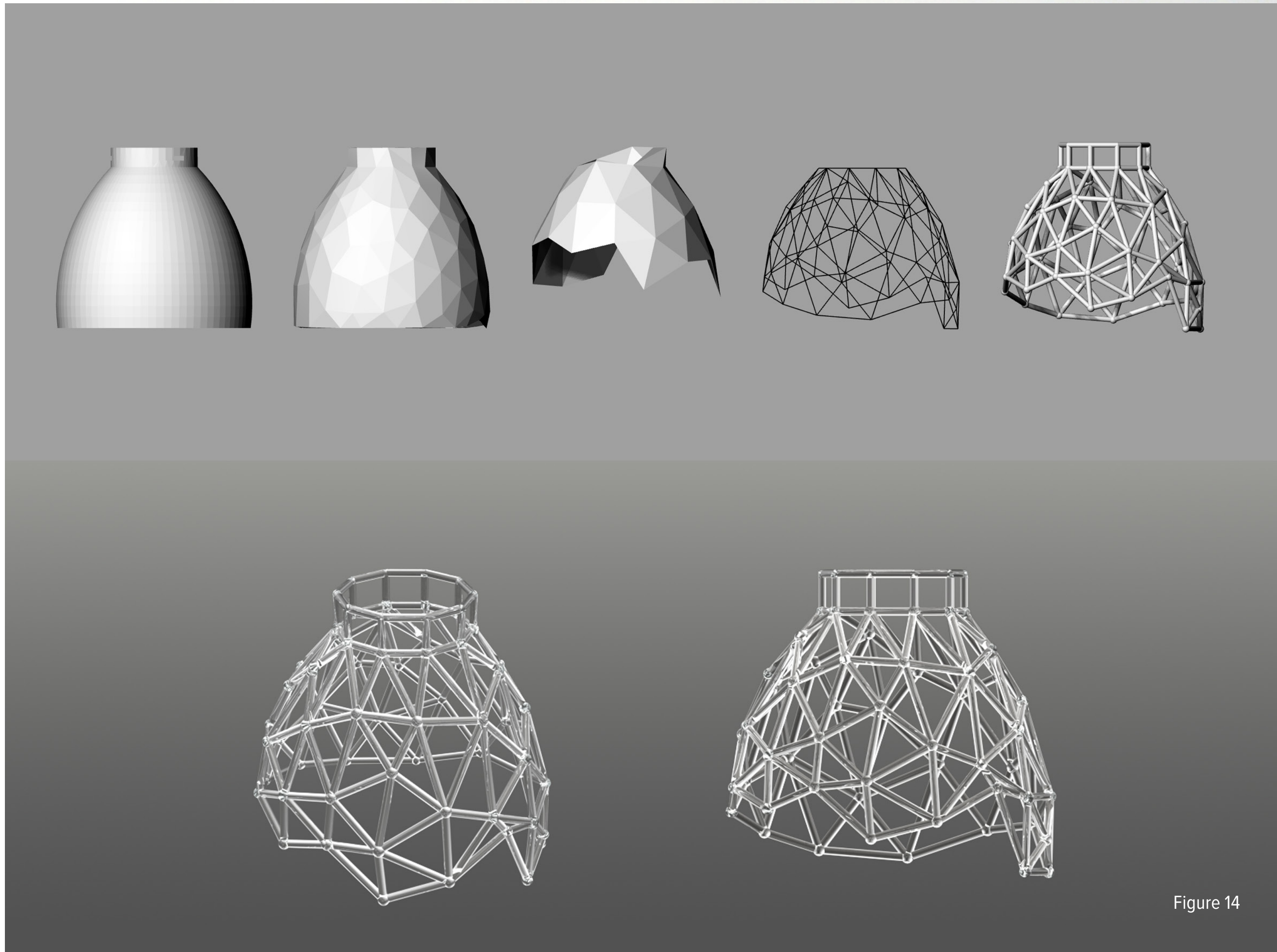


Figure 14

EXPERIMENT 03

Planned Error as a Driving Inspiration
Leveraging Technological Defects as Creative Practice

In the final project, I worked with utilizing mechanical failure, specifically a common error that occurs during 3D printing — under extruded filament. I first experimented with another common error, vibration/ringing (Figure 2), but moved on to under extrusion when my tests did not provide successful results. When filament is under extruded in solid forms (Figure 15), it is normally undesirable because it makes the whole structure collapse; however, when used in vase mode, it can create intricate surface patterns. By manually adjusting the extrusion multiplier, I was able to force the machine to produce less filament than usual and the variable of gravity allowed the pattern to occur by building on top of the previous layer.

Figure 15: Underextrusion, a typical error in solid objects

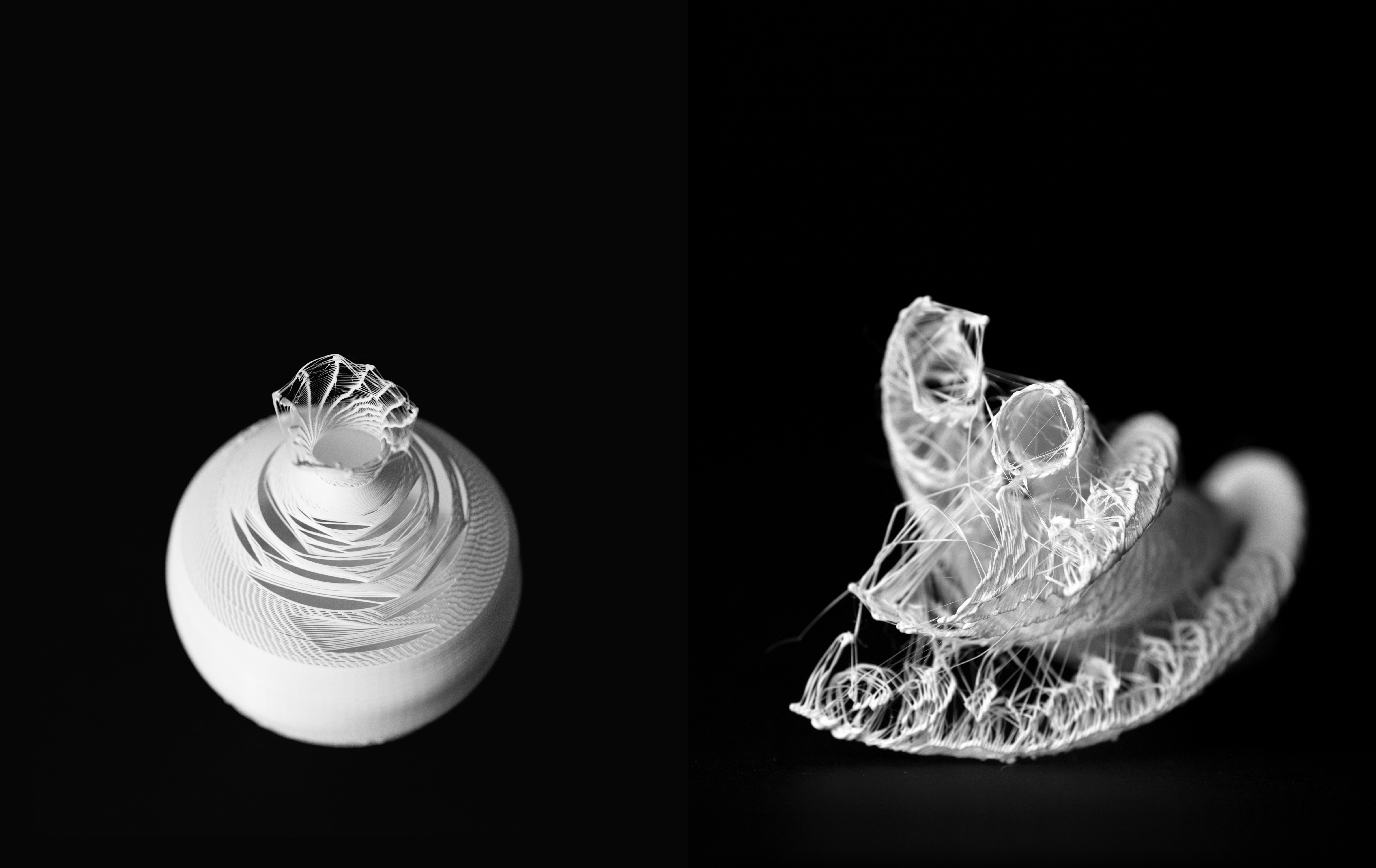
Mechanical failure often creates a result that is not the perfect machine-made product that is expected. By taking advantage of this and exploiting error in a controlled environment, I was able to produce these vessels that show the collaboration between me and the “disobedient” personality of the 3D printer.

When starting the project, I was not looking to create a ‘happy accident’ — this was very much an intentional effort to cause an error in order to see what unpredictable thing might happen. I experimented with modifying different variables, such as the temperature, extrusion multiplier, support structure density, and more. When manipulating the extrusion multiplier, I did not think I was going to get a perfect surface pattern because I was capitalizing the most delicate and unpredictable nature of 3d printing, and as shown in the photographs, the under-extruded pattern was not totally perfect. There were some failures, but all were done within a controlled environment. By using error to create something, that flaw could be compounded and ultimately ended up with a result that was not the perfect machine-made product that was expected.

This experiment was aiming for a way to bring a voice to something mechanical. The question that I tried to address was **how might one find a more human connection into the computational forms of making?**

When creating things, I tend to avoid using machines as much as possible because it almost feels too easy at times — there is a disconnect when the digital file is handed over and I receive the piece back. This project was trying to bridge that gap by creating an opportunity for collaborative effort. Both the maker and the machine have equal say in designing the object, and ultimately produce a one-of-a-kind piece that is the record of the interaction that occurred.

Additionally, due to the unique nature of the print, the vessels can not be exactly duplicated. There is a temporal aspect to the pieces — if destroyed, the object can never be recreated and causes the owner to reflect back on the time spent with the object. The use of mechanical error can ultimately form a more powerful connection to the vessels, similar to the way traditional handcrafted objects have emotional attachment because of their bespoke characteristics and occasionally, their intriguing creation story.



DISCUSSION & REFLECTION 05

CONCEPTUAL FRAMEWORK

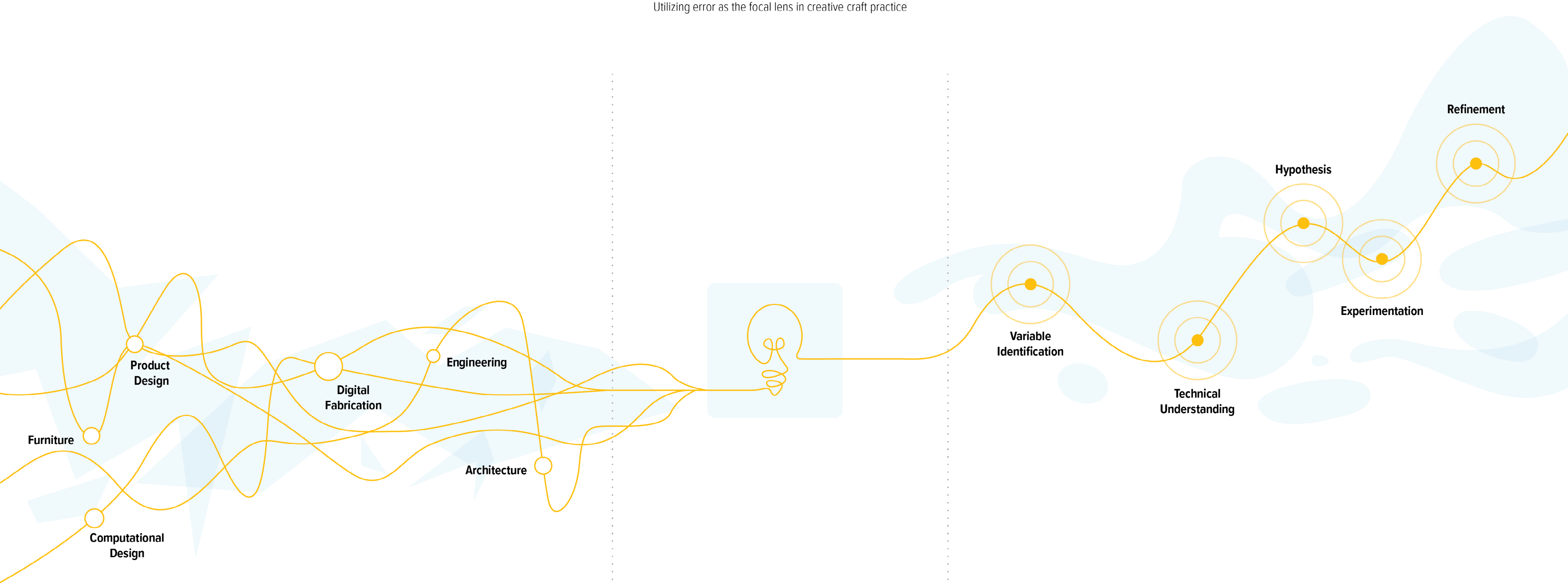
Both the theory and practice have been presented in this thesis in a personalized scope. In addition to looking at the theoretical component of error within craft, I also provided case studies and practice-based examples in order to better detail and ground my argument around error in creative practices. With both theory and practice presented, I was able to evaluate my own studies and better understand what it means to me to practice and think as a designer moving forward. I discovered what connects me to handcrafted objects and how to translate individualistic or "human" qualities forward into digital technology through a collaboration with error.

I was able to conduct research through design and developed a framework of utilizing error as a new way of uncovering emergent properties in the discovery phase of design.

For the purpose of testing my framework, this thesis limits the scale to an individual, person-to-object level. In areas where the design time is much longer, the iterative cycles are dragged on, and I would have had a harder time interrogating the theory — for this reason, I chose to limit the scale to rapid cycles and iterations. The process that was developed turned out to be similar to the scientific method of observation, hypothesis, experimentation, and repeat. This ended up being the cycle that I repeated many times in my experiments, with both successful and failed outcomes, but I would always be able to iterate and revise my experiments based on the results.

ERROR IN MAKING

Utilizing error as the focal lens in creative craft practice



Creative Craft Practice

Craft practices can embrace error as a focal point. With this new mindset, it opens up new opportunities for creativity.

Error

Craft practices can embrace error as a focal point. With this new mindset, it opens up new opportunities for creativity.

Experimentation Process

By delving deeper into embracing error, designers can start to create innovative and unique properties that add to their repertoire.

My findings can be summarized into a few key suggestions for designers:

1. It can create opportunities for discovery and experimentation. In order to be aware of the potential that mistakes can bring, one must have certain a mindset to not prematurely judge error as something negative.
2. This takes a certain vulnerability and aspect of letting go of control that many designers are not willing to go through. Since many makers consider themselves to be perfectionists, this is particularly difficult to deal with.
3. After identifying an interesting pathway, one can test allowing certain variables to fail so that emergent properties might be uncovered. This is different from the "happy accident" that we are all familiar with - it is an intentional effort to cause an error in order to see what unpredictable things might happen.
4. In the realm of digital craft, the machine must be given agency or have its "personality" shine through error. The result of this collaboration between you and the machine is a record of the interaction that occurred.

By creating this mindset of being open to error, it situates this thesis in a very specific area of exploratory design. There are obvious fields that may not benefit from this framework, but industries that deal with technological advancements will be associated because of their role in crafting a future that relies heavily on the digital. The technology that we use in aiding our design process generally aims to eliminate failure or imperfection in order to save time. The design of digital software can limit our way of thinking by prioritizing accuracy and convenience (in a black box), which can influence our way of thinking through the design process. This can be emphasized in an academic setting, where younger designers are learning to navigate creativity with a predetermined output before anything physical is actually made. By utilizing the framework of error, it can be n more experimental approach and provide pathways towards discovery that computation may not include.

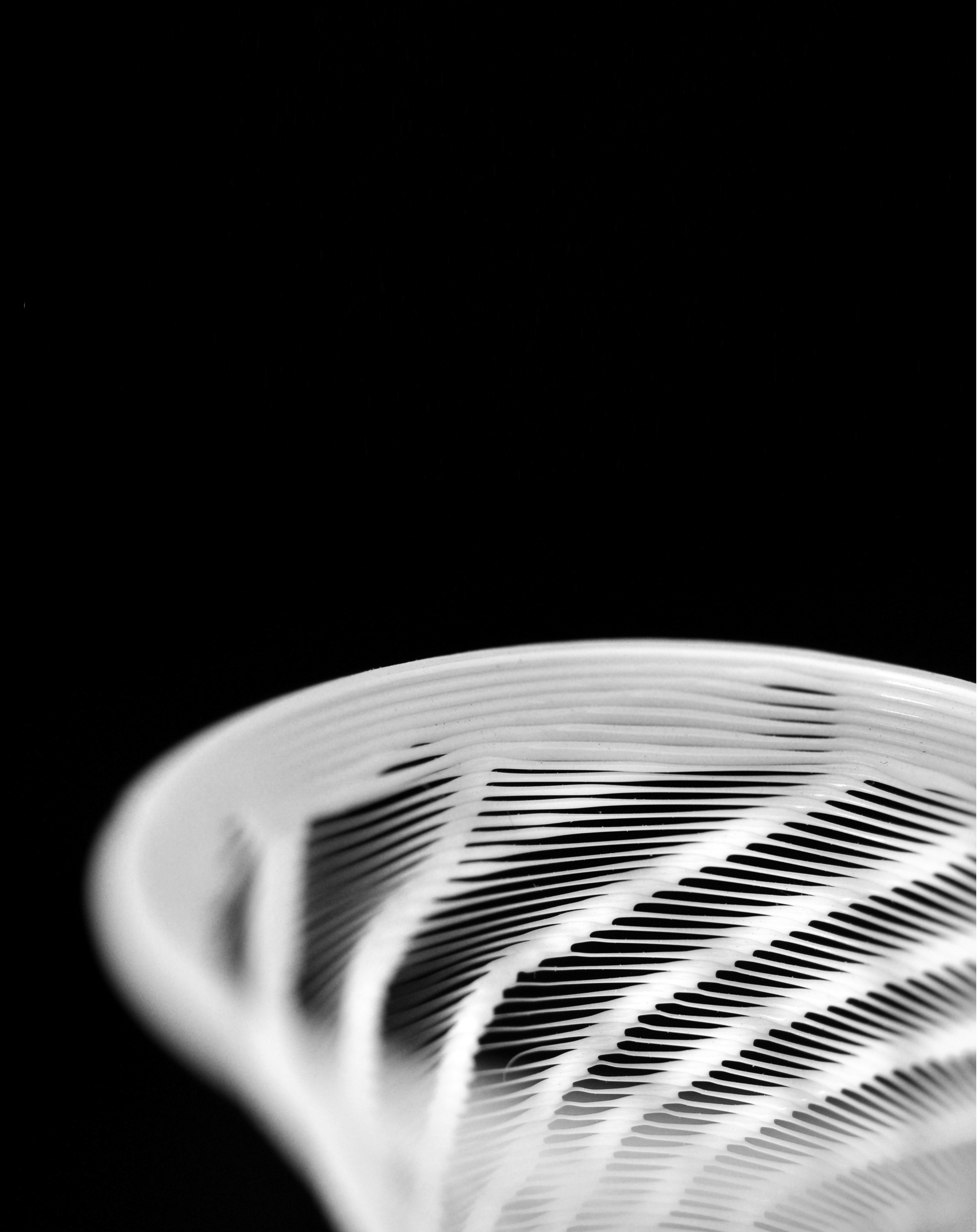
REFLECTION & EVALUATION

This thesis is a very personal reflection on how I relate to the tools that I use. Error is something that I have always tried to avoid at all costs, but this idea of using it as a new way of uncovering emergent properties changes my mentality when exploring options to take on a design project. I know going forward in future steps, this framework that I have developed can be a potential pathway to seeing new paradigms for whatever I am working on. Looking back, some of this thesis is about letting go of things, instead of starting to do new things.

Emergent properties only appear when you have relinquished control and created a space that you are not in charge of.

The mentality of letting go of control runs parallel with how we generally live — we try to control and manage everything as much as possible. We plan, control, and manipulate variables so that there is very little chance of failure. This way of working comes naturally to designers, and is reinforced by the technology that we use to develop our ideas. By forcing yourself to take a step back, you can recognize that there are other ways of discovering innovative and unique ideas.

This way of thinking is not solely constrained to the creation of physical artifacts. The framework of error can be used as a way to accelerate the discovery process. Although this may not necessarily be a solution to a creative block, it is a possible pathway that a designer could explore, which might lead to further insights. Alternatively, I do understand that this way of exploring has its negatives — there might not be a successful result and it takes time to discover these opportunities — time that industry may not have. So this way of designing may be more appropriate for an academic setting or at least in an environment where exploration over deadline is encouraged.



FUTURE CONSIDERATIONS

All of my case studies and my own projects have been heavily influenced and based in the world of craft. I chose this because of the ability to compare and contrast physical things. Due to my background, I had my own personal curiosities around handmade artifacts, perhaps simply because of my appreciation of simple things made beautifully; however, this ideology or framework that I developed in this thesis does not have to be contained to craft — it translates across fields.

While some areas are obviously not in consideration (e.g. life-dependent fields like the medical situations), many different disciplines employ a similar way of creative thinking to design. I often go back to my interview I conducted with the mechanical engineer who ended our conversation by saying that designers would become obsolete due to Machine Learning algorithms. By simply employing a new and creative way of thinking about engineering, there could be an opportunity for discovery that he had not previously considered. While this is only one example, the idea of utilizing error and giving it an important (and positive) role could be beneficial and start to question traditional ways of creative thinking.

GLOSSARY

Although the terminology used in this thesis project is already well established, I was able to reshape and direct the definitions to provide more detail in the context of design and technology. After conducting a literature review and my own projects, each term developed and became more focused as the topic of the thesis narrowed down to look at error as a collaborator for discovering creative opportunities. The terminology below contains both a generic definition as well as my own additions that relate the word to the design field.

analog craft (\a-ne-log kraft\) ***n.*** An activity that produces an object created through haptic feedback and physical touch.
In analog craft, the outcome and quality of the product is completely dependent on the craftspersons skillset and tacit knowledge.

craft (\kraft\) ***n.*** A process and knowledge that is built up through learning and engaging in the environment in real time.
Craft demands an understanding of dexterity and judgment as a response to the material and tool behaviors in order to produce a functional object.

digital craft (\di-je-tel kraft\) ***n.*** An activity that produces an object utilizing computer numerical controlled settings.
In digital craft, the outcome and quality of the product is predetermined prior to the production stage.

digital technology (\di-je-tel tek-na-lejee\) ***n.*** Computer-based technology in which data is programmed into and outputs a product that should be an exact replica of the digital file.
The expectation of utilizing digital design technology is for the output to be a flawless physical rendition of the computer model; however, due to variables that can affect the final product, this is not always the case. It is within this area where unpredictable discoveries can be made.

error (\er-er\) ***n.*** A state or condition where the final outcome does not match the intended design.
Error can be a collaborator and new way of uncovering emergent properties in the discovery phase of design.

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