

Coalesce: Leveraging Generative Tools in Industrial Design Practice

Justin Thoreau Lund

A Thesis

submitted in partial fulfillment of the
requirements for the degree of

Master of Design

University of Washington

2020

Committee:

Jason O. Germany

Sang-gyeun Ahn

Program Authorized to Offer Degree:

Design

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University of Washington

Abstract

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Chair of the Supervisory Committee:

Jason O. Germany

Division of Design

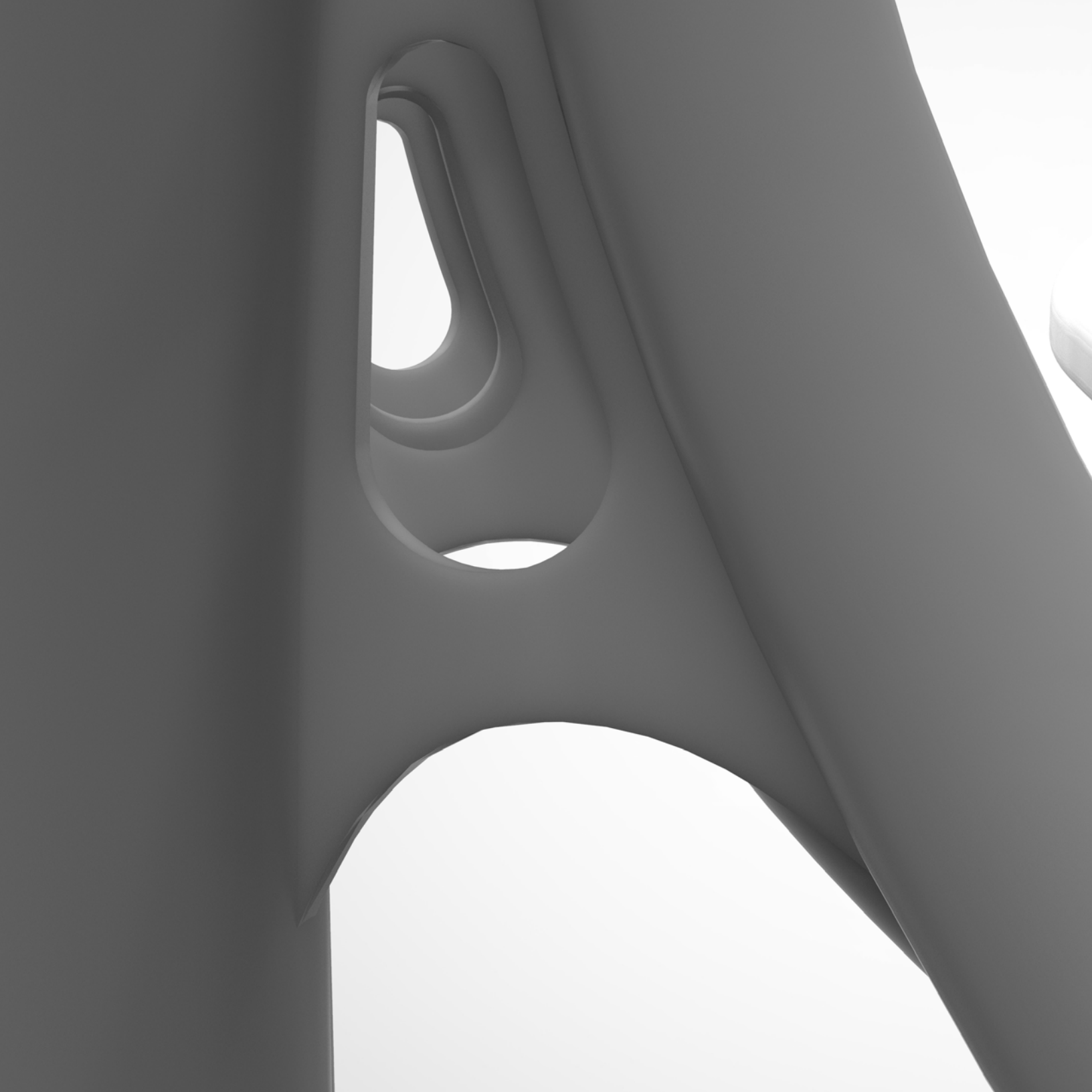
School of Art + Art History + Design

Generative Design is a design process that entails the collaboration between human designers and software-enabled machines. This thesis explores the ways that generative tools are changing industrial design, proposes some principles and a methodology for working with generative tools, and speculates about the future implications of this practice.



Coalesce: **Leveraging Generative Tools** **in Industrial Design Practice**

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Coalesce:

verb

1 : to grow together

2 : to unite for a common end : join forces

3 : to arise from the combination of distinct elements



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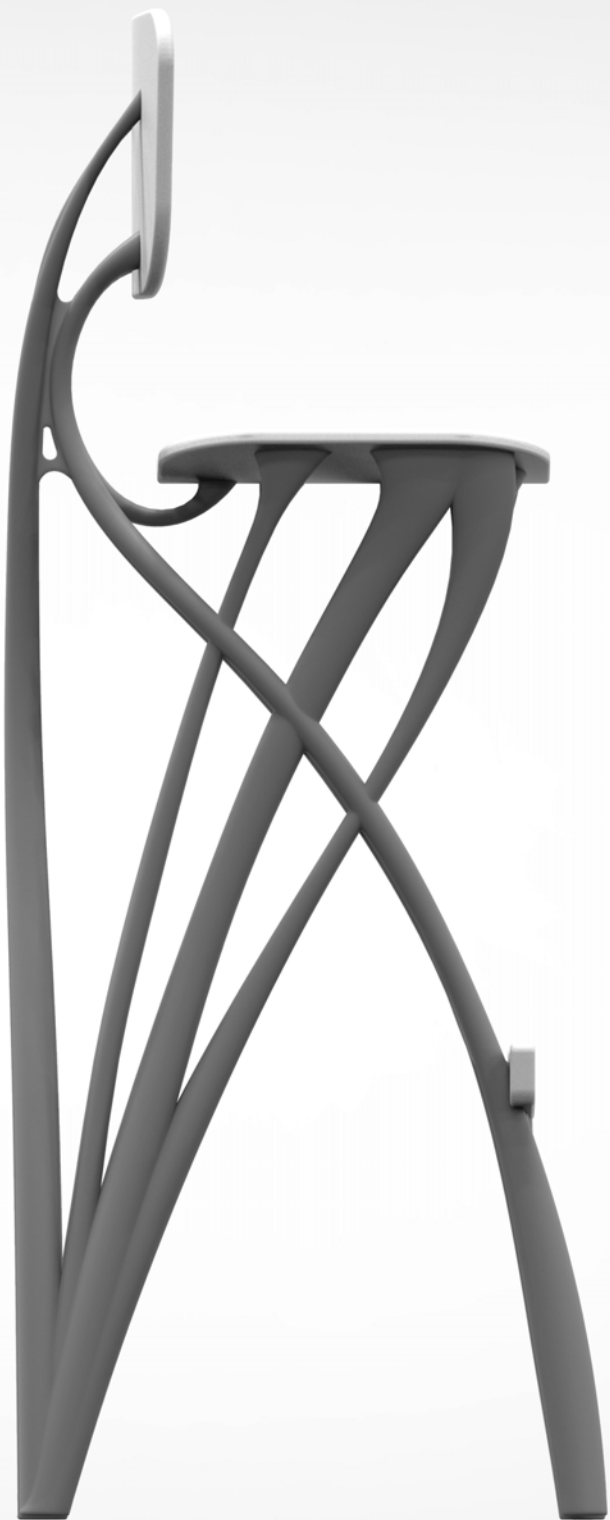
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Chair of supervisory committee:
Prof. Jason O. Germany
Division of Design

“I don’t know anyone intimately acquainted with these exceedingly complex systems ...To understand them, the systems had to be constructed, and their behavior observed”

- Herbert Simon, Sciences of the Artificial

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This thesis grew throughout the entire MDes program. Even before selecting a topic, connections were being made that would become its nervous system. New perspectives that I was exposed to, and the discussion with professors, fellow students, and my cohort that resulted, helped its form begin to take shape. This thesis has DNA from every course or workshop that I attended. Thank you collectively to the School of Art + Art History + Design, as well as these wonderful individuals:

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While my thesis had started to grow, it had a mind of its own. It threatened to go this way, and that, and at times seemed to move in all directions at once. I could not have coaxed it into cooperating without the help of my thesis committee.

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1. Towards an Unknown Horizon





Generative design (GD) is an emerging field in industrial design that is poised to radically change the way we think about mass production, products, and design in general. GD can empower designers to do more at once and to create faster. GD could help designers to customize output quickly to client needs, and to manufacture these designs in a previously impossible amount of time [2, 3].

The tools that are being utilized within GD will create a new working paradigm between the user, the designer, engineering, and manufacturing. This partnership between designers and technology could enable a new opportunity for designers to work directly with clients to create meaningful one-of-a-kind products at a price that could feasibly compete with large mass-produce-and-ship companies such as IKEA, Walmart, Target, etc. Rather than an ocean of (and oceans full of) mass-produced similarity, we could have sustainable mass customization [4].

This thesis will explore these areas, and will further existing work [5, 6, 7, 8] that has been done speculating [9] upon the ways that GD can augment, the industrial designer's creative process.





Image 1.2
A plastic island in the
Caribbean Sea [10]

2. Design Space Definition

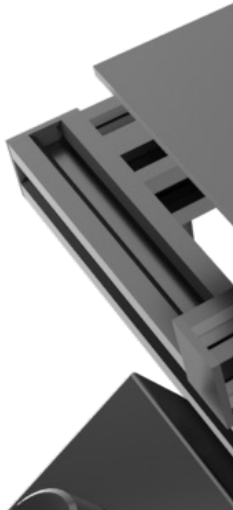
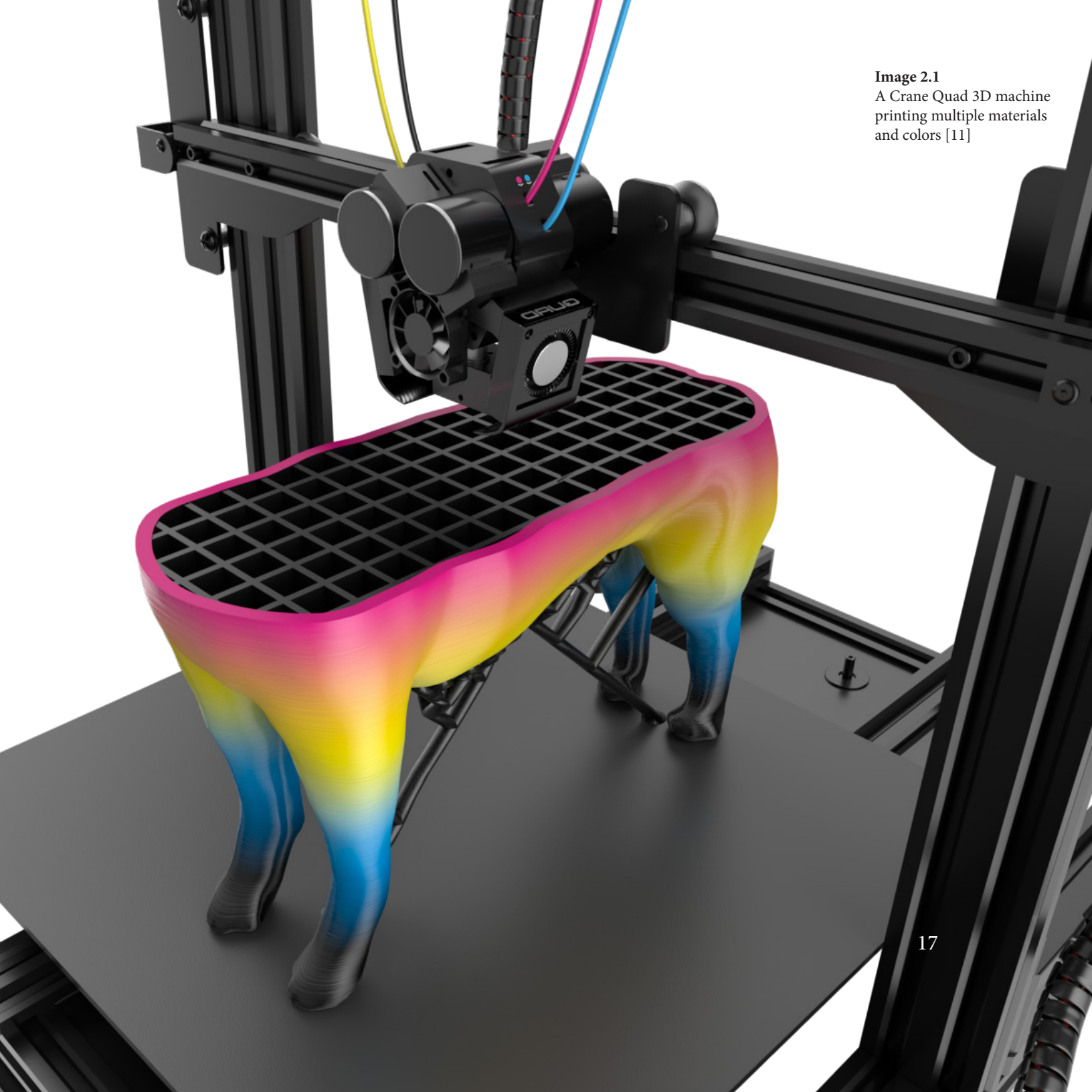


Image 2.1
A Crane Quad 3D machine
printing multiple materials
and colors [11]

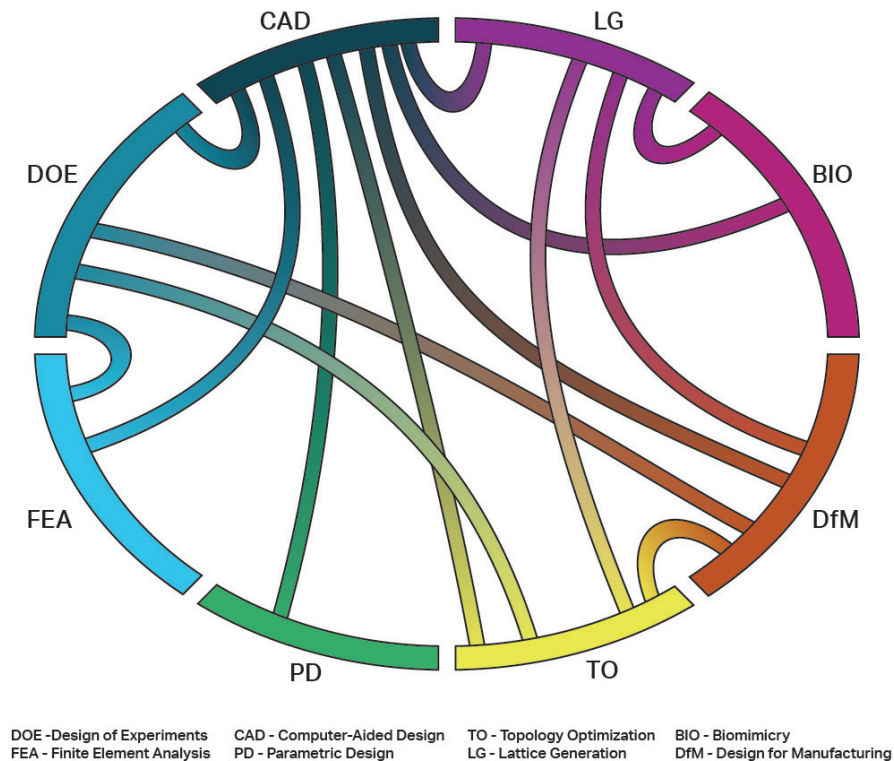


2.1. Generative Design as a System

Generative design encompasses many different fields of practice. It is not new for these areas to co-mingle and inform each other, but new technology is making communication between these fields happen rapidly. I quickly realized that defining the boundaries of this space was a bit of a wicked “ill-fitting” problem [12, 13].

A systems thinking approach helped me to understand the complexity, while visualizing the system as a chord-style diagram was helpful to conceptualize the many interrelated fields that are influencing and accelerating the speed of Generative Design.

Image 2.1.3
Chord diagram of
the major fields
influencing GD



Primarily, the main drivers of this increase in speed are artificial intelligence (AI) and 3D printing technologies. In the past, a process of structural analysis, like Finite Element Analysis (FEA), might have taken place after a design had completed an initial concept stage. However, programs today can accomplish these complex studies in parallel to design work as it happens. Similarly, lattice generation, a process for additive manufacturing that happened after a design was finished, to reduce cost and make products more lightweight, can now happen in parallel with design processes.

Interestingly, these lattices can be designed to handle stresses, much like our own bones do [image 2.1.2]. By employing biomimicry and AI, designers can use bone-growth algorithms, or any other beneficial natural algorithm such as a plant's growth pattern, to “grow” objects.

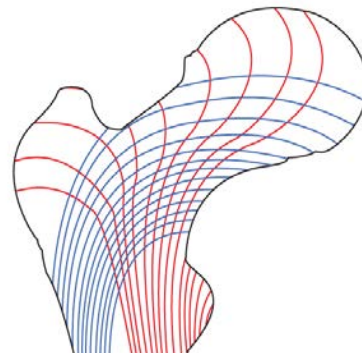
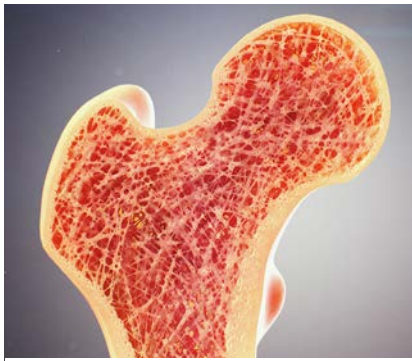


Image 2.1.2

Like natural bone structure (left) [14], objects printed with a solid outer shell and an interior latticed structure (bottom) [15], can handle tension (blue) and compression (red) [16] efficiently while significantly reducing material



Generative design tools can iteratively generate designs which account both for structural and additive manufacturing requirements simultaneously with the design process.

2.2. Definitions

Artificial Intelligence (AI) - software-enabled machines with an ability to perform activities normally conducted by intelligent beings [17].

Machine Learning (ML) - rather than being programmed, ML is a process of AI gaining new information by being taught or self-learning through repetition and analysis [18].

Computer-Aided Design (CAD) - designers augmenting their process with computers to help create, visualize, and analyze products. CAD is heavily utilized to facilitate communication between designers, engineers, and CNC manufacturing [19].

Computer Numerical Control (CNC) - 3D printers and numerous other software-enabled fabrication machines can be controlled by numerical codes derived directly from the CAD process. CNC has vastly increased production time and efficiency. Currently, CNC is most often used to refer to subtractive manufacturing processes (removing material) - this paper also uses CNC to refer to additive processes (such as 3D printing) [20].

Parametric Design - a process by which designers create objects in the CAD environment. A set of variable parameters are defined that drive the algorithmic steps used to represent the designers intent. Parametric Design allows changes to be made to earlier modeling steps that can subsequently alter each successive step [21].

Algorithm - A process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer [22].

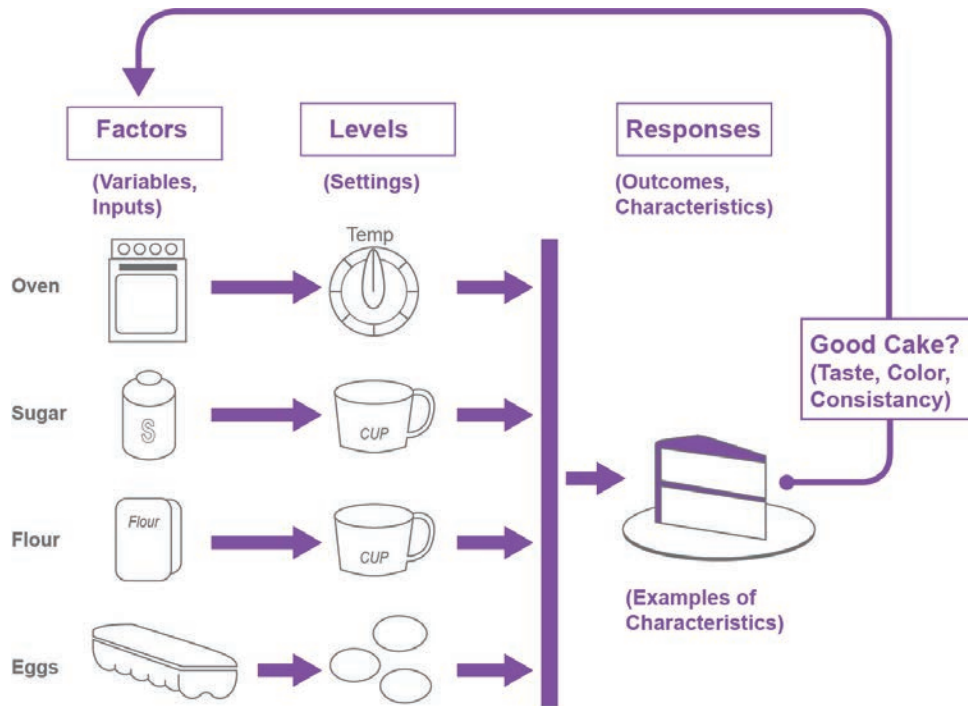


Image 2.2.1
Modified design
of experiments
diagram [23]

Design of Experiments (DOE) - Design of experiments (DOE) is a branch of applied statistics that deals with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. It allows for multiple input factors to be manipulated, determining their effect on a desired output (response). By manipulating multiple inputs at the same time, DOE can identify important interactions that may be missed when experimenting with one factor at a time. [24]

Finite Element Analysis (FEA) - A computerized method of predicting how a product reacts to real-world forces [image 2.2.2]. This is accomplished by breaking down a modeled object (1) into a “mesh” (2) of many smaller finite elements (3). Mathematical equations predict the behavior of each element and the nodes and links between each connected element (4, 5). Constraints are then applied to the object (6). Lastly, forces are applied to the model and a computer adds up all the individual behaviors to predict the behavior of the actual object as a whole (7, 8) [25].

FEA analysis not only allows a designer to see structural problem areas where a part might fail but also to see low-stress areas of a part where material could feasibly be removed. This process can be automated with topology optimization.

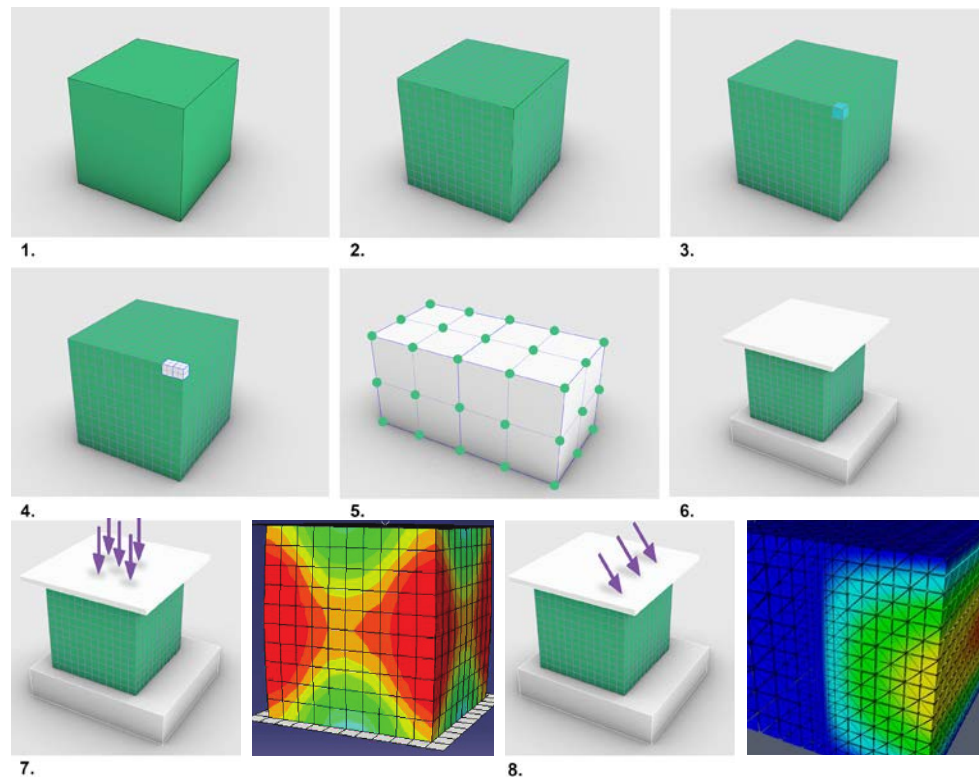


Image 2.2.2
Finite element
analysis example
[28]

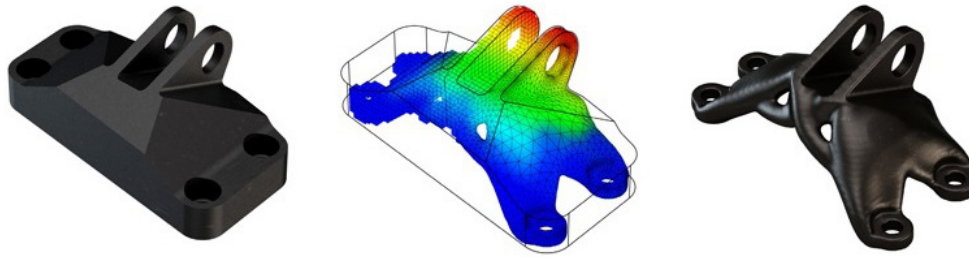


Image 2.2.3
FEA analysis and
topology optimization
[29]

Topology Optimization - an algorithm that acts on a finite element mesh to remove all redundant elements while meeting the given load criteria [30].

Lattice Generation - Flexible manufacturing allows the creation of complex internal geometries. Lattice structures, much like internal bone structure, have good strength-to-weight ratios as well as beneficial shock absorption [31].

Biomimicry - The design and production of materials, structures, and systems that are modeled on biological entities and processes. For example, ventilation modeled after termite mounds and antimicrobial surfaces inspired by shark skin [image 2.2.4] [32].

Design for Manufacturing - Designing products in such a way that they are easy to manufacture [21].



Image 2.2.4
Termite mound (left)
[33] and a microscopic
view of shark skin
(right) [34]

Flexible Manufacturing (FMs) - A system of producing products that can be easily changed during and after production to create complex products, alter existing products, or setup for new products. Some examples of FMs are computer-controlled (CNC) milling machines and 3D printers [35].

Image 2.2.4
Section view of internal
lattice structure in 3D
printed part [36]

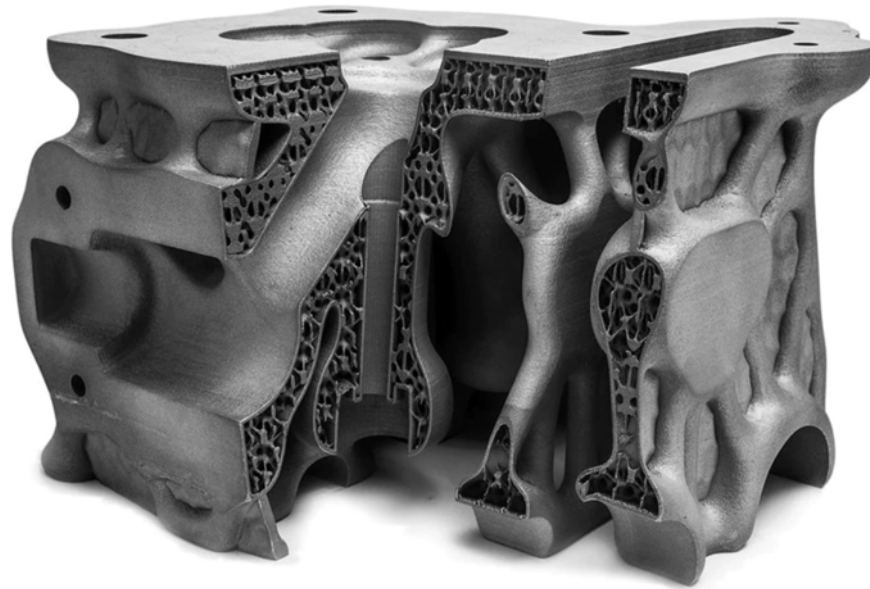


Image 2.2.5 (opposite)
3D printed electric car
concept from Hongik
University [37]

Finally, this brings us to Generative Design (GD). While GD is only recently seeing utilization in product design, it has been in use by Computer Scientists, Artists, and Architects for over a decade. There are many different ideas of what exactly generative design is and many different definitions in circulation.

To focus on industrial design, and for the purposes of this article, I have decided upon this rather broad definition:

Generative Design (GD) –

The collaboration of human designers and interconnected software-enabled tools to rapidly and iteratively produce new ideas and manufacture products.



2.3. Automation

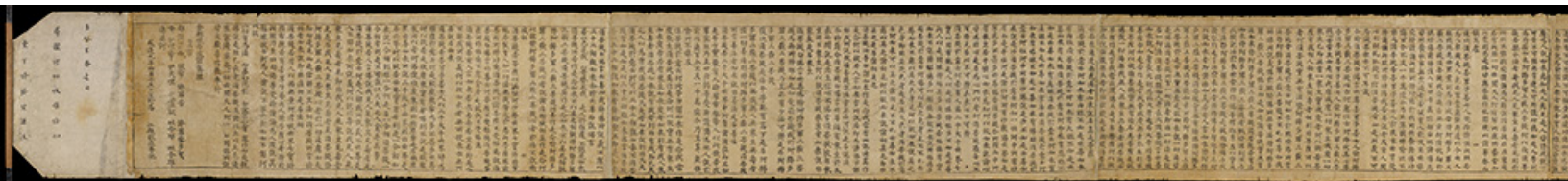
It became immediately apparent during primary research that a fear of automation is very present in relation to GD. Automation has a long history of disruption in the design industry and one can look to history as a precedent by which we can project the future adoption of technologies.

For example, the effect that improvements to the printing of books had on bookmakers, scribes, and illuminated manuscript artisans is widely studied and cited.

The exact beginning of the printed book is unknown. The earliest known surviving printed book is said to be The Diamond Sutra [image 2.3.2], printed in China around 868 BCE [38]. However, it was after 1440 BCE, with the proliferation of the Gutenberg press and its counterparts, that the world really began to see the effects that automation could have.

While many people lost their jobs, many more new jobs were created. There were many negative effects of the accelerating

Image 2.3.1
The Diamond Sutra
(below) detail (right)
[38]



spread of the printed word, but ultimately it changed the trajectory of humanity in numerous ways that are overwhelmingly seen as beneficial. Following this trajectory along, we find the rise of graphic design. Many elements of graphic design originated in support of the print industry, and as each new technological development arose, there was resistance, disruption, and ultimately job growth and positive benefits.

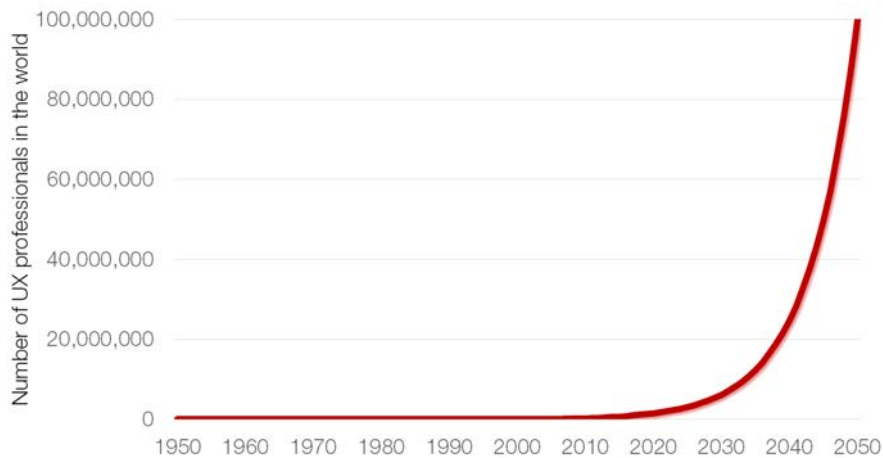


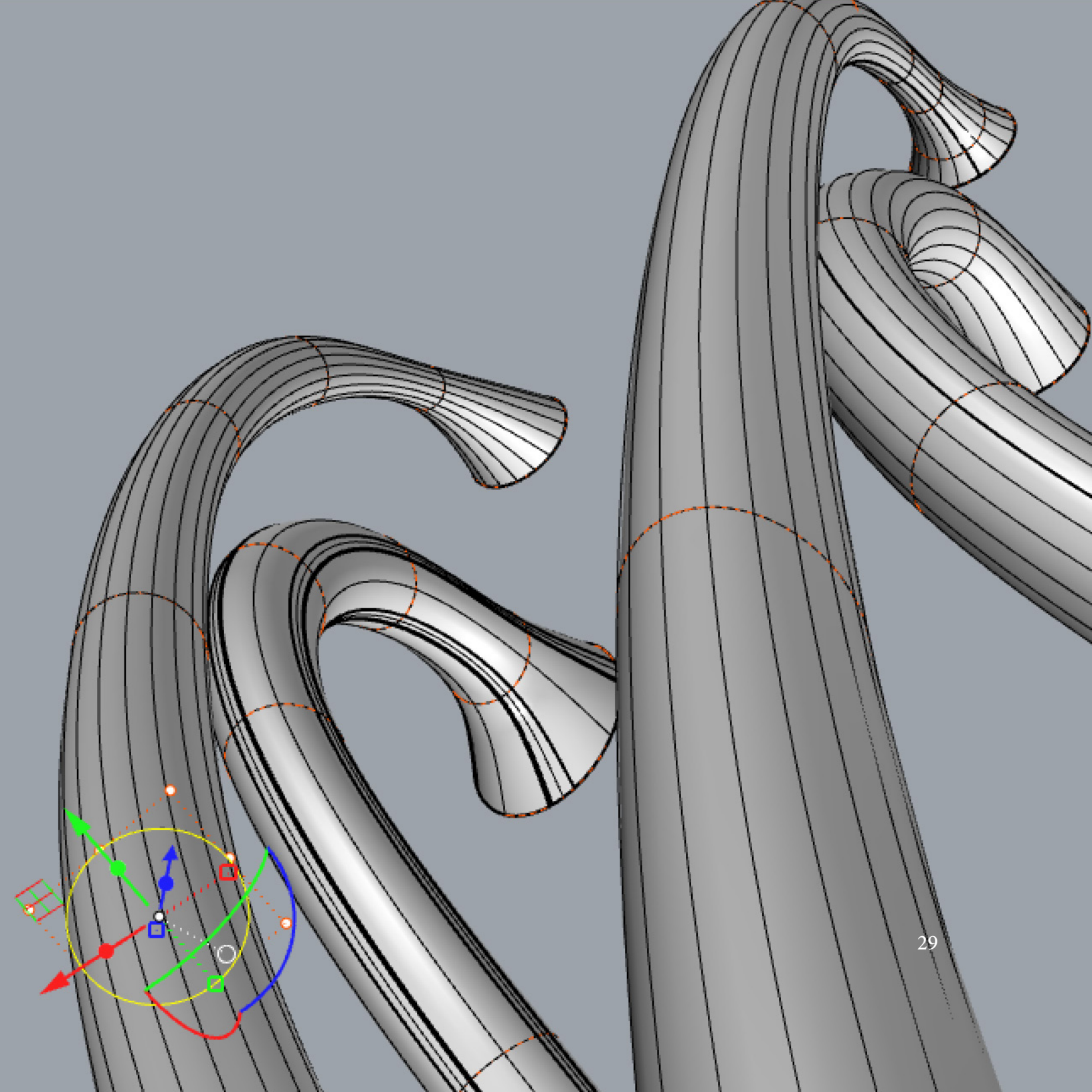
Image 2.3.2
The rise of UX and
projected job growth
[39]

Nowhere is this progression more apparent in recent history than with the rise of the personal computer and then the internet. 2D design was forever changed and many jobs were lost. However, once again, many more jobs, such as the field of User Experience (UX) design [image 2.3.2], were created and it would be hard to make a case that these new technologies have negatively impacted the design process and creativity.

From these examples and many others throughout history it is easy to imagine how GD could enable similar benefits to humanity. However, the fear of automation persists on a widespread scale.



3. Seeking Meaning



3.1. Industry Adoption

While GD is currently gaining popularity within the field of Industrial Design, GD has been around for decades. Arguably, the first adopters of GD were in the field of computer science, followed closely by engineering and architecture.

Greg Lynn, Alessi Coffee and Tea Tower

In discussion with Architecture Professor Philip Speranza, of the University of Oregon, I was introduced to the pioneering work of Architect Greg Lynn. Working with Alessi, Lynn created a very early example of a generative industrial design product with the Alessi Coffee and Tea Tower [image 3.1.1].

These vessels were not only generated with random algorithmic input but were each unique and were produced at scale in an early example of mass-customization [4]. The process was by no means efficient, and the sets were “horrendously expensive” [40, 41].

Still, this is a fascinating precedent to speculate upon further.

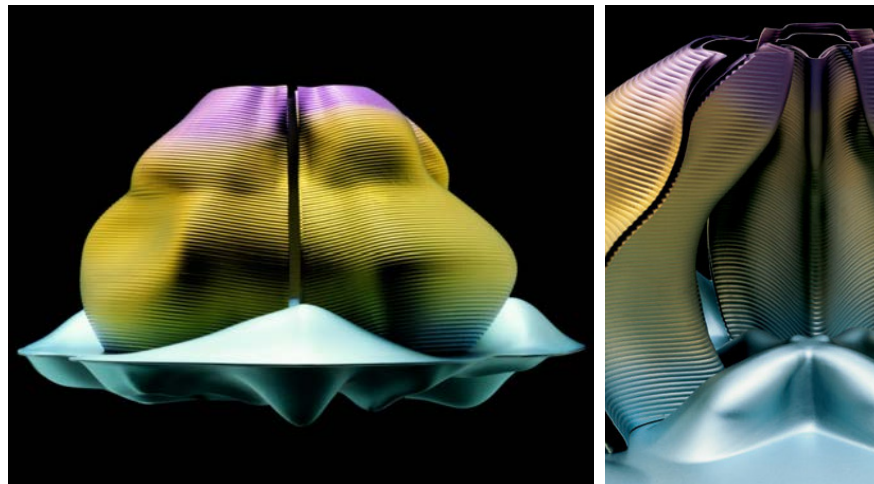


Image 3.1.1
Greg Lynn, Alessi
Coffee and Tea
Towers [42]

Computational Ideation

Industrial designers Jon Rasche and Zack Zlevor implement new tools into their traditional toolset. They present a case study in which their team increased “productivity tenfold. [43]”

Rasche and Zlevor experimented with a heavily parametric and algorithmic process. Grasshopper was leveraged to generate a large variety of design iterations within the constraints of a single product model [image 3.1.2].

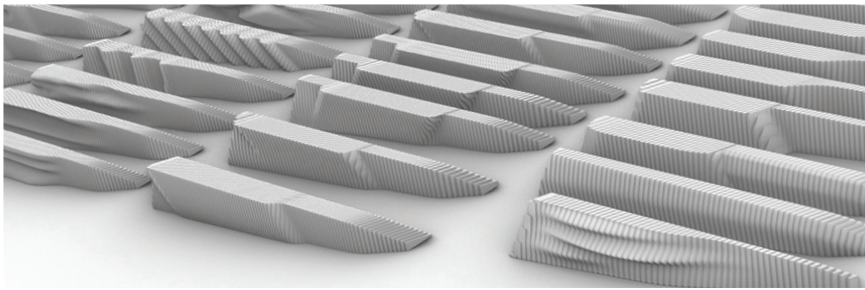


Image 3.1.2
Jon Rasche & Zack
Zlevor, Computational
Ideation [43]

Divergent

Using similar tools and speculating upon a similar area, Nathan Shirley imagines how GD can be used to iterate across an entire brand family [image 3.1.3]. Shirley asks what it would be like for a customer to subscribe to a design philosophy that lives “across all the objects in your life. [44]”



Image 3.1.3
Nate Shirley, Divergent [45]

Image 3.1.4
Philippe Stark, A.I.
Chairs [46]



Philippe Starck, A.I. Chair

Recently, industrial designer Philippe Starck revealed a generatively designed chair that he produced for Kartell in collaboration with Autodesk [image 3.1.4].

Widely represented as speculative and futuristic [47, 48], this design is more a response to software-enabled tools and manufacturing processes as they exist now in the present. While elegantly realized, this design is a singular design that is currently being produced at scale by legacy mass-production techniques [49].

Interestingly, there is a striking similarity between the initial stage of the A.I. Chair and Stark's earlier Louis Ghost Chair geometry [image 3.1.5]. It is apparent that Stark either relied on the Ghost Chair as a starting shape or used very similar (likely a 90th percentile European male) geometry to drive the form development.



Image 3.1.5
Form comparison of a
Louis XVI chair [50],
the Louis Ghost Chair
[51], an initial stage of
the A.I. Chair [52]

If this is true, it is made even more interesting by the fact that the Ghost Chair itself was directly shaped by the form of a classic 18th century Louis XVI Chair, further continuing the lineage.

Influences

As much as possible, I want to sever the connection between what I, as a designer, contain in my head about what a chair “is”, and let my customer’s personal geometry drive the form from the outset. It was hypothesized that this would allow novel design directions to arise.

Coalesce was influenced and inspired by these existing designs and aims to further speculate upon how designers could work directly with individual customers to create bespoke objects, uniquely designed to meet specific needs, and produce them rapidly at a cost that is not prohibitive.

3.2. Generative Tools

Time will tell which of the many developing generative design tools will succeed, or how they will influence other platforms. Currently, there are several well-known products, such as SEIMENS NX [53], SOLIDWORKS [54] and CATIA [55] with GD functions.

Rhinoceros 3D (AKA Rhino) [56] has a very popular plugin, Grasshopper [57], that enables GD work. Recently, Autodesk has had a sizable media presence regarding the generative functions of their program Fusion 360 [58]. There are also numerous topology optimization programs that can be used for generative design [59].

No two generative programs work the same and most have a steep learning curve. The predominantly FEA and topology optimization tools are not very useful for early stages of an industrial design process. These programs usually require a solid understanding of basic engineering principles and most generate only one outcome at a time.

If industrial designers are using the tools listed here, it is predominately for the parametric modeling functions. While FEA and parametric modeling can be a major part of GD, this thesis ultimately focused on tools that required the least amount of setup, to generate the most design iterations, in the shortest possible time. To help compartmentalize the many programs, I divided them into two categories: Active (with two sub-categories) and Passive.

Active - These tools are for analysis and/or design and allow designers a great deal of access to generative functions.

Active Analytic - These have little or no modeling tools and are primarily for analysis such as FEA. For example: Inspire [60].

Active Creative - Algorithmic and parametric functions of the modeling environment are fully accessible and editable by the designer. For example: Grasshopper [image 3.2.1].

Passive – Much of (if not all) the algorithmic functionality is handled by the computer. For example: Autodesk Fusion 360.

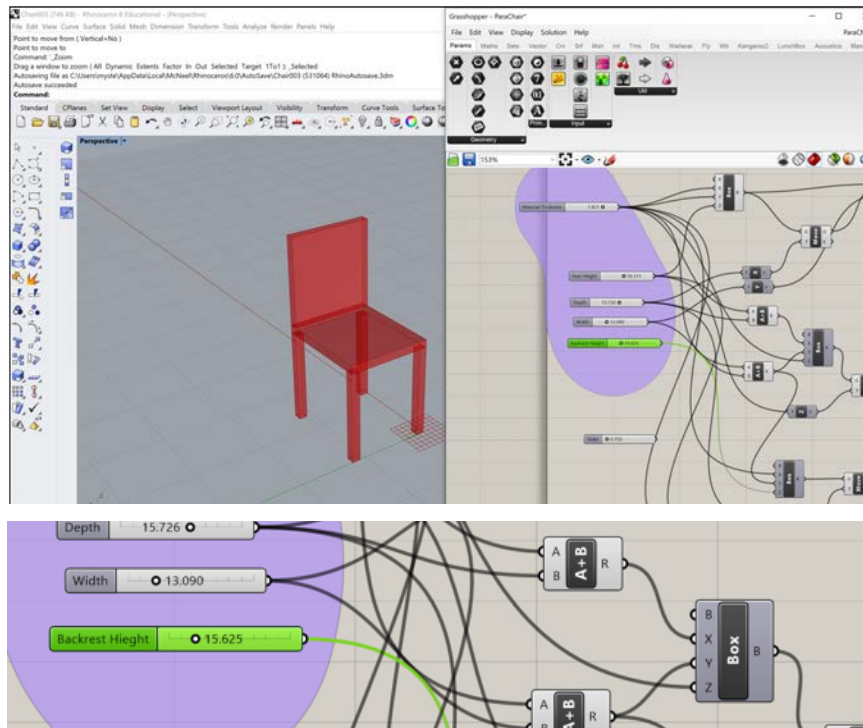


Image 3.1.3
The backrest height of a parametric chair in Rhino (left) being controlled by a slider (below) in the Grasshopper environment (right)

3.3. Online Survey

Much of the design conversation online (forums, Reddit threads, generative article comments, etc.) regarding the emerging examples of generatively designed industrial products can be divided into three main groups. Adoption, Rejection, and Repulsion.

Rejection

People in the rejection group have a fear of automation and are worried about losing their jobs to machines.

“All this effort to take designers out of the design process is disturbing!”

- Commenter 1 (article comment section)

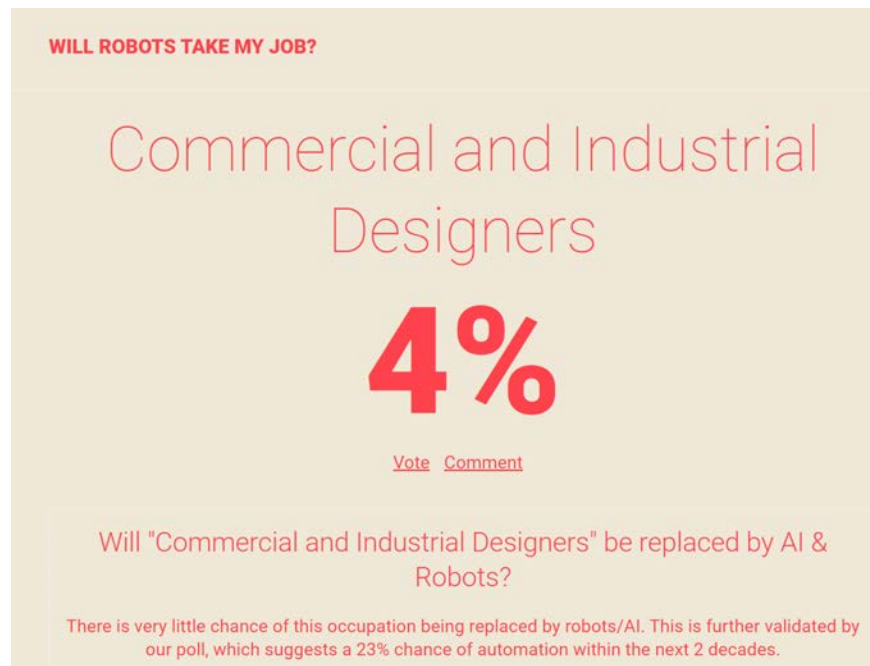


Image 3.3.1
Screen capture from
willrobotstakemyjob.com

Repulsion

In the repulsion group are many people who are repulsed by the “unnatural” look of generatively designed objects. Even though a large amount of the designs are driven by algorithms copied from nature, people feel a certain uneasiness regarding these products. Seemingly, because they are so different from what people are used to beholding, they are perceived as alien.



Image 3.3.2
Detail from 2019 VW
van concept [61]

“I’m intrigued to know if deep learning will introduce beauty and human values in the equation to find beautiful designs...”

- Commenter 2 (online forum)

“That’s why I haven’t touched it yet. All the samples I see are incredibly ugly...”

- Commenter 3 (Reddit thread)

“When it looks like bone, or is all... sinewy, it approaches the uncanny valley. Objects that look like they should be inside of a body are gross.”

- Commenter 4 (design exhibit spectator)

Adoption

In the adoption group, there are many people who see the benefits of generative design, are inspired by generative design, and would like to use it in some way. While some of these adopters may see negative qualities of GD, they see these as opportunities for improvement. Adopters view GD as a new tool that can augment their workflow.

“I think Generative and Parametric designs are brilliant, but it’s up to designers to use them correctly. With the right inputs and boundaries, I think it could make a very interesting and aesthetically pleasing element of a larger designed object.”

- Commenter 5 (article comment section)

Image 3.3.3

New Balance shoe with generative elements [62]

Image 3.3.4 (opposite)

The Kinematics Dress by generative design studio Nervous System [63]





3.4. Primary Research

I conducted loosely structured interviews with practitioners from three different disciplines. These subject matter experts actively use GD in their professions as Architects, Engineers, or Industrial Designers. One of the architects had also used GD to create generative sculptures. What follows are quotes from each discipline that best illustrate major themes in the conversation.

Architecture

“Whether designing the system, changing the parameters, or choosing the ultimate design directions, the designer will always need to make decisions.”

- Participant 1 (Professor of Architecture, Major University)

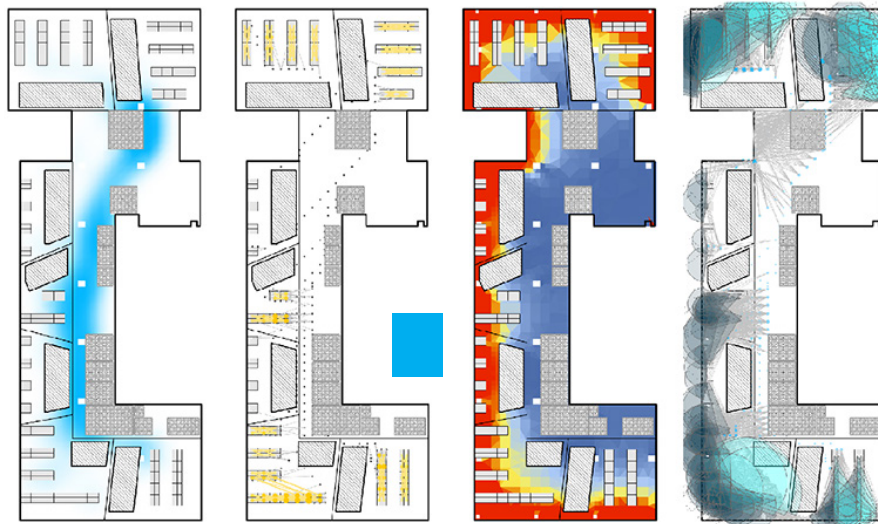


Image 3.4.1
Generative studies
considering user preferences
and environmental inputs
[64]

“For it to be fully utilized, it needs to have a more seamless integration into the process. CAD was not utilized for many years because it was so different from the traditional working method of the architect.”

- Participant 2 (Professor of Architecture, Major University)

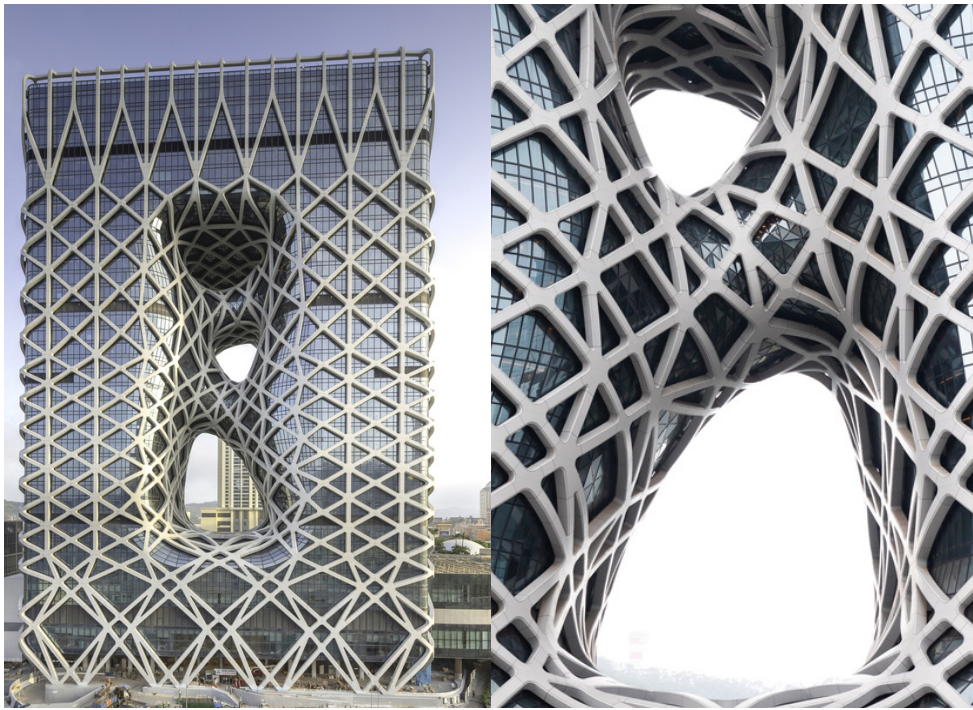


Image 3.4.2
Morpheus Hotel by
Zaha Hadid Architects
[65]

“The designer chooses. The designer designs the AI system, the designer programs the constraints of the system, the designer chooses the outcome.”

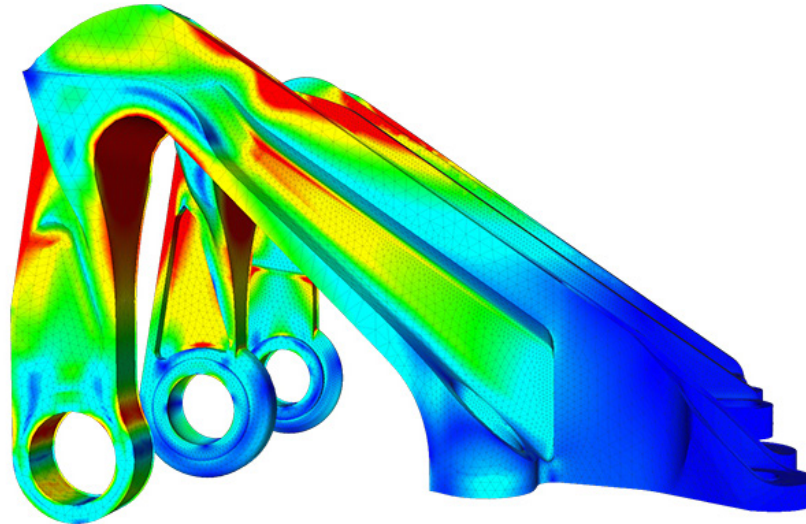
- Participant 3 (Professor of Architecture, Major University)

Engineering

“Optimization software is currently too slow and disruptive to the workflow to be utilized on anything that is quick turn. Optimization is only useful if there is going to be large production, or if safety is critical. The cost to take time to optimize is a cost that is needed.”

- Participant 4 (Senior Mechanical Designer at a prominent product development firm)

Image 3.4.3
Analyzing an aircraft
bearing bracket [66]



“Designers do not have enough understanding of basic physics and engineering to efficiently use generative design tools... It should be used mostly for cost savings and performance savings, not aesthetics.”

- Participant 5 (Mechanical Designer at a small startup company)

Industrial Design

“Repetitiveness and formal structure of products, as well a product with simple brand language, lends itself well to generative design. Iterative loops can be programmed and automated...The designer chooses final design directions and works together with the generative tools.”

- Participant 6 (Lead Industrial Designer, major consumer product company)

“Necessity drove us to use generative tools. Too few designers, with too much work, and not enough time. This drove automation.”

“The designer chooses.”

- Participant 7 (Industrial Designer, Small consumer product company)




Image 3.4.4
ADAPT™ Prosthetic Platform by Josiah Tullis & Justin Taylor [67]

3.5. Speculative Improv Workshop

This was a dual-purpose workshop. Partly, this was intended to further explore another of my research areas, the intersection of improv and design. However, I also used a theme of automation as our prompt for the improvisation to see what, if any, resonance happened between this and my thesis.

Improv has been shown to improve the brain's intuitive functions [68] and it has a long and established history. Improv has been explored quite extensively in education and by designers as an aid to the idea generation process.

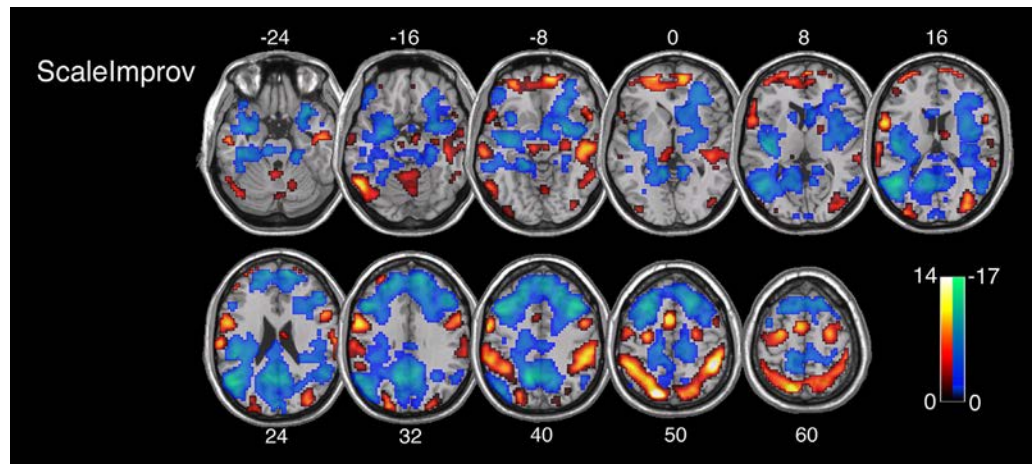


Image 3.5.1
An fMRI study of improvisation [69]

Primarily, these explorations have focused on the improv concept of “Yes, And.” This concept of “Yes, And” is seen by most improvisers to be a core tenant and fundamental philosophy of improv. “Yes, And” is the process of listening carefully to a scene partner, accepting their idea, and then building upon their idea [70].

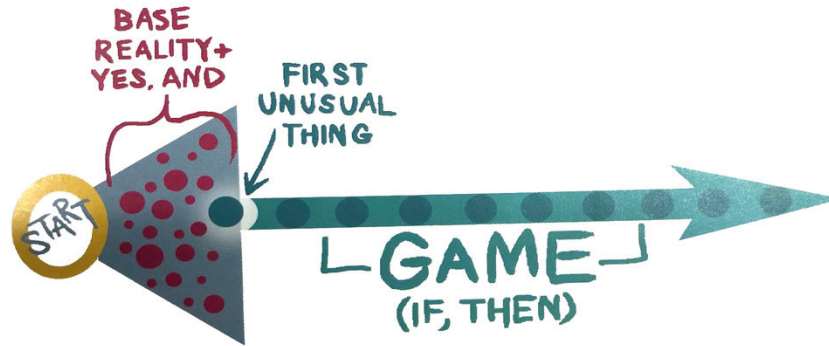


Image 3.5.2
The UCB model of comedic improvisation [71]

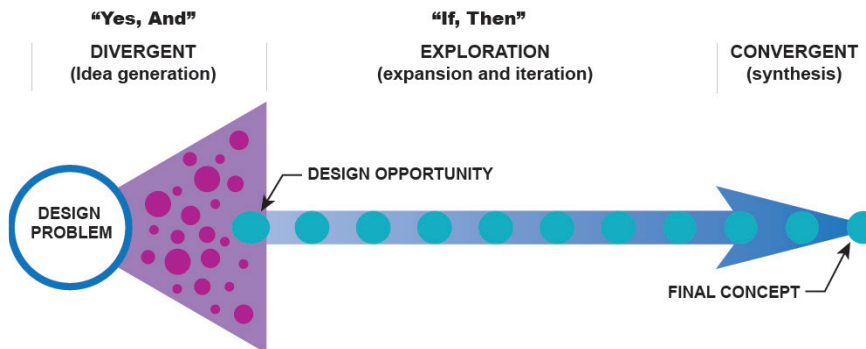


Image 3.5.3
The UCB model [71] modified to show a relation to the design process

In The Upright Citizens Brigade Comedy Improvisation Manual, the UCB suggest using “Yes, and...” to define the “Who, the What, and the Where” of a scene. This is also referred to as the “base reality” of the scene [image 3.5.2].

Players explore in the base reality until one of the scene partners find “the first unusual thing.” This unusual thing is then used to play a “game” which will be a pattern that flows throughout a scene. The players work together to both heighten and explore the game concept thus extending the funniness of the scene [71]

Recent research at the University of Strathclyde used this method of improv “game-play” in a series of workshops that began to explore how the design process could benefit from improv beyond the generative phase [72].

The workshop I facilitated on November 27th at the 10th UNIDCOM/IADE International Conference Senses & Sensibility in Lisbon, Portugal built upon the research completed at Strathclyde. This workshop explored how the “If, Then” technique, and improv “game-play”, can aid not only in expanding on immediate needs, but also in speculating about possible future scenarios.

During the first half of this workshop, participants received a participatory introduction to some basic improv techniques intended to improve teamwork, creativity, and brainstorming. Building upon this, in the second half of this workshop, participants experimented with using some advanced improv techniques to quickly explore speculative design scenarios.

Participants were of different ages, genders, countries of origin, and relations to the field of design. We had a great time creating a fabulous speculative future world together.



Image 3.5.4.
Participatory improv
introduction



Image 3.5.5
Workshop participants
as insect workers
in a factory making
e-cigarettes for robots

Some themes that arose and influenced my design thesis:

AI learning to do design

Fear of losing jobs to machines

Augmented designers working directly and quickly with clients

AI enabling designers to create bespoke products quickly

Automated designs not matching human expectations

AI not understanding human emotions and sensibilities

AI/Machines lacking empathy and doing poor design

Working with machines favorable to machine-led design

Voice interaction more favorable than physical machines

3.6. Research Through Design

To fully grasp what GD meant to me personally, I conducted several design experiments to explore GD from different angles.

3.6.1. Envisioning New Working Methods

One concept that arose in the speculative workshop, and in conversation with a primary research participant, was that of a designer working much faster and efficiently with new technology. Speculating upon future advancements in AI and modern manufacturing methods, such as rapid prototyping, we imagined an industrial designer's tools being similar to that of a modern DJ.

Some background - For a brief period, most of the physical implements used by DJs (Turntables, mixers, drum machines, samplers, keyboards, vinyl albums) started to disappear. It was not uncommon to see a DJ with nothing but a laptop. A computer could do all the work of multiple physical devices. However, DJs were now confined to the interface of one flat screen.



Image 3.6.1
Pioneer DDJ
RR Rekordbox
Controller [73]

Then, some innovative devices began to come to market that allowed the storage, processing power, and organizational abilities of the computer to be utilized while being controlled externally by devices. These controllers [image 3.6.1] could also be assigned different functions depending on the need. For instance, a pad with generic buttons could be assigned to work as a drum machine one moment and a keyboard the next.

Currently, it is the standard for DJs to use computers coupled with some form of external controller. DJs have become fully augmented by technology and can “do more faster” than ever before. Rather than put DJs out of business, technology and a human-computer partnership has given access to a vast number of people, spawned numerous new styles of music, and continuously facilitates innovation and creativity.

Compare this with the 3D mouse controllers that many 3D CAD modelers use [image 3.6.2]. These controllers mimic the action of physically rotating an object in three dimensions better than can be achieved with a standard mouse.



Image 3.6.2
3DConnexion
SpaceMouse
Enterprise [74]

While researching Grasshopper, the parametric modeling plugin for the program Rhinoceros 3D, I began to feel a little frustrated by the way I struggled to navigate and control functions with the small mouse arrow and keyboard commands.

I wondered what it would be like to have a tangible controller, like the Space Mouse, combined with the variety of controls a DJ controller has, that could be programmed with presets for a user's individual workflow. Physical sliders could be used for sliders in the program, buttons could both be used to initiate some function or programmed to activate oft used commands, track pads could be used for XY axis operations, and dials could be used for scrolling commands or rotational operations.

Using Python, Arduino, and a plugin called Firefly [75] I was able to use an external proximity sensor to control parametric modeling operations. Below, I am adjusting the height of a rectangular column by the position of my hand in space.

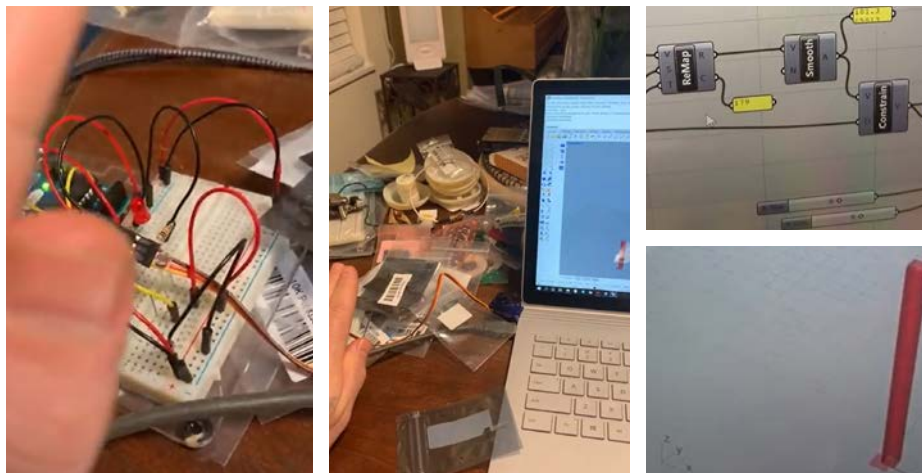


Image 3.6.1
Controlling parameters
by an external motion
sensor via Arduino,
Firefly, Rhinoceros, and
Grasshopper

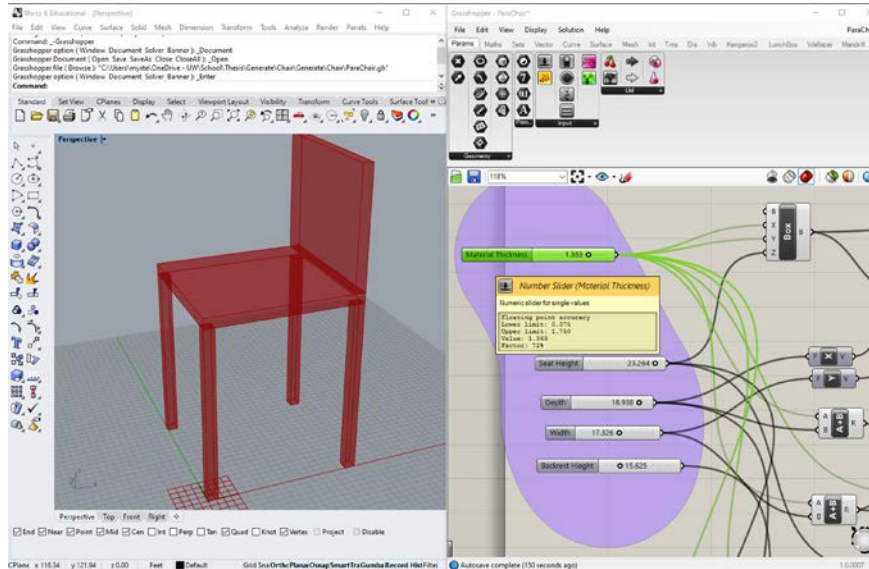
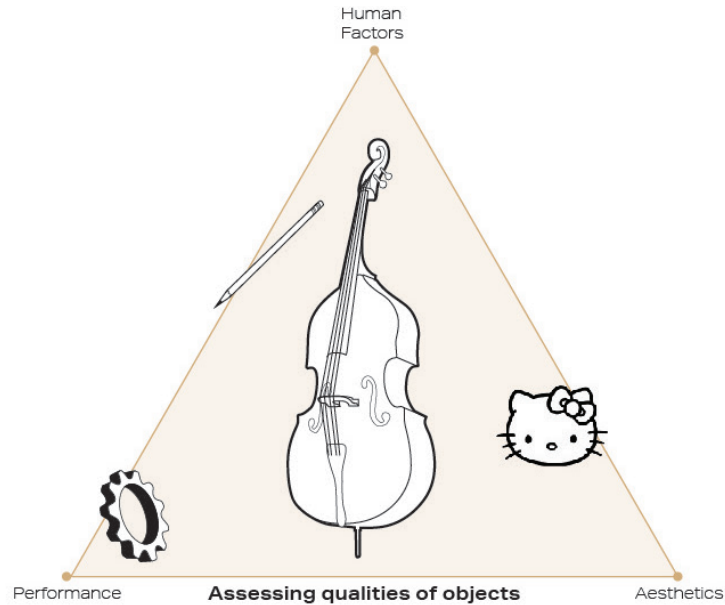


Image 3.6.2
A fluid and dynamic parametric chair

While many programs have parametric modeling, it is often a linear process that cannot be edited in a fluid dynamic way. Furthermore, changes to earlier modeling steps often “break” the model and cause later steps to fail. I experimented with a dynamic model in grasshopper that allowed for many variables to be quickly manipulated, even in tandem. I imagined each of these variables ported to devices for external tangible interactions.

In the immediate sense, this test was successful. Looking ahead, it helped to illustrate the steep learning curve I would need if I were to continue to explore this avenue. Additionally, the User Experience (UX) and interface design component alone could be an entire thesis. Because of the time constraints, I moved on to other explorations. However, this exercise helped me to speculate about the way in which future technological developments could accelerate the generative process, and would be an interesting area to explore for future research.

Image 3.6.2.1
Assessing objects
within a Design
Principles Triad
(DPT)



3.6.2. An Automated Generative Process

My primary and secondary research uncovered a wide variety of working methodologies. Currently, industrial designers working with generative design are “trailblazers”. Having no set path forward can have an amount of freedom but will also reveal many new problems with no known solution.

While exploring the generative program Fusion 360, I used three design principles to select a good candidate for a generatively enabled industrial design process. These principles were Human Factors, Performance, and Aesthetics. Throughout this process, I developed the framework that I would use throughout my final design phase. How I determined which qualities to use, as well as a more thorough description of this process is outlined in section 4.1 below.

The upright bass was selected as it was found to be a good balance of all qualities [image 3.6.2.1]. Similarly, in image 3.6.2.2, we see that every component of the bass can be analyzed in this same way. The bridge was selected as a starting point due to its position on the DPT as well as for the relatively simple forces acting upon it.

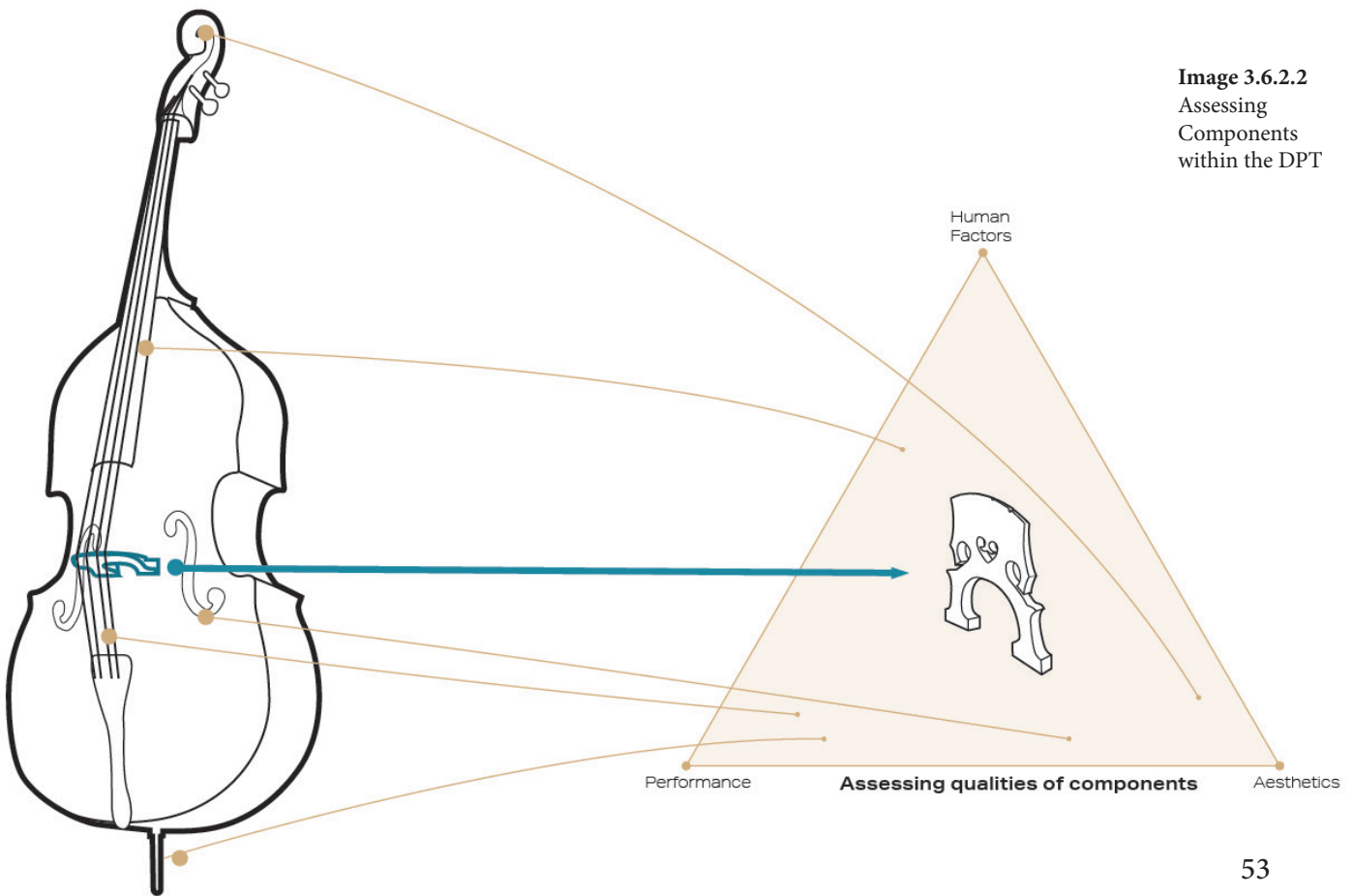
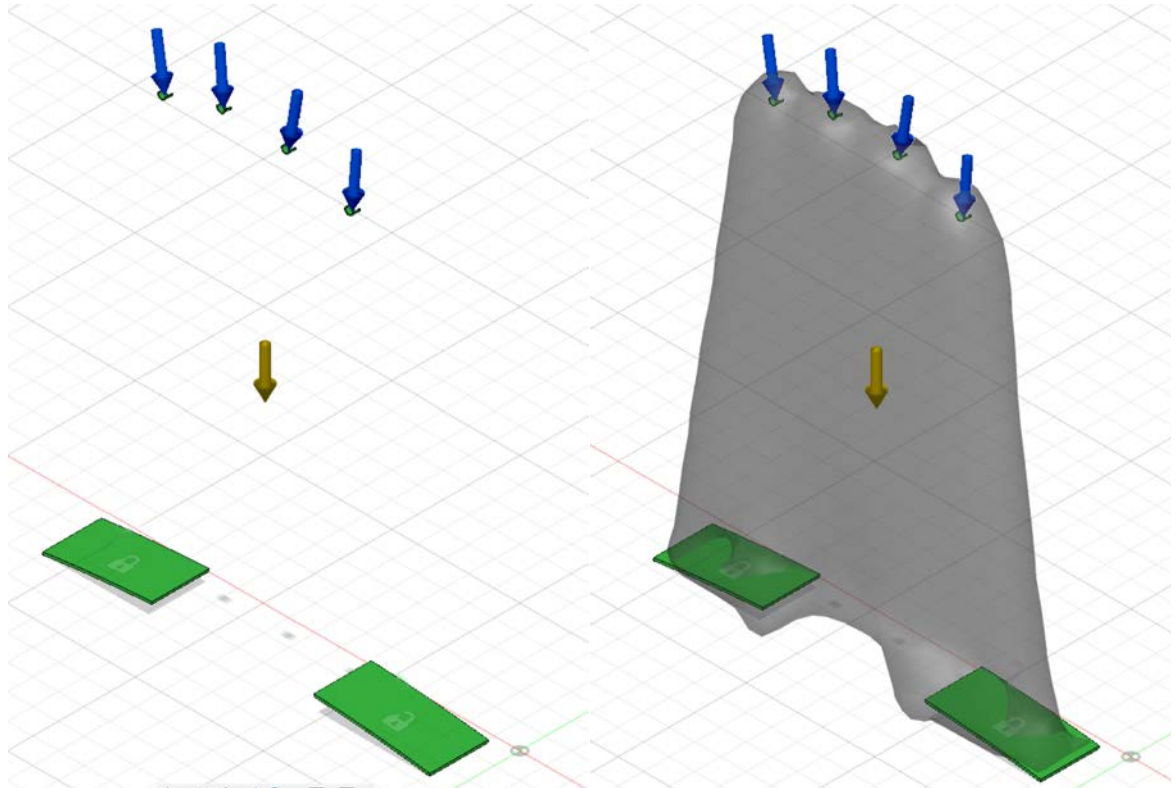


Image 3.6.2.2
Assessing
Components
within the DPT

Normally, the CAD process of an object would start with sketches, and then move through the extrusion of material and the refinement of the object. This shape would also be based on the history of the forms that came before it. However, in this example, the design started with very few constraints. The distance between the feet of the bridge was defined for functional reasons, and the exact positions of the string heights were defined. Next, the amount of force each string would apply to the bridge, and the angle of that force was calculated and applied [image 3.6.2.3].

Image 3.6.2.3
Forces and constraints
applied to the study
during setup phase
generating a preview



Next, the material, in this case ABS plastic, was chosen as well as the manufacturing process of 3D printing. Lastly, using algorithms derived from nature, and cloud computing, the program completed hundreds of iterations [image 3.6.2.4] in a matter of hours.

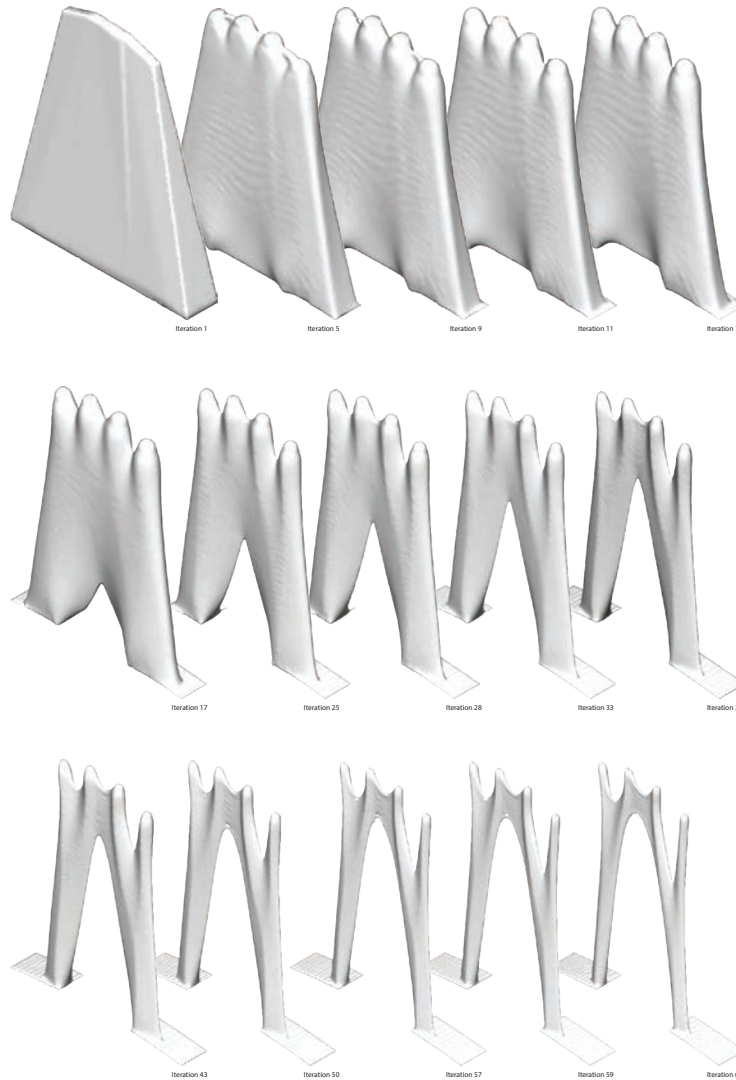
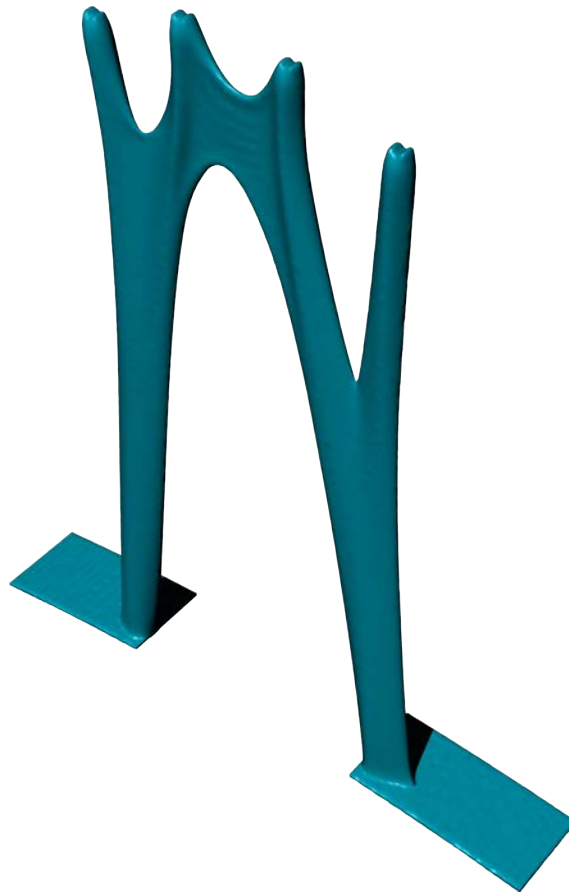


Image 3.6.2.4
A selection of iterative steps in the generative process of one study

Image 3.6.2.4 shows one variant's iterations from a set of four completely different variations. While it is true that an industrial designer could easily generate this many concepts or more in as much time or less, they would be initial concepts only, and would still need further development before manufacturing.

Unless a more traditional manufacturing process, such as milling, is selected, the forms are invariably organic in shape. This is not necessarily a direction that most modern designers choose.

Image 3.6.2.5
A generatively
produced acoustic
double bass bridge



In fact, it is more difficult to hand render initial sketches of very organic shapes. That, and the fact that our modern shape inventory is greatly influenced by the manufacturing processes of the past, seems to produce a great many geometric shapes.

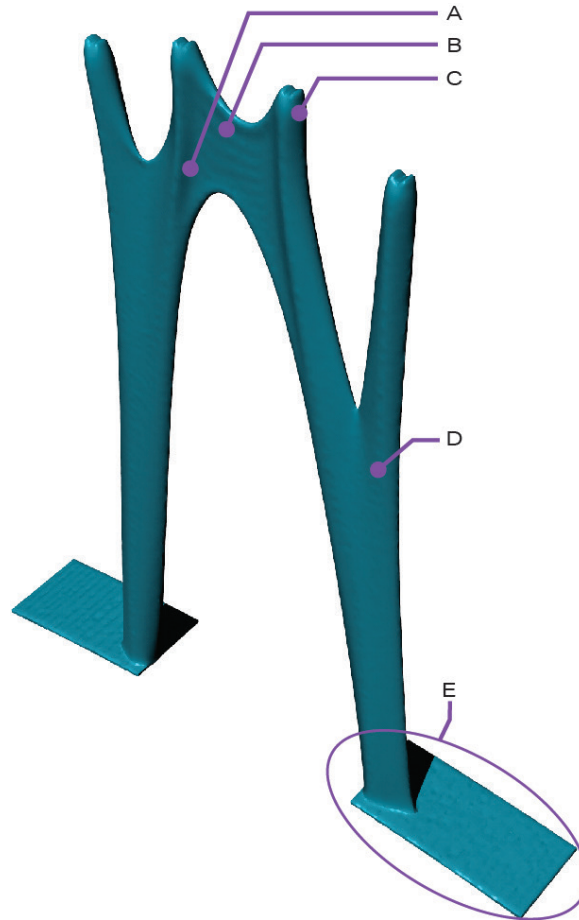
However, given the progression of flexible manufacturing, this design language is perhaps bordering on outdated. This is one of the benefits to using generative tools; they quickly allow designers to see previously hidden structural “skeletons” within objects. While the selection designers are presented with may not be the most optimum regarding human factors and aesthetics, they undoubtedly reveal new and novel design directions that can be used to further iterate upon.

AI cannot yet differentiate between “good” or “bad” aesthetics. On the other hand, a human designer cannot produce the volume and variety of forms the AI can. There is an opportunity here for the human designer to act in a way similar to a design director and curate the outcomes of the generative process. A designer still needs to choose which of the many iterations to pursue, and ultimately will need to refine the final design for a variety of reasons.

For instance, many people reacted with awe when first seeing this concept [image 3.6.2.5]. It is unique and has an interesting juxtaposition of complexity and striking simplicity. It is organic and so different from its predecessor that the shock-value alone garners it attention. Upon closer inspection we can see the way the biology-inspired algorithms can produce some of the “grotesque” or “sinewy” looks that were mentioned previously in Section 3.5.

In image 3.6.2.6 we see that the protrusions at A are reminiscent of structures like gums in a mouth, and at B the surfacing takes on an elastic, skin-like appearance. The points that support the instrument's strings, as shown at C, are very much like teeth and at D the form is bone-like. Lastly, the AI does not "see", and has no aesthetic ability to resolve the transition at E where the generated form meets the base.

Image 3.6.2.6
Areas of unease



If this design were to move towards production, there would need to be tests of the acoustic properties of the bridge. The outcomes of this test could lead to another round of GD. There is also an interesting dynamic that arises if it does perform better than its predecessor. Perhaps surrounding parts also need to be redesigned. Given that parts can be easily combined for optimization, the entire look of the bass could begin to change. Additionally, there would still need to be quite a bit of surfacing work to do, even on this relatively simple shape, to resolve its form. These discoveries led to the next experiment in section 3.6.3.

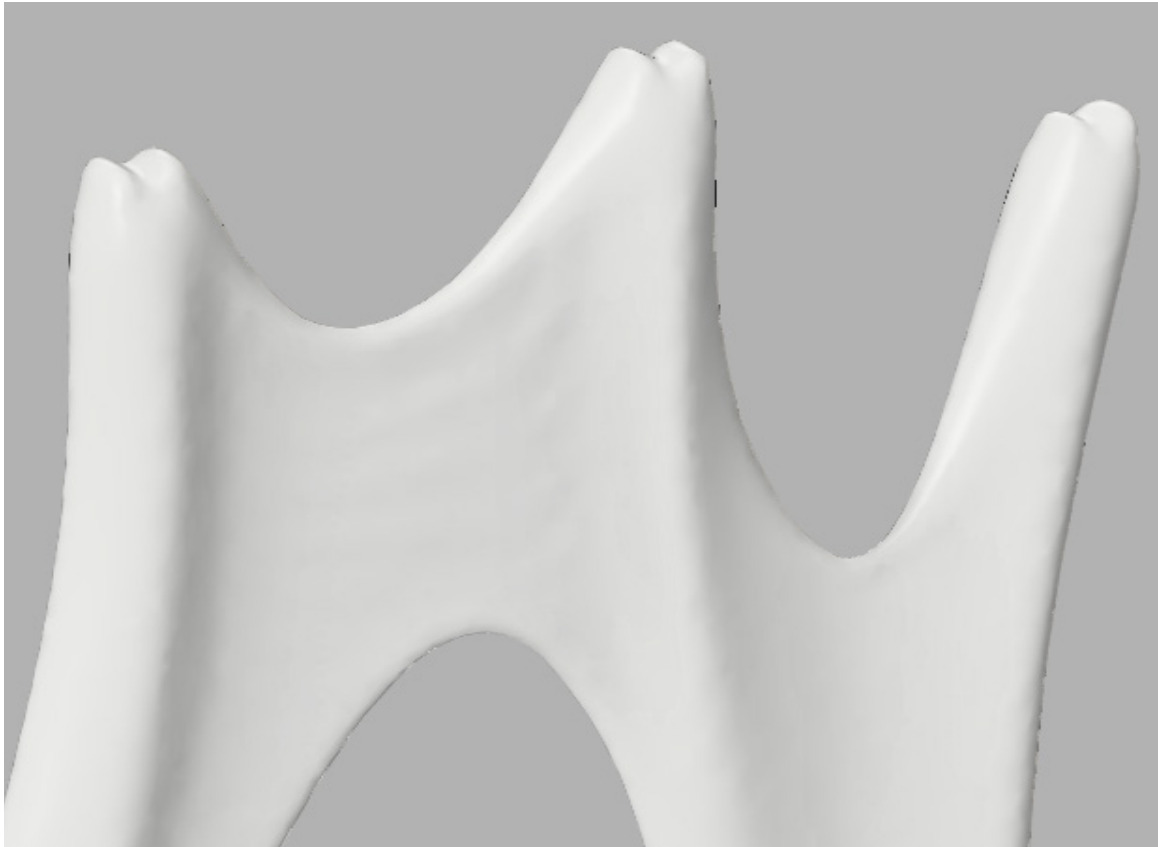


Image 3.6.2.7
Detail of “teeth”
on the final
bridge concept

3.6.3. Aesthetic Exploration

Industrial designers are (albeit practical, methodical, and rigorous) a very creative group. Most of the Industrial designer's process is a creative one. Being an industrial designer myself, I am much less interested in the ways that generative tools could do design work for me, but how they could augment my ability to do work.

During a conversation with Industrial Design Professor Sang-yeun Ahn, we discussed the concept of using generative tools to “uncover the hidden form of objects” as a means of inspiration and uncovering novel form direction.

Image 3.6.3.1
A generatively
produced bike
frame [76]



By utilizing GD, designers can see the “minimum essence” that is needed for a product to function. This can be used as a scaffold to iterate on top of. This inspired a quick study using a very alien-looking generative bike frame I had found online [image 3.6.3.1].

According to the researchers who engineered this frame, it was a very appropriate answer to all the forces acting upon it.

However, visually, it is not harmonious or approachable. To human sensibilities it looks unsafe and unresolved. Using the final, fully generative, bike as a sketch underlay, I quickly iterated over it with sketches that simplified and merged geometry...



Image 3.6.3.2
One of a series of overlaid sketches

...and further explored possibilities by applying a variety of design decision-making processes while refining the overall form.



Image 3.6.3.3
A final sketch concept derived from the generative frame

While these quick sketch experiments did not produce something I would introduce as a final concept, they did expediently reveal new insights about how structure could be arranged, and brought to mind several new ways that a surface might be manipulated to create visually interesting forms that function well structurally and greatly reduce materials.

3.7. Research Implications and Design Direction

An interesting cyclical flow of design begins to happen when one component of an object, like a bike or a double bass bridge, is redesigned and optimized. The redesigned object now interacts with other components differently. The question arises of whether neighboring components should be redesigned as well.

Furthermore, boundaries need to be established or they will blur. With an acoustic double bass for example, when each part that interfaces with another is redesigned, or, as is often the case in manufacturing, multiple parts are combined, at some point the object no longer resembles its predecessor. When is it no longer a bass? When does it become some new instrument? And exactly how alien can it become before too many possible users are repelled or confused?

Teaching AI to produce contextually relevant aesthetics is a fascinating area of research that I would like to explore given more time. This relates as well to the psychological and emotional responses of the public to generative design. Some more questions arose from these inquiries.

Are people innately repelled by these kinds of forms? It seems inconsistent that so many people might see both a tree in a forest or a coral in the sea as beautiful, but a similarly shaped form underneath their dining room table as something sinister. Is it built into us, or, are we merely conditioned by the shapes of industry? Is our understanding of what product forms should look like only determined by the planar rectilinear forms of traditional manufacturing techniques? Is our conception of how organic a form can be decided by the constraints of draft angles, wall thickness, and the limitations of the casting process? Are we conditioned by the limitations of poorly trained CAD users? It seems worthy of study.

While I could not completely change gears and dive into this area of inquiry, it did reinforce for me the opportunity space for industrial designers to serve as mediators between generative outcomes and more pleasing acceptable shapes for humans. I felt very inspired by the idea of “hidden structure” and using the generative tools to unveil new forms as points of inspiration.

I also enjoyed thinking of new ways in which the tools might be used. However, I knew that to do this well I would need to fully engage with the process. Meanwhile, the ideas that had come up surrounding working with individual clients was promising. I decided that I would work on a bespoke product in a traditional industrial design process that was augmented by a generative process as much as possible.

By engaging with the process in this way I hoped to establish a precedent by which I might further speculate about the future impacts and opportunities of GD. Additionally, I hoped to study the process strategically and extract a framework for this GD process that could be repeated and improved upon.

4. Constructing a Framework

- RESEARCH STATEMENT
 - ↳ OUTLINE
 - ↳ EXPANDED OUTLINE

□ THESIS GRAPHS & CHARTS

- DESIGN VS CRAFT VS GENERATIVE
- △ TRIND EXPANSION

□ THESIS 3D MODELLING WORK

- MOCKUP?
- CARDBOARD?
- SOLID MODEL WORK?

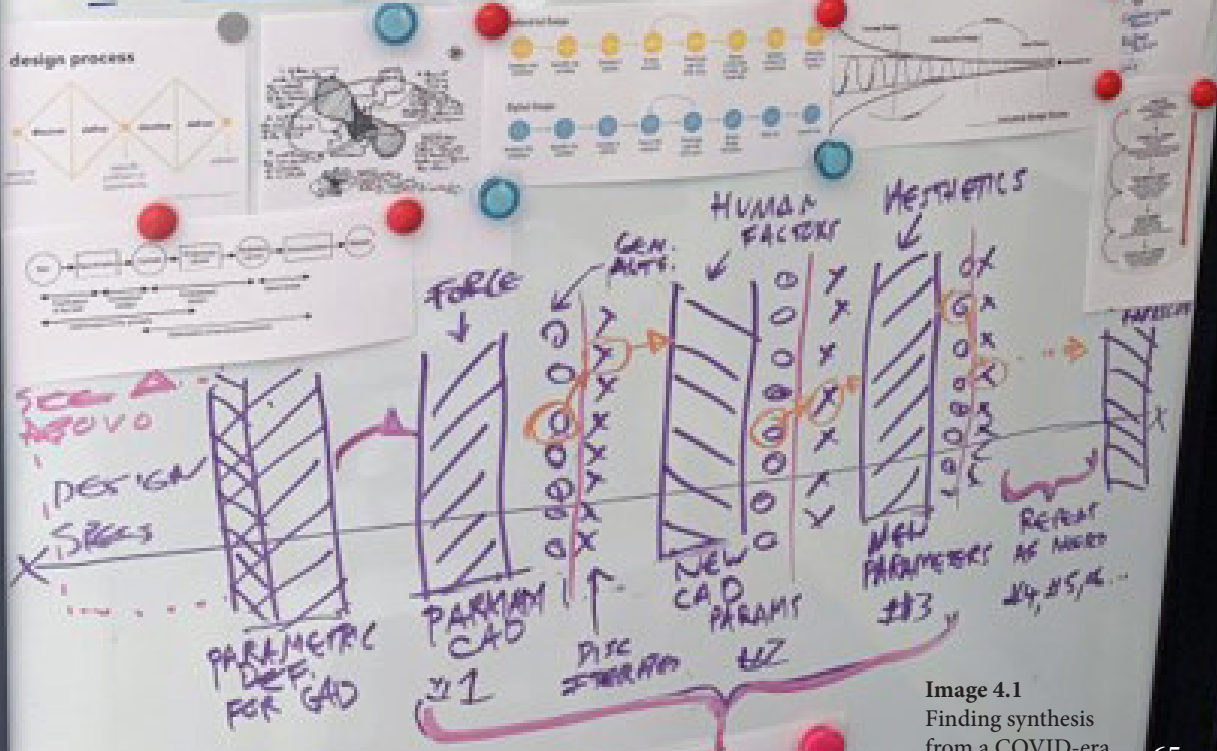


Image 4.1
Finding synthesis
from a COVID-era
home design studio

ROLE OF INDUSTRIAL DESIGNERS IN THE PRODUCT DEVELOPMENT PROCESS

The design process is the "craft" built.

4.1. Guiding Principles

To find a product that would be a good candidate for a generatively augmented industrial design process, I selected some driving principles that could guide the decision. These guiding factors were derived by listing qualities or factors that industrial designers consider while working. These were then grouped by affinity into larger collections until there remained three main guiding principle groups.

These guiding principles were Human Factors, Performance and Aesthetics. These helped differentiate industrial design objects from artistic objects, which may not have any Human Factors or Performance requirements, and engineering objects with no Aesthetic requirements. It was helpful to visualize this as the Guiding Principles Triad (GPT). It was found that objects situated in the center of the GPT would be considered ideal for a generative industrial design process.

For example, in image 4.1.1 we see a metal gear from inside of an engine that could almost be made entirely by a machine-driven generative process. Rarely, if ever, seen by a consumer, this part could be sent directly to manufacturing. This places the gear along the Performance/Aesthetics axis.

Additionally, other than considering the access a repair person might need to service the part, human factors are not much of a design driver. So, along the Performance/Human Factors axis the gear is placed much closer to performance. Several other factors contained within the guiding principles group of Performance, such as reduction of material, engineering requirements, and manufacturing processes, pull it even further into the corner of the GPT.

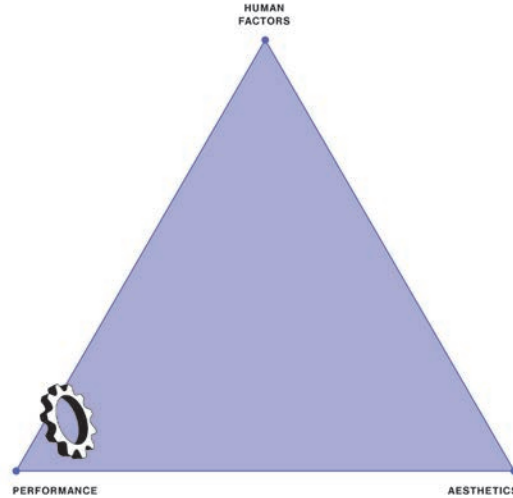


Image 4.1.1
A gear situated
on the GPT

A humble Ticonderoga pencil also lies on the performance-human factors axis but sits much closer to human factors [image 4.1.2]. Aesthetics, while important for some things such as brand recognition, are not a major factor. A pencil needs to work and be comfortable in the hand. However, as anyone who has used a pencil for an extended period knows, it is not that comfortable. Some qualities like cost, and manufacturing process limit its progression towards the human factors corner.

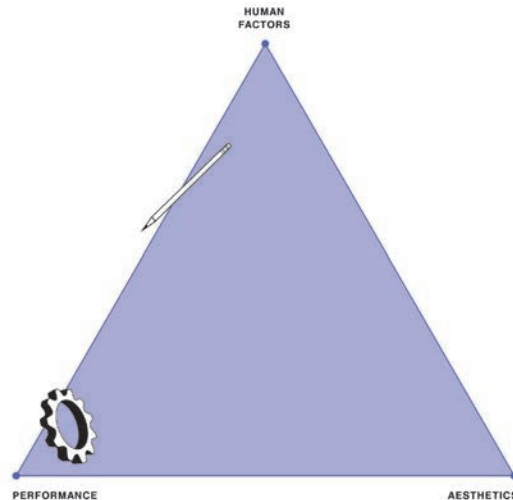
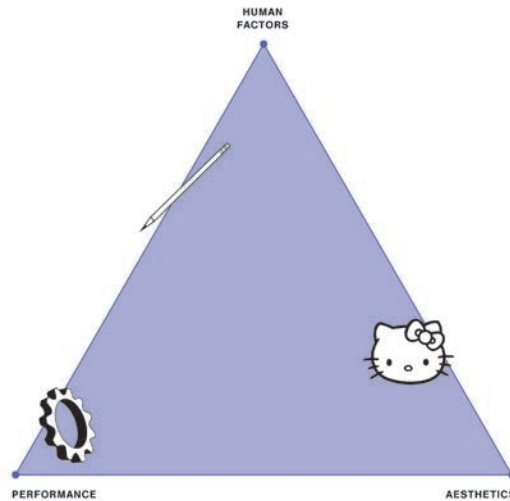


Image 4.1.2
A pencil and a gear
situated on the GPT

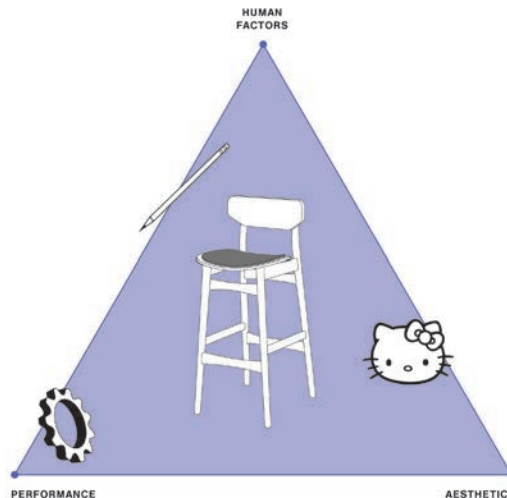
If we look at a Hello Kitty sticker for contrast, we find that aesthetics is much more important than human factors. Most certainly, the driving quality of a Hello Kitty product is cuteness—often at the expense of quality.

Image 4.1.3
A Hello Kitty sticker
added to the GPT



This brings us to the stool. A bar-type stool was the object that was found to be a good candidate for the design phase. It was a good balance of all three guiding principles.

Image 4.1.4
A chair in the center
of the GPT



As previously described in section 3.7.2, this same process for analyzing objects using the GPT can also be used to analyze objects on a component level. Referring to image 4.1.5, one can see how the chair's back support might need more of a designer's attention than a bracket hidden beneath the seat of the chair.

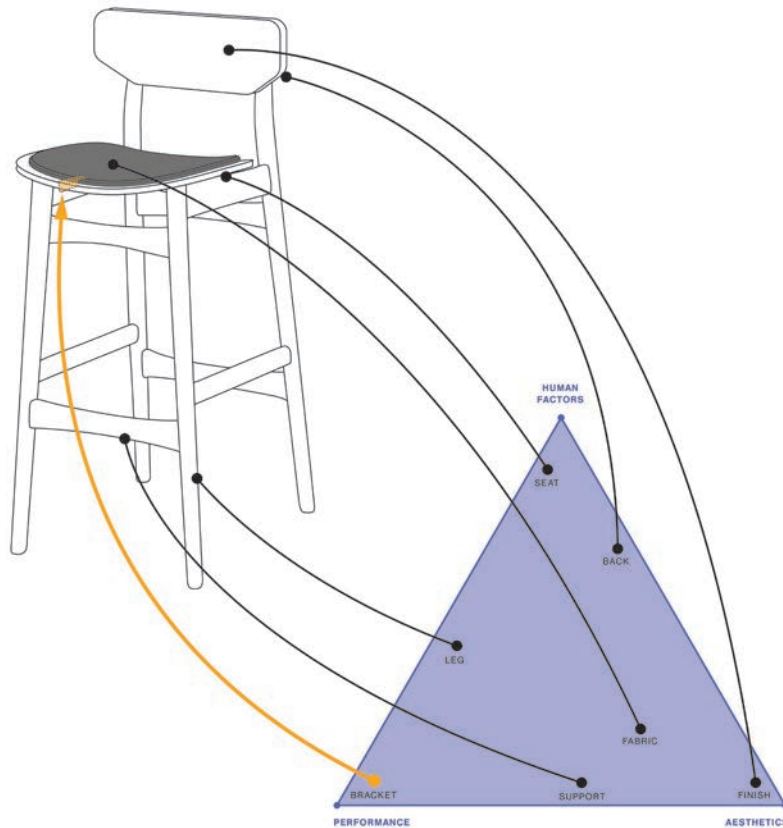


Image 4.1.5
Analyzing a chair's
components on the
GPT

This bracket is largely driven by cost and engineering requirements and would likely be created through a mechanical design process. This part could feasibly be generated completely by a generative design process which is currently how the majority of GD is being used on the product scale.

4.2. Existing Frameworks

Generative Mechanical Design (GMD)

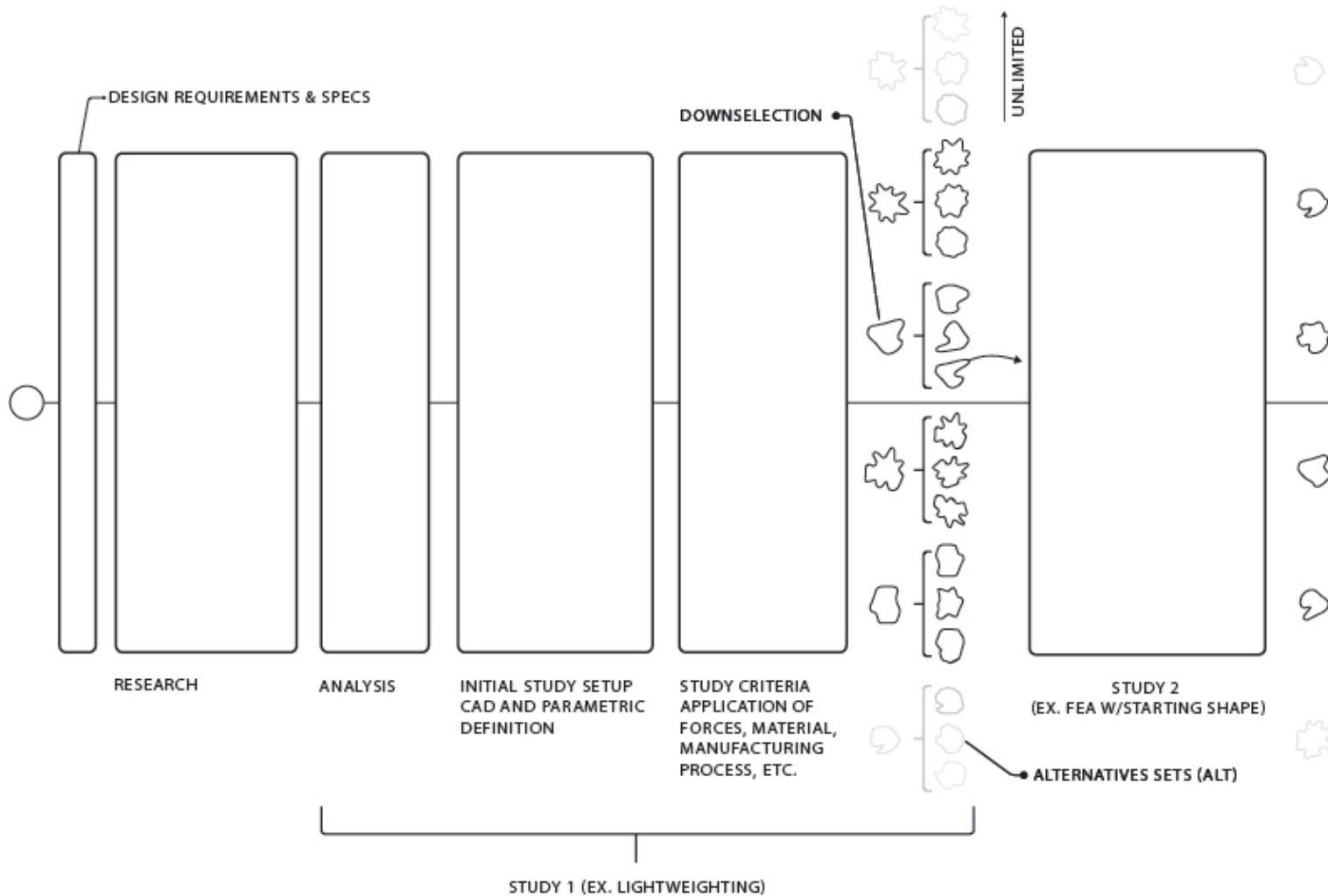
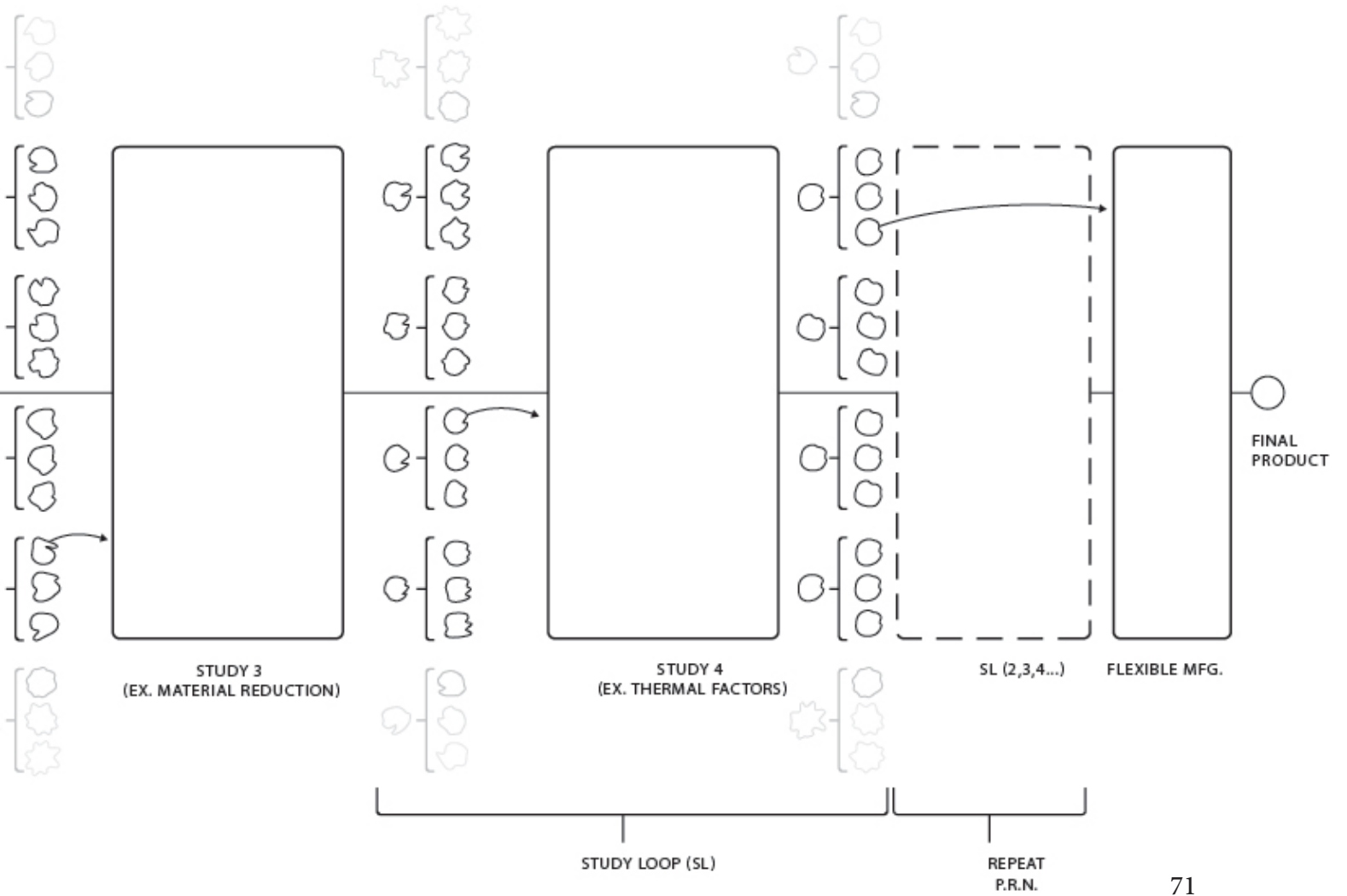


Image 4.2.1

A generative mechanical design (GMD) process



Traditional Industrial Design (TID)

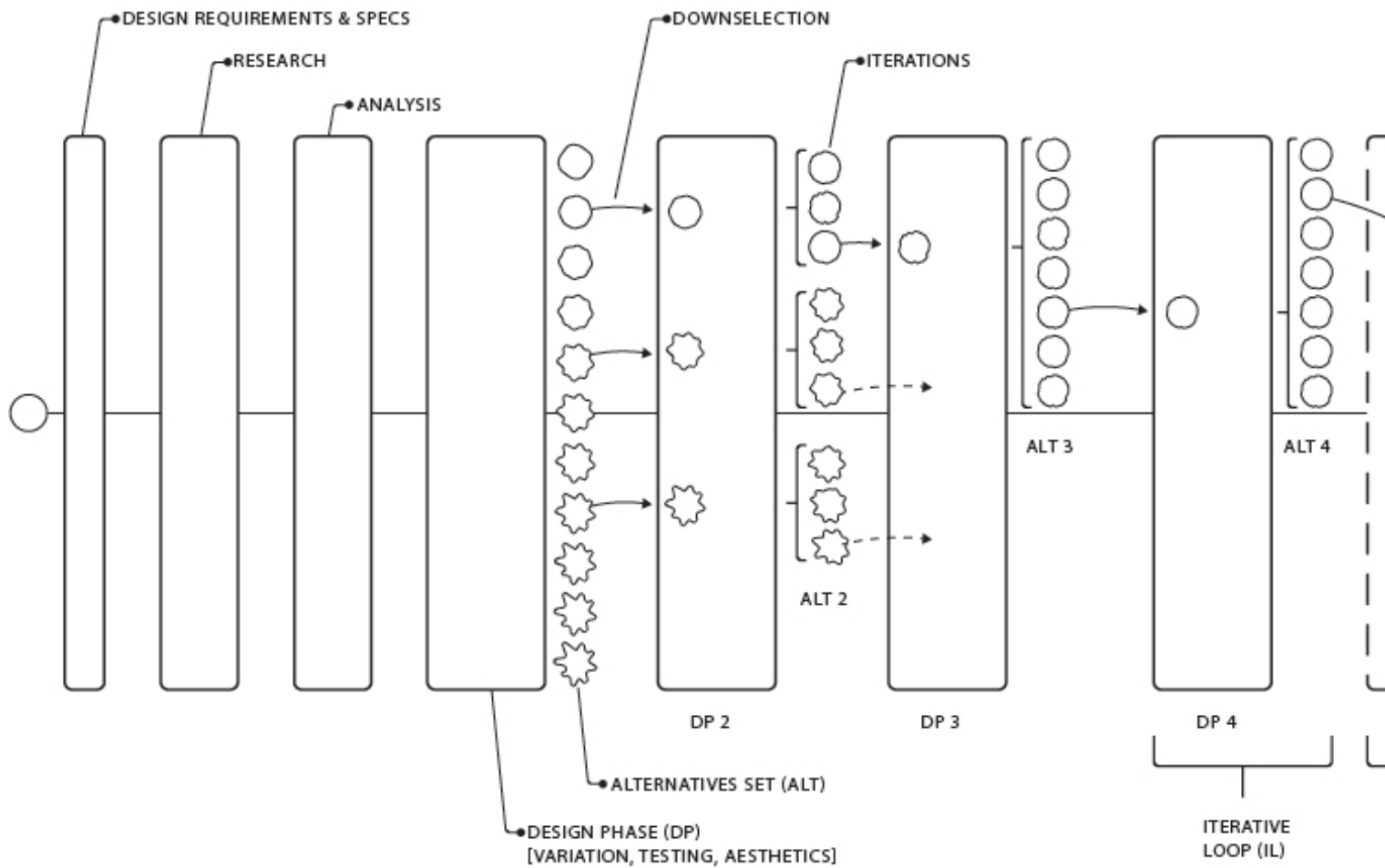
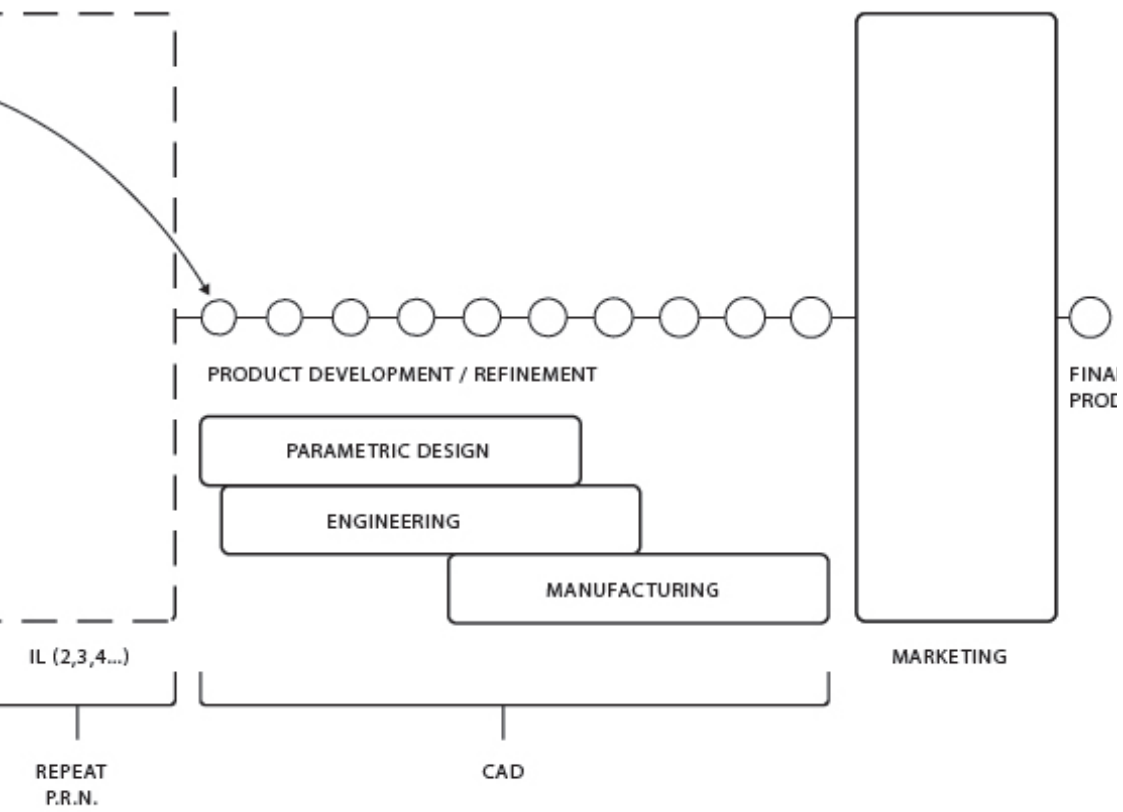


Image 4.2.2
A traditional industrial design (TID) process



Traditional Bespoke Craft Design (BCD)

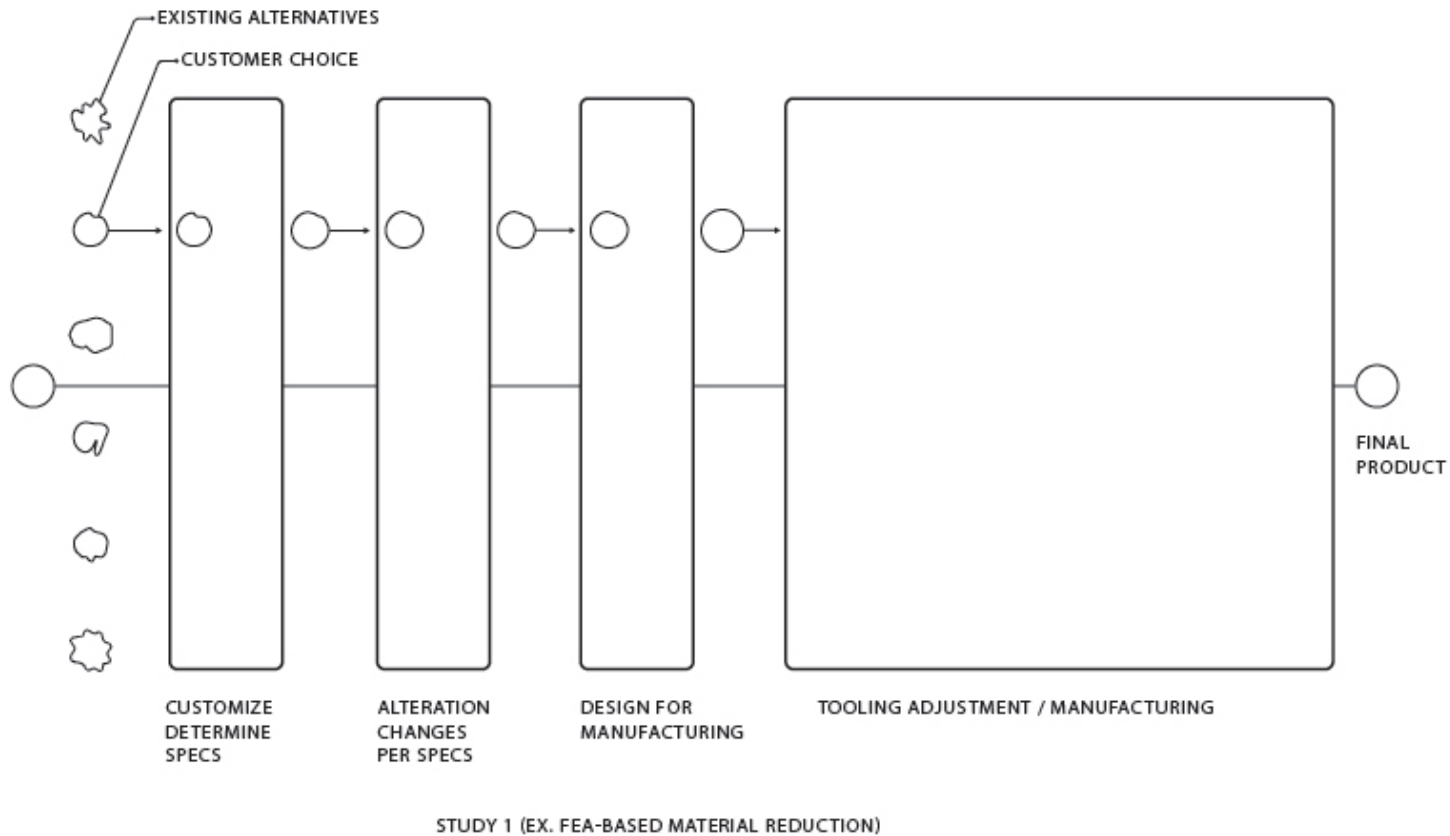


Image 4.2.3
A traditional bespoke craft (TBC) process

Existing Frameworks

To effectively illustrate the way in which my generatively aided design process differed from existing processes, it would help to briefly describe three existing processes that are closely related to my thesis topic. On the following pages are diagrams for three current workflows: a generative mechanical design process, a traditional industrial design process and a bespoke craft process.

For the purposes of this thesis, I have created some simplified diagrams to help convey information. These are by no means exhaustive of every detail, nor are they representative of every designer's process in these domains. These diagrams are composites based on my research, first-hand knowledge, and experience. I will first walk through the Generative Mechanical Design (GMD) process in detail to explain the various sections of the diagrammatic system and then will quickly move through the other two diagrams.

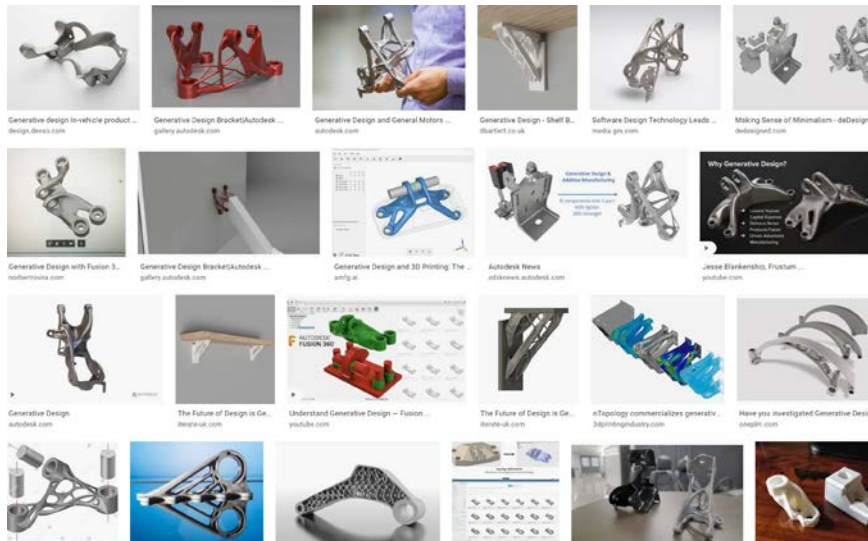
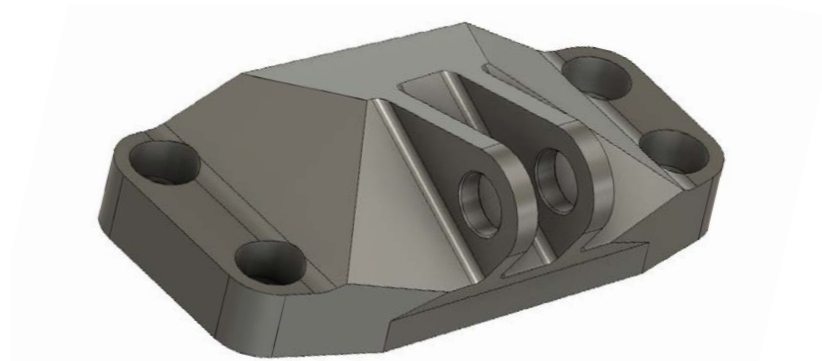


Image 4.2.4
An image search for generative design [77]

4.2.1. Generative Mechanical Design (GMD) Process

First, to explain how generative design is being used most often on a product, we will pick up where we left off in the previous section with an engineered bracket. Given the brackets position on the triad in image 4.1.5, it would be a perfect candidate for a GMD process [image 4.2.1]. This is also evidenced by the plethora of strange looking brackets that appear from a simple image search for generative design [image 4.2.4].

Image 4.2.1.1
Jet engine loading
bracket [78]



To begin the process, we start with an existing bracket. We can imagine that a company has already invested much time and resources into its development. The existing bracket has been engineered to be as strong as possible while being as light as possible based upon traditional manufacturing processes. However, now the company producing this bracket can reduce cost by using flexible manufacturing and wants a modest redesign.

In image 4.2.1.2, we see an initial stage where analysis is done to determine how this part might be optimized with a generative process, a CAD model is created, and the constraints, such as where it interfaces with other parts, and where fasteners attach, that need to be maintained, and these are placed in the modeling environment.

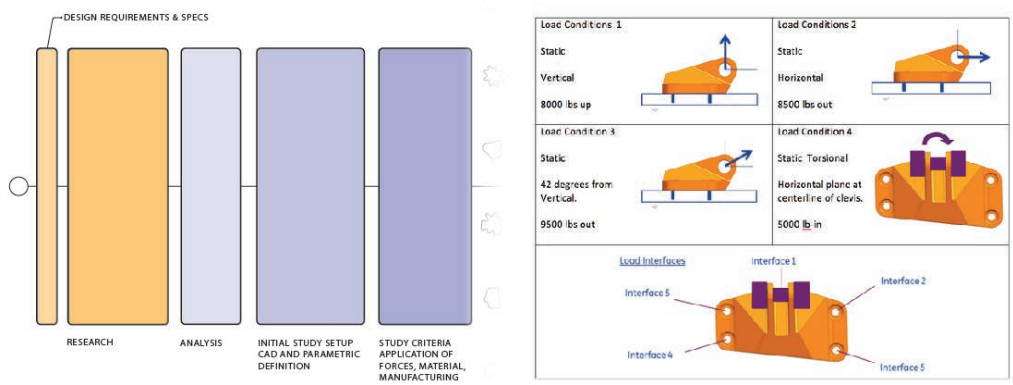


Image 4.2.1.2
GMD process diagram detail with bracket requirements [79]

Next, the model is “lightweighted”. Since this bracket will be 3D printed in metal rather than machined out of a block of solid metal, new geometries can be used that would be impossible to fabricate previously. Depending upon initial constraints, this process could be entirely internal, or, could affect the outward look of the part.

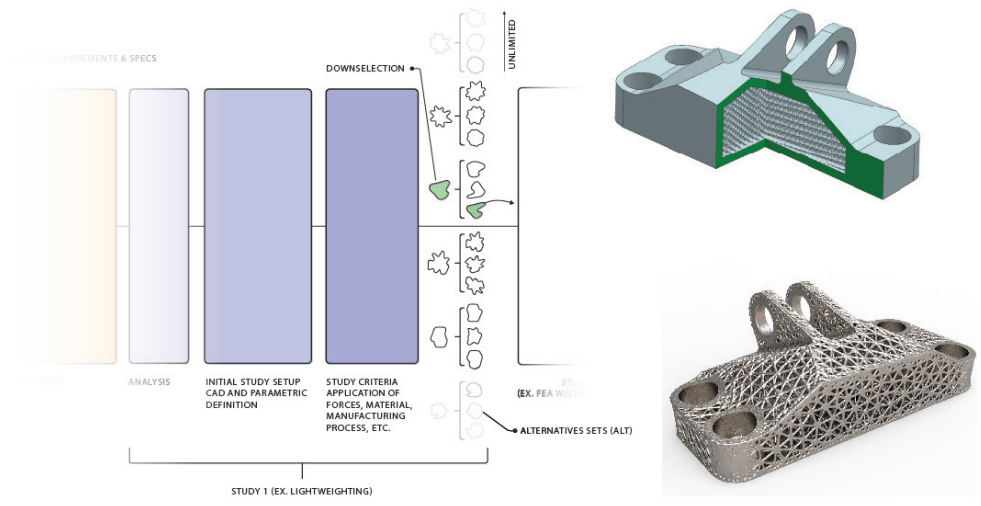
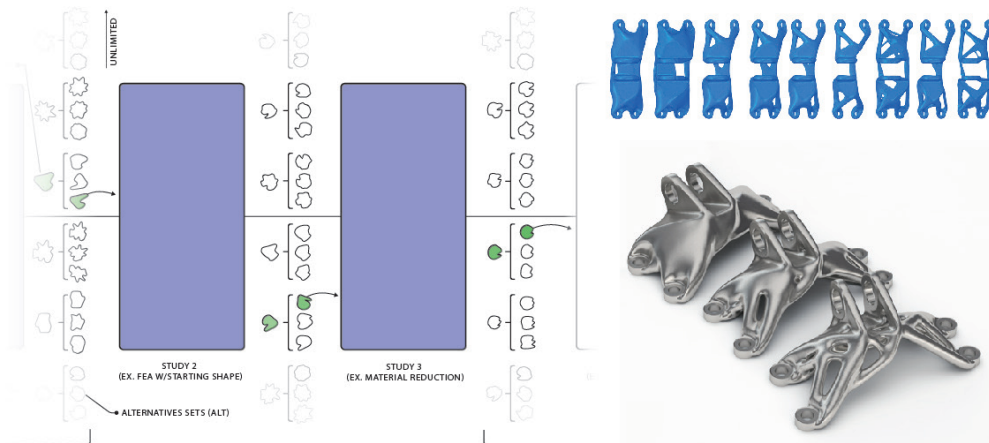


Image 4.2.1.3
Internal lightweighting (above) [80] and a completely lightweighted part (below) [81]

After defining all these criteria in Study 1, the generative software will generate many different variations (alternates) of the bracket form, each with its own series of iterations [image 4.2.1.4]. Here is where a human driven curatorial process must take place. One of the outcomes is chosen to either become the final product, or, as is often the case, the outcome can be used as a basis, or “starting shape” to run further studies.

Image 4.2.1.4
Bracket iterations in
plan view (above) [82]
and perspective view
(below) [80]



A hypothetical scenario illustrated by the diagram might be that Study 1 looked at various lightweighting options which revealed an acceptable form. Next, this form was used as a starting shape to reduce material further using FEA in Study 2. Next, after choosing a new starting shape for Study 3, a similar test to Study 1 was run to further reduce material within the constraints of the new shape.

This process of curating alternates (or selecting one of the many iterative steps that led to the alternate) and running sequential studies is represented in the diagram as a Study Loop.

These Study Loops can be repeated as many times as the need arises, or to use the Latin phrase favored by the medical community, *pro re nata* (P.R.N.).

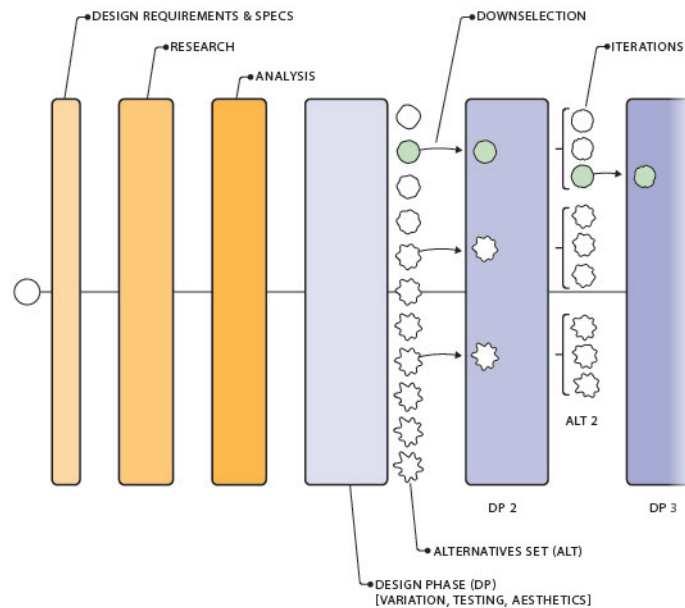
Finally, outcome of the GMD process can be sent directly to a 3D printer for fabrication. It is important to note that, while machines are doing a lot of work traditionally done by humans, a human is still setting up the studies and curating the outcome. It is also important to consider that most brackets, and much of what can be found as examples of generative design online, are design processes driven mostly by the guiding principle of performance.

Performance speaks not only to the engineering requirements, but also the design for manufacturing considerations. Because many of these existing examples are intended to be made by flexible manufacturing processes, geometry that has previously been impossible is made accessible. As this technology becomes more accessible and easier to use, we will begin to see many products designed in this way. While objects such as brackets and gears may not be highly visible, human-facing products will benefit from a human designer's eye for human factors and aesthetics.

4.2.2. Traditional Industrial Design (TID) Process

It would help us now to investigate a similar diagram for an industrially designed product. Again, we have an initial design requirements and specs phase of similar duration. This is followed by a research phase that, in the case of industrial design, is not as long as the GMD research. Much of the research done by an industrial designer is integrated throughout the design process. Often, this initial research (as well as requirement & specification preparation) has already been done by the client and is presented to the designer.

Image 4.2.2.1
TID Process
diagram detail



During the design phase, the designer is responsible for generating many different ideas, selecting promising design direction and initial concepts, and then iterating as much as possible upon these concepts to fully explore the design.

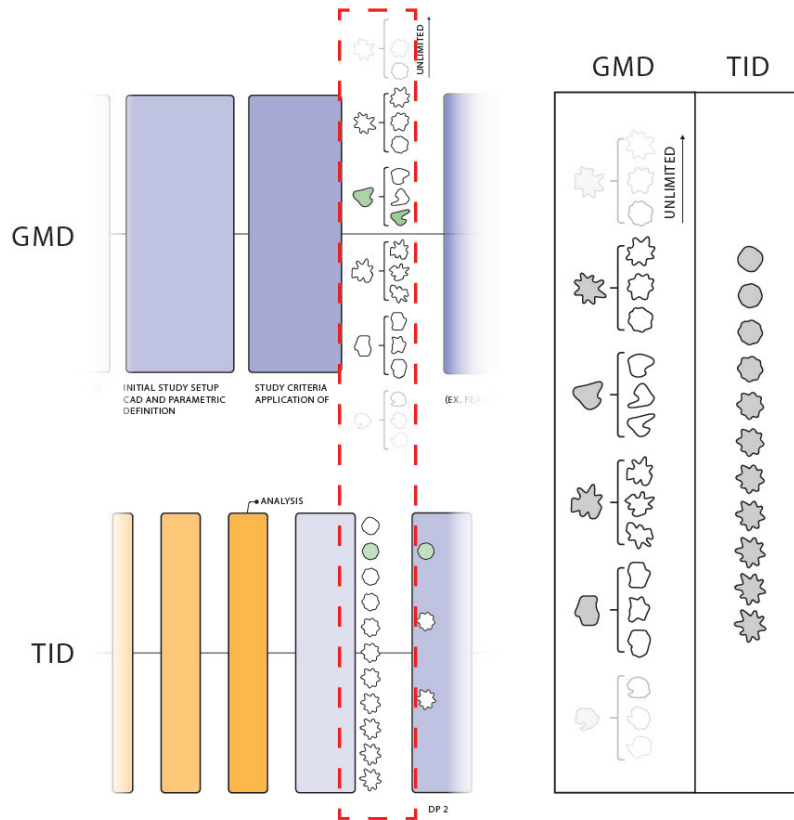
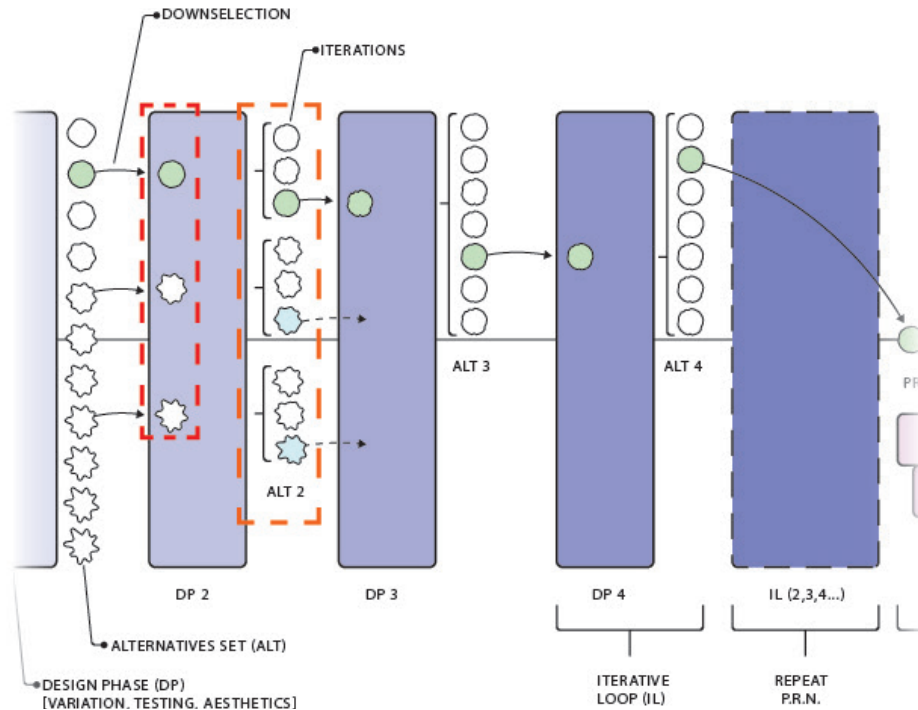


Image 4.2.2.2
 Comparing design
 concept variations
 between the GMD
 and TID processes

Looking at the Alternates Set (ALT 1) in image 4.2.2.1, we can see that there is not as much deviation between concepts as with a generative process [image 4.2.2.2]. Industrial designers analyze their process as they work and produce appropriate designs that fit the criteria outlined in the requirements and specifications. While AI will generate numerous strange and inconsistent forms, a trained human designer will avoid these. However, by doing this, many new and novel form directions are certainly missed. Additionally, the ability to quickly ascertain the most efficient pathway for forces to move through an object would be an asset to most industrial designers.

Image 4.2.2.3
TID Process
diagram detail



Rather than homing in on one single direction, as with the GMD process, several promising design directions often move through initial Design Phases (DPs). This is represented in image 4.2.2.3 by the concepts in the red and orange dashed rectangles.

This process of considering multiple shapes is an ability that generative programs do not do easily, if at all. While each generative study can be set up to handle a great amount of complexity at once, and there are many concepts generated, it feels rather linear. Currently, a human designer can select a form to become a starting shape, but it is very challenging to set up a study where multiple forms are guiding the outcome of a generative process.

For human designers it is common to hold multiple points of inspiration in mind while working. During an industrial design downselection process, colleagues, clients, or a design director often help to select the best candidate to move forward through

additional design processes. This helps the designer to remove themselves from any attachment they might have to certain designs, as well as provides refreshing perspectives and multiple points of view.

In the red rectangle [Image 4.2.2.3], we see a situation where three possible directions are chosen, and design iterations are upon each distinct form. Next, in the orange rectangle, we see a situation where a singular direction has been chosen with the green iteration. However, some qualities from the two light blue forms are found to be desirable. The designer then works with the inputs to find balance and harmony through additional DPs.

This process of iterating on previous designs throughout a DP and then moving through a downselection process is referred to on the TID diagram as an Iterative Loop (IL). ILs are repeated P.R.N. as time, budget, and scheduling constraints may allow.

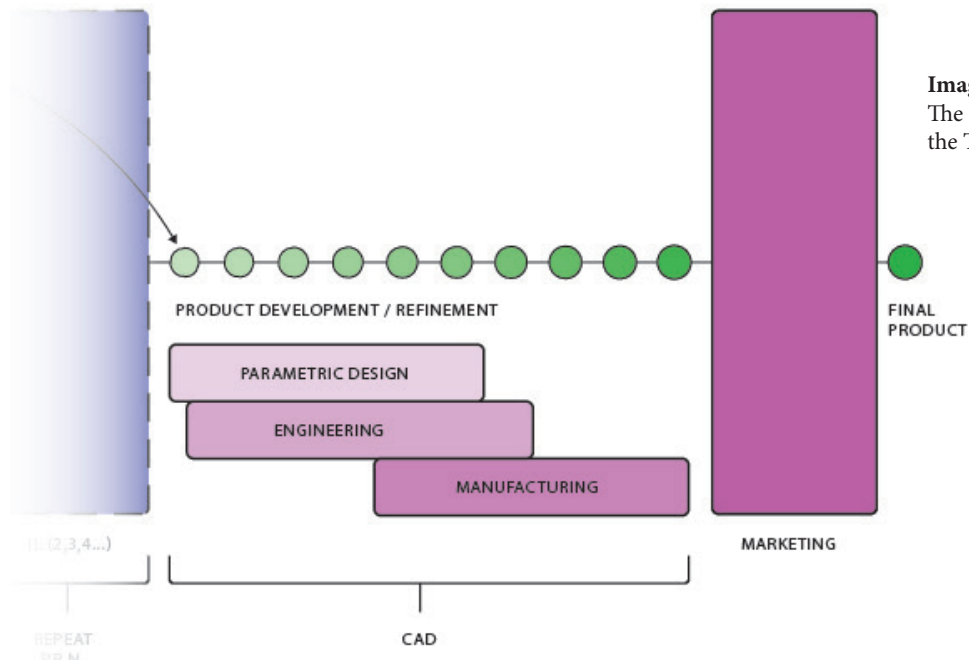


Image 4.2.2.4
The final stage of the TID process

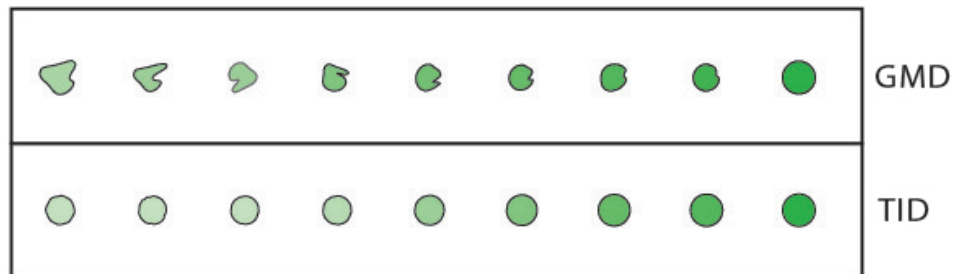
In Image 4.2.2.4, we see the final stage of the TID process. Ideally, the form will not change considerably throughout the CAD process as the industrial designer will have considered much of the manufacturing processes, CAD modeling, and basic engineering functions while working through the design phases.

Here, we see the parametric design, engineering and manufacturing phases overlapping and running parallel to the product development and refinement phase. This represents the non-linear quality of this phase as the designer collaborates with (or performs) these different disciplines. This is also indicative of the way these processes inform and influence each other.

In the TID process, the manufacturing related areas (in purple) are much longer than the GMD or BCD processes as the product is being prepared to be produced for mass consumption. The traditional ID process and its subsequent product development cycle can be a very expensive investment for a company to make.

Hence, at the end of the TID process we see a marketing effort to raise awareness for the new product in an effort to increase profits. Another interesting comparison between the TID and GMD diagrams is the variation in form development throughout the process [image 4.2.2.5].

Image 4.2.2.5
A comparison of
GMD and TID
design variations



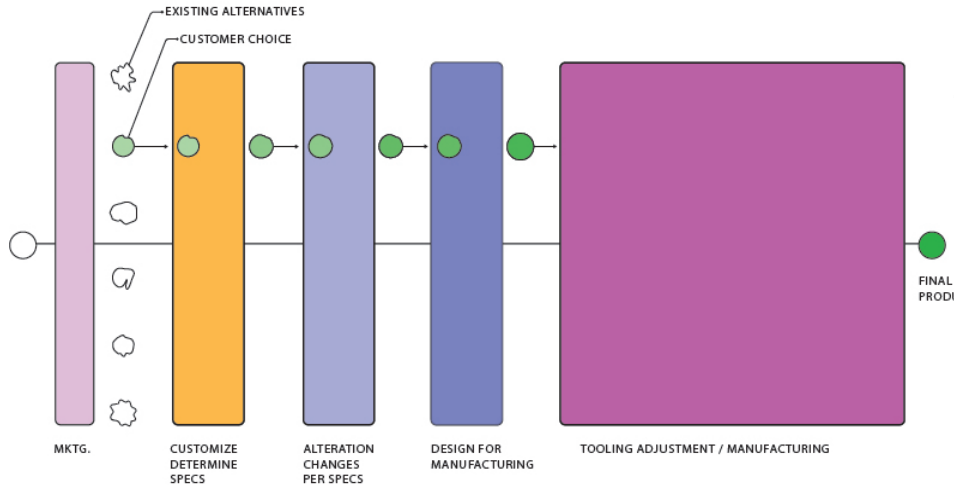


Image 4.2.3.1
The Traditional
Bespoke Craft Design
(BCD) process

4.2.3. Traditional Bespoke Craft Design (BCD) Process

Currently, a traditional Bespoke Craft Design Process (BCD) would perhaps serve our individual user best. In Image 4.2.3.1 we see that marketing is done at the beginning of the process to advertise a variety of previously designed models. In this diagram we can see that the set of alternates appears first, as these are furniture pieces that have been designed, and the BCD craft person has tooling set up to quickly fabricate these objects. We can also see that, once an initial model is selected, there is not much variation, iteration, and refinement throughout the process. The customer has already selected the desired outcome and after a brief customization and alteration period, the designer can move quickly through the design for manufacturing phase.

In a sense, the BCD designer is also the engineer and fabricator, and is very familiar with the critical information needed to move forwards with fabrication. The fabrication phase is much longer than other methods in this example as this is a one-of-a-kind object being fabricated by one person. There is also a deal of tooling adjustment that needs to happen due to the custom measurements and requirements of the customer.

Generative Industrial Design (GID)

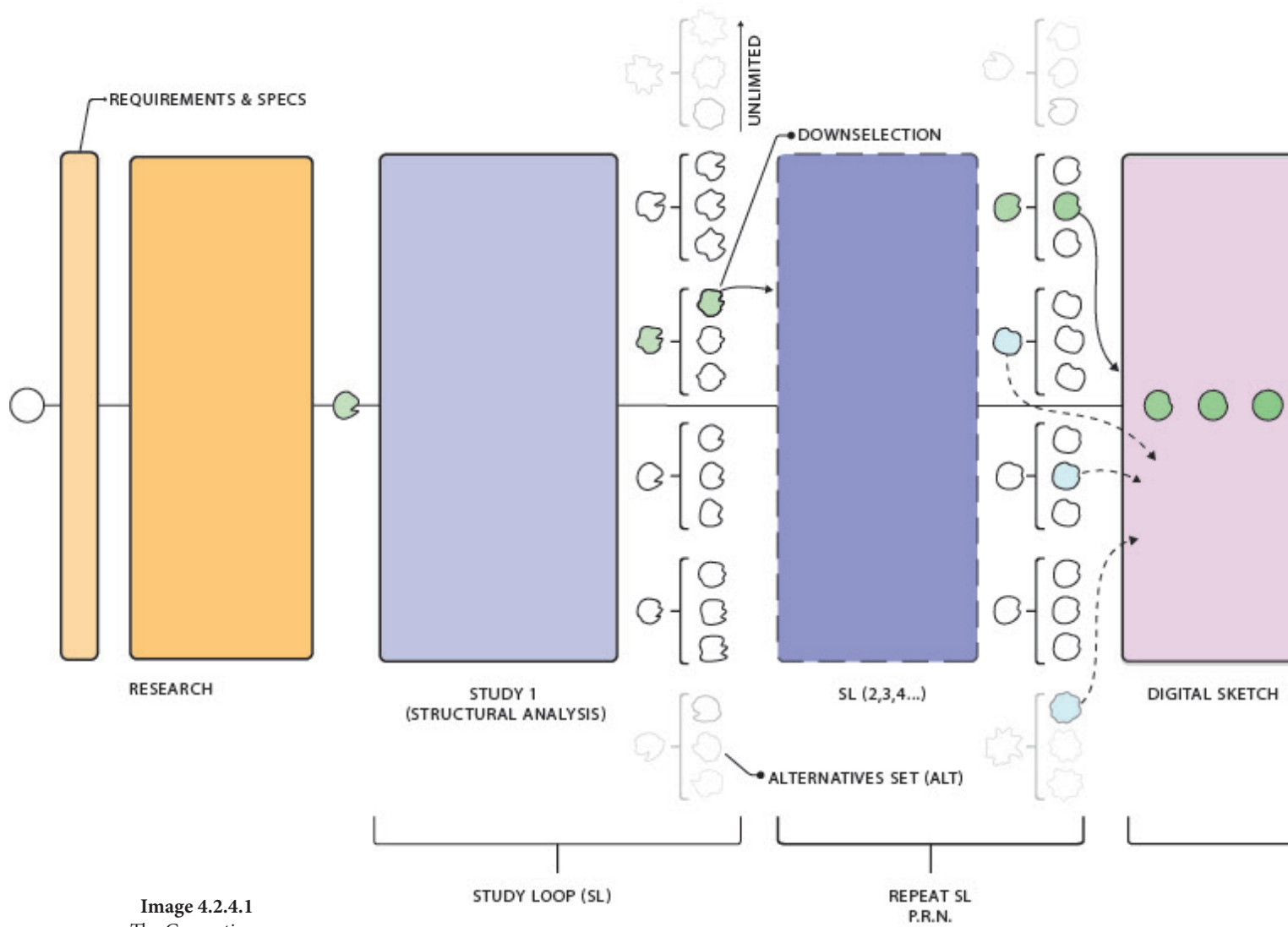
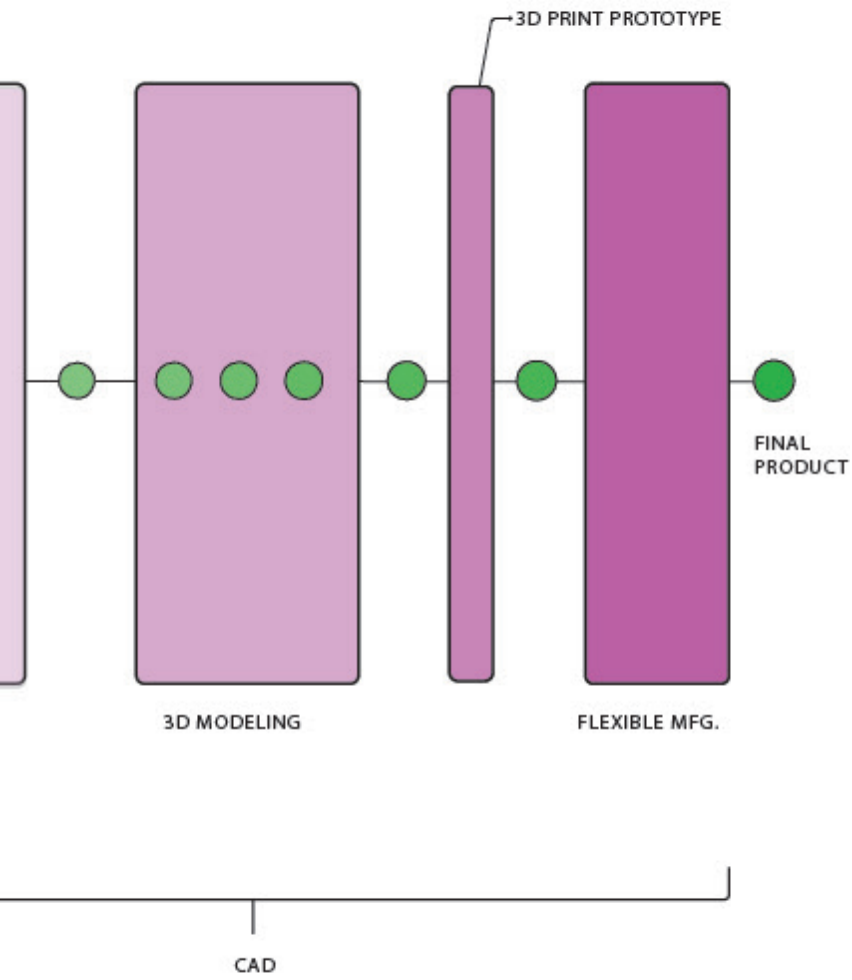


Image 4.2.4.1
The Generative Industrial Design (GID) process



4.2.4. Generative Industrial Design (GID) Process

Now that we have seen three analogues, we can use these to compare to the generative design process that I used throughout the design phase of this thesis. Below [image 4.2.4.2] is a brief look at the “DNA” that makes up the GID process. Next, I will go through the GID process more in depth while relating stages of the process diagram with actual examples from the thesis project.

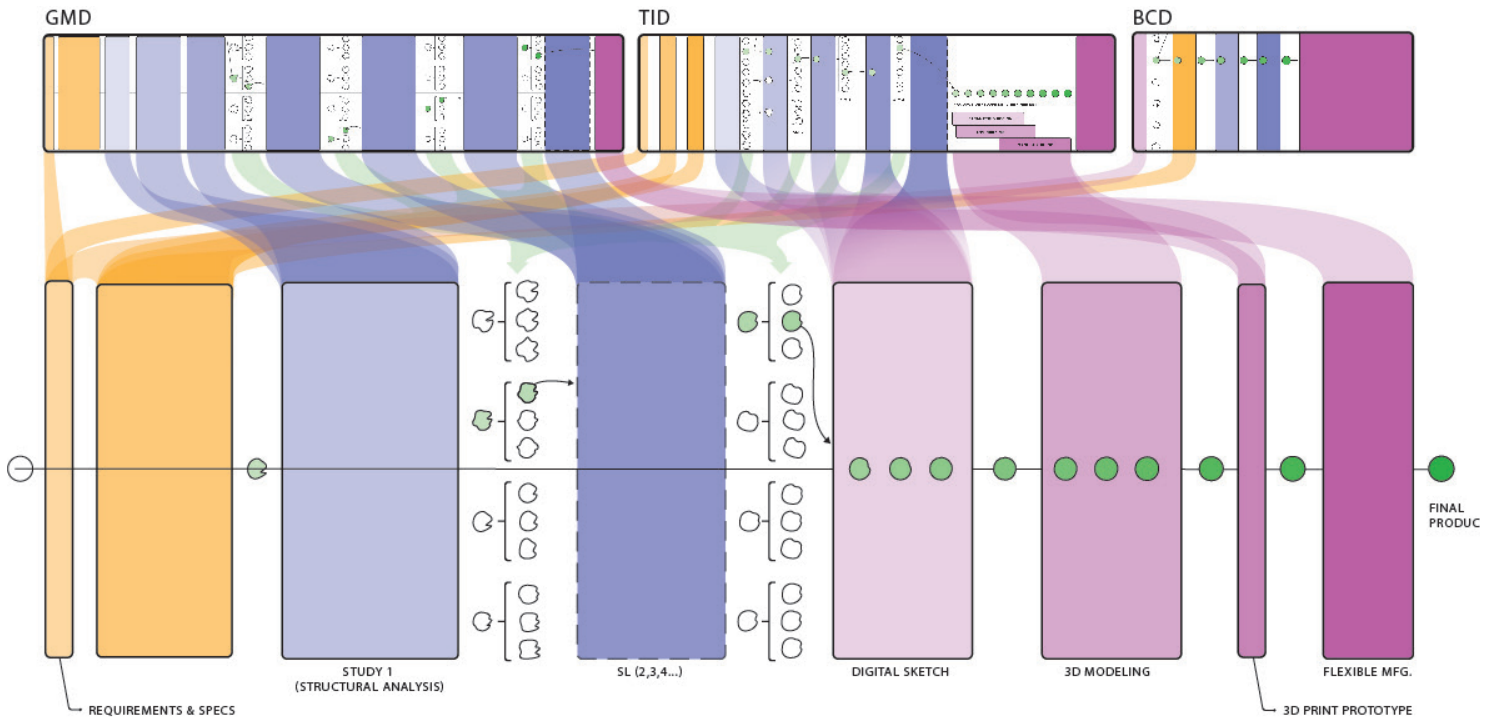


Image 4.2.4.2

How existing frameworks informed the GID process

4.3. Collaborating with Other Entities

My research and design explorations had pointed me in the direction of a bespoke product for a single user. I wanted to speculate on a future where a designer could meet a client with specific individual requirements, efficiently determine their exact specifications, and work with them to quickly produce an object to meet these needs.

What would it look like for an industrial designer, working with software-enabled tools, to rapidly ideate, refine, prototype, and produce a three-dimensional product? Could it be affordable for an average person to obtain a bespoke product in this way?

About this time in my process, the world was just beginning to react to a growing development that would disrupt many schools and design projects...

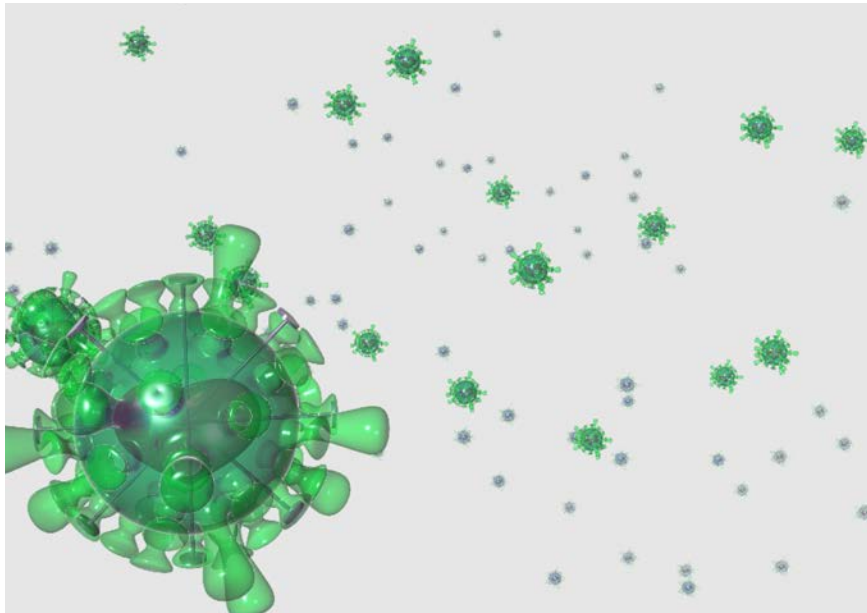


Image 4.3.1
COVID-19, a
novel disruption

4.3.1. Close Quarters

I do not mean to downplay any of the unfortunate effects that have befallen people due to COVID-19. Aside from illness and death, COVID spread massive amounts of anxiety and uncertainty throughout the planet. Personally, my world was rocked. Dealing with grad school, a family, a high school-aged daughter, and a rising fear of my future job prospects crashing to a halt along with our economy was a challenge.

However, relating to my thesis specifically, I was lucky. I had to change gears a bit, but I was fortunate that the “client” in my research project was my wife, Nico, who was in lock down with me throughout the process [image 4.3.1.2].

Nico very often has a hard time finding a chair that is the appropriate size for her. Her geometry does not match that of the 90th percentile human form that most furniture is made for [image 4.3.1.1]. Even adjustable furniture that is made to supposedly meet her size range is often ill-fitting and unsuited for her particular geometry [detail, image 4.3.1.2]

Image 4.3.1.1.
Josephine, modified from Dreyfuss (left) [83] and “Must-have measurements for comfortable seating”, from WOOD Magazine (right) [84]

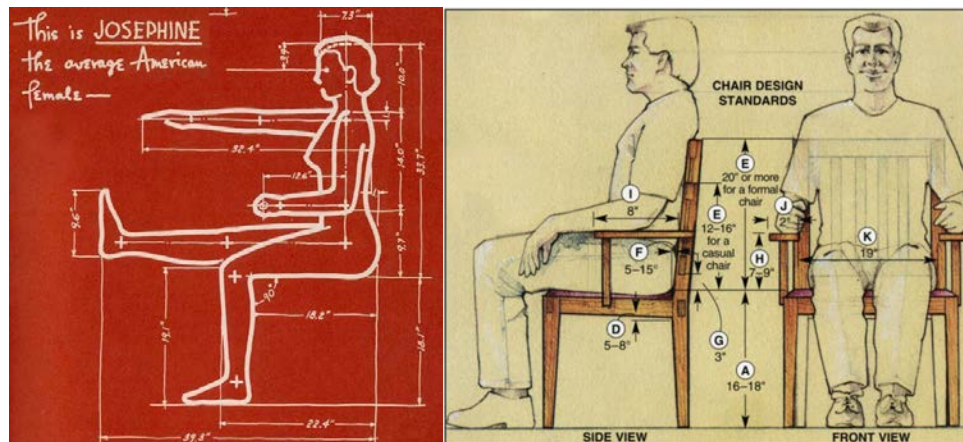
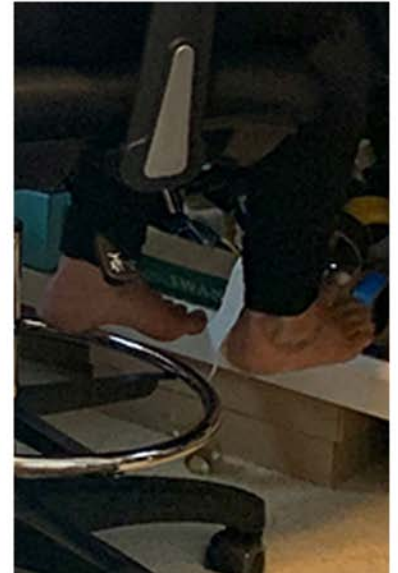




Image 4.3.1.2.
The author sitting
comfortably and
Nico with one toe
tentatively perched on
a temporary rest



Normally, a custom-made chair would be too expensive for Nico to purchase and this seemed like an ideal extension of how generative design might be utilized in the not-too-distant future. Granted, the hybrid design process that I used would not be an affordable approach. The intent was that by engaging with generative design in this way, I could more appropriately speculate about how it could be used in the future as technology improves and these different processes converge.

4.3.2. GID Research Phase

Working so closely with my client over a long period of time helped me to speculate about what a future manifestation of the industrial designer might be. I had the opportunity to observe many things that a BCD craft person might miss in their brief research phase. Additionally, knowing my client intimately brought to mind the role of an interior designer who works consistently with one client for many years. Perhaps a designer would work repeatedly with clients to get to know their tastes and create entire families of interrelated objects?

I was able to witness moments such as how far the back of chairs were from Nico's back most of the time [right, image 4.3.2.1] or the time when I found Nico in a very comfortable working position [left, image 4.3.2.1] It was not lost on me that she had employed multiple ad hoc approaches to finding a good position.

Image 4.3.2.1

Nico at work (left) and at play with Rasputin (right)





Image 4.3.2.2.
Nico Lund
Sitting with Uncomfort
Part of the The Uncomfort of
Sitting series
Oil on Canvas
30"x40" [85]

These included propping up a work surface with makeshift rests, stacking thin books on top of each other until a desired height was achieved, and using a puffy jacket to add just the right amount of lumbar support.

In fact, this has been such persistent annoyance for Nico, for so long, that she has dedicated a series of paintings to this phenomenon entitled, *The Uncomfort of Sitting* [image 4.3.2.2].

Many measurements were made [image 4.3.2.3] and a thorough interview was conducted [image 4.3.2.4] to determine the ideal shapes of contact surfaces and seat, back, and resting foot positions.

Image 4.3.2.3
Finding the measurements
of the most comfortable
chair



Image 4.3.2.4
Interviewing Nico about
working habits



4.3.3. GID Design Phase

Generative Studies

A stool without arms was selected as the best candidate for this experiment as Nico would be using this chair to work at a variety of locations that had similar working heights (easel, worktable, counters) and would most often be leaning forward working on artwork or an electronic device. Not having arm rests simplified the process slightly and using a higher seat with a footrest simplified the intricacies of the floor-to-seat-to-table height ratios.

These surfaces were modeled in Rhino, brought into Fusion 360, and then forces were applied based on Nico's measurements and behavior while working. A quick preview is generated if the model has been set up correctly [image 4.3.3.1].

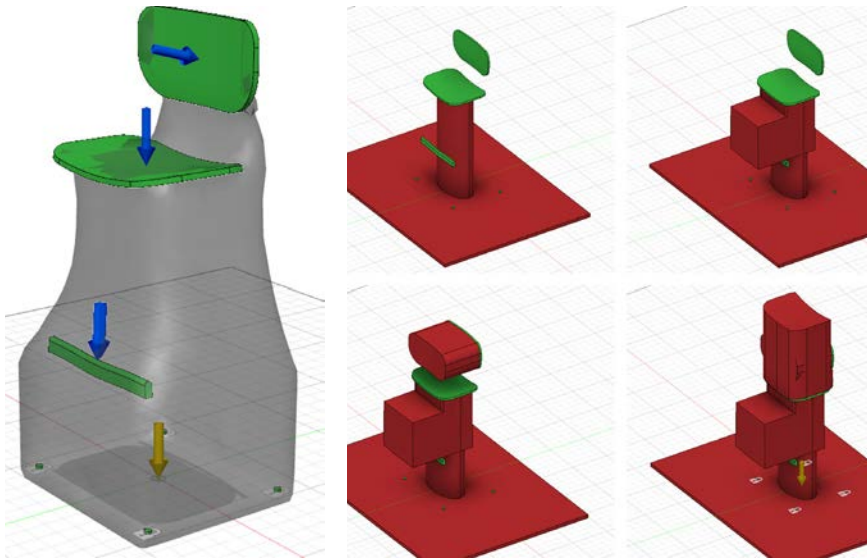


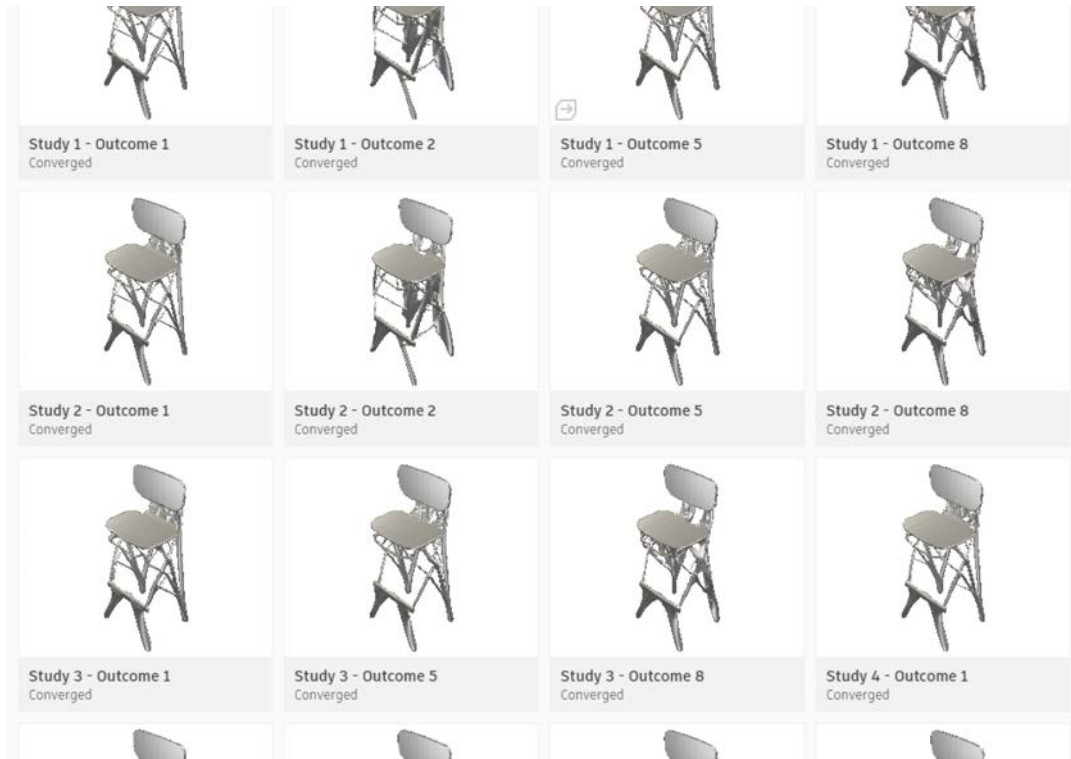
Image 4.3.3.1
Forces and constraints applied to a generative study with a preview (left)

Image 4.3.3.2
Multiplying Stay Out Zones (SOZs) (right)

New model geometry, called Stay Out Zones (SOZs), needed to be created and many quick studies ran to verify that model material was being created in a way that seemed appropriate [image 4.3.3.2].

Appropriateness in this case was determined predominately by human factors and aesthetics, although, as the process continued it became apparent that the program often created models that would simply fail under human use.

Image 4.3.3.3
Many iterations were produced in a relatively short period of time



The computer-assisted generative process can produce multitudes of design variations. However, from my experiments during this thesis project, there were almost none that were immediately functional [image 4.3.3.4]. Even when experimenting with using the most appropriate alternate as starting shape, for modeling material to coalesce around, the results were still too complex, irregular, and unpleasant to human sensibilities.

It was apparent that a balance needed to be struck between spending a laborious amount of time setting every possible force vector, and the serendipitous outcomes of just letting the program run. Another challenge with SOZs, was that if too many were created, they essentially became a “mold” that the model material would be confined in. This defeated the purpose of letting the software “grow” the chair on its own, so a balance needed to be struck there as well.

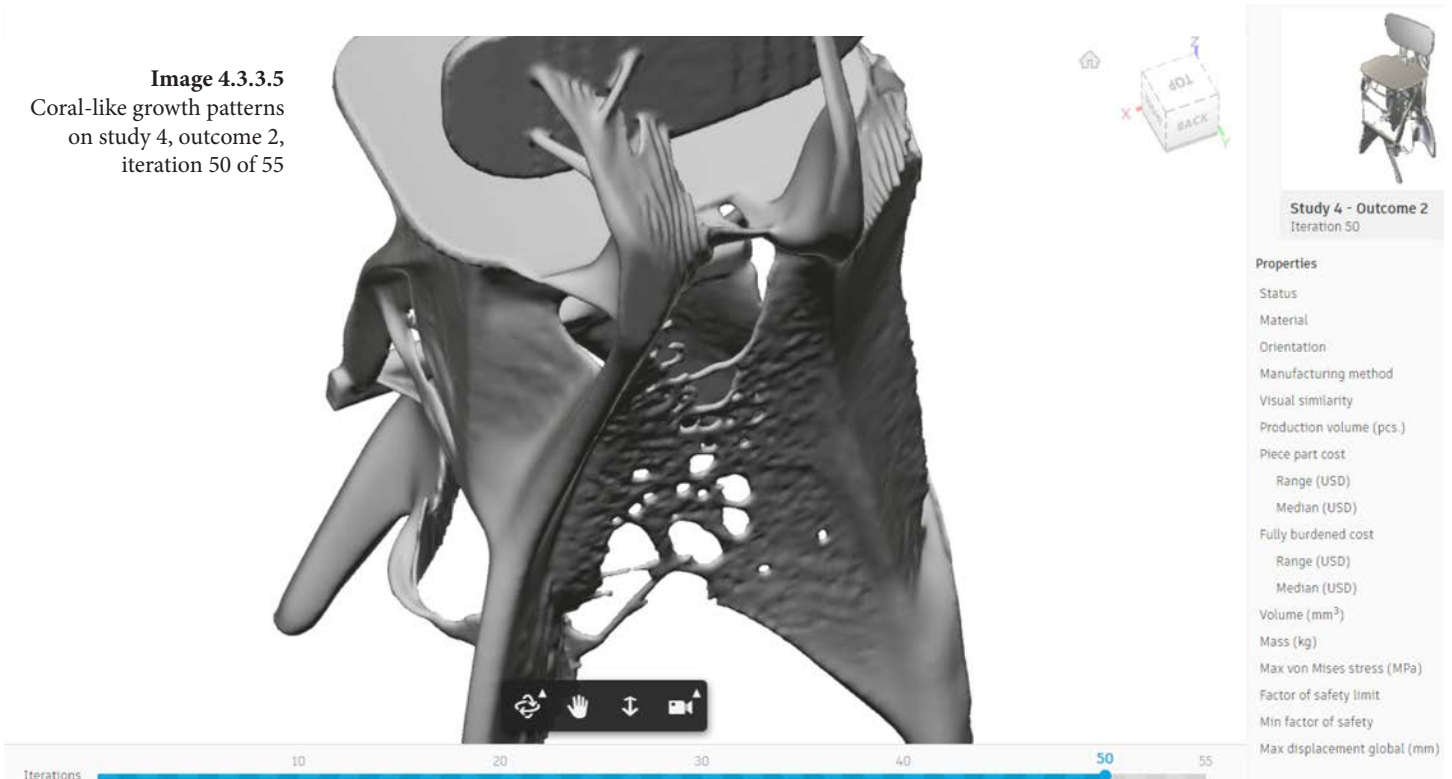


Image 4.3.3.4
Strange iterations (above)
and a detail of interesting
features (below)

Another area of interest was that each of the many design alternates contain a history of every design iteration that the software produced while it determined what was a final variant [image 4.3.3.5]. Often, models contained iterations numbering in the twenties and thirties, but it was not uncommon for another version to have over sixty iterations.

Many times, from a cursory view of the final versions, it seemed that they were quite similar, however, searching back through the iteration history would reveal interesting pathways that were taken by the software to attain similar final results. In a few instances, these earlier iterations contained design elements that were desired in the final stool.

Image 4.3.3.5
Coral-like growth patterns
on study 4, outcome 2,
iteration 50 of 55



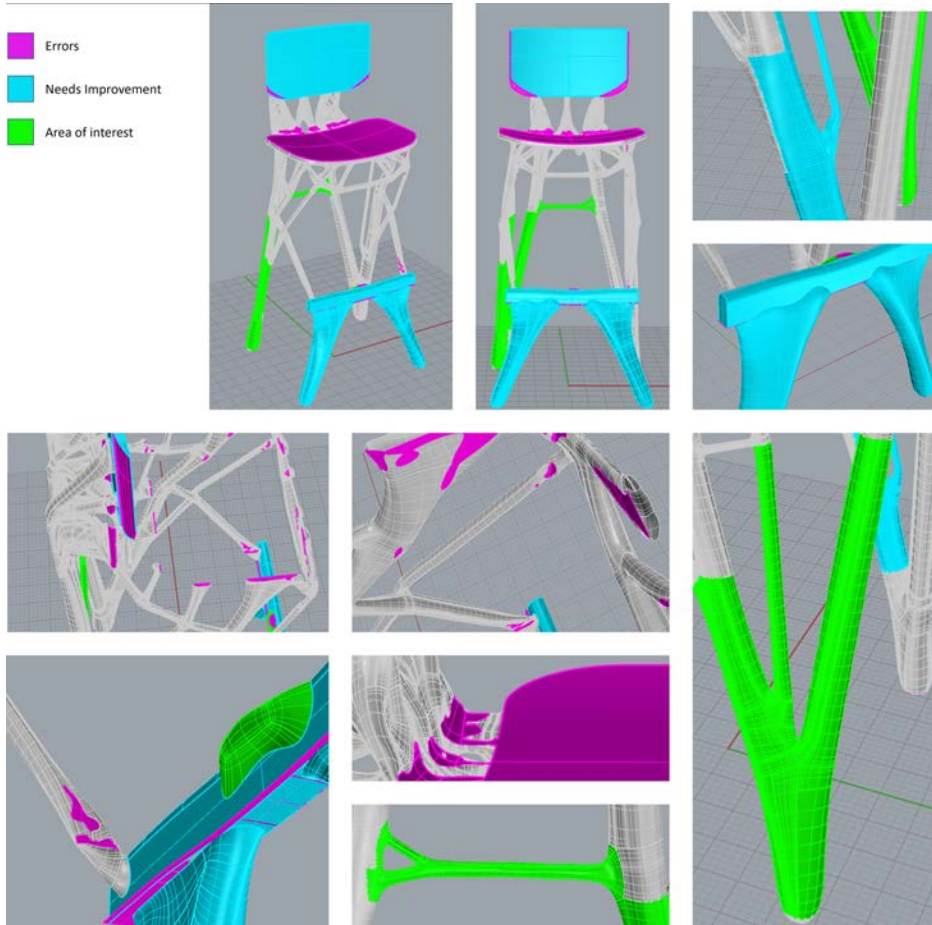


Image 4.3.3.6
Documenting the
many outcomes

In another sense, relating to novel design directions, the strange results were stellar. While one complete generative outcome may not have provided enough cohesive human factors and aesthetics principles to move directly to manufacturing, there were areas of certain models that unveiled promising structural approaches and generative outcomes. I created design documents for generative outcomes to track inspirations as well as areas that needed further design considerations [image 4.3.3.6].

Occasionally, geometry was cut into by touching areas occupied by a SOZ. Many of these areas of space reservation were merely general guides for the generative process. However, rather than moving back into the initial setup phase and re-modeling SOZs, I labeled these areas as “errors’ for later repair [image 4.3.3.6].

Curating Generative Designs

For the purposes of this paper, I am referring to the process of looking through the many variations that the generative program created as, “curation”. Being that the computer did so much of the work after initial setups, it is more akin to the work a design director might do with a team of designers. However, since there is no immediate “direction” that can be given to the machine assistant, it is more like a curation process.

Image 4.3.3.7
The composite model



Although the forms were significantly shaped by myself throughout the design process, I wanted the final design of the stool to relate to the process by which it was created. Since the software could not produce a single unified design for me to work from in the refinement stage, I moved back into Rhino and created a composite of several models [image 4.3.3.7].

Generative Inspiration

Reference renderings were exported to use as underlays in a digital sketching process [image 4.3.3.8]. A few main themes carried most of the design direction. These were symmetry, variety between separate elements, variety within continuous elements (for example thick to thin transitions), repetition, and elements (such as bone-like or tree-like elements) that related to algorithmic design.

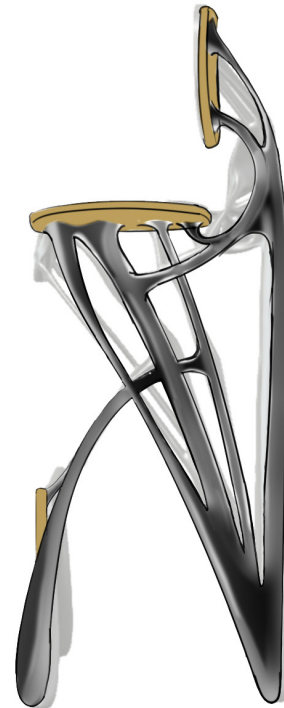
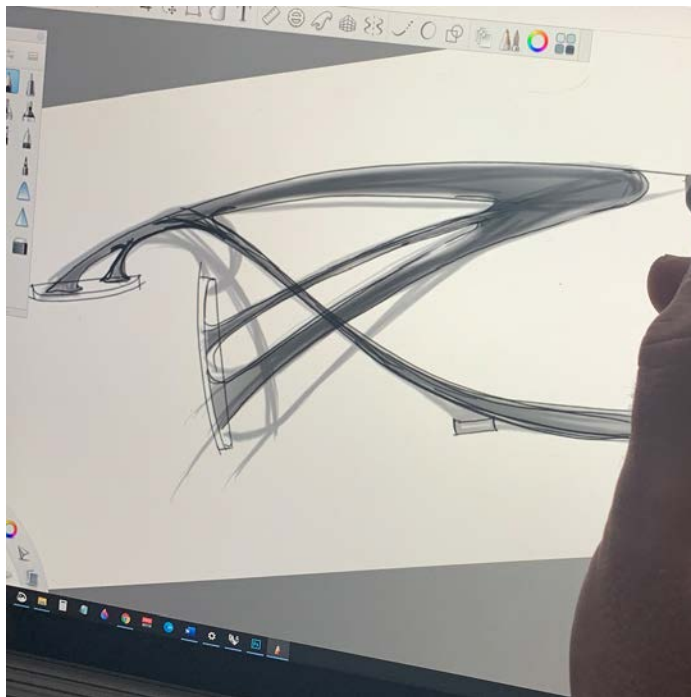
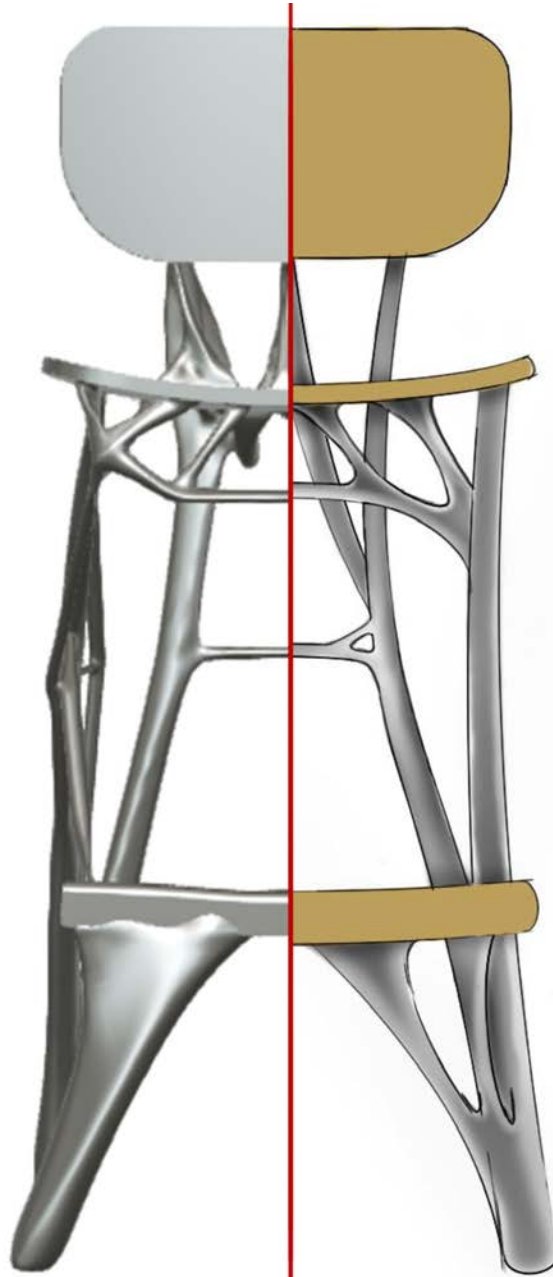


Image 4.3.3.8
Digital sketching over
composite model
underlays

Image 4.3.3.9

A comparison of an original
generative outcome next a
generatively inspired sketch



There was also a set of aesthetic choices that were made based on a designer's acquired knowledge of pleasing, and structurally appropriate forms. It would be hard to categorize every one of these decisions as many are happening simultaneously and contained as tacit knowing-in-action [86]. This is one component of the design process that makes it hard to imagine how we might someday teach AI to create locally appropriate aesthetic choices.

Another process that greatly affected the final design was simplification. Some of the main approaches to simplification: the reduction of redundant parts, simplification and generalization of visual motion, reduction of surface complexity and unification of form language. One aspect of this process that was nuanced was dealing with random and angular "branch" design elements.

Some examples: The rear legs often fanned out and upward in a form reminiscent of plants and trees. This feature, arising from random computational design guided by algorithmic constraints, was chosen to stay in the final design. This feature was unified according to the aforementioned design constraints and mirrored to the other side of the chair [image 4.3.3.7].

The front legs consistently were formed as lumpy globular forms that did not relate well to the rest of the form. For this part of the chair, the front legs, inspired by the rear legs, were designed completely by me to reflect and communicate visually with the rear legs [image 4.3.3.7].

The software consistently handled the forces beneath the front of the seat by forming a bridge-like "truss" feature. This feature was integrated into the final form with some structural and aesthetic changes [image 4.3.3.9].

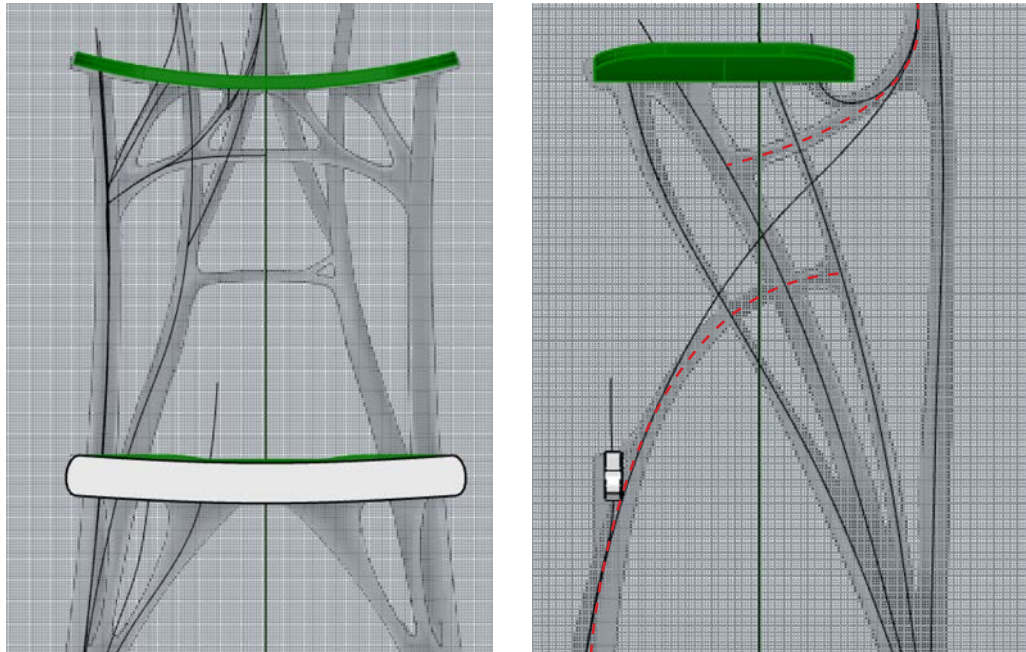
All features were made symmetrical across the left/right axis except for one feature. On the back of the chair, about halfway down the form, was a cross support that would often form for structural reasons. Like most generatively produced elements, this was asymmetrical, and this quality was kept as a strong link to the generative process.

Taking Shape

Next the sketches were imported into Rhino and used as background references for 3D modeling. Here, the form was further refined. For example, on the right side of image 4.3.3.10 there are two disconnected curves (dashed red lines) that were unified into one continuous flowing curve.

Initially, these curves were created in planar orthographic views.

Image 4.3.3.10
Making design decisions while modeling curves over sketch underlays



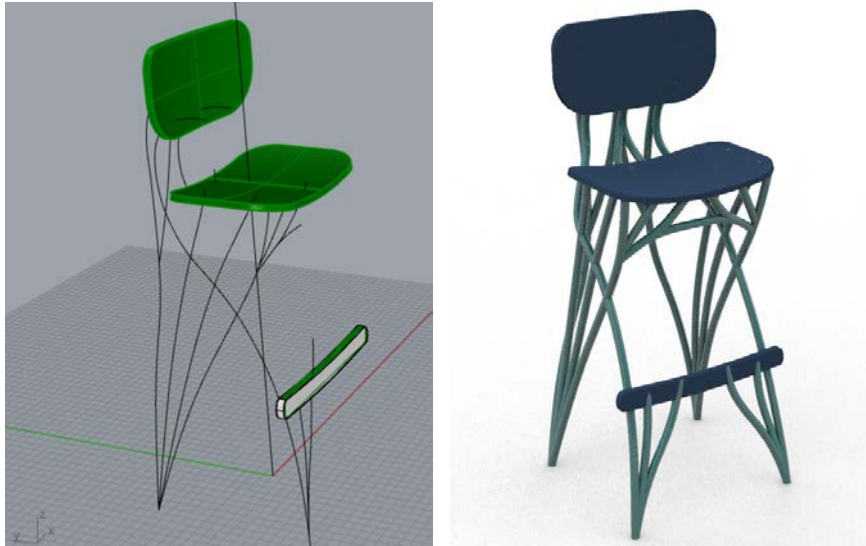


Image 4.3.3.11
Sweeping curves with uniform diameters to validate visual lines and communication between elements

Next, I worked with the curves in three dimensions. Using a technique of quickly sweeping all curves with a uniform diameter [image 4.3.3.11], I was able to regularly validate the basic form before moving into more complex surfacing.

Care was taken to produce smooth simplified curves and very clean surfaces. Every part was inspected for continuity, faired using control curves, and evaluated with stripe maps [image 4.3.3.13].

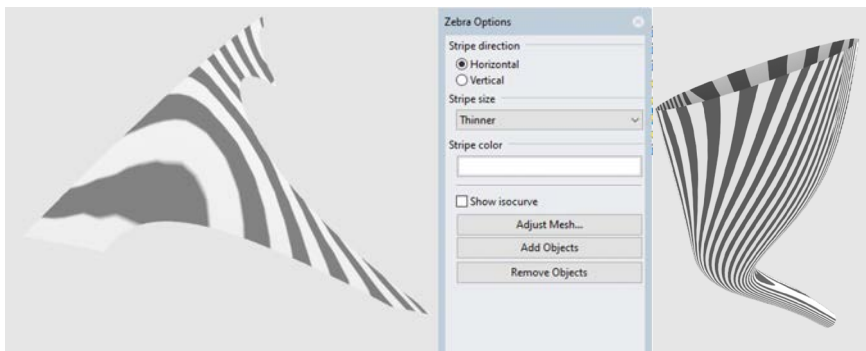
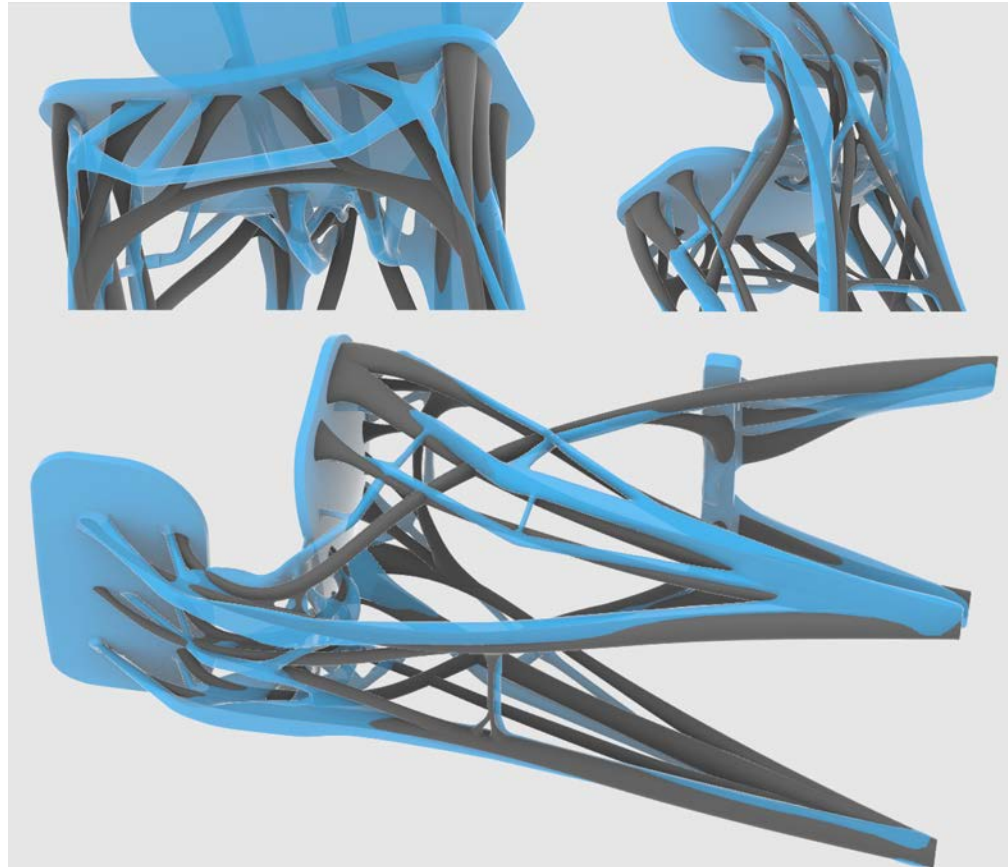


Image 4.3.3.13
Checking surfaces with “zebra” stripe maps

It occurred to me that the model I was creating was now three steps removed from the generative originals. The process of originals > composite > sketch > 3D modeling could very well alter the form considerably and I wanted to make sure that it stayed closely related to the generative outcome. To accomplish this, an original outcome from the generative software was used as a scaffold throughout the modeling process. This model was turned off and on regularly to check against the newer version and an attempt was made to find harmony between the two. [image 4.3.3.14].

Image 4.3.3.14
Original 3D
geometry used as a
scaffold for new 3D
geometry



Prototyping

Normally, I utilize hand modeling techniques to quickly prototype tangible models to validate in 3D. Due to the restrictions of working from home during COVID, without access to studio and shop space, 3D prototyping was used exclusively to validate 3D form [image 4.3.3.15].

This process took many hours for a six-inch object. However, considering recent research at Northwestern University [80] that has produced a printer that can print a person-sized object in hours, it is easy to speculate upon the fast printers to come.

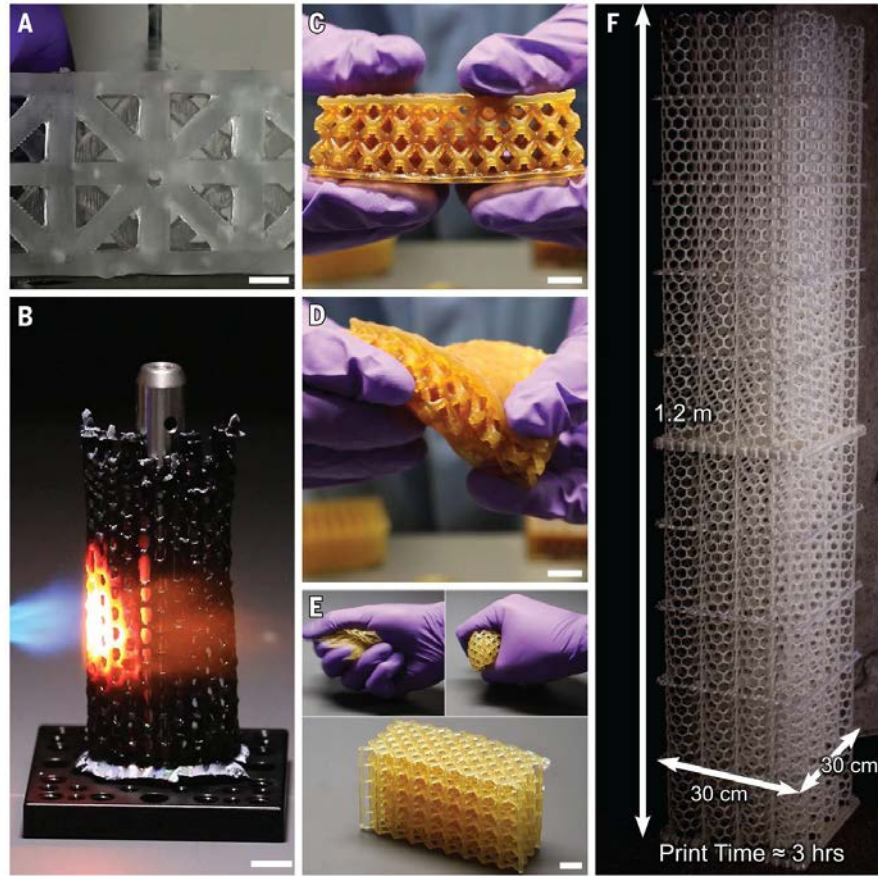
Feasibly, a generative industrial designer will be able to quickly scan a client, rapidly design an object and produce a full-scale prototype.



Image 4.3.3.15
From left to right: preparing a file for 3D SLA printing, a finished print with support structure, validating designs with a tangible prototype

Image 4.3.3.16

A variety of materials that can be printed by the HARP (high-area rapid printing) printer. At the right is an impressive structure given its short print time [87]



Additionally, current achievements in material ecology such as the work by Neri Oxman [88] are producing new 3D printed materials from natural sources that are able to be completely dissolved and feasibly reprinted [image 4.3.3.17]. Not only that, but like in nature, the material can take on different material properties. I imagine a future scenario where a generative designer, after testing with a client, dissolves the prototype. Then, after making some quick changes at their (possibly voice-assisted) mobile design center, quickly reprints another full-scale model for their client.



Image 4.3.3.17
Neri Oxman, Aguahoja I
[88]

Refinement

After evaluating the prototype, and reviewing it with Nico, some minor changes were made to the model. It was decided that we would validate the form once more in a half-scale version before moving to a full-scale version of the chair. I worked virtually with a CNC specialist to separate the final model into easily machinable parts and to reduce the amount of material that would be lost in the subtractive process.

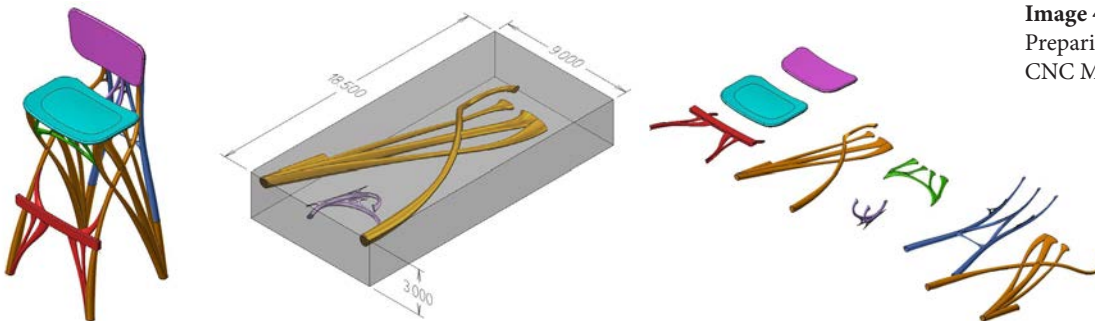
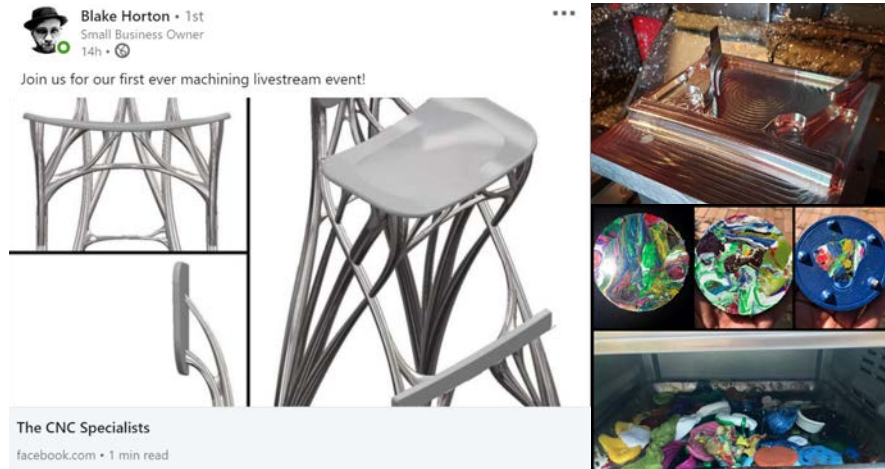


Image 4.3.3.18
Preparing parts for
CNC Machining [89]

Image 4.3.3.19
A livestreamed CNC machining invite (left) [90], an image from the event (upper right) and machined recycled consumer HDPE (below right) [89]



Another subtractive option from The CNC Specialists, the shop I worked with, is a recycled consumer waste HDPE material that is currently in R&D. Ideally, when the time, cost, and sustainability of 3D printers has improved, this project will be printed as an additive process out of an ecologically and structurally sound material.

This project pointed towards other possible futures when I received a Facebook invitation to The CNC Specialists first ever livestreamed manufacturing event [image 4.3.3.19]. Unfortunately, at the time of writing this thesis, a software problem with the CNC machines and a general delay of service due to COVID-related issues have put the stool's final realization hold.

Active Algorithms

Up until this point, I had not closely investigated the algorithms producing the generative designs. As briefly discussed in section 3.2, Autodesk 360 is a passive program. This to say, that the functions controlling the generative process are opaque. To experience more of the algorithmic nature of the design process, I turned back to Grasshopper to design a seat cushion.

Experimenting with the plugins Lunchbox [91], Kangaroo 2 [92], and Weaverbird [93], I created a preliminary cushion concept. I used different combinations of these tools to experiment with algorithmically driven patterns. Like my earlier experimentations with Grasshopper, I realized that I would need more time with these plugins to fully realize a design. Nonetheless, the ability to control the generative process was enlightening.

3D patterns such as this cushion, will soon be able to be printed seamlessly along with more structural elements. Changing material properties such as strength, flexibility, and even translucency will be utilized to allow a vast number of products to be rapidly produced.

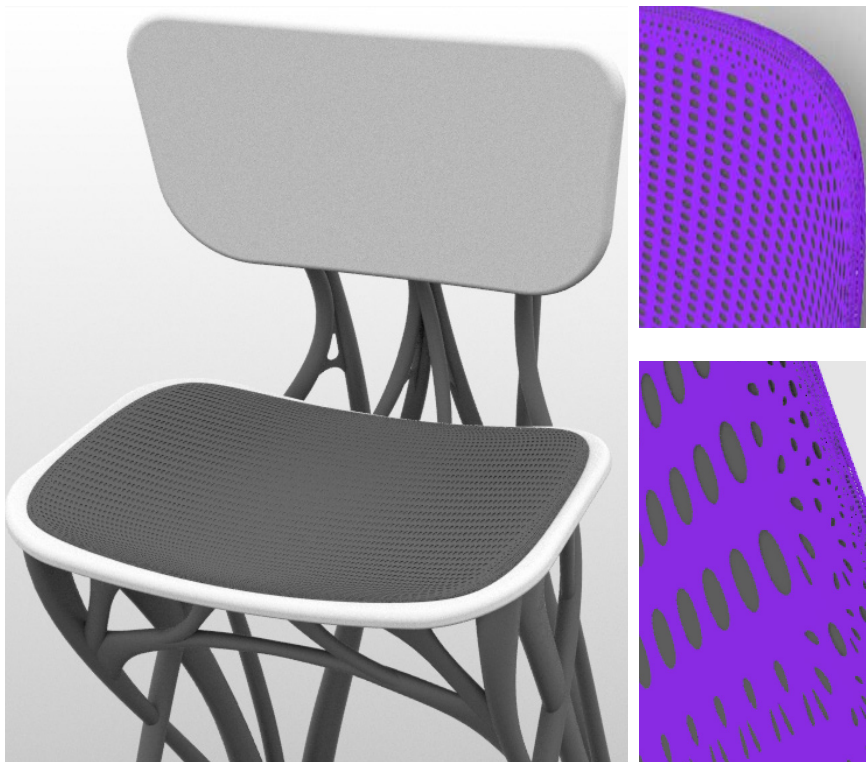


Image 4.3.3.19
A generative seat cushion (left) with details (right) of the algorithmic patterns

5. Finding Coherence

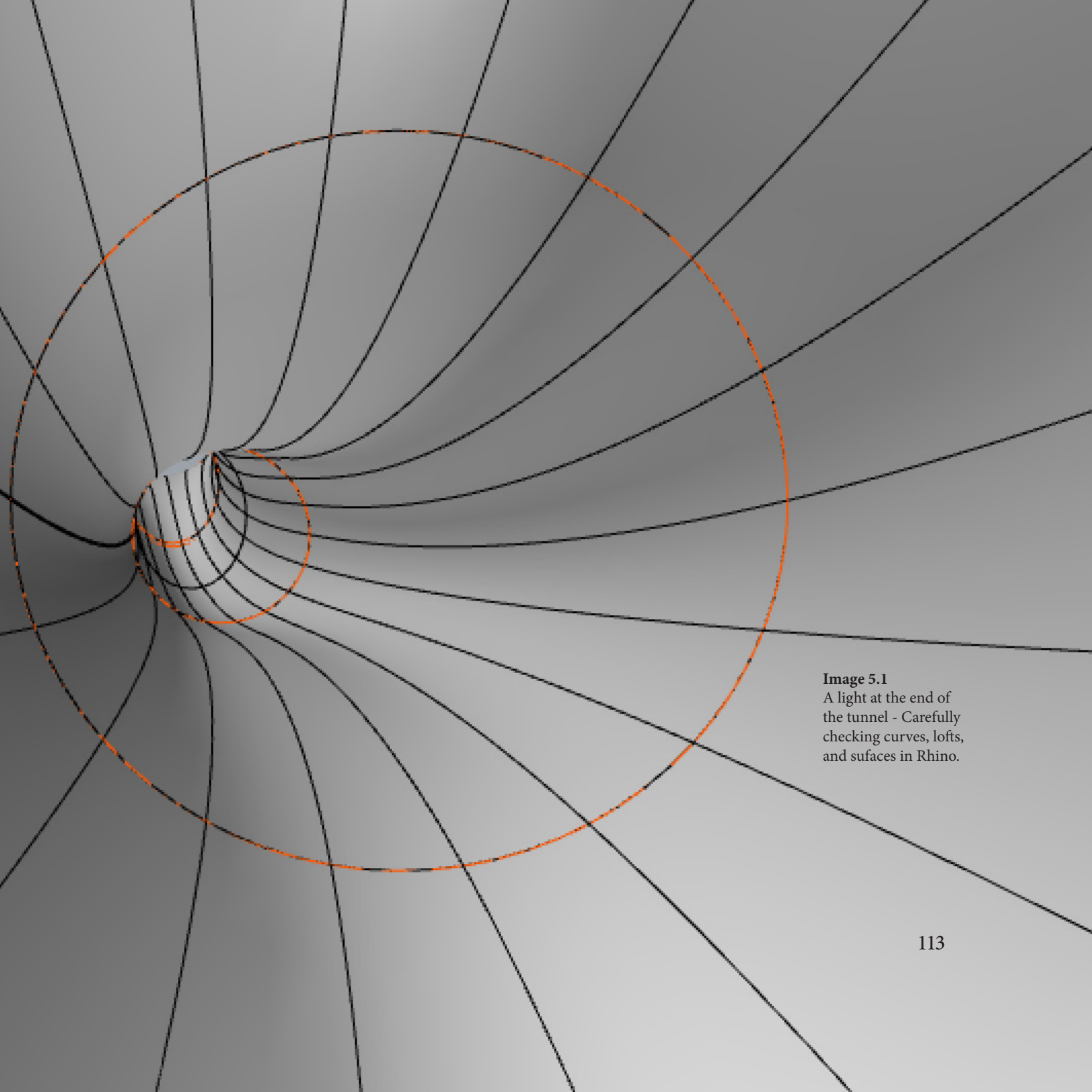


Image 5.1
A light at the end of
the tunnel - Carefully
checking curves, lofts,
and surfaces in Rhino.

Generative Blended Design (GBD)

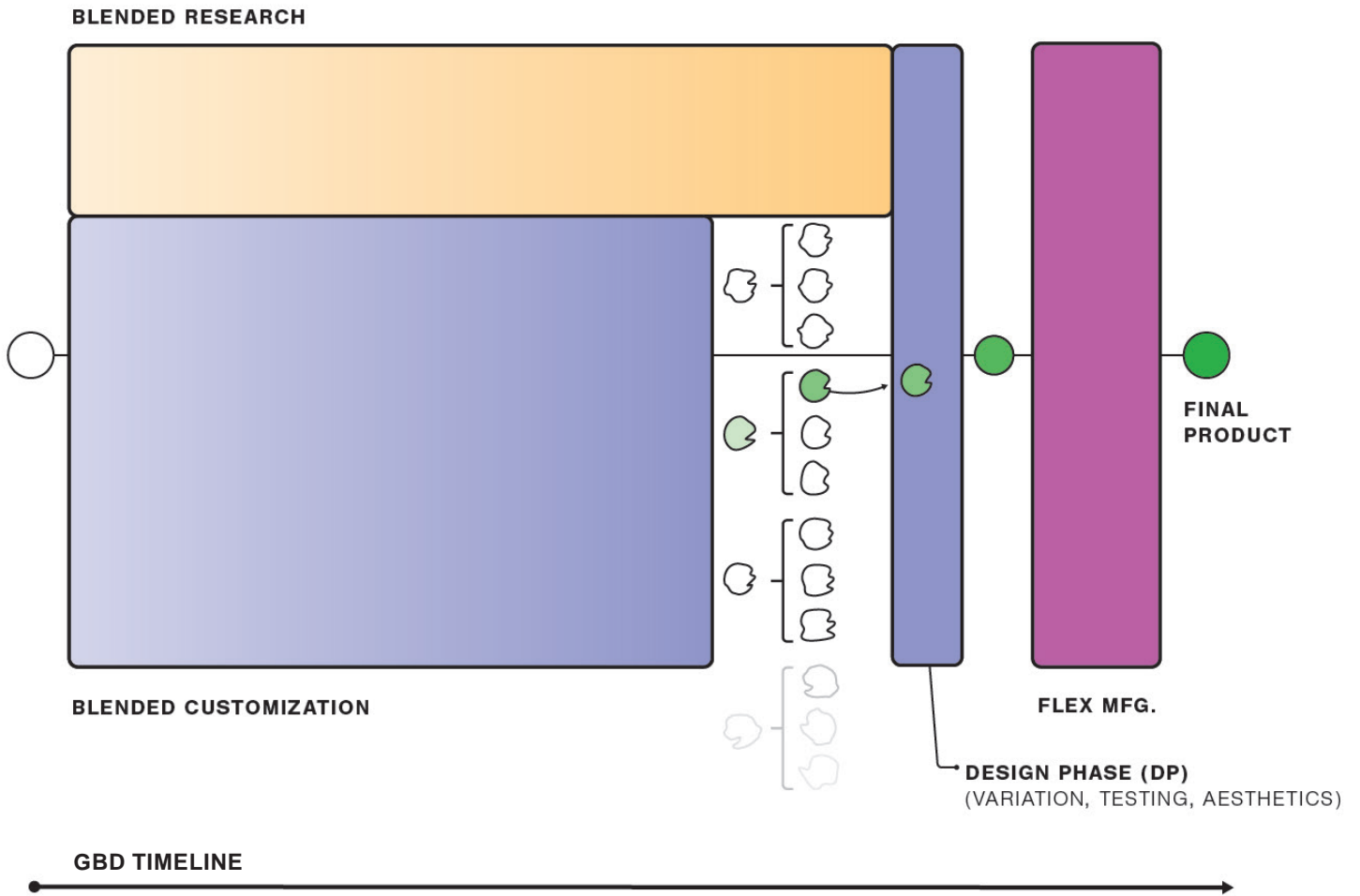


Image 5.1.1
The GMD Process

5.1. Generative Blended Design (GBD)

Throughout my research, interrogation, design, and reflection, insights arose that hinted at possible futures. The idea that most resonated with me was that of a GBD process [image 5.1.1].

Blended Research

This refers to a process of ongoing research that happens before, during and after a given design process. For example, an ongoing relationship with a client, and a previous table design, could influence a future set of dishware.

AI is also considered to be blended into this research process, influencing algorithms and parameters based on the client's behavior, object usage, and reviews of other objects.

Blended Customization

Informed by blended research running parallel to this process, AI assists with scanning, modeling, and generating concepts. AI and software-enabled machines communicate during this phase to adjust tooling and manufacturing processes ahead of time. This is dynamic and can change as designs evolve thus greatly reducing manufacturing times.

Design Phase

While still curated and finalized by a human designer, the design phase is much faster with less need for multiple phases due to the collaboration with AI.

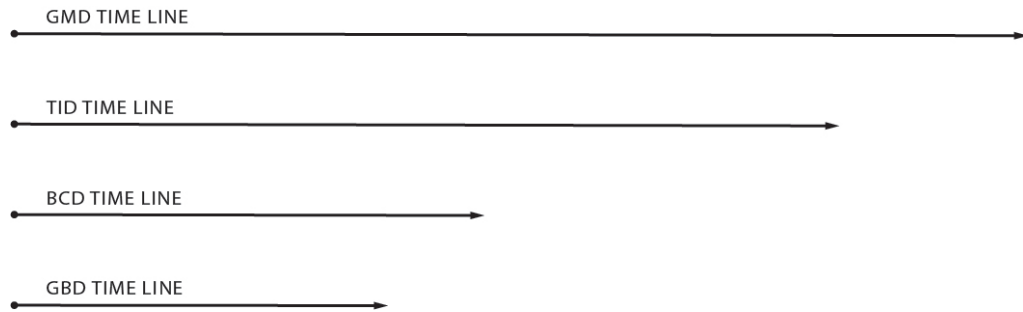
Flexible Manufacturing

A final product is created in a short period of time.

Timelines

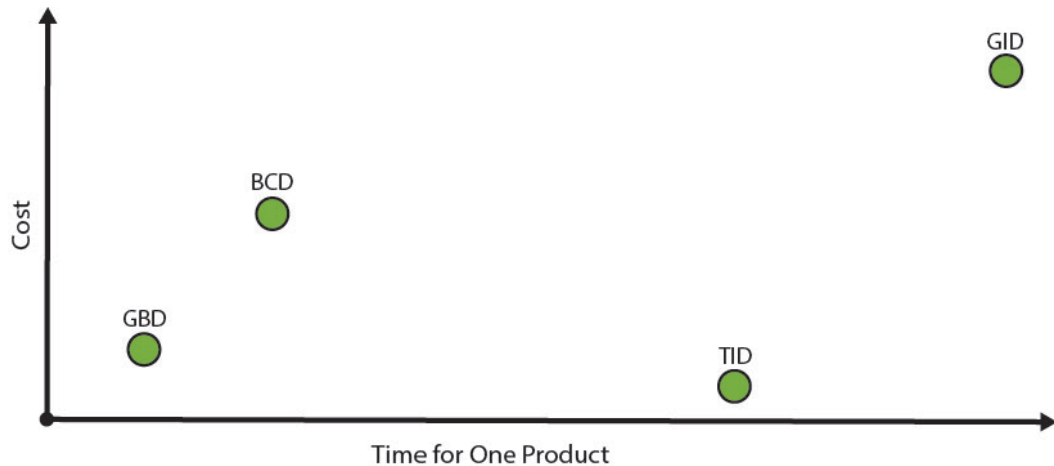
At the bottom of image 5.1.1 is a timeline. This represents the total projected time from the project's initiation to a final concept. This and all previous diagrams were created to have a relative time scale. In this way timelines from all processes can be easily compared [image 5.1.2].

Image 5.1.2
Comparing
design process
timelines



By adding generalized cost projections we can further evaluate the different processes.

Image 5.1.3
Speculating
upon generative
product costs



5.2. Coalescing

I had no idea how complex this thesis would become. Even after all of the practice with systems thinking, lectures about mapping complexity, readings on information architecture, and discussions about wicked problems, I was still somehow surprised by the depth and breadth. It was a little daunting to navigate the overlapping areas of the many fields that make up the emerging space of generative design.

Through this process, I have come to understand the territory, the tools, and the perspectives of experts operating in the field. I have gained an understanding of how the public perceives generative design and its products.

Furthermore, I have engaged personally with a generative process and developed a framework for a generative industrial design method which served as a platform for speculation. This process allowed me to see that generative tools could be used in a much more nuanced way than how they are predominantly being employed presently.

I am thankful for the time I have had to explore this space. It was rewarding to uncover so many different elements and to see them all come together in the end.

Coalesce:

verb

1 : to grow together

2 : to unite for a common end : join forces

3 : to arise from the combination of distinct elements

5.3. Reflection

Why is it so important for Nico to have a chair that fits? The immediate answer is that I love her and hope to alleviate a persistent annoyance from her life. On a grander scale, the chair represents many things.

Rather than a future where the “optimum” sizes and shapes of products are dictated by predominantly white male designers and a capitalist mentality for maximum profit and mass production, we have an opportunity to create a future where designers can work collaboratively with clients to create objects uniquely suited to the needs of people.

Perhaps these become heirloom objects, or at the very least, they are long-lasting, meaningful, functional, and enjoyable to use. If an object needs to be taken out of service, let us hope that it will be made from materials that are safe and easy to repurpose. In this vein, from a circular economic point of view, generative technology can massively reduce waste and optimize material usage. Energy could be saved from more efficient manufacturing processes and generative tools could allow designers to produce bespoke objects affordably.

Of course, this is not just about comfort. The ramifications of this kind of process on accessibility will be immense. In this case, I investigated a chair for my wife, another scenario could be a prosthetic limb, custom wheelchairs, and entire vehicles. Currently, these kinds of objects can be prohibitively expensive. In the future this does not have to be the case.



Image 5.3.1
A rendering of Nico
sitting on a Coalesce
stool.

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