Advantages of the Engineering Designer

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Abstract

Mid-century designers leveraged post-WWII manufacturing techniques to blend form and function. This thesis demonstrates the similar capability of a designer with an engineering skillset. Following the examples set by past mid-century modern designers, as well as incorporating personal ethics and perspective, a chair design project in injection molding is performed and discussed. The research concludes that engineering methodologies alone in product design are often too limited in defining constraints. Furthermore, some professionals should operate in the same space in which all products live—between engineering and design. Conducting the chair design project inside of this “space between” resulted in an authentic product (one whose aesthetic direction is driven by constraints), faster iteration, and other key advantages.

Keywords

Product design, engineering, industrial design, interdisciplinary, mid-century modern, plastic injection molding

Preface

I find the marriage of technical knowledge and aesthetic skill to be the most rewarding career experience for me. Product design is a field that offers this blend, and I have taken a unique path in education to reach this desired role.

My undergraduate career involved five cooperative education rotations, each consisting of a semester working in the field. The first two rotations I completed were in manufacturing engineering. Manufacturing in a job shop setting is a demanding field—I took this position after learning that employers typically look for this sort of experience in their design-engineering teams. After learning the basics of how parts are made through collaboration with a machine shop, I was ready to look for a design role. My next three rotations placed me on a design team during the development of a new flagship product. This experience was exactly what I had been looking for…

However, working with an industrial design consultant made me realize that there was so much more I needed to learn. I could make parts that could be manufactured and assembled, but that was my limit. It was up to the industrial designer to make the parts cohesive, human-friendly, on-brand, and pleasing. These elusive aspects of a product felt so much more opportune for innovation—I needed to learn this way of thinking.

Acknowledgements

I would like to express my deepest gratitude towards my thesis committee: Committee Chair Peter Chamberlain, for guiding me throughout this project and helping steer my thinking off the ground; Committee Member Thomas Huston, for providing input on the core of engineering methodology; and Committee Advisor Jeff Welsh, who helped develop my design intuition further than I thought possible. Additionally, this endeavor would not have taken place without Nick Germann, for his extraordinary assistance in the manufacturing of ten complex mold halves, as well as all of the employees of the DAAP Rapid Prototyping Center—especially Max Lange and Nika Umnov.

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Introduction

Mid-century designers leveraged post-WWII manufacturing techniques to blend form and function and make authentic designs. This thesis demonstrates the similar capability of a designer with an engineering skillset: an engineering-designer. Prominent mid-century modern designers and architects who exemplify the blend of technical and aesthetic technique are examined and their relevant conversations about the interaction between engineering and design are outlined. Following the examples set by these past designers, as well as incorporating personal perspective, a chair design project is performed and then evaluated. After emulating the processes defined by mid-century modern design, the thesis demonstrates that combining engineering and design fields lends to an authentic product-making process, as well as other advantages. Final conclusions are then drawn based on the research as well as lessons learned from the design project experience.

Form and Function

Spanning roughly from the end of WWII to the 1970s, mid-century modern design is characterized by new manufacturing breakthroughs born out of wartime demands. These new making techniques played a pivotal role in shaping this era. For example, manipulated (bent) plywood, previously utilized in airplane fuselage components and in Eames' military leg splint, gained popularity in furniture during this period. The need for simplicity and scalability in manufacturing processes was core, as established by the Industrial Revolution—a democratization of fabricated goods. The departure from ornate embellishment toward simplified form driven by manufacturing constraints signifies a shift towards **authentic** design, where elegance takes precedence over arbitrary decoration. In such products, the interplay between form and function becomes pronounced rather than a focus on one aspect or the other. Arbitrary decoration is replaced by technical functionality as the driving force for the aesthetic. The mid-century modern era best exemplifies authentic design since the designers of the period were deeply connected to cutting-edge manufacturing techniques.

In the context of this thesis, **form** is defined as the essence of an object, reflecting the maker's intent, and intended for a human audience's emotional and sensory reception. **Functionality**, on the other hand, pertains to a design's ability to meet constraints, such as load-bearing capacity or ease of manufacture. Many considerations, such as human factors, fall between these definitions of form and function. Conversely, contemporary professionals are often partitioned into either category without any in-between. When engineers focus solely on functionality and designers on form, crucial problems such as ergonomics or emotional impact can lie unaddressed. Without a bridge between these disciplines, the basic understanding of how design choices impact both form and function is compromised. Therefore, an engineering-designer is essential for ensuring that products achieve a harmonious balance between form and function.

The choice and order of words in “engineering-designer” are deliberate. The more common term that one may use would be design engineer, but the connotation of this name implies an engineer who designs—that is, the core framework of action is engineering-based. To indicate the larger breadth required to successfully consider form and function, engineering-designer is more accurate. This role is defined as a designer who has a base in engineering; one who uses deep technical knowledge to inform design decisions throughout the entire process.

A typical engineer’s process consists of the following: define constraints, conduct analysis, and engage in manufacturing processes. A designer’s process is similar to the above; however, they often emphasize human factors and prioritize insight-gathering. In other words, a designer dedicates more effort in the initial research sector, while an engineer belabors the end product and the associated models needed to achieve the end result. This distinction is an oversimplification and may not apply to a significant portion of product-makers, but it serves to outline one interpretation of the difference between typical design and engineering roles, especially set by corporate and educational systems.

Figure 1: The breadth of products.

Figure 2: The breadth of product-making professionals.

As illustrated above, the individual roles found in corporatized structure may not capture the entirety of a product design process. Like an assembly line, these roles exist so that professionals can focus on a more concentrated region in the overall procedure and repeat that work over and over again. Also, many professionals' interests or skillsets may have narrower scope than others—this is not problematic on its own whatsoever. This thesis argues that those professionals merely collaborate more deeply throughout the process. Too often does so-called collaboration equate to tossing work over a wall. A varied team tackling each step of an overarching cohesive process should be the goal. However, if an individual has an inkling of interest and ability to envelope both engineering and design, this should be welcomed into education and companies as a highly desirable role. The making process can happen without a back-and-forth, or rather, the back-and-forth takes place entirely within the mind of the engineering-designer. The human brain is still one of the best machines to take large amounts of complex inputs and think creatively about potential solutions. A maker who can wrap their mind around as many constraints as possible will find success.

Historical Background: Midcentury Design

Several key figures made lasting impact in the era of mid-century modern design, guiding the activities undertaken for this thesis. Pertinent examples of their statements on the relationship between technical knowledge and design are reflected upon.

Ray and Charles Eames:

This extraordinary pair of designers defined the mid-century era of design by asserting: “Design is an expression of purpose, and a method of action.” Eames places heavy emphasis on constraints, even asserting that the "key to the design problem" lies in the designer's ability to recognize them. Charles Eames also notes that all designed objects have a use, even if very subtle—including pleasure (1969).

Their philosophy emphasizes the need for breadth of personal ability to define all constraints of a design problem.

Charles Eames also discusses the risk of deriving form from analysis, which may be incomplete. To him, true analysis takes months to years, and examines more than market interest or competitive benchmarking. The whole range of personal impact to social reflection must be addressed, and the functionality and footprint examined at each level. Therefore, this thesis proposes that the best chance of conducting a thorough analysis lies in eliminating the partition between engineering and design. Successful creation incorporates both frameworks for an absolute analysis and definition of all constraints, including their weights.

Le Corbusier:

Corbusier argues that architecture mediates between man and the landscape; that the landscape actively participates in the experience (Rabaça, 2016, p. 110).

In product design, an object exists between a person and a function. Drawing a parallel to Corbusier’s statement: the function must participate in the design just as much as the person. Contemporary design focuses heavily on the human aspect but can fall short on integrating the function. For example, minimalistic design trends are often guilty of oversimplification to the point of losing significant functionality. A chair with straight clean lines and flat surfaces may be appealing to the eye but lack proper interface to allow for human comfort.

Henry Dreyfuss:

Dreyfuss agrees with Eames that design starts by outlining constraints. Specifically, designers collaborate with engineers to develop models and measure compromises. He defines design as “to contrive for a purpose,” noting that it equally belongs to engineers as much as designers. Dreyfuss also emphasizes, like Eames, the necessity of research, which can often be risky, requiring specific methods to gather proper information (Dreyfuss, 1959, p. 83).

Again, this thesis contends that these specific methods lie in design methodology and education, with engineering being a necessary language to attain the necessary depth to design.

Enzo Mari:

Mari can be considered as a highly artistic designer, who may have some distance from the average engineer. However, even he noted that "the project has two main paths which are tested for connection or convergence continually, just like two railway lines are connected by many sleepers" (Ryan, 1997, p. 30). Mari speaks of two facets in every product endeavor: artistic character and technicality. He emphasizes the importance of an object having a certain “insight.” This insight provides the object with life, and without this aspect, the object is not successful.

Mari acknowledges that products must stand on two feet: one concerned with logistical constraints such as cost and material, and the other with the art and emotion of the thing. But, to an engineering designer, the invention may come directly from the line of logistical constraint—forming an ultimately cohesive body. The separation of logistical constraint and art/emotion becomes more and more arbitrary. The Bauhaus elaborates on this notion, later discussed in this thesis.

Alvar Aalto:

In the context of modern architecture, Aalto critiques a “surface level rationalization,” highlighting its tendency to overlook the human aspect of design.

He underscores the importance of integrating technical precision with human-centered considerations, suggesting that a purely technical approach can lead to superficial outcomes. (Kim, 2009, p. 10)

Through the lens of this project, then, the role of an engineering-designer extends beyond mere functionality to encompass a deeper understanding of human needs and experiences. Modern day engineering is guilty of being surface level. By embracing design-thinking, engineers can infuse their creations with depth and meaning distilled from the nature of what it takes to make a product. A holistic approach to design that merges technical expertise with empathetic understanding ultimately results in more meaningful and impactful solutions in product development.

Eero Saarinen:

Saarinen expressed “three fundamental tools for a new style: functional integrity, honest expression of structure, and awareness of our time” (Saarinen, 1961, p. 29) Functional integrity includes human factors, functional analysis, life cycle, and manufacturability—all typically engineering-sided considerations. Honest expression of structure could, therefore, be considered as a designer-sided facet… however, one would also say that engineers often work towards this as well. Especially in designs that are at the cutting edge, say, a fighter jet—designers are not involved in the outside footprint of the airplane (although they are heavily relied upon for the cabin). In this case, engineers are performing significant design, as all designers ought to, in supporting the pillar of honest structure. The wings, engine, flaps, and all other components are placed to serve the greater function of flying performance. In the same way, for products of all kinds, designers should be relied upon to find this greater function and generate a form which serves this function. For objects without such extreme physical constraint, engineering alone is ill-equipped to fulfill this need.

12 Precepts of Modern Design:

Edgar Kaufmann Jr. writes an elaboration of modern design principles (similar to Saarinen):

1. Modern design should fulfill the practical needs of modern life.
2. Modern design should express the spirit of our times.
3. Modern design should benefit by contemporary advances in the fine arts and pure sciences.
4. Modern design should take advantage of new materials and techniques and develop familiar ones.
5. Modern design should develop the forms, textures, and colors that spring from the direct fulfillment of requirements in appropriate materials and techniques.
6. Modern design should express the purpose of an object, never making it seem what it is not.

7. Modern design should express the qualities and beauties of the materials used, never making the materials seem to be what they are not.
8. Modern design should express the methods used to make an object, not disguising mass production as handicraft, or simulating a technique not used.
9. Modern design should blend the expression of utility, materials, and process into a visually satisfactory whole.
10. Modern design should be simple, its structure evident in its appearance avoiding extraneous enrichment.
11. Modern design should master the machine for the service of man.
12. Modern design should serve as wide a public as possible, considering modest needs and limited costs no less challenging than the requirements of pomp and luxury. (Kaufmann, 1950)

In the principles above, engineering is the primary toolkit necessary in numbers one, four, five, and seven. Without a technical background, how can designers be expected to address these points deeply? These particular principles continue to uphold similar pillars as previously highlighted by Eames, Saarinen, and other contemporaries of modern design, and demonstrate the need for a large breadth of experience.

Bauhaus Principles:

The Bauhaus similarly generated principles to guide modern design:

1. Mass production and industrialization should be the primary concerns of the student and that of individual craftsmanship.
2. Schools of design should bring together the arts of paintings, architecture, crafts, and industrial design and eliminate the differences between applied arts and fine arts.
3. Schools of design should have faculties, some of whom are progressive in thought and creative in practice to balance those who are primarily interested in the preservation of the traditional techniques and theories.
4. Students should be a part of and participate in current twentieth century activities and should not seek refuge in the security of the past. (Adams, Pappas, Van Dommelen, 1961)

The Bauhaus drives home the idea that handmade craft is associated with exclusivity, and that product development must be democratized to serve the broader population. It highlights the disparity between the limited availability of artisanal products and the widespread demand for accessible goods. Recognizing the inevitability of mass production, the Bauhaus underscores the importance of integrating artistic principles into industrial manufacturing processes. This approach advocates for a synthesis of applied and fine arts, aiming to bridge the gap between aesthetic creativity and functional utility in product design. By embracing this philosophy, engineering designers create objects that not only fulfill practical needs but also resonate aesthetically with a wide audience.

Anecdotally, a conversation during research of this thesis postulated that the downfall of American automotive design began when car designers disconnected from their technical “hot rodding” roots. Upon research, it seems that most blame is pointed at over-regulation for vehicle safety and fuel economy as the cause for ugly automobiles (Tucker, 2021). While the initial point is certainly believable, even the second has pertinence to this discussion. Cars from the “golden era” were certainly designed by enthusiasts, and people who understood the passion of driving. Automobiles had simple panels, clean lines, and a distilled, distinctive aura to them. The design of the body communicated the nature of the vehicle. While regulation is certainly challenging to address, it merely is an additional set of constraints to leverage. Modern auto designers are extremely focused on what is possible, rather than what should be done. Body panels have become extraordinarily complex as progressive dies and stamping houses enable multi-dimensional shapes. Engineers are guilty too—the technology under the skin of the car is complicated and finnicky—ever since the debut of computer-aided design. In the end, though, the regulation-driven flatter front ends, higher belt lines, and smaller windows do not necessitate arbitrary body lines, heavy faceting, and fake air intakes. Furthermore, it could be the case that designers *are* responding to each constraint and functionality, but it is the exponential growth of said functionality that has made car makers scramble. Automobiles are just one market that has exploded in recent history with new constraints arising daily. Designers who are ill-equipped to deal with a plethora of constraints will not be able to produce a successful product. Those makers who have to deal with the most constraints, whether it be from regulation, market, or economy, are the ones who should have the most experience in both technical and design methods.

The research above highlights similar notes in the discourse of pivotal key figures and movements in midcentury design. The synergy between technical knowledge and design thinking is core. Ray and Charles Eames, Le Corbusier, Henry Dreyfuss, Enzo Mari, Alvar Aalto, and Eero Saarinen all advocate for a comprehensive approach that integrates a portfolio of engineering-esque experience with human-centered consideration. Their philosophies emphasize the need to recognize constraints and conduct thorough research to create proper solutions to a design problem. Additionally, the principles of modern design and the Bauhaus movement further reinforce the notion to blur the boundaries between applied and fine arts. To achieve a successful and innovative design outcome in the modern era, an interdisciplinary approach is not only recommended, but necessary.

Project

To further investigate the advantages of an engineering-designer, a product design project is ideal. Such an investigation yields learning opportunities from both the process and the final outcome, and the specific nature of physically making something can illicit information that otherwise is unobtainable. Defining this thesis-related project must begin with considering what constitutes a proficient engineering-designer. Drawing insights from Eames and Dreyfuss, it is evident that there must be a mastery of defining constraints. Delineating the project's boundaries, an engineering-designer defines various constraints, minimizing the need for arbitrary decisions. These constraints are informed by many different experiences, resulting in a strong foundation for the project's development. Here are some of the constraints for this project:

Constraint Definition

Major:

- Time: the project must be completed as part of a graduate educational track and is limited to one year of effort. Actions must be managed by charting and tight scheduling.
- Cost: the project is entirely self-funded, and therefore must minimize cost by adhering to a specific budget, minimizing external process time, maximizing personal labor.
- Manufacturability: the project must be able to be rapidly prototyped. Processes are limited to handcraft, one-off machining, 3D printing, and

other prototyping methods of making. There is no access to large scale manufacturing plants.

- Form: the essence of an object, successfully reflecting the maker's intent for a human audience's emotional and sensory reception, must be demonstrated successfully, and linked to the functionality of the object.
- Functionality: the ability to meet physical constraints, such as load-bearing capacity, as well as working features, must be demonstrated successfully, and linked to the form of the object.

Minor:

- Materiality: the makeup of the product must be able to be easily sourced and replenished. The chemical makeup of the materials used should contribute to the feasibility of the project.
- Audience: the project should address human factors and be designed for as large a population as possible.
- Sustainability: the product should stand the test of time and not be harmful to the environment. Material waste should be limited.

Incidental:

- Accidental: the timeline and budget of the project should be able to withstand any reasonable setbacks, such as machine crashes and design problem-solving or iteration.

- Supply Chain: materials are dependent upon market availability and shipping times.

Circumstantial:

- Preference: Consumer perception among the current era must be adequately addressed.
- Sensitivity: cultural impact must be considered so that any norms are upheld and not violated.

Manufacturing Process Selection

After outlining constraints, the final project definition begins to take shape. Given that the project seeks to develop a product whose design is distilled from its manufacturing process, this process must be defined first. A suitable manufacturing technique is one with unique or challenging constraints. Again, more constraints can actually ease this process rather than inhibit it, since decision-making becomes more informed as the number of constraints increases. Based on this, plastic injection molding is selected. Objects made by this process are heavily controlled by their nature: first, they must come out of a mold. This means that all faces must have a draft angle; that is, surfaces are oriented so that they can release and eject from a mold. Any features that must be included but would otherwise lock the part in the mold need to be made by removable cores. Furthermore, the plastic parts themselves need to have a thin and consistent wall thickness to avoid surface defects and ensure a proper fill. Because the parts must be shells, reinforcing geometry is necessary to result in a mechanically stable part.

Contemporary plastic components also often deviate from the principles of midcentury modern design thinking. Many conceal their hollow nature by placing the open face against a surface or facing the floor. Additionally, molds are texturized to obscure tool marks from the manufacturing process. While texture can serve practical purposes such as providing grip, concealing defects, or allowing an easier release from the mold, removing the marks left by the manufacturing process raises questions about the authenticity of the design. Witness marks to the process, such as ejector pin locations and gates, are seen as defects and trimmed or hidden. However, some current techniques, such as trimming away flashing, are necessary to remove sharp or inconsistent leftover material. This discussion serves as a devil's advocate for questioning the conventions of the modern process, while also acknowledging the practical considerations that drive certain practices. Moving forward, more investigation will follow features of the process which could be elucidated to reinforce the concept of an "authentic" design, and which current finishing techniques should be preserved.

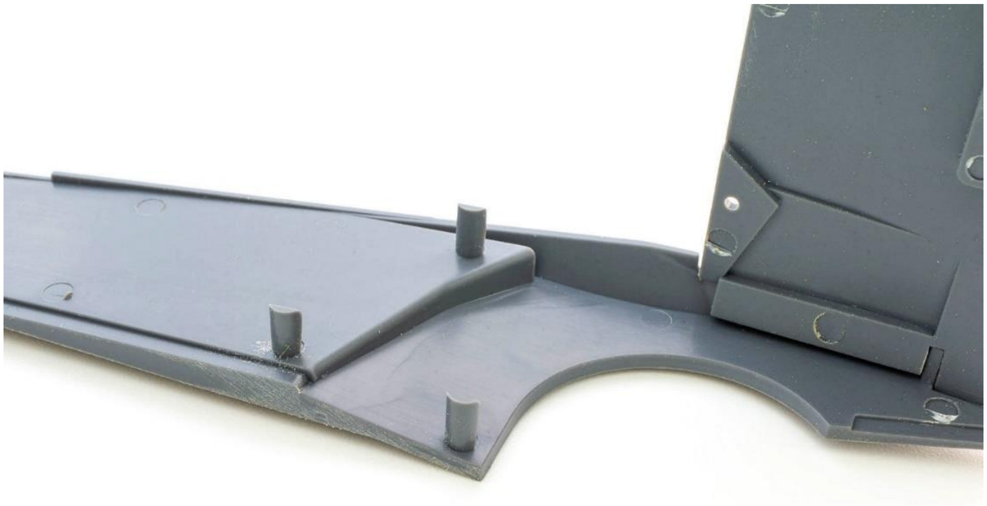

Figure 3: Ejector pin defects (circular imprints) and gate defects (raised cylinders) (Vale 2022).

To convert the injection molding process into a small-scale craft suitable for this project, changes are required in both mold design and injection material. The molding material must be selected first, followed by a compliant mold substrate. Instead of molten plastic like ABS or Nylon, an ideal casting medium for this purpose would function at room temperature. One solution is a two-part casting resin, which is distributed in liquid form. Upon mixing, these materials cure into a hardened part. The resin selected for this process must have a long working time and low viscosity, so that it can flow into all features of the mold and allow trapped gas to evacuate. Additionally, it must not heat up to the mold's melting point while curing—the curing process for these sort of resins is an exothermic reaction and can release a significant amount of heat. Therefore, a two-part, long working time, deep pour, urethane casting resin was selected which meets all of these constraints. As for the mold substrate, one candidate is high density polyethylene (HDPE), known for its non-stick nature and machinability. This material is used in an adjacent process, where tabletops are made by pouring over top of HDPE sheets. The resin is known to be able to release from this surface, especially with the aid of a mold-release agent. Large sheets of HDPE are also relatively inexpensive and readily available, making them suitable for mold construction. With the final materials selected, product selection then commenced.

Product Selection

Considering the need for the object to demonstrate a marriage between engineering and design, it should have some component of human use as well as engineering challenge. Looking to the past, whether they meant to or not, most designers defined their career perspective through the design of a chair. A chair has a significantly larger scale than any handheld object and must properly deal with the full weight of a human. Also, the nature of this thesis is to define a design perspective. Truthfully, there is no better object for the subject of this project.

Ideation

After having defined the product to be a chair and the materials to be used in the process, rough ideation began. Three different interpretations of a plastic chair were considered:

Figure 4: Three plastic chairs.

1. A fully plastic chair with assembled components.
2. A bi-material chair with metal structural components and plastic human-facing components.
3. A fully plastic chair with a shell-like construction.

An investigation into the first interpretation yielded some interesting insights. Considerable thought was given to considering the best methodology for joining the parts—borrowing significantly from the realm of woodworking. Figuring out how components with draft angles could fit tightly into one another posed a significant challenge. Computer-aided design was utilized in this step to examine how different shapes could offer the support and rigidity necessary for a chair. As this idea became more polished, it became apparent that there was no guarantee that the final parts could hold the full weight of a person reliably. The resin has a full list of determined material properties, but successfully modeling how these plastic parts would behave requires finesse, and adherence to the noted properties heavily relies upon successful casting procedures, which were already being pushed to their limit. Therefore, the design pivoted to interpretation two, a bi-material chair, as interpretation three would have similar challenges.

Interpretation two initially was not considered due to the risk of the additional material distracting from the plastic components. However, a bi-material chair is a much more authentic design since plastic components typically are not used in high-load situations. Having a skeletal frame to handle the loads freed up the design so that the plastic parts could be used solely for the human interface. They also still served a mechanical function of holding the skeletal frame together. Initially, a bent-plywood and resin design was considered. This direction would require an extreme twisting of any conventional molding method, as all wooden components would be loaded at once into a large-scale mold, and resin poured in to bind the parts together like a glue. This methodology was tested and deemed successful, but this direction still suffered from the same issue of guaranteeing a rigid-enough structure to support a human.

Figure 5: Resin and plywood test.

Plywood panels are not typically load-bearing, and the design still relied heavily on resin to formulate the joints, which are the locations of most stress. The final pivot in design direction involved making an aluminum frame that went floor-to-seat. This frame could then interface with a plastic seat pan and seat back. Additionally, leg covers were made in plastic to address any side loading on the legs, since their shallow mounting point in the seat pan could not have held them firmly enough. The final design direction was set by blocking out the shapes of the components, and the finalized molding process testing commenced.

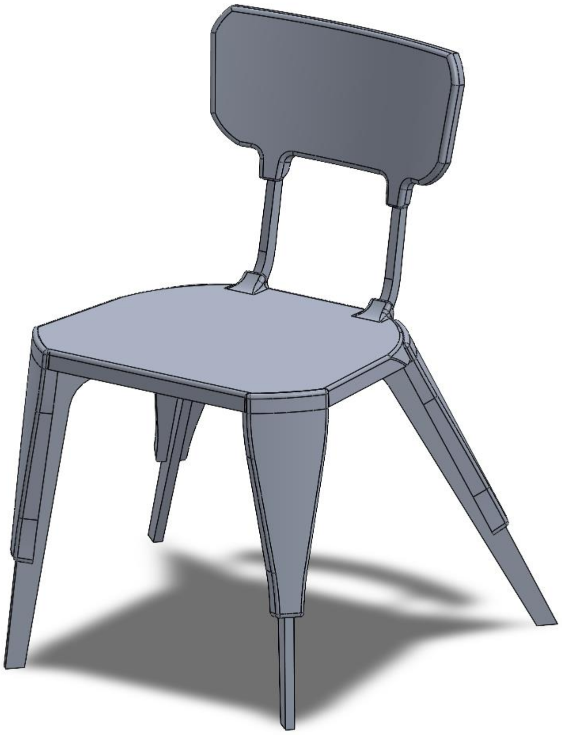

Figure 6: Preliminary chair with block components.

Testing

To evaluate the performance of the selected materials in molding, an arbitrary shape was modeled similar to the state that the chair components were in. This shape was then hollowed out and reinforced with a rib structure, resulting in the final geometry of the test part. Next, sprues and vents were added to the part as solids (A sprue is the channel through which the molding material flows into the mold cavity, and a vent is a path for gas to evacuate the mold cavity as it is filled with material). Finally, a block is placed over this model, and the previous geometry is subtracted from this block, leaving a negative of the part, including the sprue and various vent holes. The block was split into two halves, forming a completed mold (this total process is outlined in the appendix). The resulting geometry was submitted to a prototyping shop, who programmed a tool path for each mold half and machined them out of stock HDPE material. Test pours from this mold showed the following:

- A pour cup is necessary to hold material above that which is flowing in and provide back-pressure to ensure a full fill of the mold cavity.
- The vents needed to be larger in diameter to allow the resin to fill them, pushing out all trapped air.
- Risers were needed so that the part could drink material back as it cured and shrank.
- The resin releases easily from HDPE, and this process would yield successful chair components.

Note that another manufacturing method provided solutions for these problems—pour cups and vents are features commonly used in sand casting metalwork.

Finalizing Design

Now that the process had been finalized, the chair needed to be finished. The chair dimensions had been made with the help of Dreyfuss' *Measure of Man and Woman* and used measurements between a standard style and lounge chair. A plywood mockup of a chair was made to evaluate these dimensions in the physical realm. After assessing the prototype with qualitative feedback from individuals of various physical builds, dimensions were refined and finalized. The parametrically modeled chair was then adjusted to fit these changes, such as increasing seat pan height by an inch, etc. Then, the parts were ready for modification to generate the molds. The components were hollowed out, and the reinforcing rib geometry added. Several iterations of rib structure were examined. The final direction established a system for the chair: in areas close to the skeleton, a dense truss structure was placed. As distance from the supports increased, the truss structure becomes less dense. This corresponds well to the stress concentrations, as well as correlates the two varied materials and their roles.

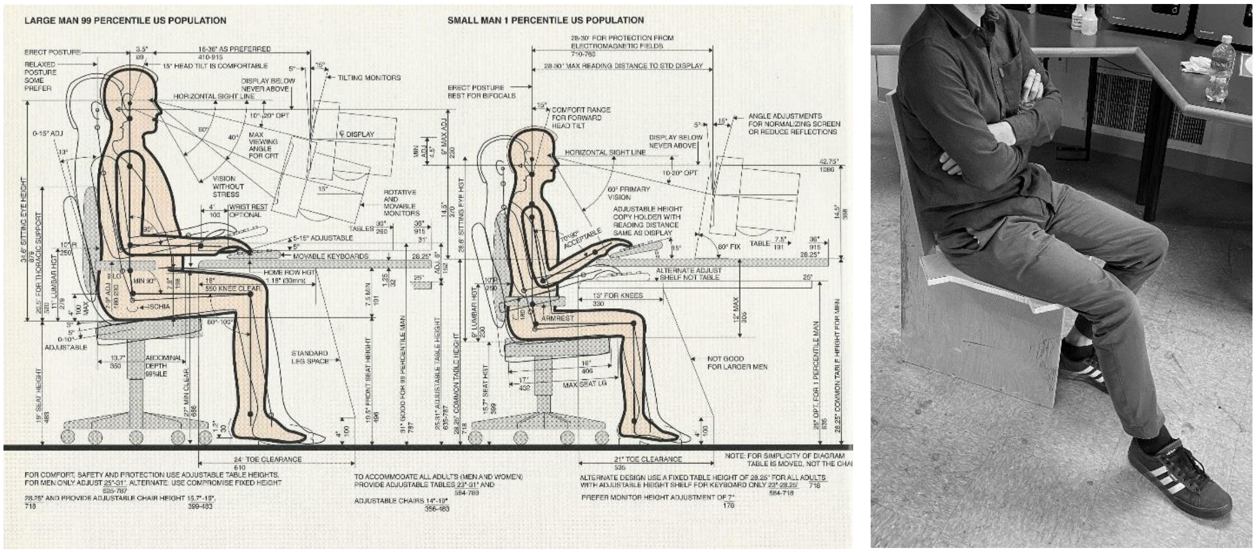

Figure 7: *Measure of Man and Woman* (Tilley, Dreyfuss, 2002) and prototype chair testing.

After the parts were completely modeled, sprues and vents were added. The sprues were placed so that they could fill the part from the lowest points—a technique garnered from local resin molding experts (Scott Model, Inc.). After this, the part geometry was subtracted from a block and split, forming mold halves. Cores were added so that cross-holes would be present in the parts without needing to drill after they come out of the mold. Larger diameter holes were counterbored to allow placement of a pour cup and risers. Final materials and geometry were submitted to a prototyping facility for manufacture.

The skeleton of the chair required some engineering-based technique to guarantee a proper structure. The American National Standards Institute (ANSI), alongside the Business and Institutional Furniture Manufacturer's Association (BIFMA), promulgate consensus standards for lounge chair design and testing for a 275-pound mass person (95th percentile male). There are a multitude of tests that range from static, dynamic, and durability (2023). Furniture designers send their chair prototypes to laboratories to be evaluated against these kinds of standards. For the sake of simplicity, the chair in this project will be designed to support 1,000 pounds, so that it should be able to pass the standards testing laid out by ANSI/BIFMA X5.4 (which do not test at or above this weight) without a reasonable doubt. First, a simple frame profile was modeled and analyzed using finite element analysis (FEA). This method first converts the geometry to a large number of tiny simple solids such as cubes and prisms. Then, fixtures and loads are applied to the model, simulating real life conditions. For the leg frame, 137 pounds was placed across the top surface where the seat pan would be. The bottom face of the legs were fixed because there would be rubber feet holding them rigidly on the surface of the floor. Next, the computer calculates stress/strain values for each simple shape throughout the part, highlighting regions that may be problematic.

The first analysis of the frame, shown below, outputted a failure load of about 1,400 pounds.

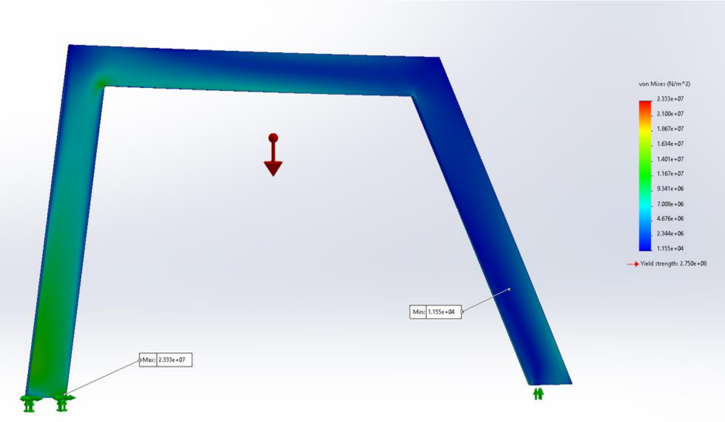

Figure 8: Initial finite-element analysis.

This shape is therefore overdesigned and can be reduced in size. After tapering the legs and placing the cuts in the part required for assembly, another FEA test was run, shown below.

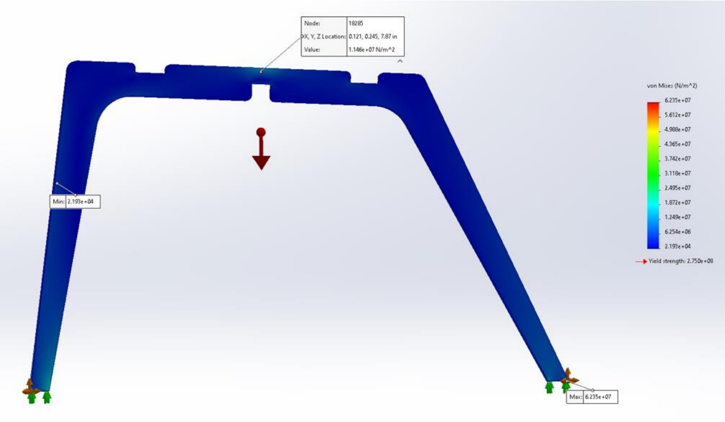

Figure 9: Final finite-element analysis.

Note that, while having less material, the stress flow in this shape is improved by adding generous radii in corners. This component had a total failure load of about 1,100 pounds, which is above the target and deemed suitable for the chair. A similar process was also performed for the seat back braces.

Another consideration for user safety is in the tip angle of the chair—that is, at what point would the chair fall over if a person leaned back on the rear two legs. Estimating a user center of mass from *Man and Woman* (Tilley, Dreyfuss, 2002), an estimated fore-to-aft tip angle for the chair design was found to be approximately 25 degrees.

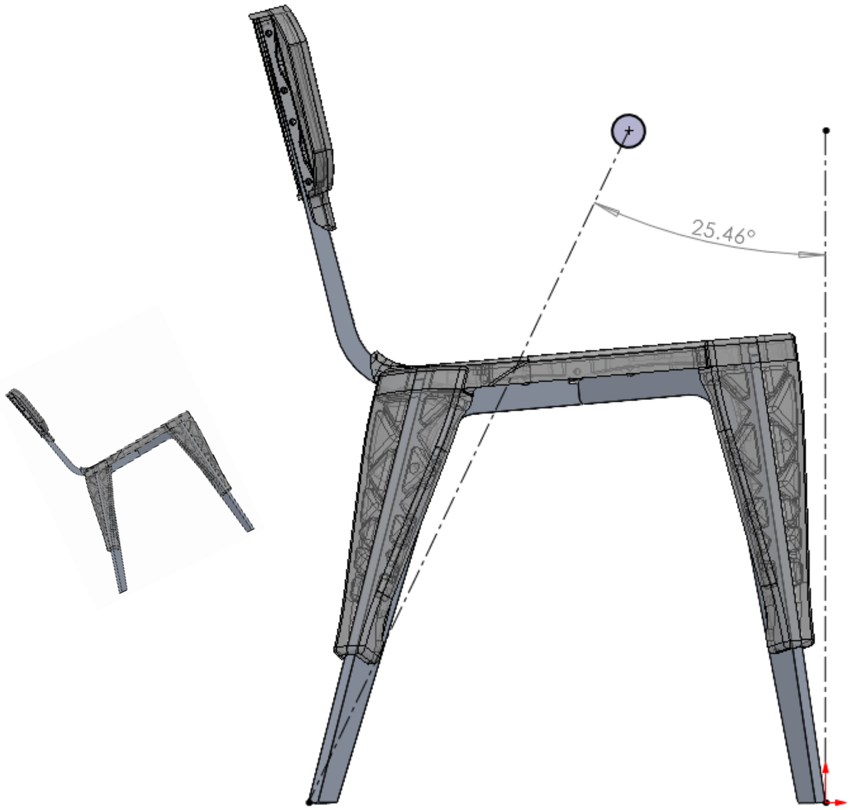

Figure 10: Chair tip angle.

This angle is a direct result of the design balancing the rear leg splay. Since the legs are crossed to properly support human weight and reduce stress in the plastic holding them together, any amount that the legs are splayed back also splay side-to-side. Sticking out too far from the sides would inhibit the ergonomics of the chair with objects near it, as well as make a tripping hazard. A tip angle of 25 degrees was determined to be acceptable, especially since the difference in weight of the metal legs to the plastic/back braces was not included in the analysis. The center of gravity would be lower than pictured, and result in an even more agreeable tip angle. The side-to-side tipping angle is more stable than most chairs due to the outward leg splay, and also rotates about a line more askew than a traditional chair, making the specific angle value not relevant. Since the design of the chair has more conventional front legs, the aft-to-fore tip angle was not further considered; especially since the lounge-style nature of the chair has a rearward center of gravity.

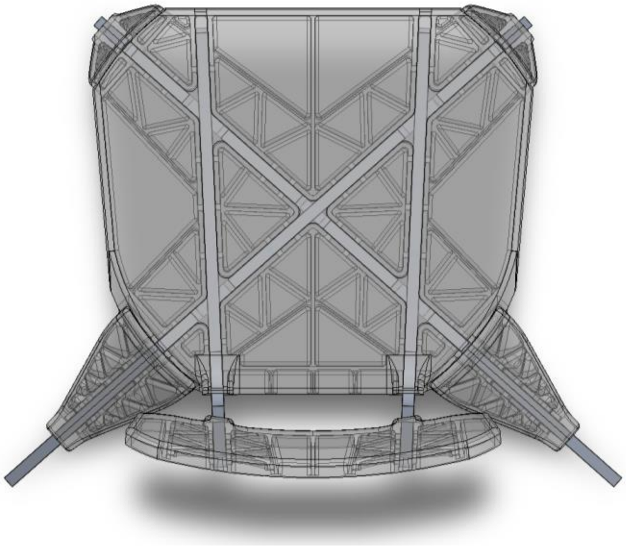

Figure 11: Leg splay as seen from above.

One final engineering consideration is in the assembly of the components. Since holes can be placed in the plastic parts by mold cores, this would be the best method to guarantee a locational tolerance. Additionally, holes could be waterjet cut into the frame as the whole assembly is cut, again offering the best locational tolerance. The holes in the plastic parts were made slightly undersized, so that they could be drilled to the final diameter after they are molded. The final diameter of all of the holes was made to be ¼” nominal. Spring pin fasteners were selected to address any issues with hole tolerance or circularity in the waterjet cuts. These pins can flex to guarantee an interference fit that does not put a large amount of outward pressure on the holes. Since these pins are not particularly strong in their holding force, a large number of them are necessary to keep the chair together. This was determined to be the final direction for the assembly method.

Once the molds were machined, resin could be measured, mixed, and poured. Parts were left to cure for 6 hours, and then removed from the molds. Ejection features were not necessary since the HDPE was so nonstick and all components had suitable draft. The frame was finalized and waterjet cut from a ½” thick sheet of aluminum. Final steps in manufacturing included chamfering the metal parts to dial the fit within the plastic components and the trimming of any flashing and leftover material from the vents and sprues. The bases of both the sprues and vents were left on the part rather than fully “finished” (hidden) to experiment with their value as features rather than trying to sweep them under the rug. Finally, the parts were pinned in place to the metal frame and rubber feet were added, constituting a fully assembled chair.

Figure 12: A completed chair assembly.

Conclusion

Key Points from Research

First, mechanical engineers shape form from functional analysis, but this analysis is often too limited. Design thinking and research methodology provide a better chance for success, focusing on the necessary breadth in product design—form, function, and human needs.

Second, recognizing all constraints is the key to properly defining the design problem at hand and requires synthesizing engineering and design methodologies. An object is conceived at the intersection of human needs and functions, where the role of function in design is equally crucial to human factors. Engineering and design are therefore inseparable components in the constraint definition process.

Third, mid-century modern design, influenced by Bauhaus principles and visionary designers, embodies a genuine ethos bridging engineering and industrial design. This era succeeded because the process was rooted in manufacturing technique, led by designers--- not just engineers.

Fourth, internal corporatized job structures and university education enforce the partition between engineers and designers and require change if ever to achieve an engineering-designer.

Key Points from the Project

Based on this research and through education in both engineering and design, a product design project demonstrates how blending these fields yields a unique approach to making an object. Basic industrial design techniques, such as ideation, rapid visualization, and human factors research, help guide the form of a chair simultaneously with engineering considerations such as manufacturing process, standards and testing, and functional design. Product designers need to know all of these tools so that they may implement them at the proper times in the process. Contemporary designers are unable to address all constraints since some are based in heavily technical regimes known only to engineers.

Lessons learned from the project itself are more specific, especially regarding the choice of manufacturing processes. Again, contemporary plastic design tends to conceal ribs and hollow structures in injection molded components. Leveraging the ribs and hollow nature as design elements rather than hiding them offers more opportunities for innovative design. This mirrors the efforts of mid-century designers in their connection to manufacturing and engineering. The resulting product represents itself, requiring little outside intervention since the manufacturing process leaves its mark. Decisions are based on feature sensibility. Arbitrary choices are limited, based on the process chosen. The chair made at the end of this project addresses this arbitrary choice that permeates most current products. Nothing is hidden, as nothing takes away from the design of the chair. Additionally, the process marks which are left behind leave as many hints as to where the chair may have come from as possible. The chair embodies a fusion of form and function, embracing technical origins and therefore delivering a unique design experience fit for the contemporary era, where most consumer products are not so clear about their origins.

Zooming out and examining the process for the project itself, rapid iteration was a key factor to success. Multiple ideas were quickly digested and made into a highly developed form. The number of constraints realized through a design and engineering lens allowed this rapid development. This thesis postulates that professionals who widen their breadth will experience easier ideation stages, allowing for quicker or more developed results.

The study focuses on blending product engineering with industrial design—however, there are no indications that this fusion would not also work between other fields of form. That is, engineering married to fashion design would likely offer similar benefits. The results imply an ethic that transcends any particular field: authentic design relies on constraints which are found through both technical rigor and creativity.

For the Future:

This thesis serves as a case study for research into a re-establishment between engineers and designers. To reach this audience, it will be submitted to design and engineering journals. Also, its insights will inform a cohesive approach in a product design career. As these principles evolve through practical experience, they will be reintegrated into education through instruction, helping to encourage any next generation designers who recognize the vital need to fuse design and engineering.

Glossary

Thesis Body Terms

Note: these terms are defined in the context of this thesis only.

Authenticity: A lack of arbitrary decision-making, representing a product’s relation to constraints, especially from manufacturing processes.

Constraint: A parameter that influences the design of a product.

Industrial Design: The school of thought dedicated to the creation of a product, especially with relation to its form.

Product Engineering: The school of thought dedicated to the creation of a product, especially with relation to its function.

Engineering-designer: A professional who possesses both engineering and design intent, capable of blending both fields towards the generation of an authentic end product.

Form: The essence of an object, reflecting the maker's intent, and intended for a human audience’s emotional and sensory reception.

Function: A design's ability to meet constraints, such as load-bearing capacity or ease of manufacture.

Injection molding: A manufacturing process which produces plastic components by forcing a plastic material into a mold, where it solidifies into a final shape.

Mid-century Modern: An era spanning roughly from the end of WWII to the 1970s, characterized by manufacturing breakthroughs and significant design development.

Modeling and Process-Specific Terms

Boss: A raised feature from the surface of a part.

Draft: The nature of part faces being angled in such a way that allows removal from a mold.

Fillet: A curved surface added to a sharp corner.

Gate: To determine the location of features necessary for molding (sprues/vents).

Geometry: A generic name for the shape of a part.

Key: To add features to mating parts which locate them together properly.

Parting Line: An area of poor surface finish resulting from seepage between two mold halves.

Shell: To hollow a part out to a certain specified thickness. Some faces may be left open as specified during this operation.

Sprue: The main pathway that liquid casting material travels through before forming a part in a mold.

Vent: Smaller than sprues; these pathways allow for gas inside a mold to evacuate as it is filled.

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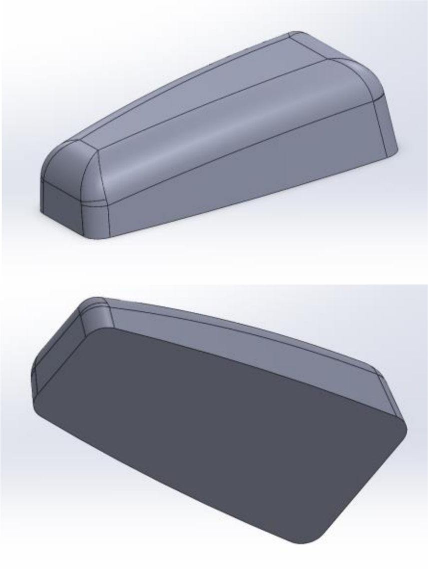
Appendix

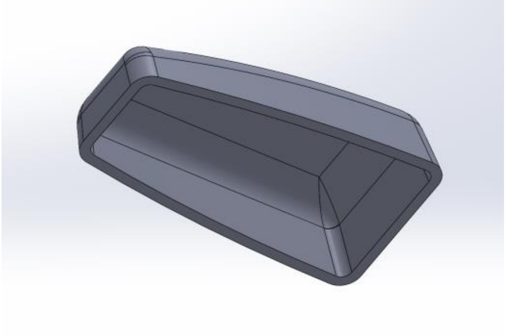
Mold Modeling Procedure:

Step 1:



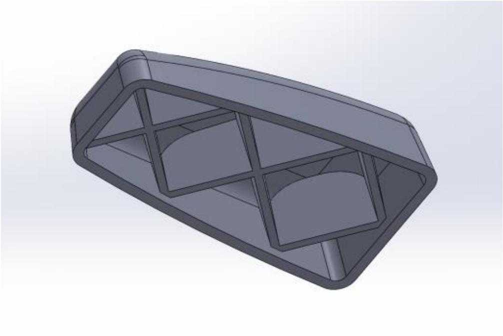
First, the form is established. A generic **geometry** is selected for this test.

Step 2:



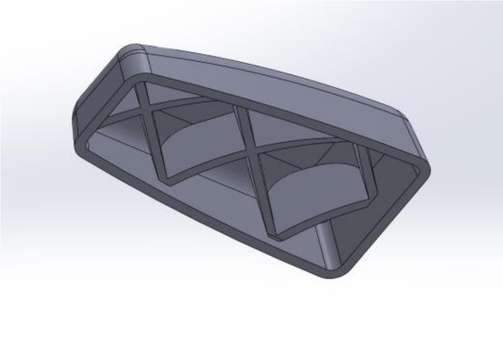
Then, the form is **shelled** to an acceptable wall thickness for the application—.25” in this case. This dimension is selected based on mechanical needs and material limitation.

Step 3:



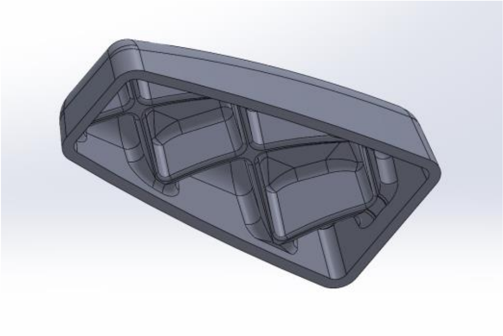
Next, ribs are added to structurally reinforce the form. Without ribs, it would be too flexible and potentially break under load. Typically, rib wall thickness is approximately 50% of the part wall thickness.

Step 4:



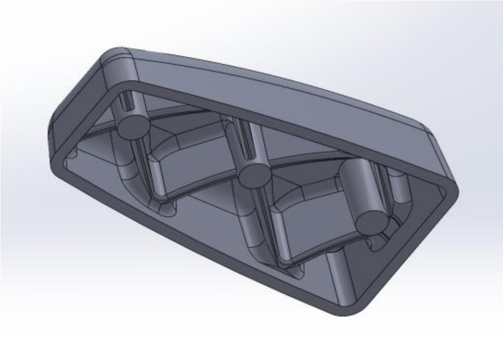
Next, the height of the ribs is reduced. There are several reasons this is done– first, the bottom portion of the ribs are not adding much performance to the structure, and can be considered as waste material. Secondly, reducing the height of the ribs means that the corresponding mold’s features do not need to be machined as deep. This saves machining time and cost.

Step 5:



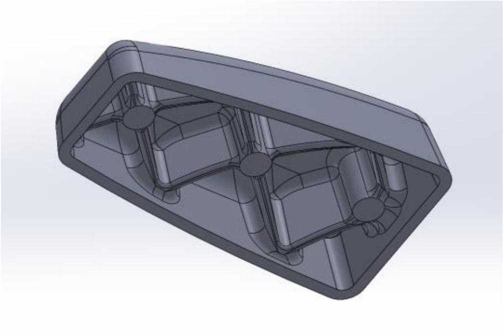
Then, **fillets** are added to the **geometry**. Again, there are several reasons this is done– first, sharp corners lead to stress risers when any load is applied to the part. This means that fractures would be likely to occur in those regions. Adding more material there to spread out the stress reduces the likelihood of fracture. Secondly, the machining of complex curved contours is most easily done with a ball-nose end mill, which leaves behind radiused geometry.

Step 6:



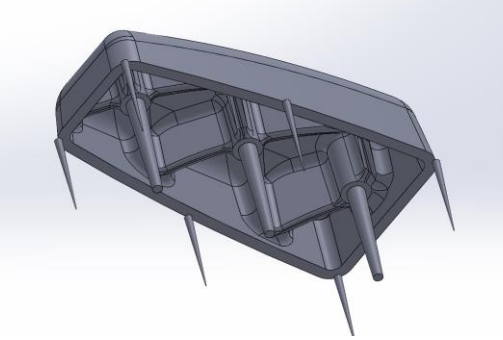
Next, supporting **bosses** are added to the rib geometry. These help reinforce the rib intersections, ease mold machining, and provide a good zone for **gating**– meaning a large, flat surface with minimally critical surface finish requirements. These locations will be where the casting resin will be poured into the mold to form the part.

Step 7:



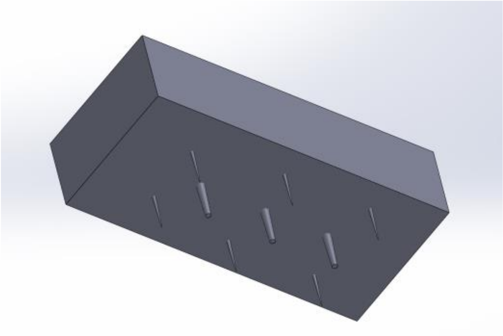
Corresponding **fillets** are added to this new feature.

Step 8:



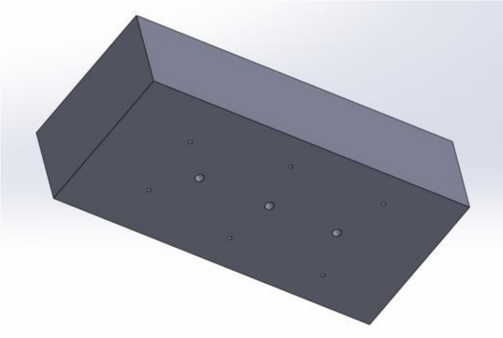
Since this part will be used to make the mold by subtracting its **geometry** away from a block, the **sprues** and **vents** are added. The three larger cones will be used as the tunnels to pour casting resin into the mold void. The six smaller cones are vents, and are used to allow air to flow out of the mold as resin pours in and guarantee that the resin will fill the entire mold. Note that these features, like every other feature in this part, are **drafted** so as to allow part ejection from the mold.

Step 9:



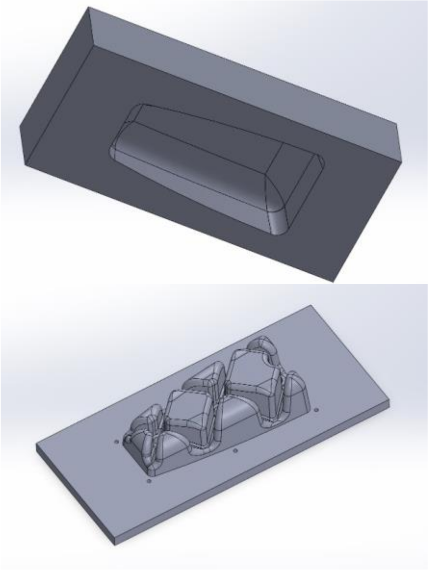
The block that will form the mold is now made over top of the part, ensuring it is fully enclosed except for the **sprues**/**vents**.

Step 10:



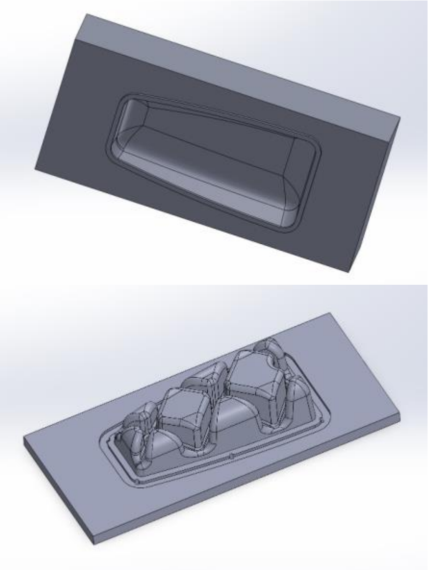
The part is subtracted from the mold block, leaving a negative of its **geometry** inside.

Step 11:



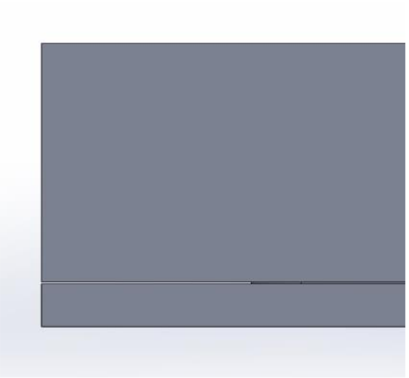
The block is split into two parts, creating a two-part mold so that the part may be ejected after casting. This establishes the **parting line**. The block is split in such a way that the **parting line** will be hidden along the inside corner of the part.

Step 12:



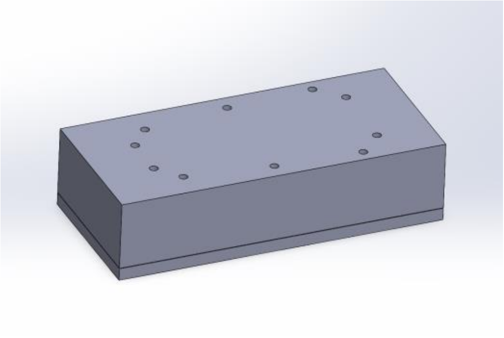
A contour is cut into the bottom mold and extruded into the top mold. This serves the dual purpose of **keying** the two molds together as well as providing a smaller surface area for the clamping pressure to act on, making a tighter seal and preventing leakage of casting resin.

Step 13:



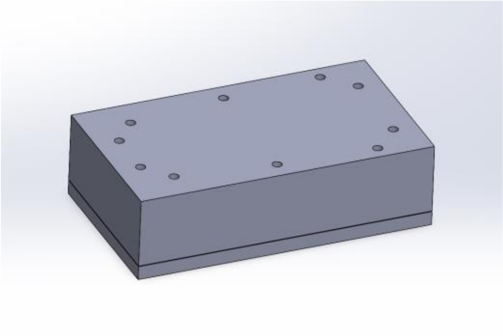
To ensure that the seal receives the compression force from the bolts, relief is added to the non-critical faces of the mold. This also ensures that the **keying** features perform optimally.

Step 14:



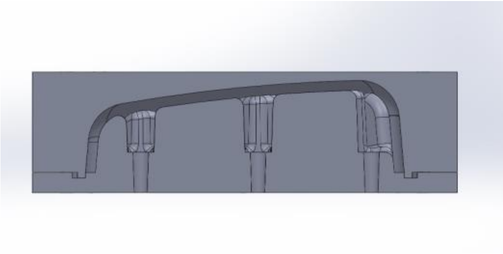
Bolt holes are made that go all the way through the mold. They are placed around the **geometry** in such a way that the compressive force is evenly distributed and optimal in critical areas such as corners.

Step 15:



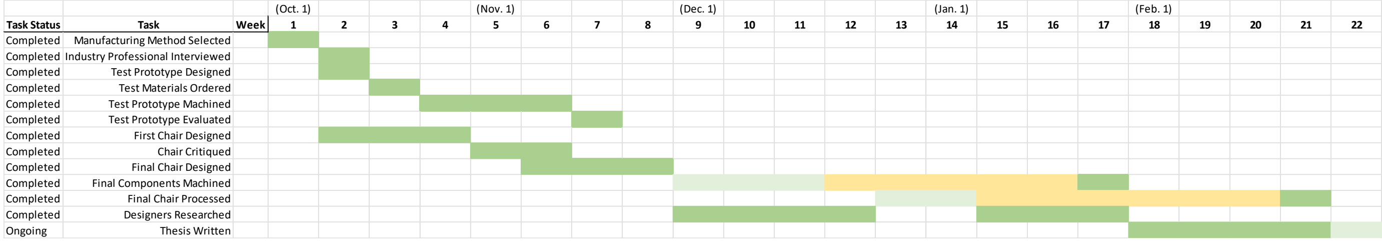
The extra mold material is removed so that each face has a machined, toleranced finish. This is up to the preference of the machinist.

Step 16:



The two-part mold is ready to be manufactured.

Process Imagery:



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Task Status	**Task**	**Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
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Figure 13: Thesis Gantt chart.

Figure 14: Exploring plastic joinery.

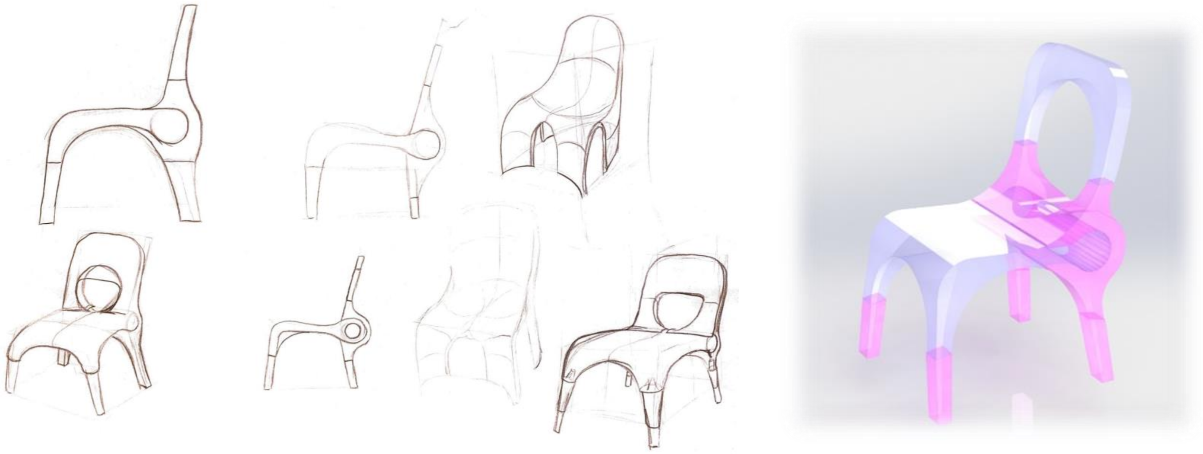

Figure 15: Iterating assembly and using CAD.

Figure 16: Further developing a plastic chair assembly.

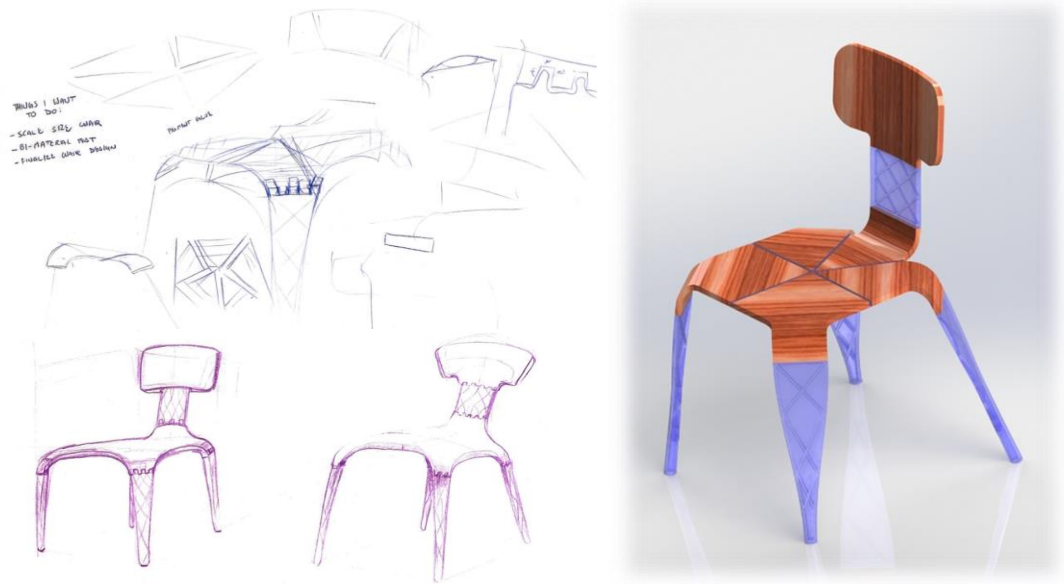

Figure 17: Pivoting to a bi-material chair.

Figure 18: Pivoting to an aluminum frame.

Figure 19: Defining a ribbing system; finalizing chair design.

Mold Design:

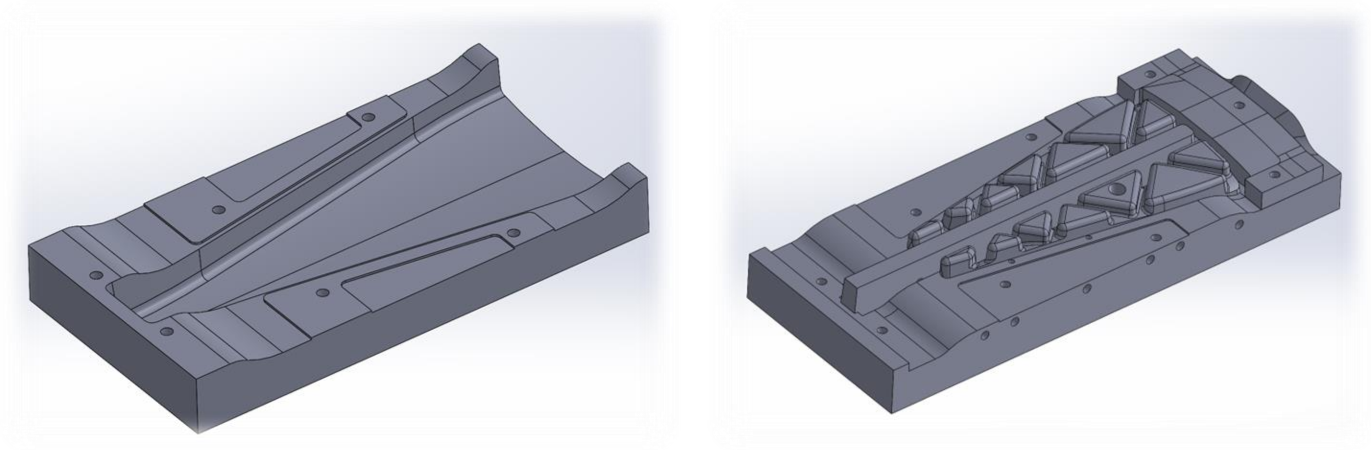

Figure 20: Leg mold.

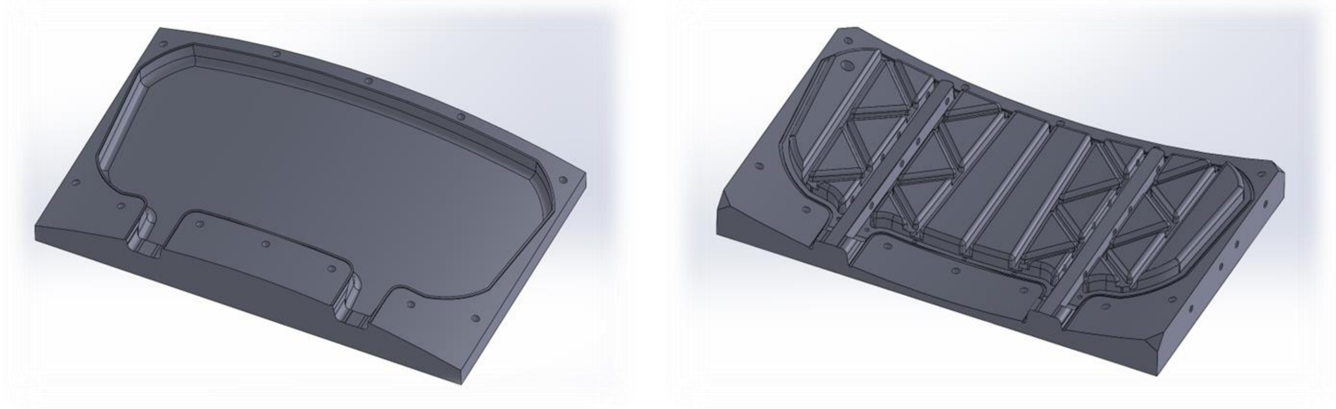

Figure 21: Seat back mold.

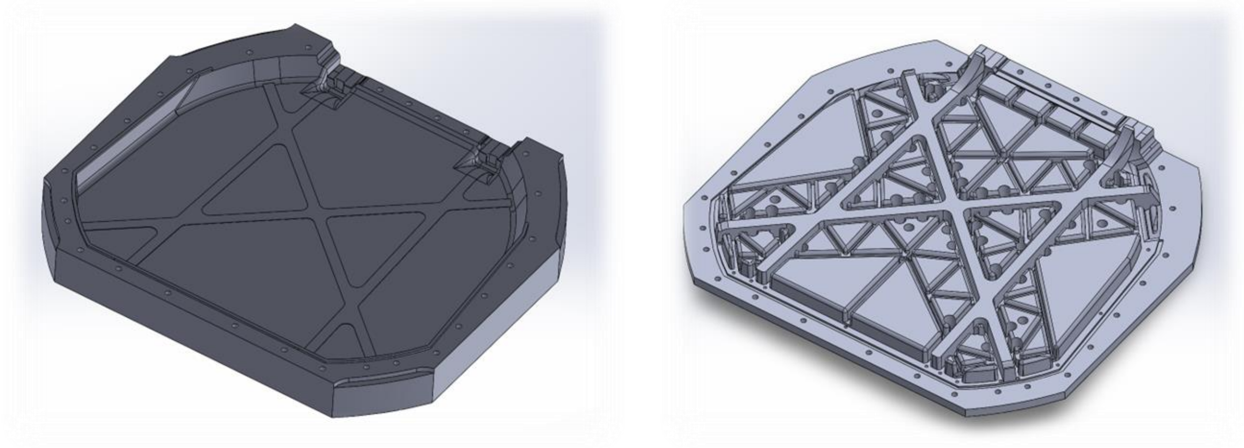

Figure 22: Seat pan mold.

Selected Snapshots:

Figure 23: A fiberglass-insert pour from the process test mold.

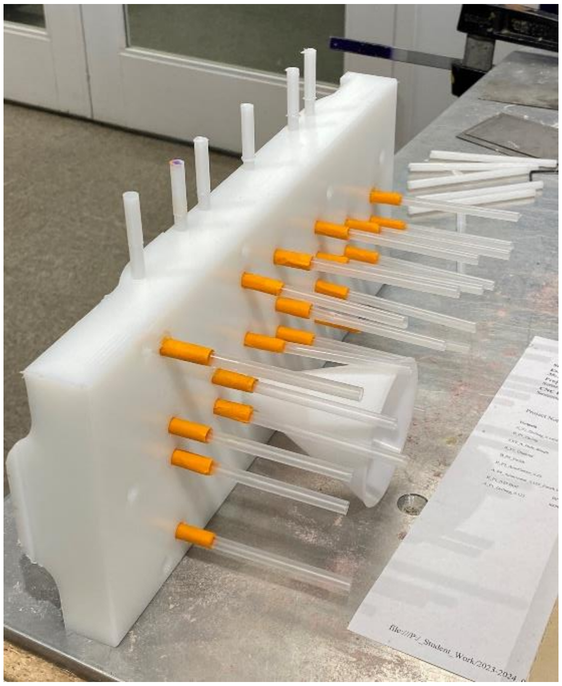

Figure 24: Inserting mold cores, risers, and pour cup into the leg mold.

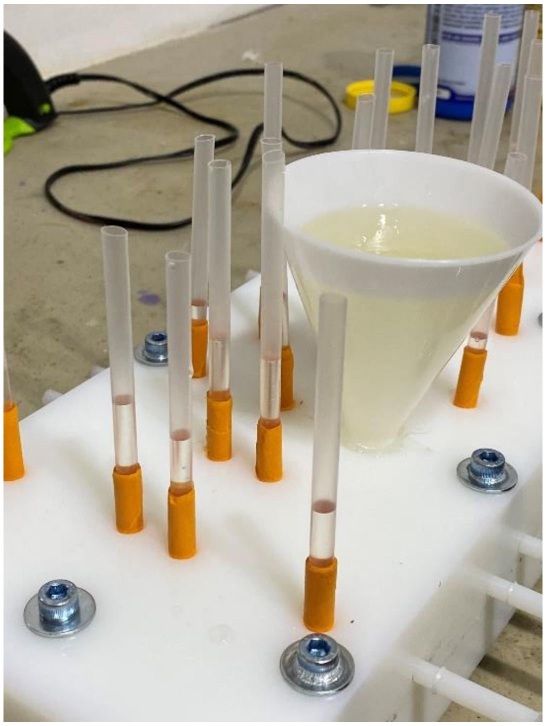

Figure 25: The leg mold after pouring.

Figure 26: Machining the seat back mold.

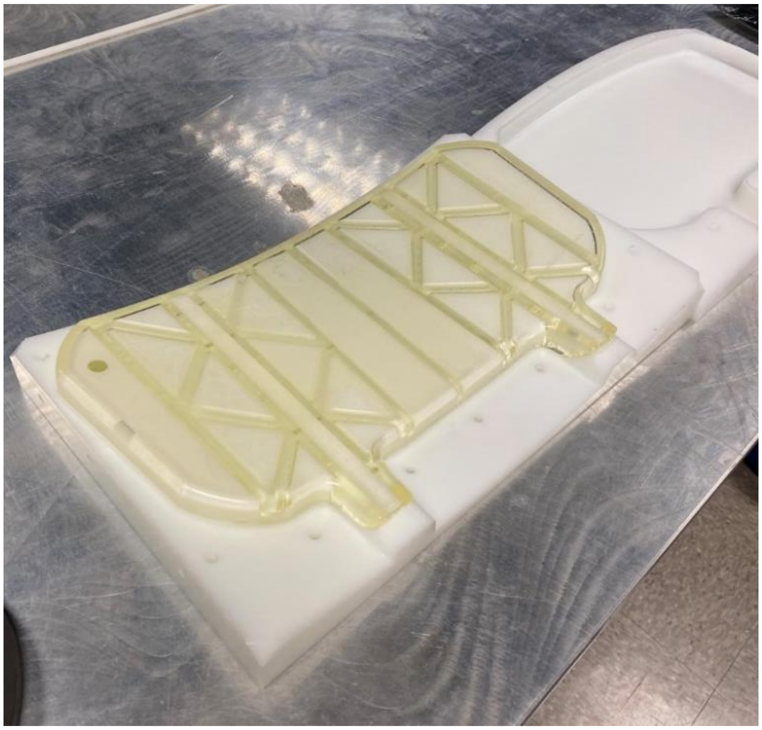

Figure 27: A seat pan during de-molding.

Figure 28: Machining the seat pan mold.

Figure 29: Nearing final chair assembly.

Figure 30: Documenting the final chair in the DAAP Photo Lab.