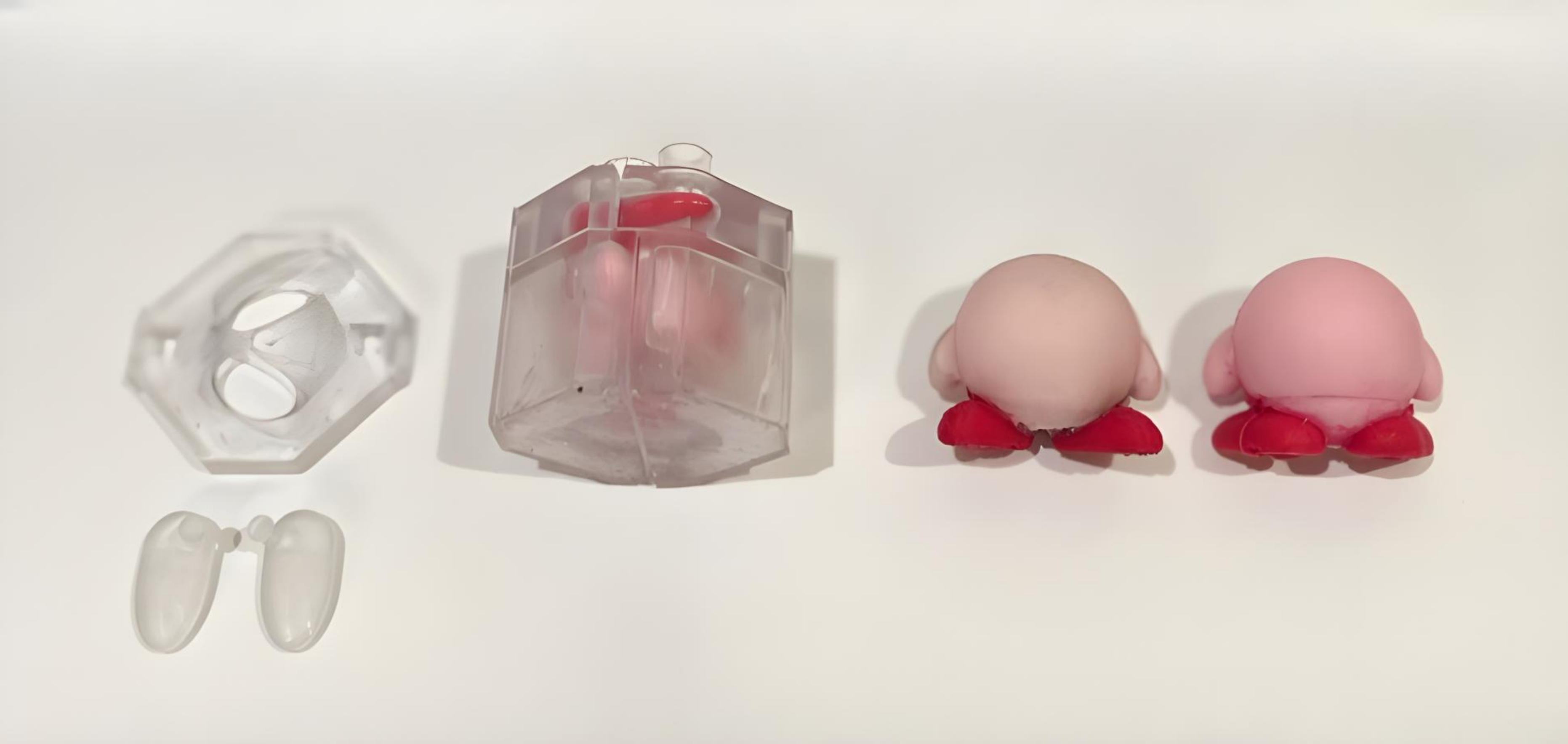
PROJECT 4:
KIRBY SILICONE MOLD



TRISTAN LINN

Background

Background:

1. Design a fixture or tool that takes advantage of AM in support of another manufacturing process.

2. Design or redesign a part into one that utilizes shape optimization, generative design, or latticing to improve Strength/Weight ratio or other characteristics without sacrificing performance.

Problem:

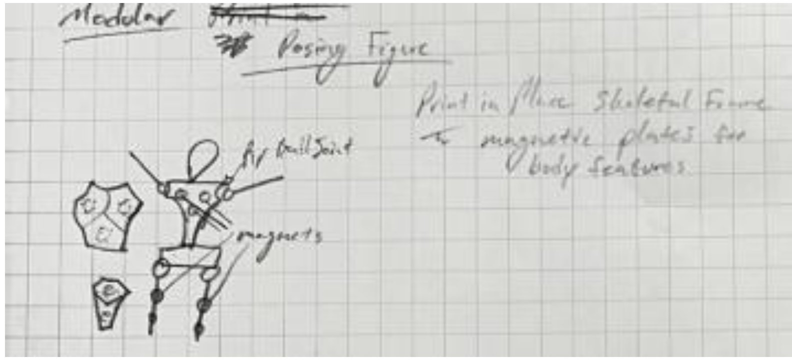
Design a fixture or tool that takes advantage of AM in support of another manufacturing process and use shape optimization, generative design, or latticing to improve performance.

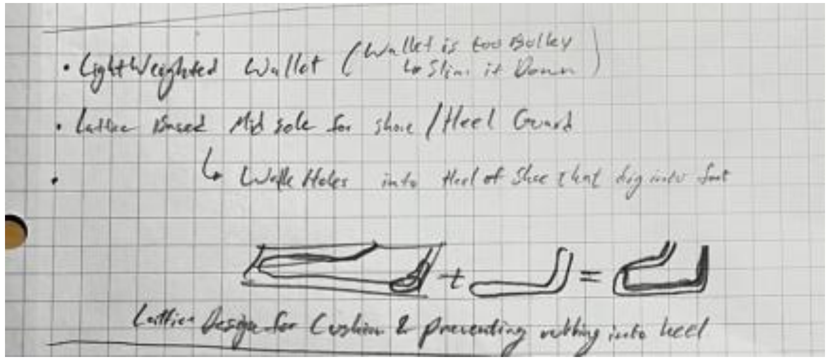
Project Prompt Ideation

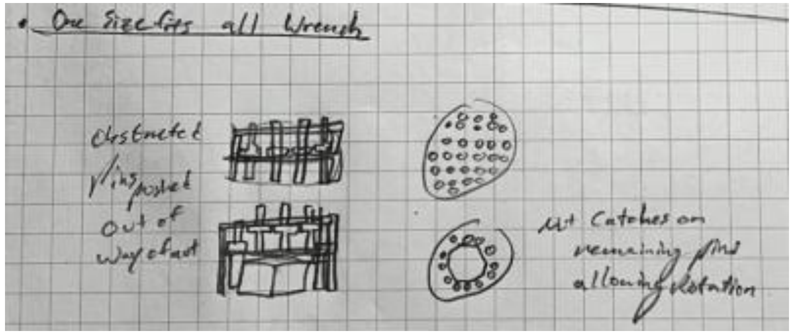
Here are some of my initial ideas that leveraged Additive Manufacturing Techniques and generative design or shape optimization.

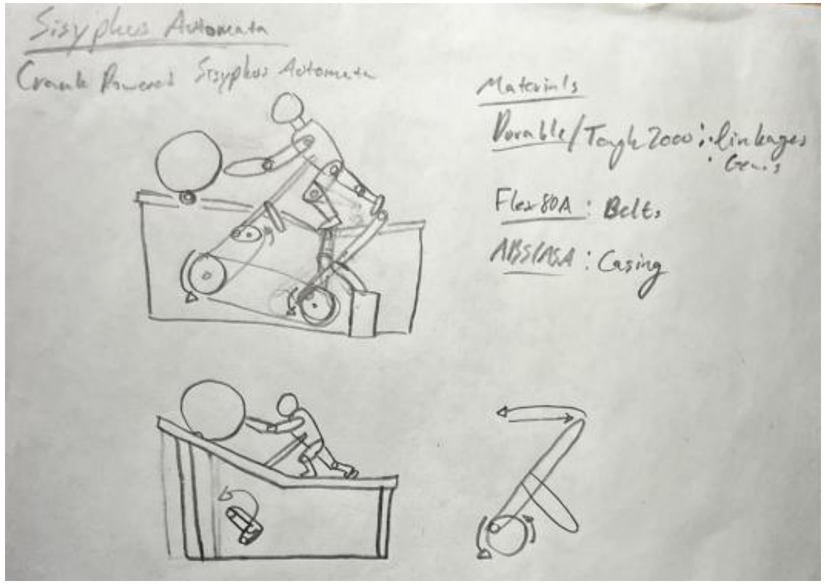
These ideas were weighed against the project prompts, looking for projects that had purposeful optimizations and evident use of AM techniques, with equivalent self motivations for completing the project.

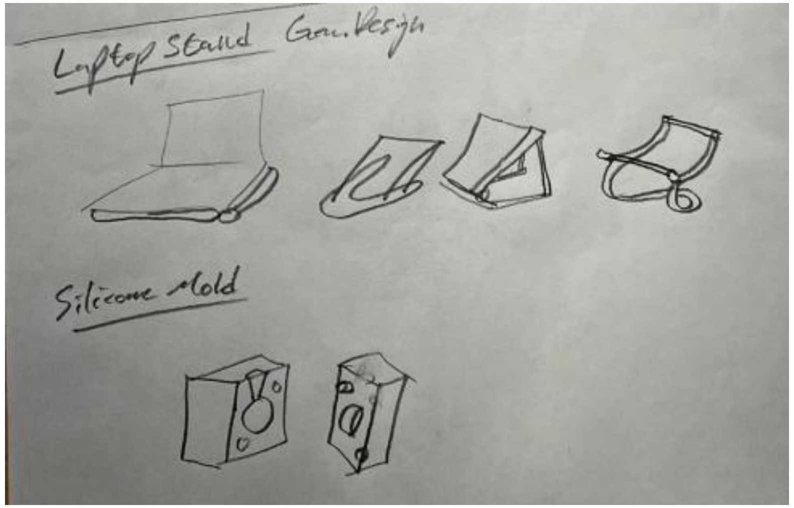
For these reasons, the primary candidates were a modular posing figure, a laptop stand, and stamp embossing.











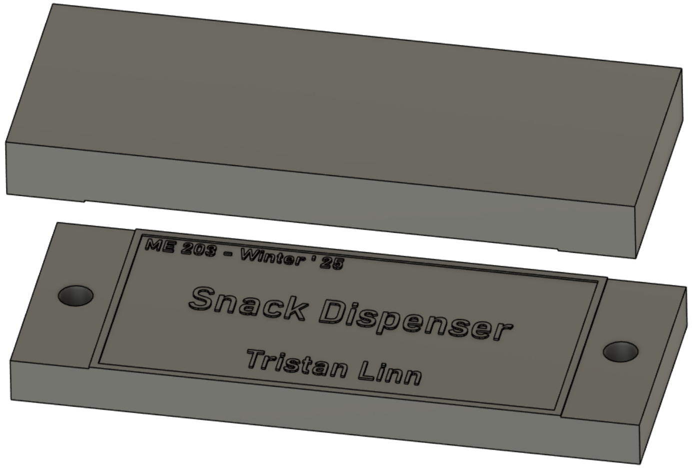
Project Prompt Ideation

All top candidates were explored, and the following were determined:

- The modular figure showed sufficient AM techniques but not enough optimization cases.
- The Laptop Stand had potential optimizations, but no interest in the project.
- The Stamp embosser / coin minting were sufficient in optimization methods and AM design, but insufficient drive behind the project.

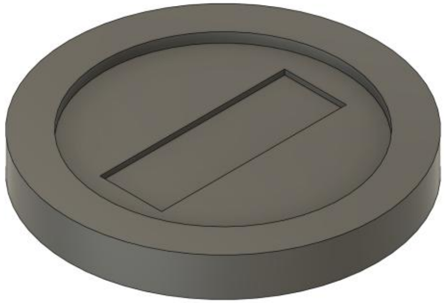
Magnetic Modular Figure

Sheet Metal Stamp / Embosser



Laptop Stand Generative Design

Coin Minting



Project Definition

After candidates were explored a final candidate of silicone molds was chosen as an ideal project satisfying all three project constraints: AM utilization, Sufficient Optimization Cases, and Project Motivation.

Chosen Project Background:

Utilize AM and optimization techniques to support and explore the manufacturing process of silicone mold making and pouring.

Silicone Part from Printed Mold

Problem Statement

Problem:

I want to explore the process of silicone mold making, creating a multicolor silicone part. I am also a fan of Nintendo videogame characters and want a figurine for my desk. This problem is one of an explorative project, learning about silicone mold making, and finding a solution that can support multicolor silicone pouring and is sufficiently satisfying for the end user (myself). For these reasons, the character Kirby was chosen for silicone molding, due to its two-color design, simplistic geometry, and utilizing the fact that both Kirby and silicone are elastic (squishable).

Problem Statement

Design Function:

Design an additive manufactured pouring mold that is used to cast a multi-color silicone figurine.

Design Intent:

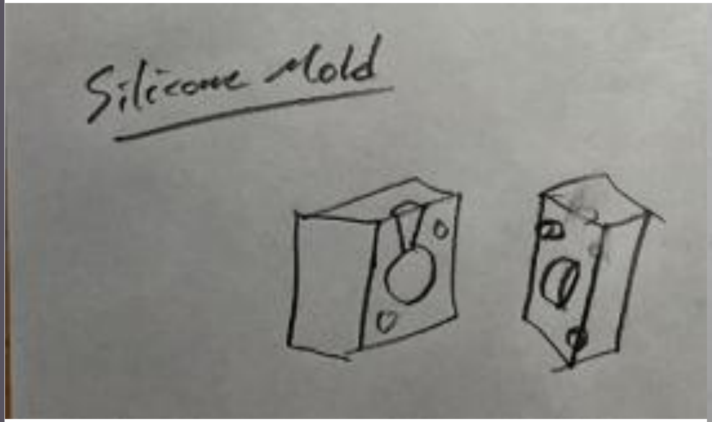
- Utilize Shape Optimization to reduce the volume of the mold, lowering the cost to print.
- Design for the use case of two silicone pours for two different colors.
  - Modular Mold Pattern that is relatively easy to remove and install.
- Final mold should resemble the character Kirby in shape and color.

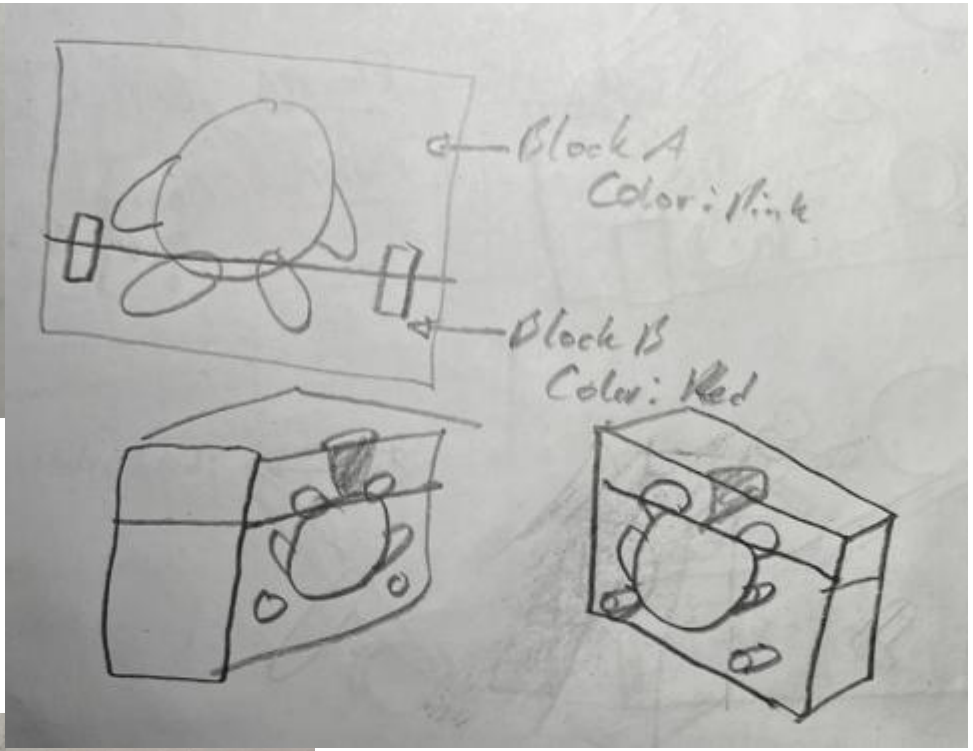
Since the project is open ended and to reduce the cost of printing the figure size of 1inch was chosen as a 1/8th scale model of Kirby.

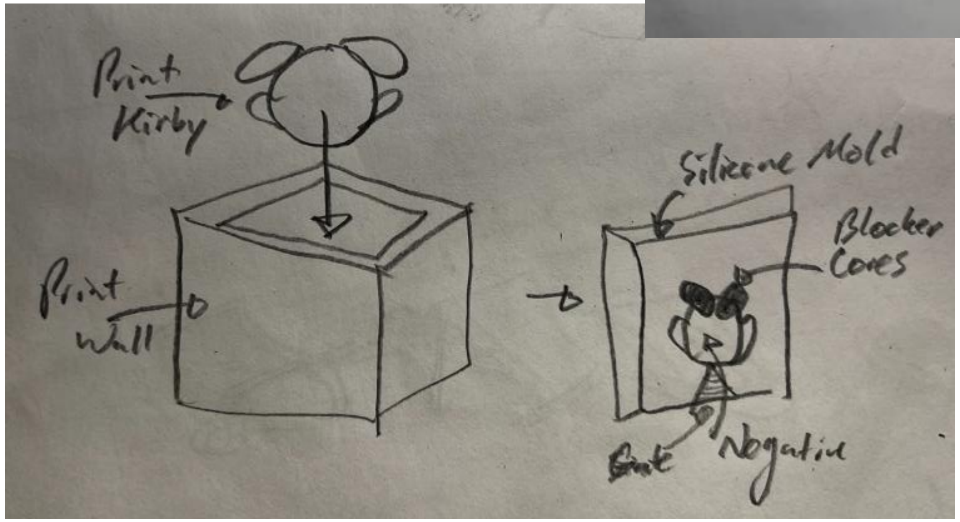
Conception

After ideation, it was decided that to satisfy the optimization use case requirements the mold itself would need to designed and printed. This involves designing a modular multistage mold to achieve the two-color design requirement.

Using AM allows for a customized parts with complex manufacturing geometries to perfectly match the desired character to be created







Use Cases

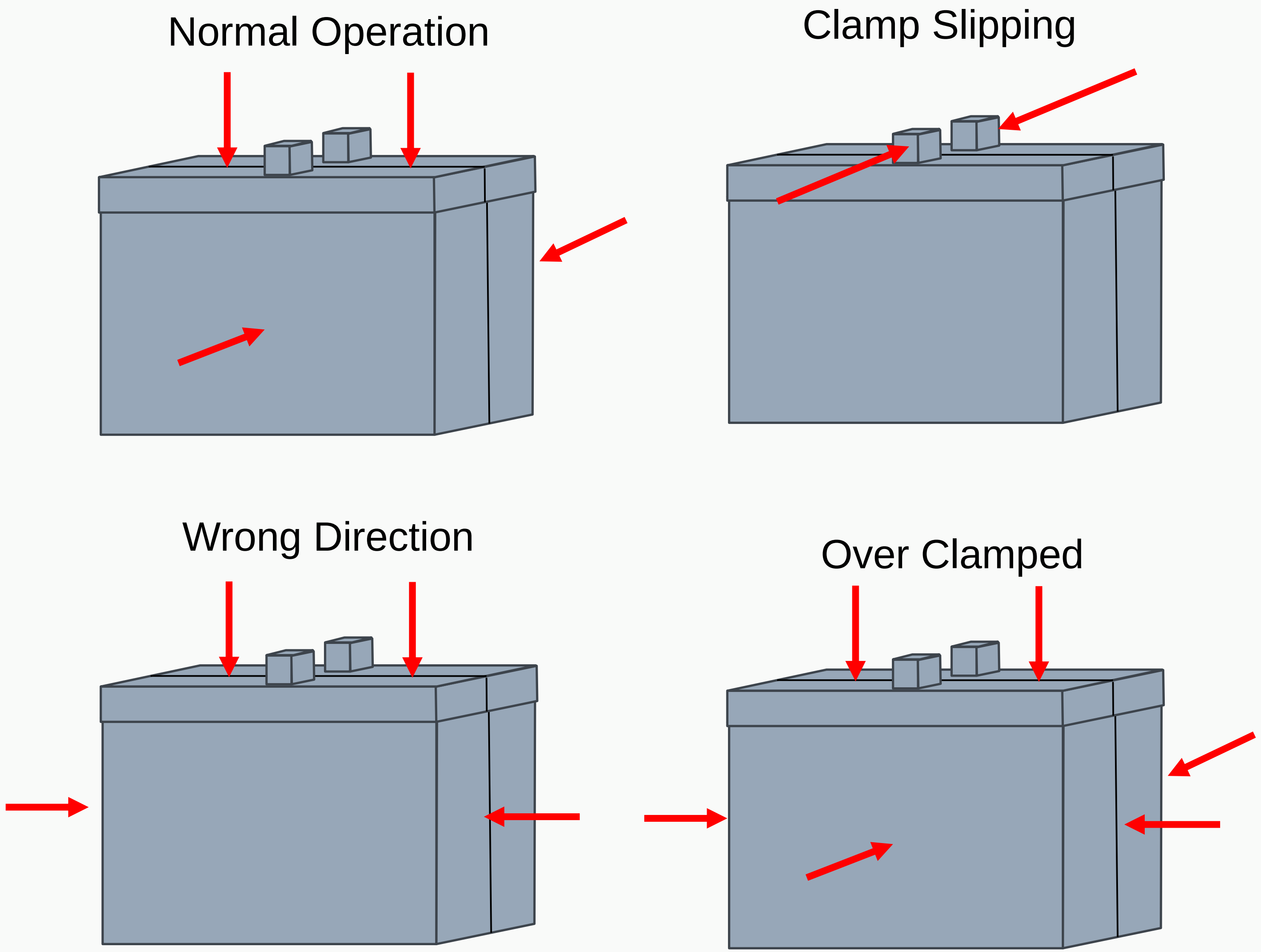
During operation there will be two primary clamping forces

- One from the flat side without seams and one from the top of the mold.

Improper use cases are as follows:

- Clamping in the wrong direction (on seam)
- Clamping from both directions (Over Clamping)
- Clamp Slipping and applying load on guide pins.

All Clamping loads were taken as 20 lbs. This force is an overestimate for sufficient mold clamping. (Only need enough force to keep mold immobile during curing process.



Material Analysis

Due to the low forces and stress incurred during operation a **focus on utility** was used during material selection, with an **emphasis on bearing able to see inside the mold** to verify if air bubbles or pockets formed.

To this end both Clear and Durable Resin were considered. Tough 2000 and PLA are used as a baseline references.

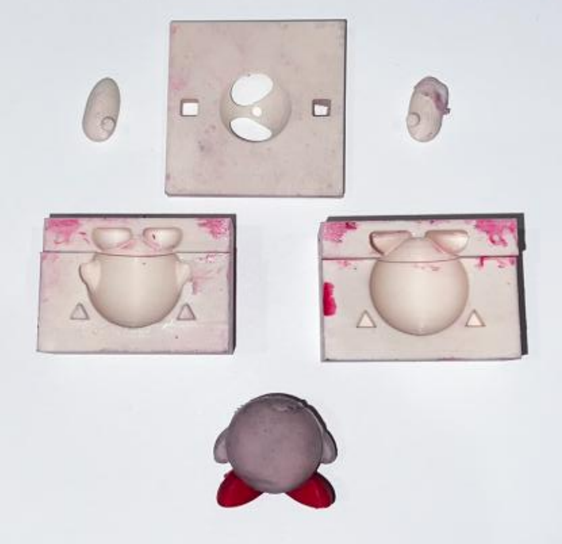
The material selected was **Form Labs Clear Resin** for its ample strength, rigidity, cost, and more importantly its Clear transparency.

Durable was not chosen, despite being more flexible in case of misuse, due to its translucency. It was also discovered during prototyping that clear was sufficient to withstand clamping forces without being too brittle.

For all silicone pouring, **Smooth Sil 940** was selected for it's shore hardness A of 40 allowing a firm yet soft squish to the figure, as well as having a base color of pink, matching the character.

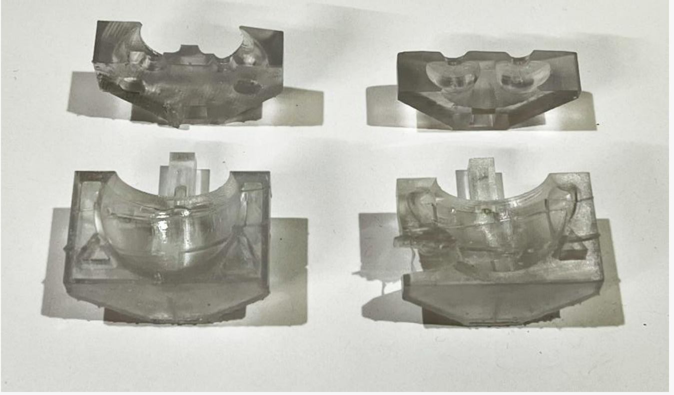
	Clear	**Durable**	**Tough 2000**	**Basic PLA**
UTS (MPa)	60	28	46	31
Flexural Strength (MPa)	105	24	65	76
Elongation at Break / Max Deformation	8%	49%	48%	12%
Transparency	Clear	Translucent	Opaque	Opaque
Cost	\$0.14/mL	\$0.28/mL	\$0.28/mL	Free (<\$3/120g)

Prototypes



<u>PLA Proof of Concept</u>

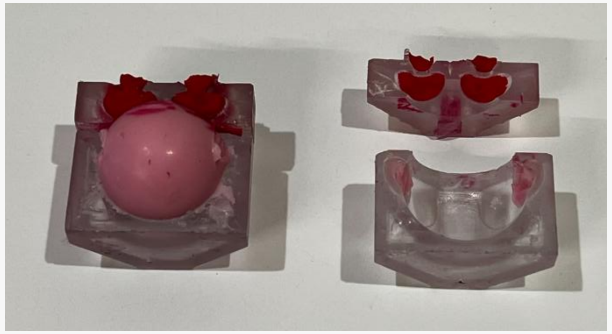
- Not enough clearance in Guide pins (0.005 in)



<u>Clear V1</u>

Print Fail on Manual Hollow due to no internal support

- Tolerance cleared for square peg (0.01 in); triangle peg not cleared (0.01in)

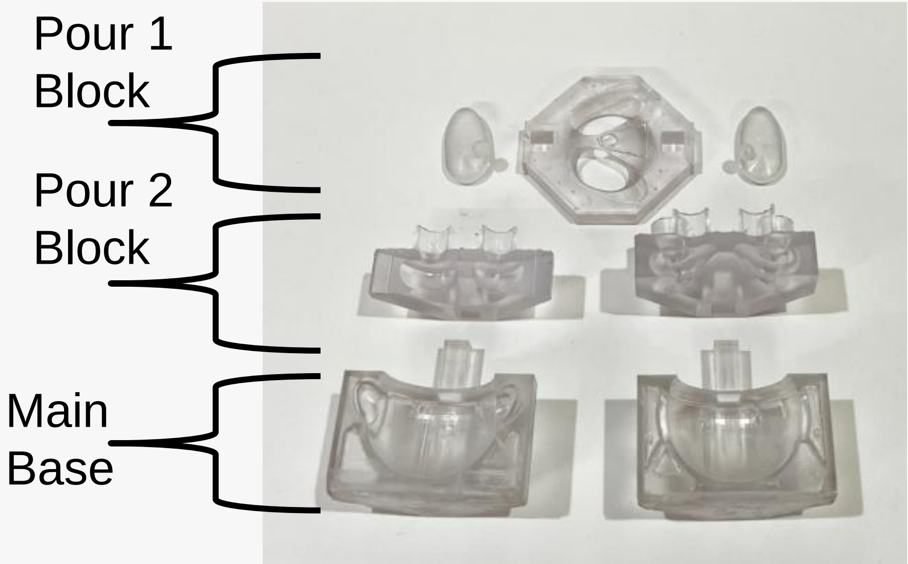


<u>Clear V2 and V3</u>

Tolerance of 0.02 in matched for V2 and V3.

- V2: Used Preform Hollow to print.
- V3: Pouring Basins were added to allow for excess silicone to pour into mold during settling and curing.
- **No Demold Spray was used, and parts could not be recovered.**

Prototypes



<u>Clear V4 (Success)</u>

- Used Internally Supported Hollow
- Seamline created was due to insufficient silicone during pour / leakage and not enough clamping

<u>Clear V5 (Success*)</u>

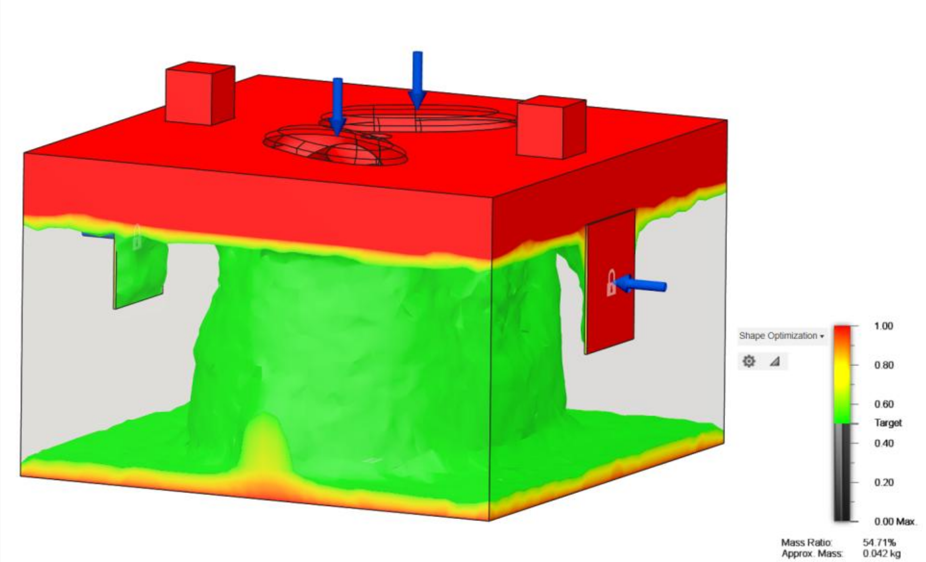
- Success with sufficient silicone in body. Insufficient Silicone added in shoes due to forcing a misorientation of Part
- *Triangle Peg to main body snapped during assembly

<u>Final Prototype</u>

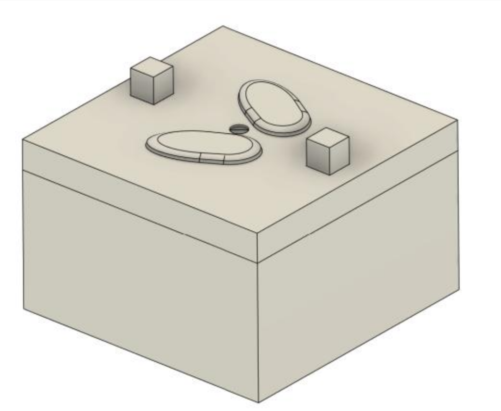
- Triangle Alignment peg reduced two one peg to avoid over constraint. One pin and the flat face is sufficient for alignment when using a clamp.
- Reused V5 Pour 1 Block.

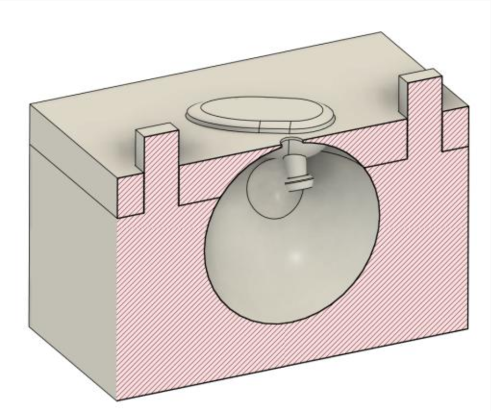
Design Iteration – Shape Optimization

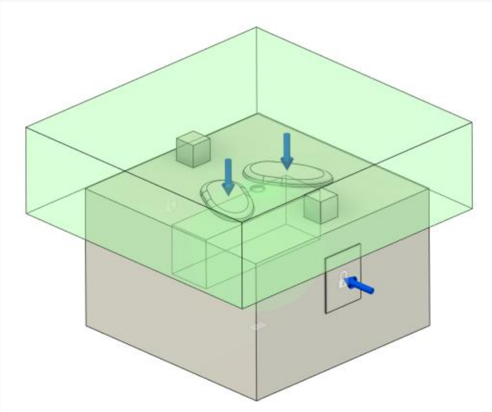
A Shape optimization study was run to find how much material could be removed from the PLA Prototype before printing in Clear Resin on the Form 4. The Normal Operation Case load was used with a 10lb clamp load, resulting in over 50% volume reduction and evidence that both the base and clamp surfaces can be moved to the outer wall surface of the Main Base Geometry, baking in the flat feature geometry.

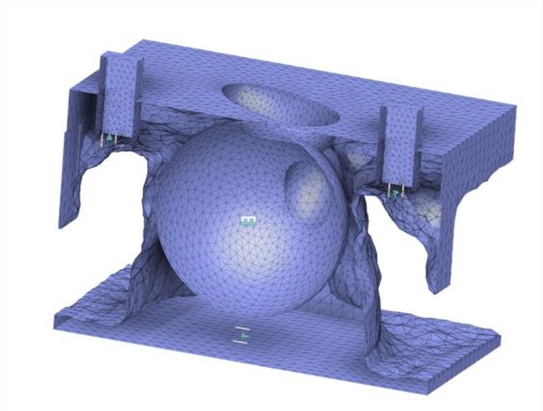


- The Central Pillar of the optimization was taken as inspiration for future prototypes V2+





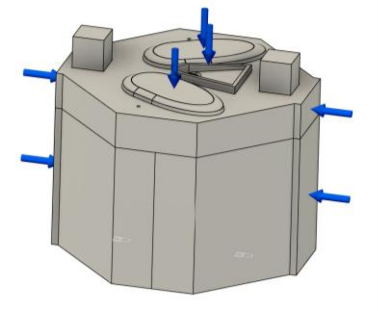




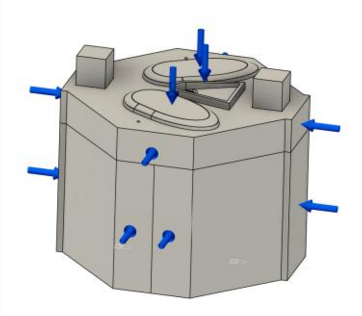
Design Verification – Simulation

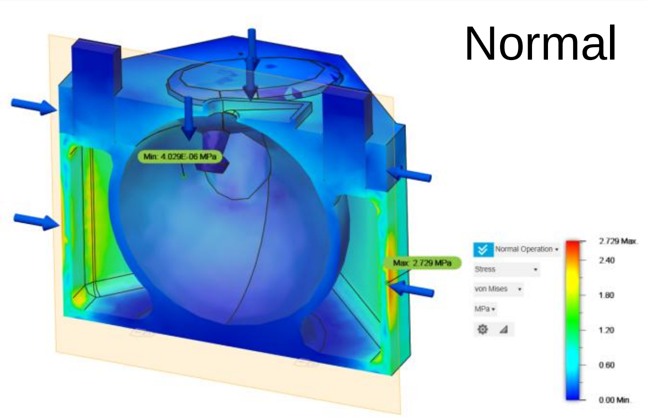
A Simulation was run in the pour one configuration through all four use cases (correct and improper). All clamp forces were of 20lbs. **Overall Factor of Safety was 12+. Maximum Stress of 8 MPa and Deflection of 0.016mm.** The mold can withstand the clamping force needed for pours with deformation and reusable for multiple pours.

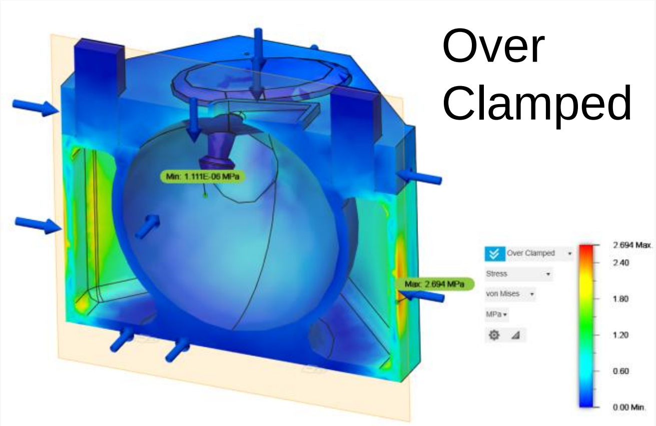
Normal



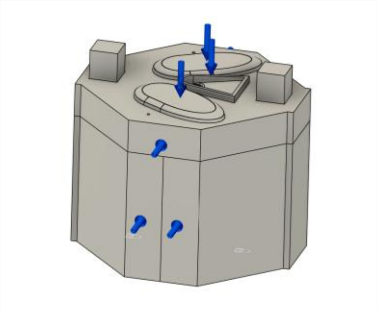
Over Clamped



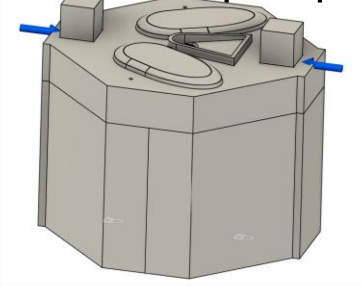


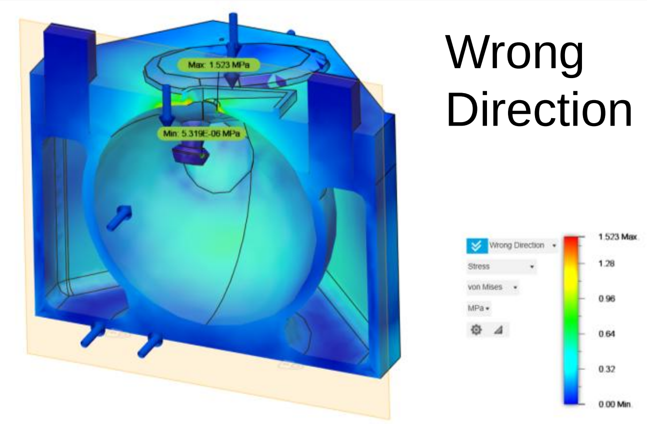


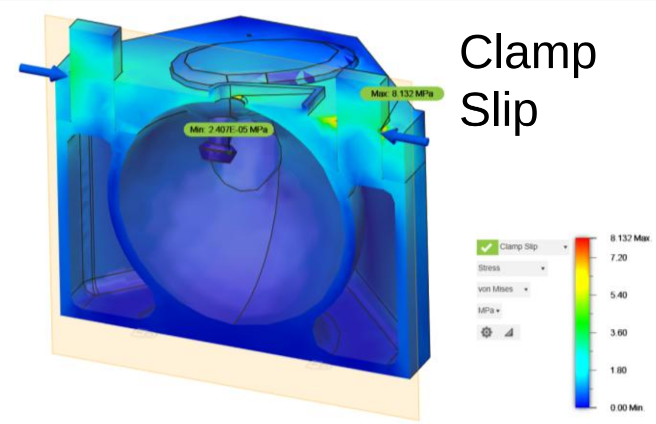
Wrong Direction



Clamp Slip

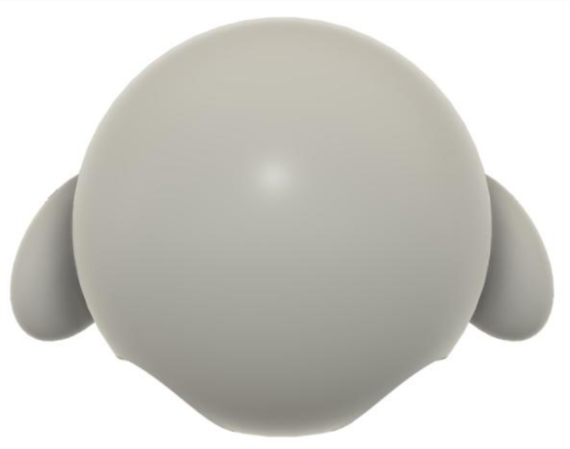


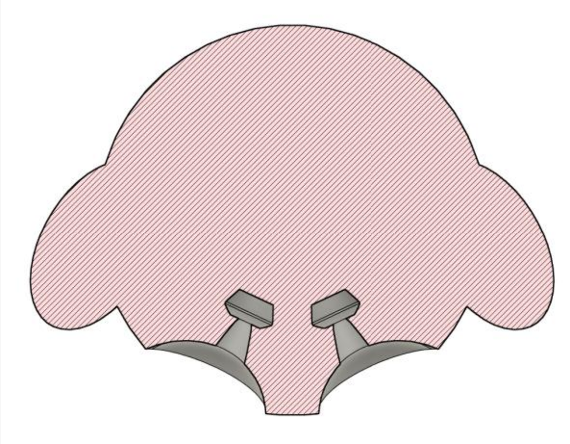




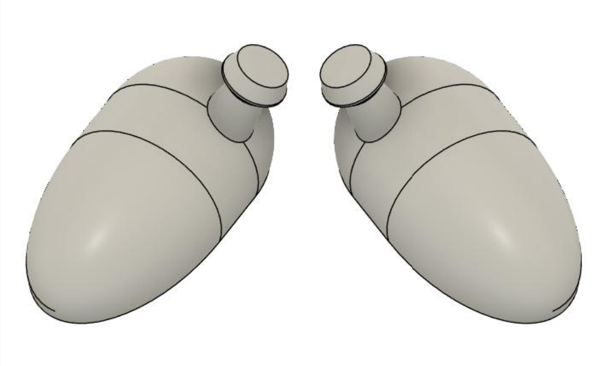
CAD Screenshots - KIRBY

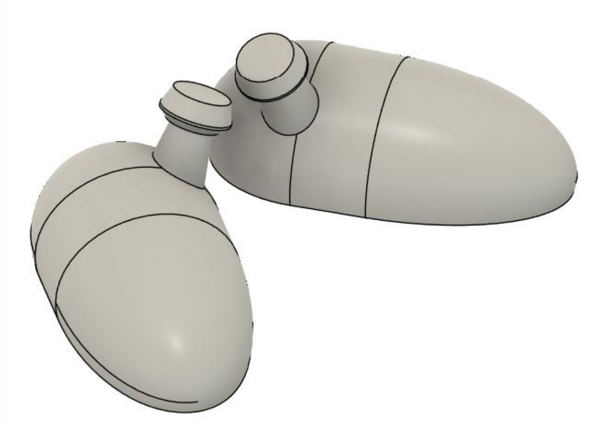
Main Body



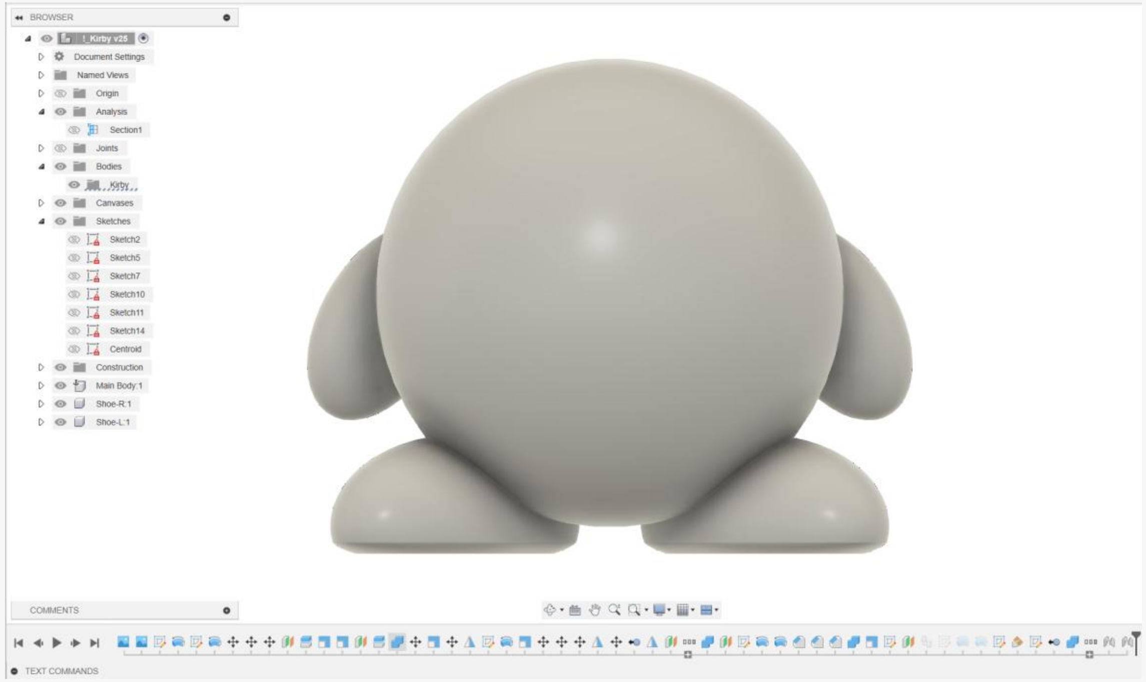


Shoes



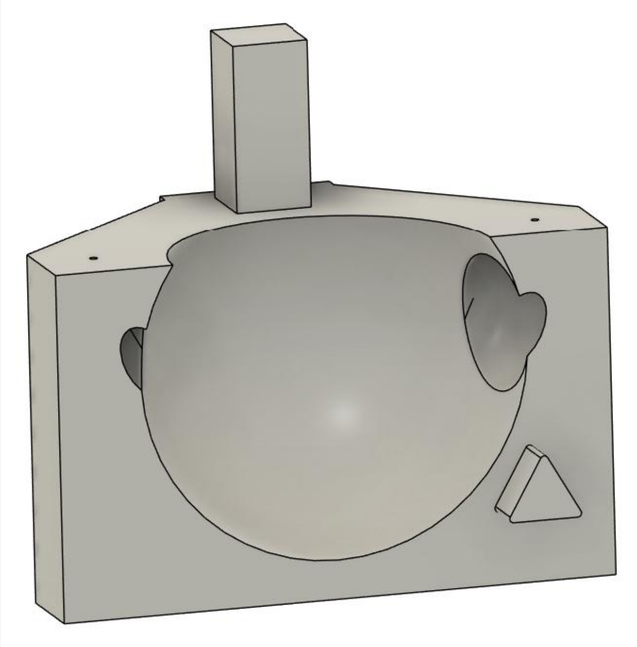


Kirby

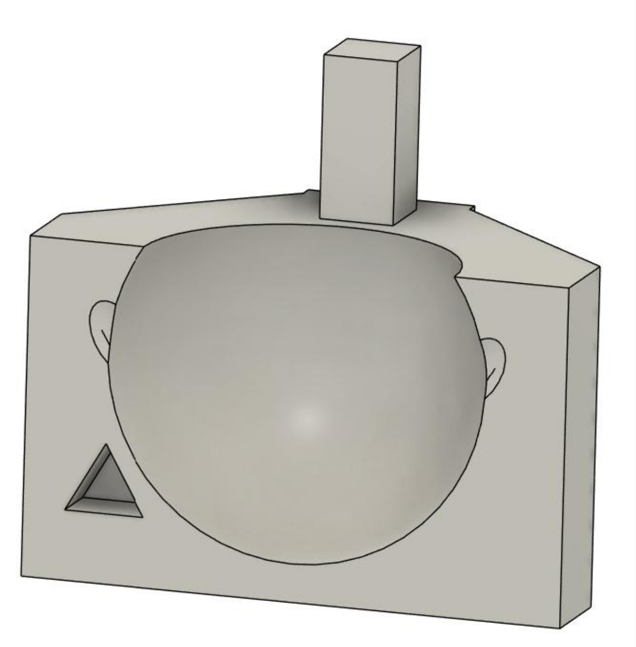


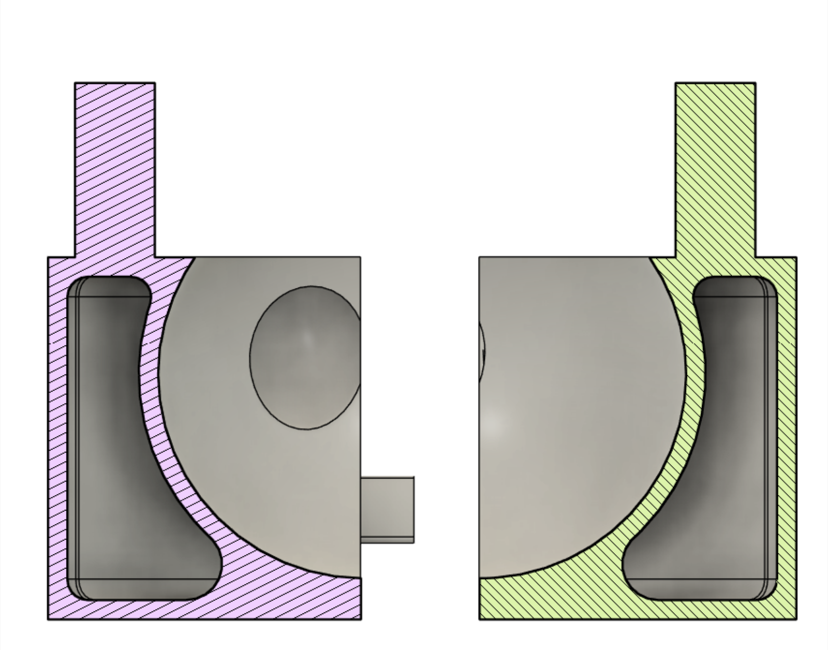
CAD Screenshots – Main Base

Base A



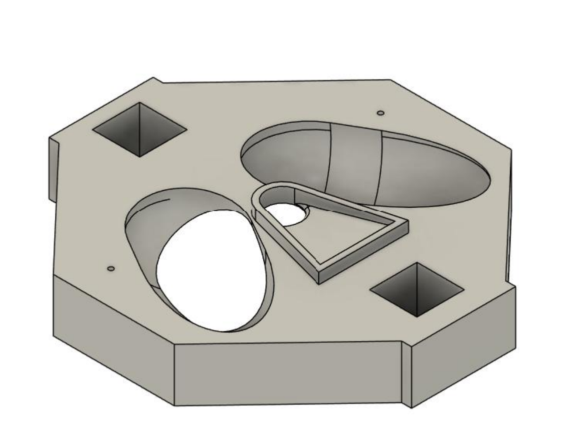
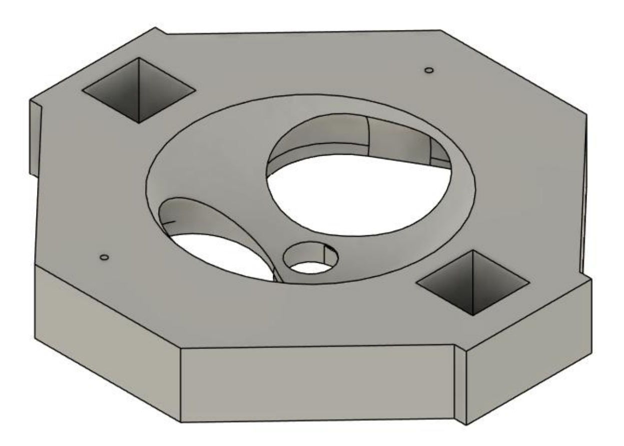
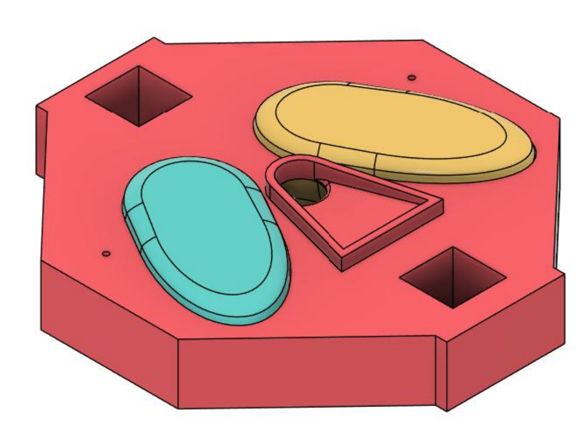
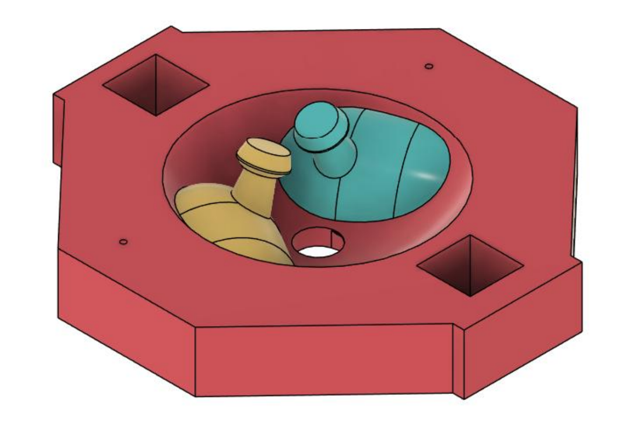
Base B



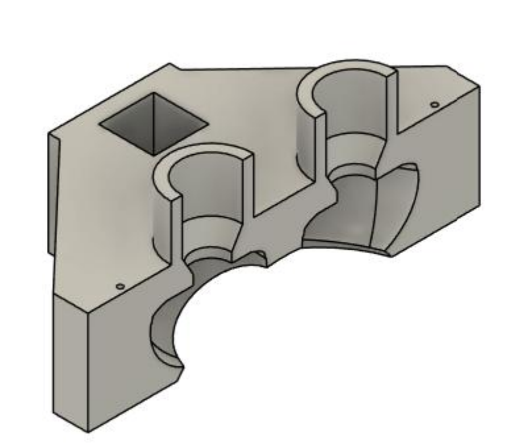
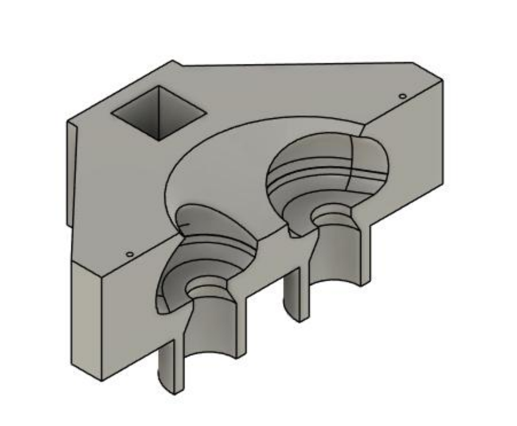


CAD Screenshots – Pouring Blocks

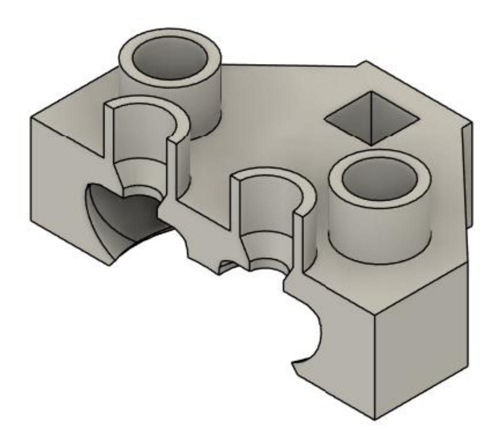
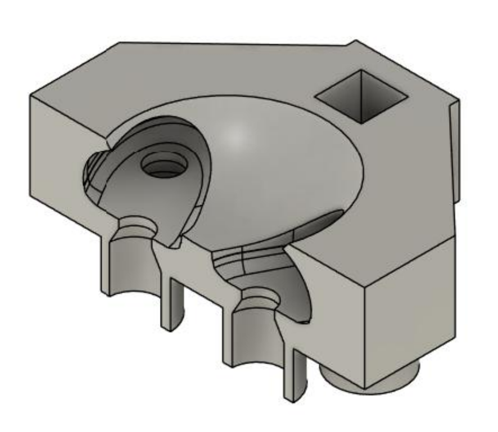
Pour 1 Block

Pour 2 Block A

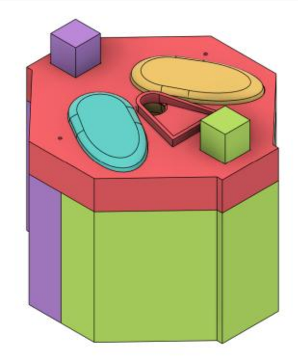



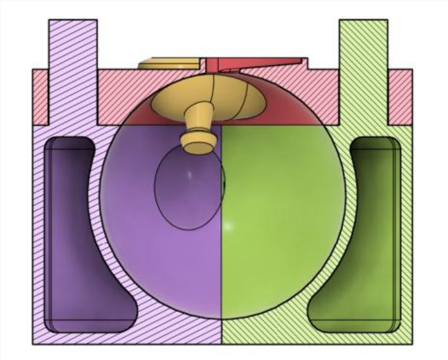
Pour 2 Block B

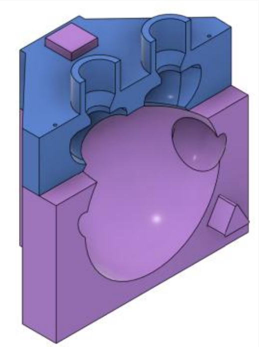
CAD Screenshots – Pouring Blocks

Pour 1

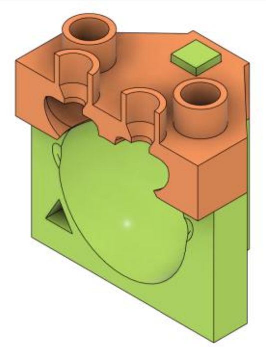




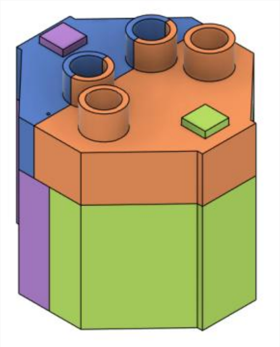
Pour 2 - A

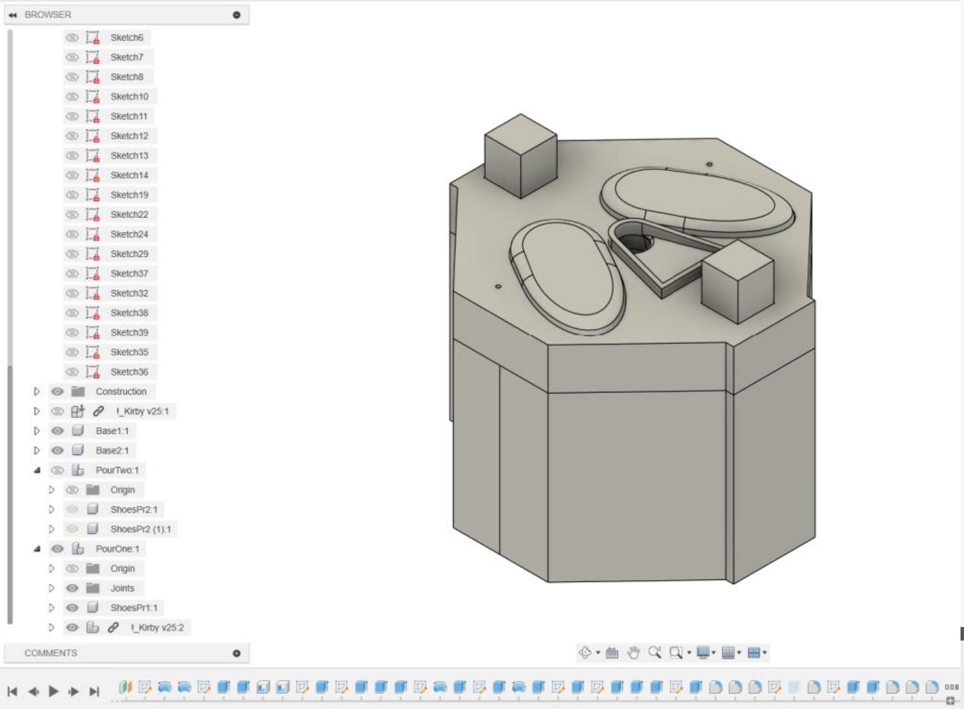


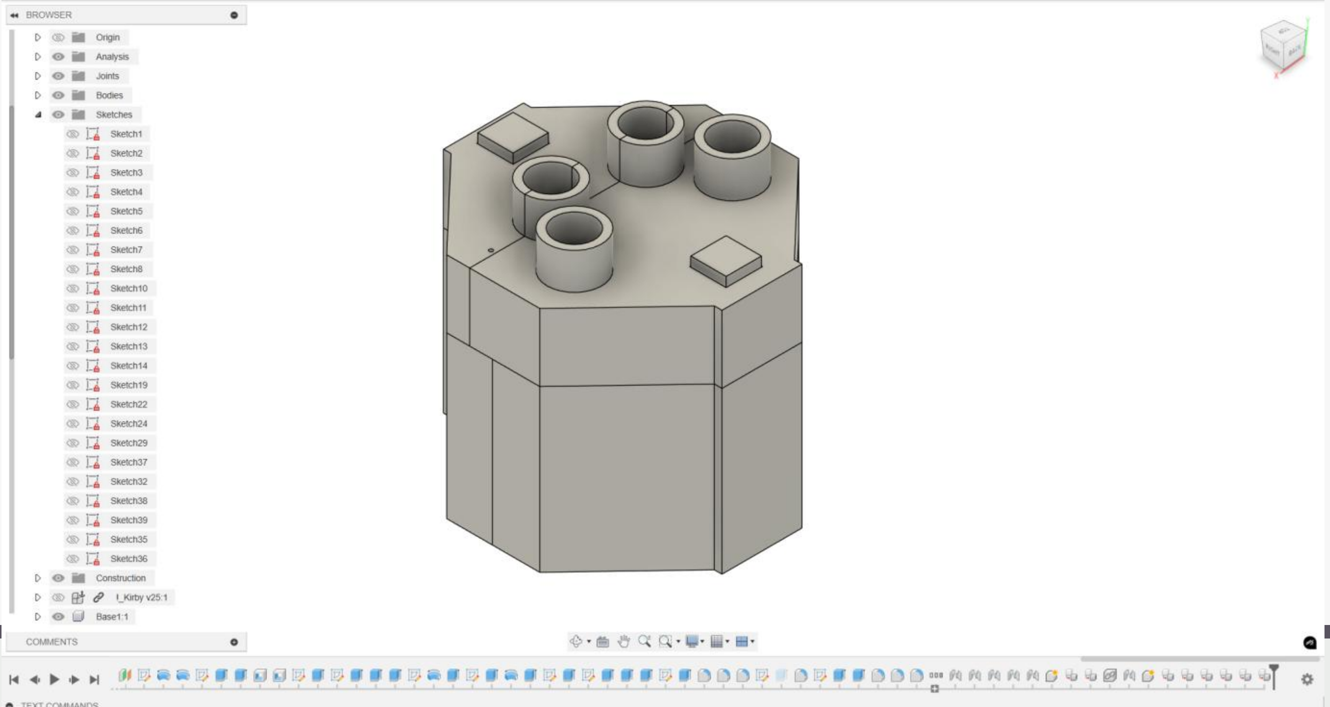
Pour 2 - B

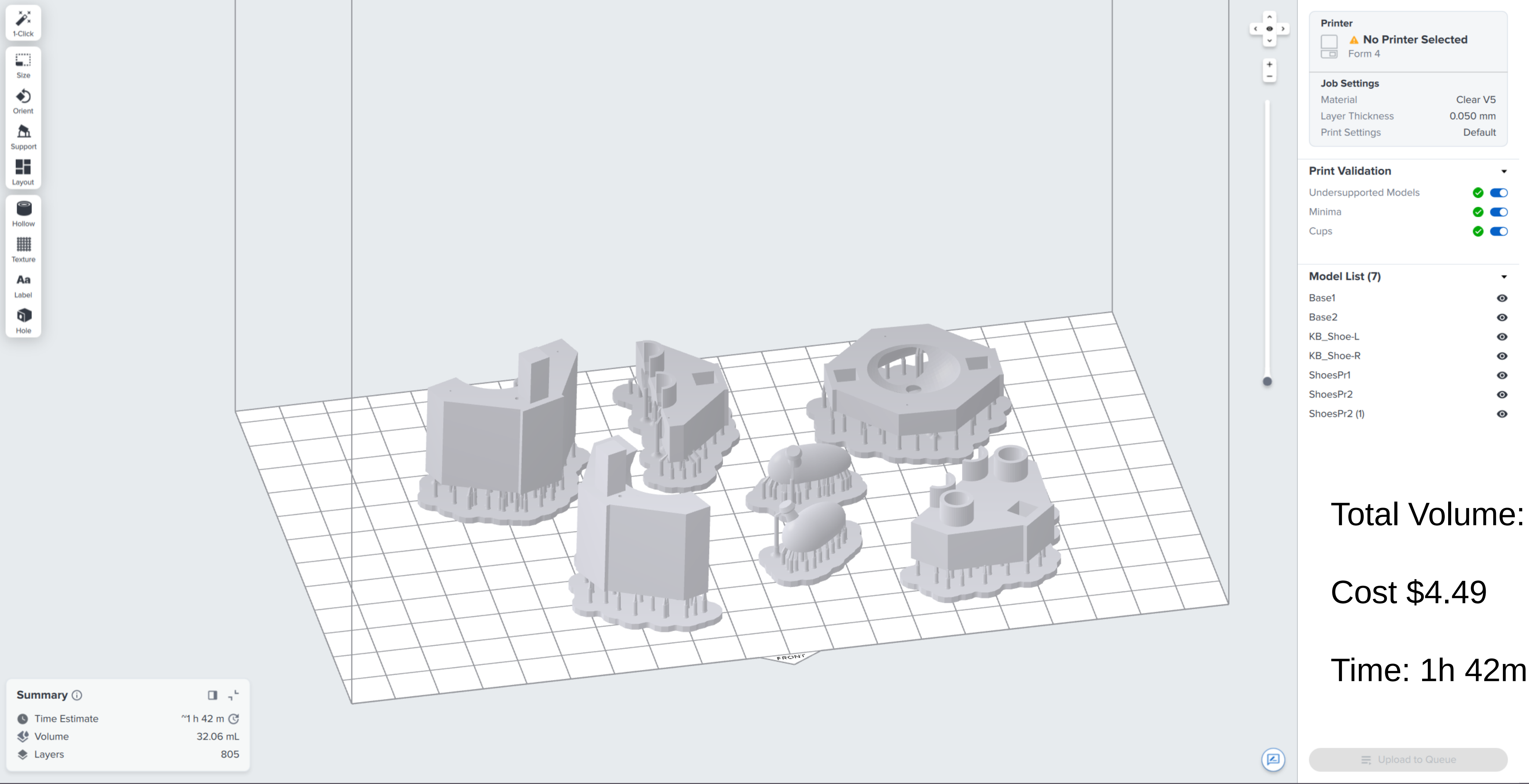


Pour 2









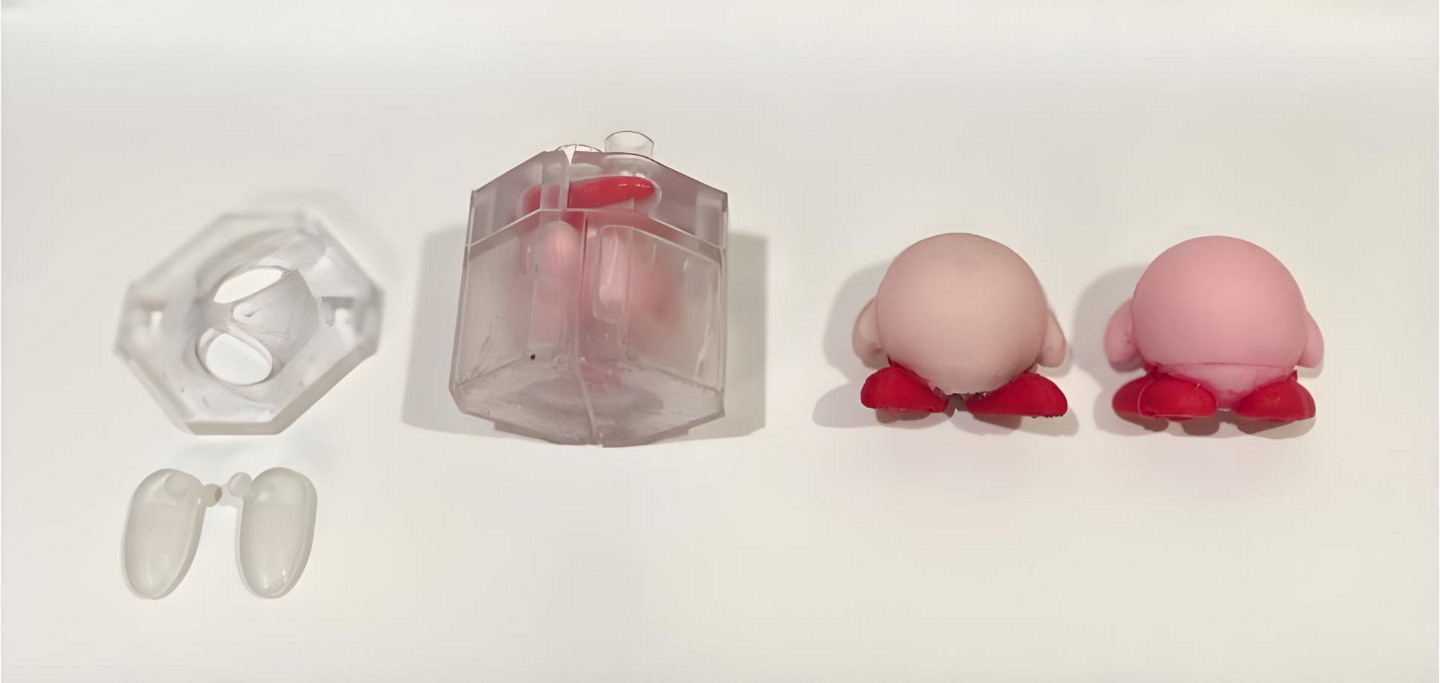
Total Volume: 32.06 mL

Cost $4.49

Time: 1h 42min

Slicer Screenshots - PreForm

Final Prototype



Performance

Pour Test: The critical success of the mold is if it can cast two different colored silicone pours into the shape of Kirby.

Result: **Success**

The final cast Kirby doe have two distinct color boundaries and resembles the shape of Kirby.

Future Improvements:

During the final pour there was a misorientation of mold blocks, flipping the shoes on Kirby and causing leakage. A future improvement would be to design more noticeable, built in, features to only allow only one orientation, beyond the faces sitting flush in the current design. Also, there were minor sinks in the shoes due to insufficient amounts silicone reaching the part before becoming too viscous / tacky, I would increase the size of the gates for the silicone pouring into the mold, as well as add vacuuming the mold once silicone is poured into the operation procedures.

Reflection

Concept Sketches and Ideation: I invested a lot of time into ideation and jumped on a project before getting the necessary approval, causing several pivots and explorations in the project. This did eat up time but led to a final project that I am happy with and am satisfied of the result.

- **I should get final project approval before investing time into CAD for future project.**

Prototyping and Testing: I used the silicone molding station at the PRL for the first time and caused critical delays in the project by rushing my pours and missing the demolding spray step. I also prematurely demolded the final cast and misoriented the shoes on the model backwards, causing a forced leak. This does not affect the efficacy and success of the mold pattern; it simply highlights areas to mitigate user error for future improvements.

- **I should write down an operation sequence to ensure no step is missed during testing. I should also consider ways of fool-proofing modular systems during the design stage.**

Final Product: The final product assembles nicely and having it in the clear material is very helpful in noticing sinks and air bubbles. I think the gates to the shoes could have been wider, and there should have been fool proof way to not have misorientations in the pour blocks. However, if giving the proper time for conducting a pour, these issues become minimal or are fully resolved. However, in terms of final silicone parts, the pigments are messy to use, but the final result of two separate part colors is great. All errors in final casting are a result of user error and not the mold pattern itself. **The overall mold design successfully fulfills all intended design requirements, and the project is a success!**

Budget

Time	Hours
Ideation / Ideation CAD	20 hours
CAD	12 hours
Bambu Print	1.2 hours
Form Labs Print	18 hours
Silicone Pour	4.5 hours
Logistics	6.3
Total Time:	**61 hours**

Cost:	
FDM Filament Prints*:	$1.17 (~47g)
Silicone and Resin:	$33.23 (~200 mL – Clear)
Total Cost:**	**$33.98**
Total Hypothetical:	$4.20
Running Costs:	$0.75
Running Hypothetical*:	$10.60 (441g) (~200 mL)

*Cost is hypothetical, all prints were free by being under $3.

**Total Cost does not include $7.88 from project 3