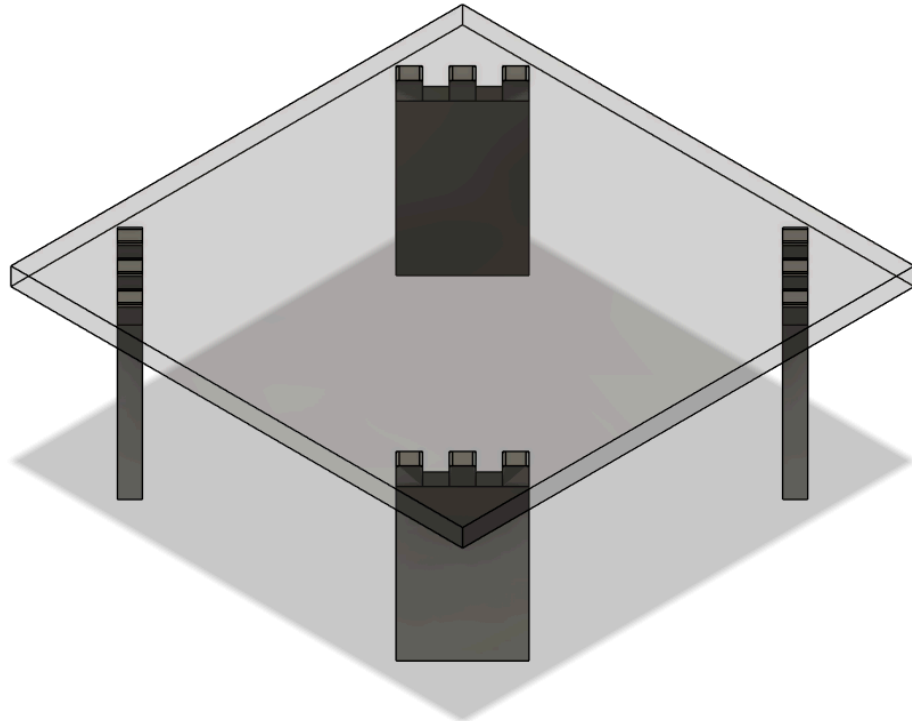


Project 5 Final Report

ME 270: Design for Manufacturability

University of Illinois Urbana-Champaign



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AB8-4

May 8, 2026

1. Product Design Specification

All Chosen PDS Elements for Pugh Matrix are Highlighted in Green

1. Performance

- a. Assembled stand must be structurally stable and must hold products up to the 6" x 6" max footprint without wobbling or collapsing. Parts should not bend with time, nor should they wear with repeated assembly/disassembly.

2. Environment

- a. Stand is intended for indoor retail or exhibition use. Climate-controlled environment is not necessary, but more than short term exposure to outdoor weather conditions is not recommended.

3. Service Life

- a. Stand must last initial assembly, disassembly (for storage or transportation), and should last at least 2.5 years of reasonable daily continuous use without needing to be serviced.

4. Maintenance

- a. The stand must be easily cleanable by a damp paper towel (with a little bit of dish soap is allowed) without dust collecting in odd unreachable areas.

5. Target Costs

- a. Minimize laser cutting cost/time (\$40/hr) and material usage to minimize overall cost

6. Competition

- a. Stand must compete in the product market with existing mass-produced display stands. Stand must show a competitive advantage by offering a unique no-tool easy assembly.

7. Shipping

- a. The disassembled stand pieces will define the size of the box. However, the box size and hence the design dimensions must be optimized to place as many boxes as possible on the standard 48" x 40" shipping pallet.

8. Product Volume (Quantity)

- a. 50,000 units must be produced.

9. Packing

- a. Design must be able to be packed flatly with all parts fitting inside a single box with minimal void space.

10. Manufacturing Process/Facility

- a. The stand must be manufactured by Jackson Innovation Studio's Laser Cutters.

11. Size

- a. 6" x 6" is the max footprint the stand has to accommodate, so the stand's base plate must be 6" x 6". The vertical walls can be 2.9" so they fold inwards and lay

flat. This way, the total component height inside the box (using $\frac{1}{4}$ " thick Acrylic) is $\frac{1}{2}$ ".

12. Weight

- a. Stand must be lightweight to be assembled easily by users while retaining enough strength to support display items of reasonable weight.

13. Aesthetics and Finish

- a. The stand must look visually appealing and sleek for professionally and attractively displaying retail objects and exhibition items. Edges must be clean.

14. Materials

- a. 12" x 12" acrylic sheet of $\frac{1}{4}$ " thickness from Jackson Innovation Studio.

15. Product Life Span

- a. Stand must withstand at least 5 years of reasonable daily continuous use before structural or aesthetic failure.

16. Standards, Specifications, and Legal Aspects

- a. Design must fit such that its packaging is optimized for a standard North American pallet size of 48" x 40". Design must have a CAD model with detailed engineering drawings with GD&T. Easily comprehensible assembly instructions must be provided to the user.

17. Ergonomics

- a. User should be able to assemble stand with no tools in a minimal time.

18. Customer

- a. Retail store owners, bakery owners, trade show exhibitors, jewelry store owners, home/apartment/room owners

19. Quality and Reliability

- a. Designs must ensure functional interference fits that allow components to fit together tightly without needing extra tools to assemble or disassemble. Assembly/disassembly should not require extensive force pushing together or pulling apart.

20. Shelf Life

- a. Acrylic will not degrade while stored in shipping containers in proper packaging as the stand will be. Therefore, shelf life is indefinite.

21. Processes

- a. 2D profiles of legs and baseplate shall be laser cut from acrylic sheets. Legs shall be press-fit into base plate once laser cut.

22. Timescales

- a. Phase 1: Design due April 24, 2026
- b. Phase 2: Fabrication due May 1, 2026
- c. Phase 3: Inspection and Final Report due May 8, 2026
- d. Factory production rate is based on one eight-hour shift per day.

23. Testing

- a. Stand must pass inspection regarding dimensions, GD&T compliance, and manual press-fit checks.

24. Safety

- a. Laser-cut edges must be safe to handle without gloves (edges must not be too sharp or abrasive). The design must withstand the maximum intended load

without fracturing, shattering, or tipping to prevent injury or damage.

25. Company Constraints

- a. All design work will be in Autodesk Fusion in the ME/TAM 270 Hub in our designated team folder. Easily comprehensible design and instructions requiring no extra clarification.

26. Market Constraints

- a. Shipping overhead costs heavily control profit. At a 50,000 unit scale, inefficiency in packing will increase cost significantly.

27. Patents, Literature, and Product Data

- a. Jackson Innovation Studio will provide reference data for given acrylic thickness/sheet properties.

28. Political and Social Implications

- a. No political implications
- b. No social implications other than clear communication across engineering teams

29. Disposal

- a. Easy assembly/disassembly without adhesives so parts can be taken apart and recycled in specialized facilities at the end of life span.

Justification for PDS Elements chosen for Pugh Matrix:

Based on the PDS above, we selected nine criteria that most directly influence the design choices in order to create a well-functional acrylic stand optimized to a 50,000 unit production run.

Shipping, packing, and size were chosen from the PDS as criterion for the Pugh matrix, as they directly influence the optimal logistics behind the production and distribution of the acrylic stand at this large scale. Shipping was selected as a priority and assigned a 20% weightage due to the given constraints of using a standard 48" x 40" shipping pallet. Size and packing followed closely in order of priorities. Packing, assigned a 15% weightage, refers to the parts of the stand fitting as flat together as possible to reduce void spaces and maximizes how dense the shipping pallet itself can be packed. The size, assigned a 10% weightage, and dimensions of each part of the stand directly influence how well and optimally each unit can be packaged and packed. Size also determines whether the stand will be able to hold the maximum object footprint given as a constraint. **Ergonomics and performance**, each assigned a 15% weightage, were also chosen from the PDS as some of the core constraints/requirements of the stand detail that it must be easily assembled/disassembled without much force needed and that the stand must not wobble and must remain structurally sound when under a reasonable load up to its maximum. **Quality and Reliability**, assigned a 5% weightage, was selected for similar reasons in that the stand must support the required maximum load weight and size. **Manufacturing**, assigned a 10% weightage, was selected and to be considered due to the limitations of lasercutting as the designated manufacturing process: for the stand to be laser cut, all parts must be the same thickness, laser kerf must be accounted for, and fewer fine detailing leads to less tolerancing issues in assembly. **Target Costs**, assigned a 5% weightage, was chosen as pricing a product is a very important aspect of creating a business plan and product placement and must be considered to ensure that our acrylic stand holds a competitive advantage in the market for being easily

assembled and very reasonably priced while holding good **Aesthetics/Finish**, which was the last chosen criteria. Assigned a 5% weightage, this was chosen to ensure that the design aligns with the target audience's primary usage of the stand to display/exhibit objects, often for retail purposes. The stand's aesthetics must add to the object's, not take away from it.

2. Design Concepts

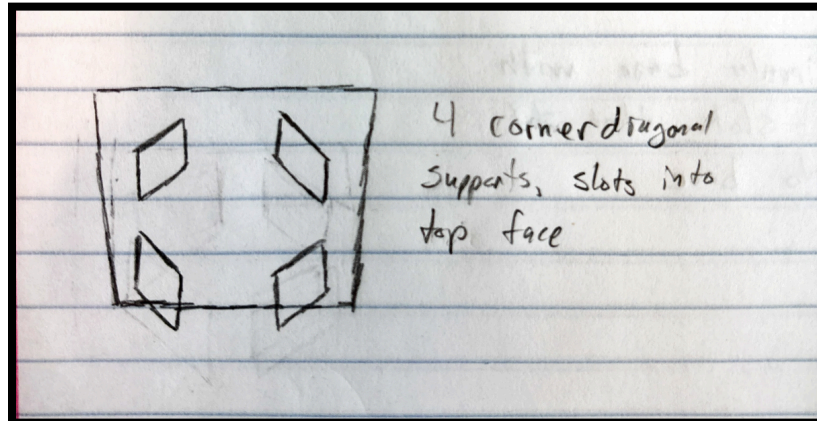


Figure 1: Image of design concept 1 (4 corner diagonal supports)
This is a simple design that will offer reliable stability

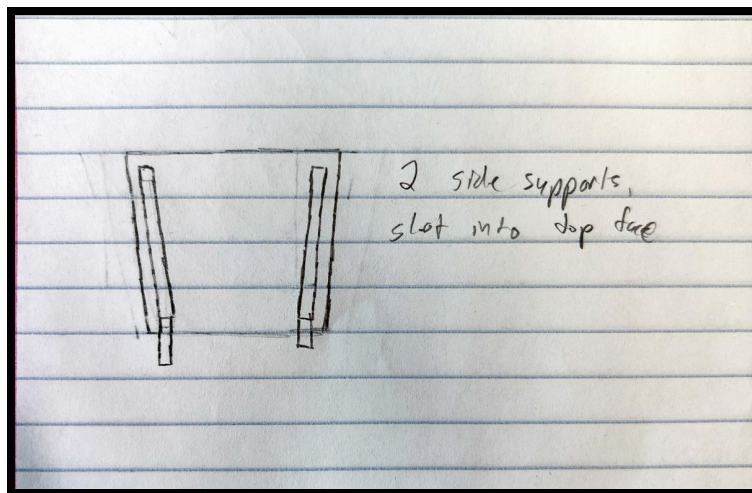
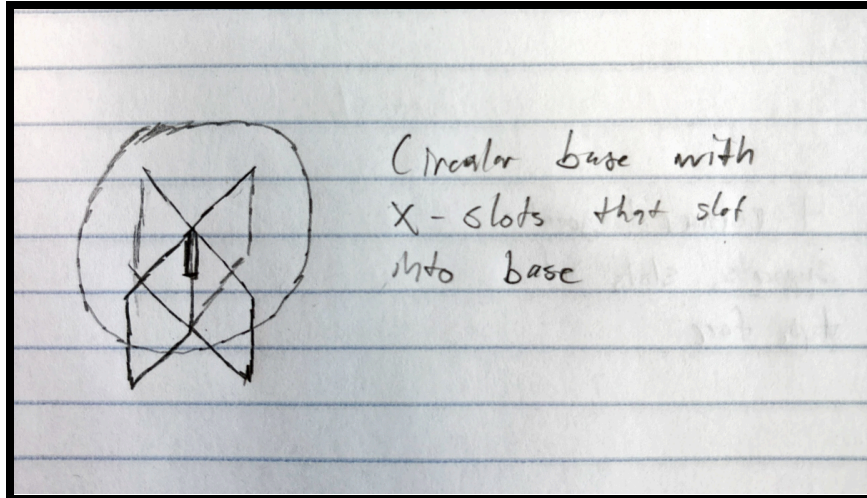


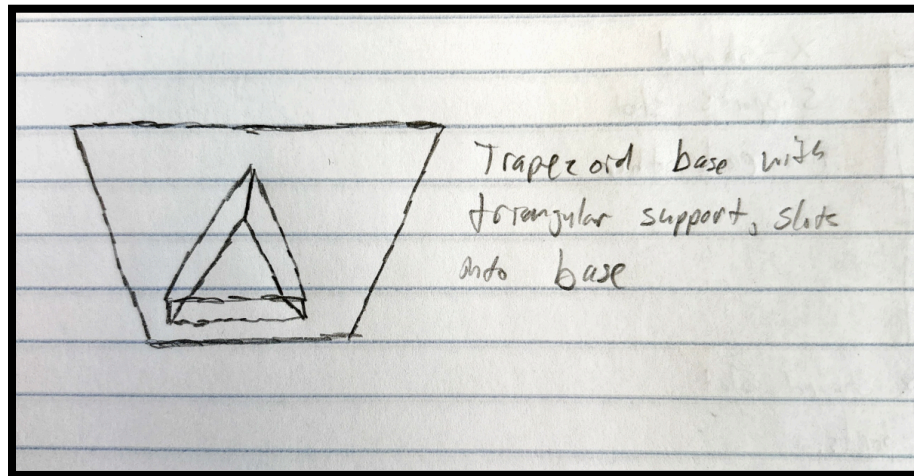
Figure 2: Image of design concept 2 (2 side supports)
This is another simple design with minimal components



Circular base with
X-slots that slot
into base

Figure 3: Image of design concept 3 (circular base with x-slots)

This is a design that will have increased stability and still be easy to assemble



Trapezoid base with
triangular support, slots
into base

Figure 4: Image of design concept 4 (trapezoid base with triangular supports)

This is a complex design which can be more aesthetically pleasing

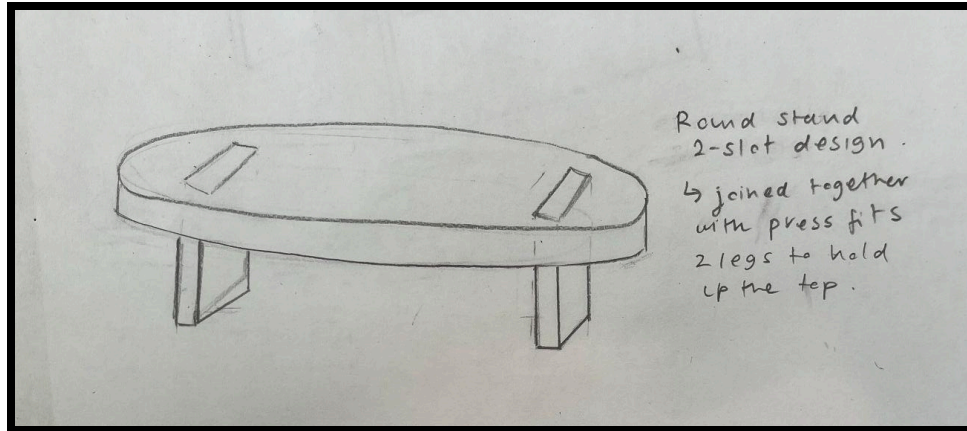


Figure 5: Image of design concept 5 (Round stand with 2-slots)
This is another simple design that will be easy to assemble

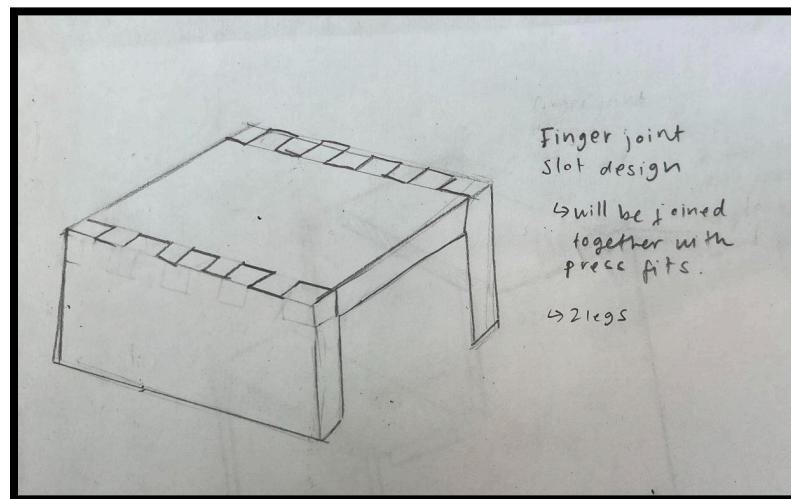


Figure 6: Image of design concept 6 (Finger joint slot design)
This is a design that will offer higher stability

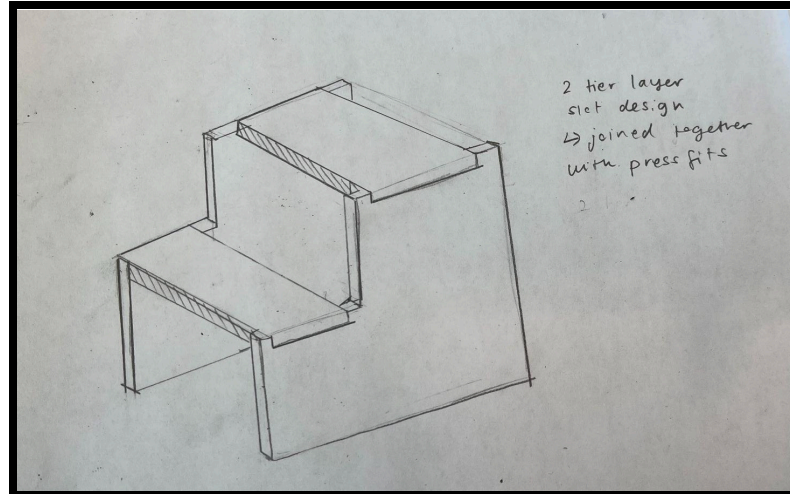


Figure 7: Image of design concept 7 (2 tier slot design)
This design is more complex and is more aesthetically pleasing

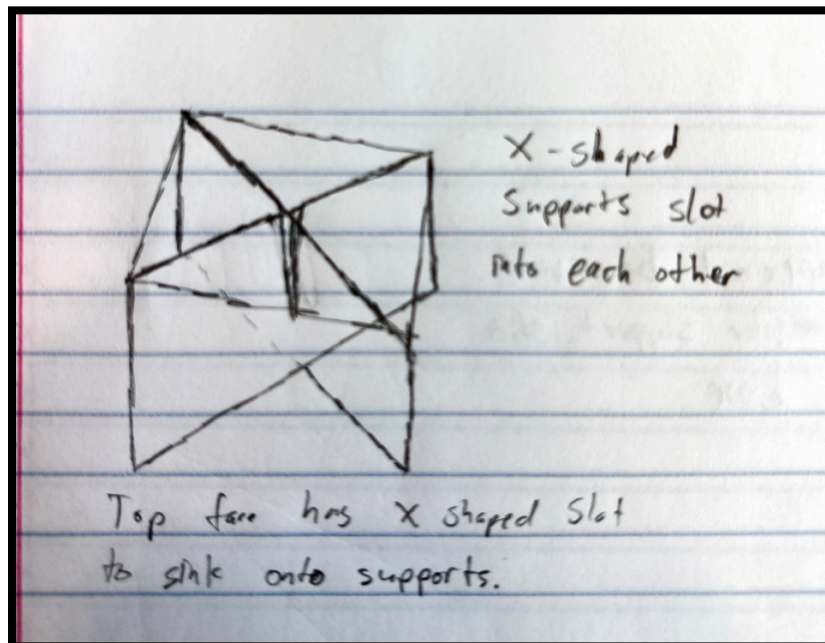


Figure 8: Image of design concept 8 (x-shaped supports)
This design offers high stability while keeping ease of assembly

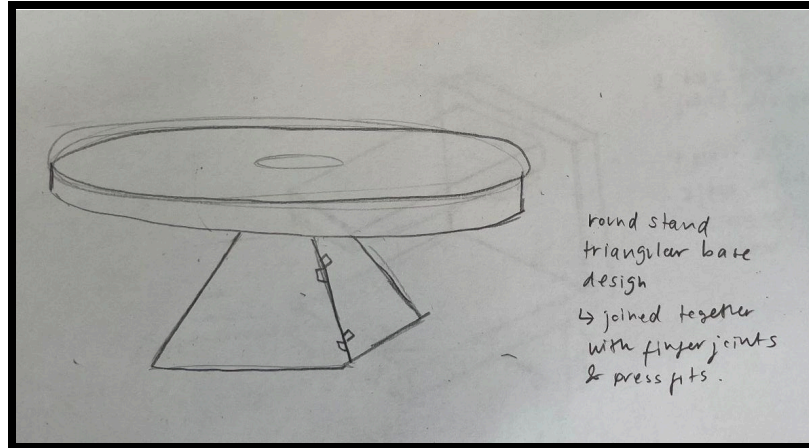


Figure 9: Image of design concept 9 (Round-stand triangular base)
This is a more aesthetically pleasing design while keeping stability

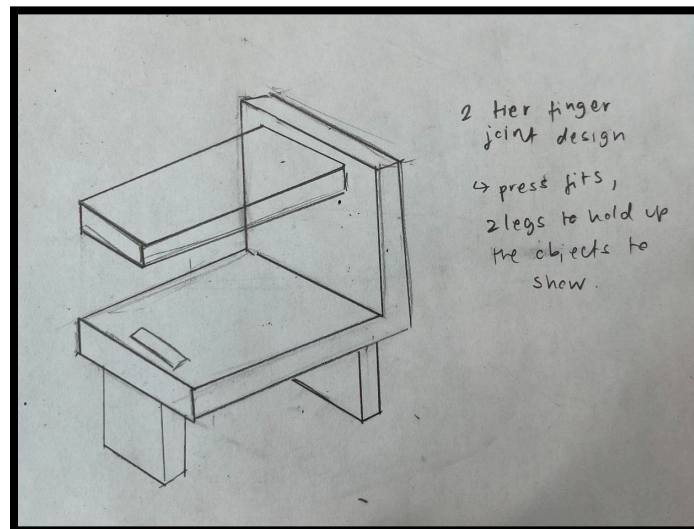


Figure 10: Image of design concept 10 (2-tier finger joint)
This is a more complex design that can allow for more functionality than other designs

3. Pugh Matrix Analysis

Datum:



Figure 11: Image of the datum piece taken from the website

https://www.target.com/p/white-3-tier-cupcake-stand-spritz-8482/-/A-89280717?sid=943S&TCID=PDS-336243049&gclsrc=aw.ds&ds_rl=1246978&ds_rl=1247068&gad_source=1&gad_campaignid=336243049&gbraid=0AAAAAD-5dfbh2qVTOSzXVktz9VwV8F30l&gclid=CjwKCAjwwJzPBhBREiwAJfHRnf9NI-1K1M7dUBCyZLmYqZw3bz4fIGd-ENHipsrUYv26KvtDscA9ARoCjooQAvD_BwE

Table 1.0; Pugh Matrix for Initial Sketches

Criteria	Weight	1	2	3	4	5	6	7	8	9	10
Shipping	20%	+1	+1	0	-1	+1	+1	0	+1	+1	0
Ergonomics	15%	+1	+1	+1	0	-1	0	+1	+1	+1	0
Packing	15%	+1	+1	+1	0	+1	+1	+1	+1	0	-1
Performance	15%	+1	0	+1	+1	-1	+1	0	+1	0	-1
Manufacturing	10%	+1	+1	0	0	+1	0	+1	0	+1	0
Size	10%	+1	+1	0	0	+1	+1	0	+1	+1	0
Target Costs	5%	+1	+1	+1	0	+1	+1	0	+1	+1	0
Quality/ Reliability	5%	+1	0	+1	0	+1	0	0	+1	-1	-1
Aesthetics/ Finish	5%	0	0	+1	+1	-1	0	+1	+1	0	+1
Total		0.95	0.75	0.6	0	0.3	0.65	0.45	0.9	0.55	-0.3

Our pugh matrix is organized such that each criteria is designated a weightage percent correlating with that criteria's importance toward the final prototype. Each design is scored with a +, 0, or - rating. These ratings are then summed accordingly (+ becomes +1, 0 stays 0, - becomes -1) and multiplied by the designated criteria percentage. We then chose the highest rated design (highlighted in green) to move onto the next stage of the design process. This approach allows for more critical criterias to have a larger impact on the design choices.

5 Selected Design Concepts: 1, 2, 3, 6, 8

4. Detailed Sketches:

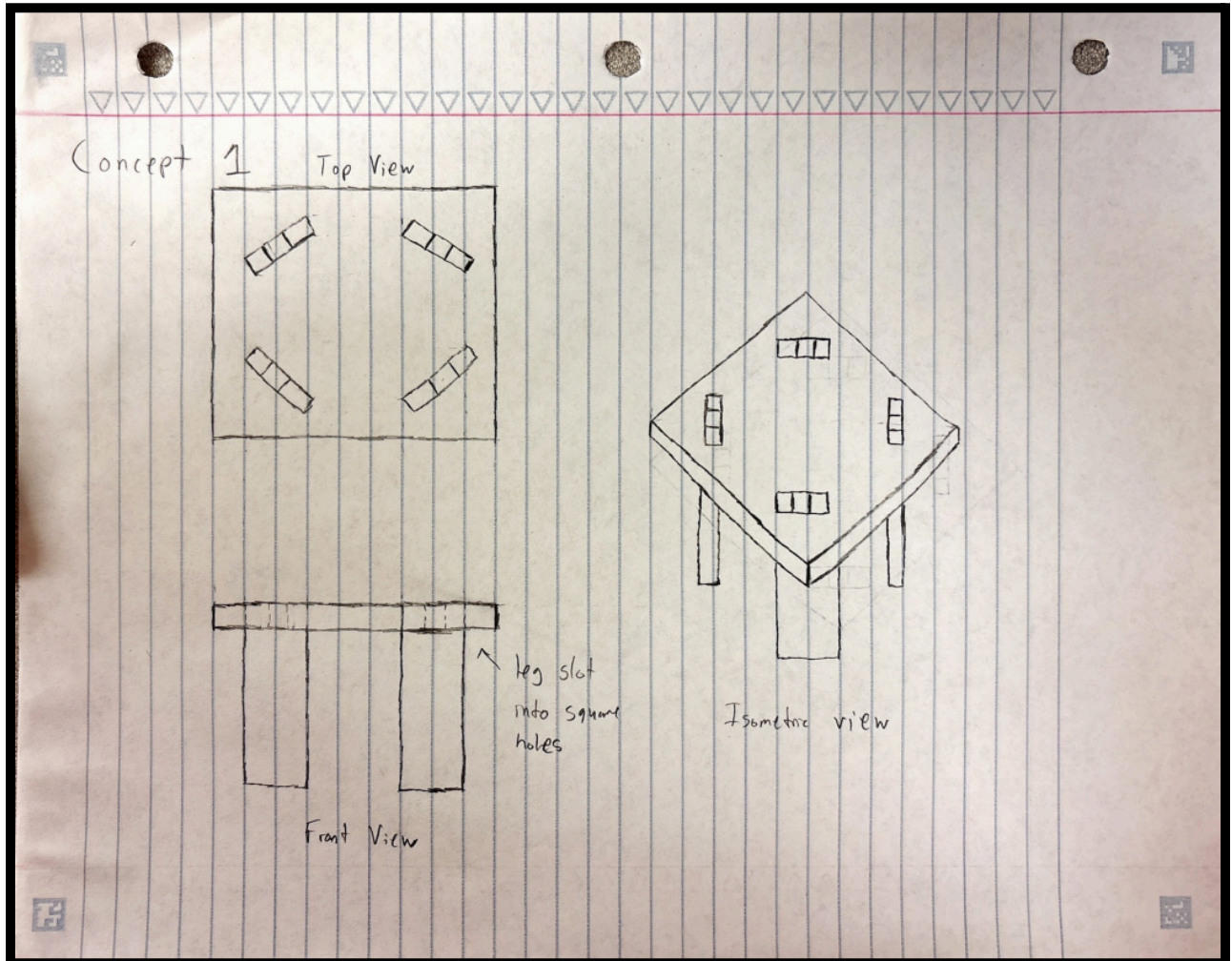


Figure 12: Detailed Sketch of Concept 1

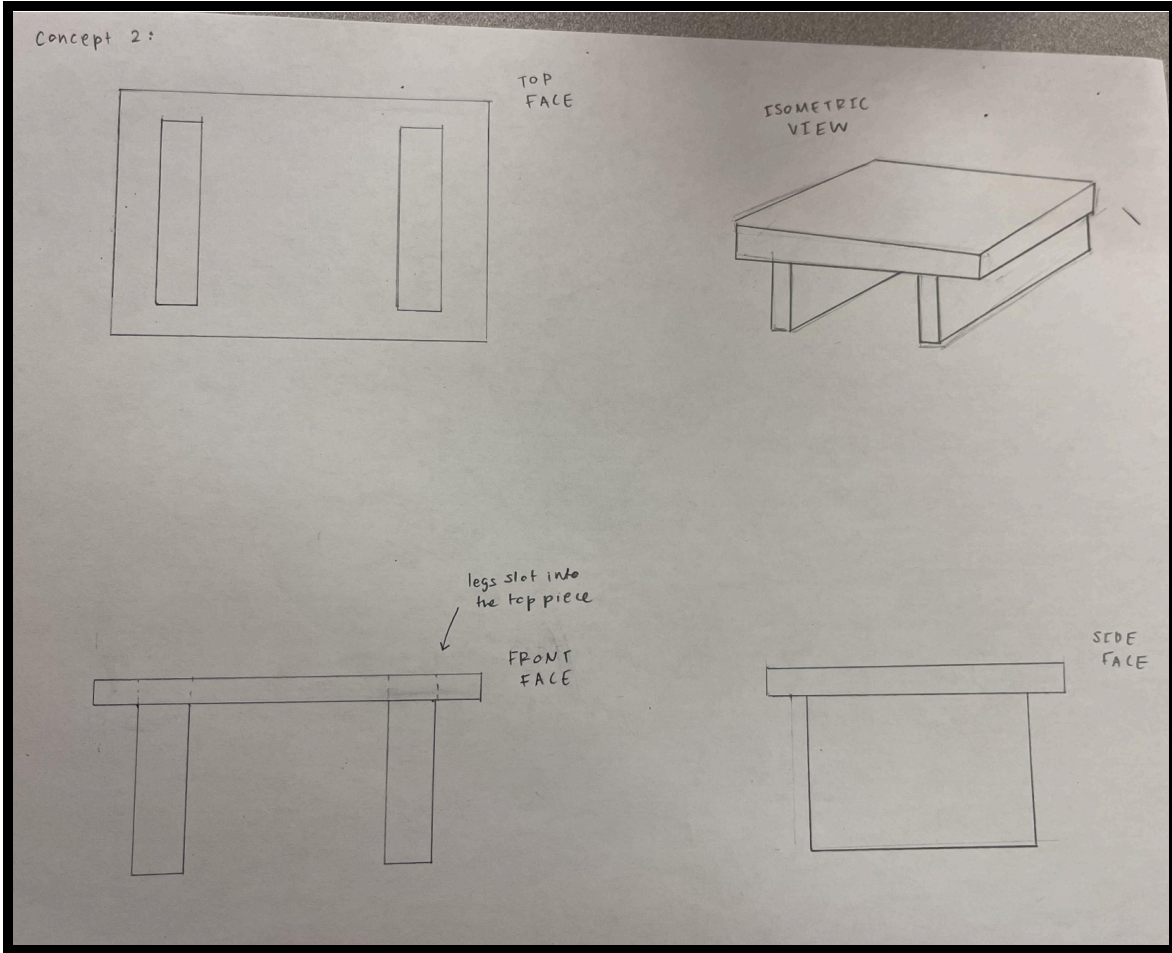


Figure 13: Detailed Sketch of Concept 2 (2 side supports)

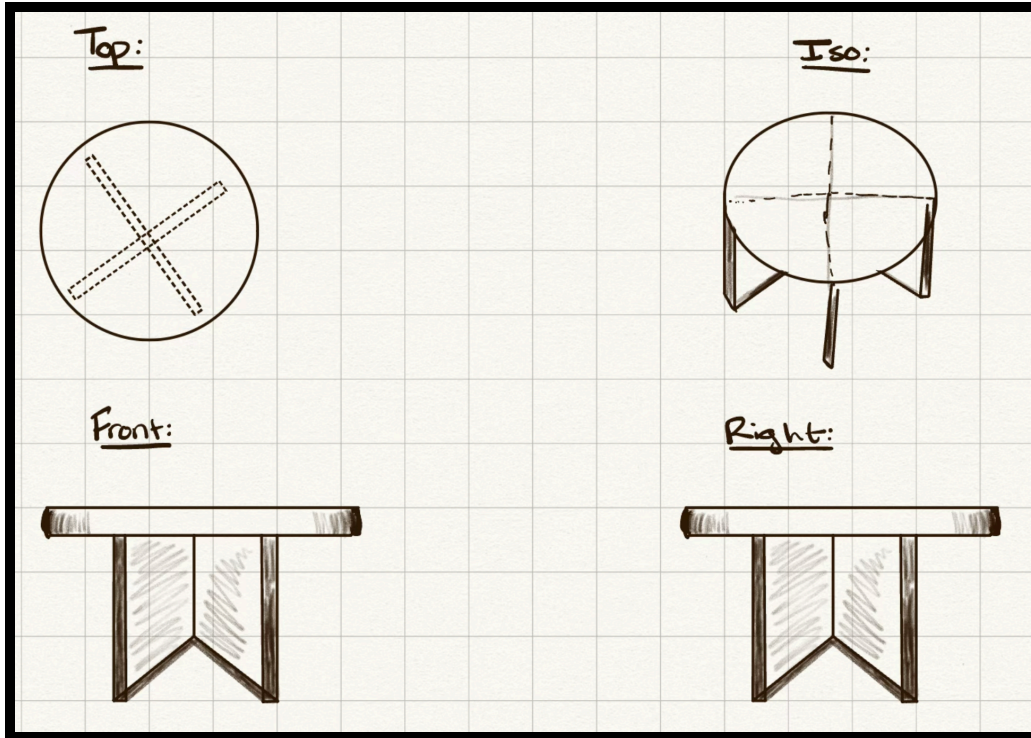


Figure 14: Detailed Sketch of Concept 3

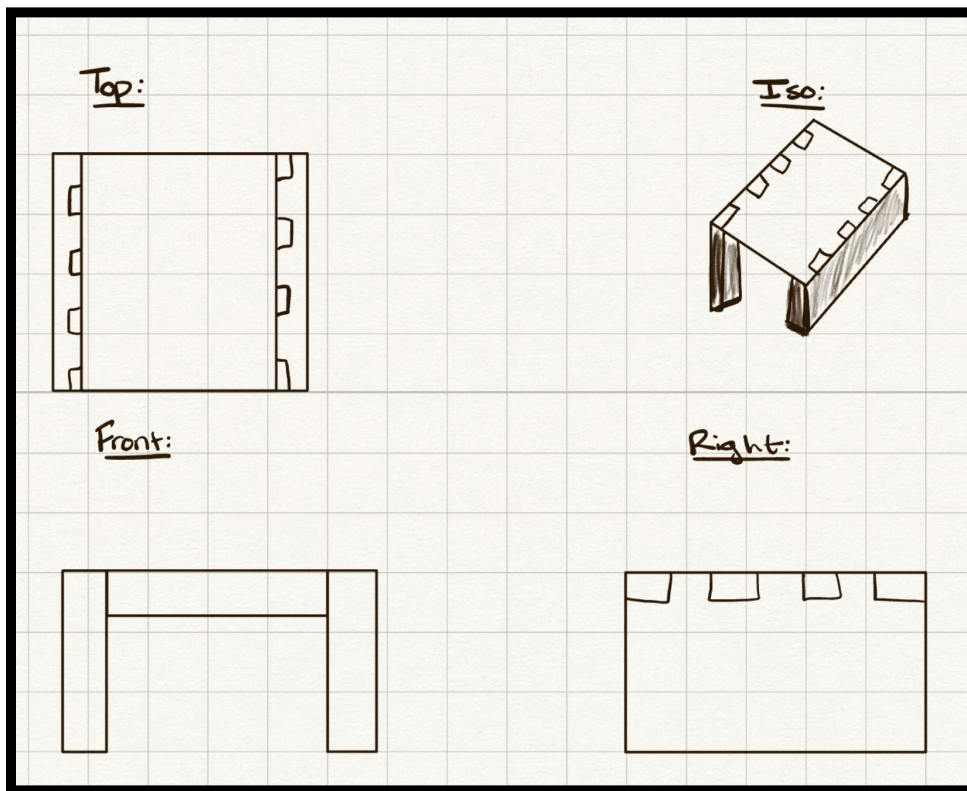


Figure 15: Detailed Sketch of Concept 6

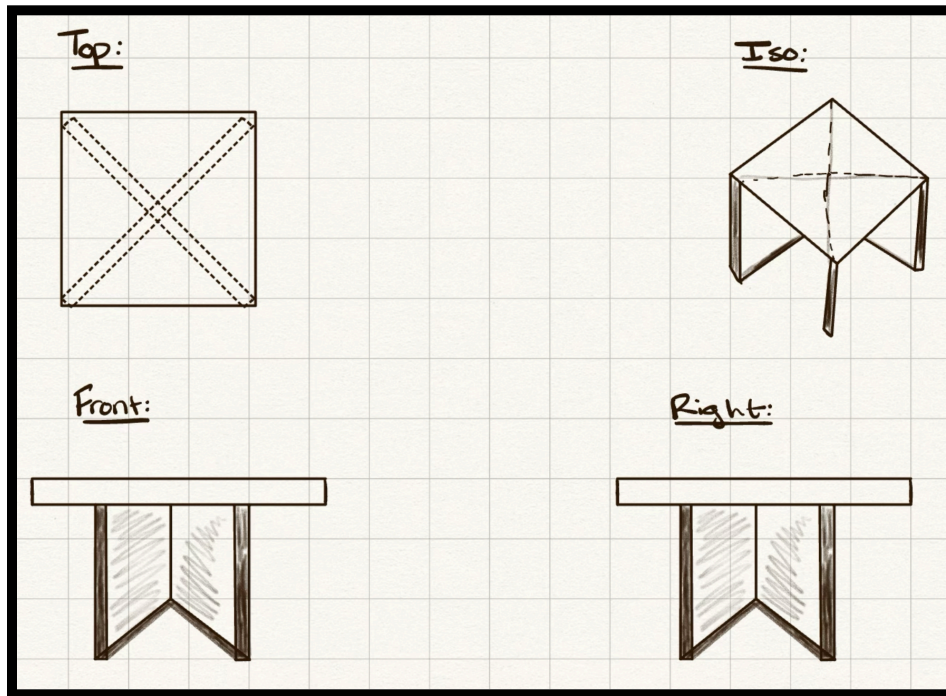


Figure 16: Detailed Sketch of Concept 8

5. Pugh Matrix Analysis for Detailed Sketches:

Datum:



Figure 11: Image of the datum piece taken from the website

https://www.target.com/p/white-3-tier-cupcake-stand-spritz-8482/-/A-89280717?sid=943S&TCID=PDS-336243049&gclsrc=aw.ds&ds_rl=1246978&ds_rl=1247068&gad_source=1&gad_campaignid=336243049&gbraid=0AAAAAD-5dfbh2qVTOSzXVktz9VwV8F30l&gclid=CjwKCAjwwJzPBhBREiwAJfHRnf9NI-1K1M7dUBCyZLmYqZw3bz4fIGd-ENHipsrUYv26KvtDscA9ARoCjooQAvD_BwE

Table 2.0; Pugh Matrix for Detailed Sketches

Criteria	Weight	1	2	3	4	5
Shipping	20%	+1	+1	0	0	0
Ergonomics	15%	+1	+1	0	0	0
Packing	15%	+1	+1	-1	-1	-1
Performance	15%	0	0	0	0	0
Manufacturing	10%	0	+1	0	0	+1
Size	10%	+1	+1	0	0	0
Target Costs	5%	+1	0	0	0	0
Quality/ Reliability	5%	+1	0	+1	+1	+1
Aesthetics/ Finish	5%	+1	0	+1	+1	+1
Total		0.75	0.70	-0.05	-0.05	0.05

Our pugh matrix is organized such that each criteria is designated a weightage percent correlating with that criteria's importance toward the final prototype. Each design is scored with a +, 0, or - rating. These ratings are then summed accordingly (+ becomes +1, 0 stays 0, - becomes -1) and multiplied by the designated criteria percentage. We then chose the highest rated design (highlighted in green) to move onto the next stage of the design process. This approach allows for more critical criterias to have a larger impact on the design choices.

Selected Design: 1

Design 1 was chosen as the strongest option because it scores the highest in the Pugh matrix. Its simple design geometry makes it well-suited for manufacturing by laser cutting. Its sizing/dimensioning make it easy to pack flatly as all four legs can be stacked cleanly on top of the base plate such that it totals to only 2 layers of acrylic, optimizing the packaging by minimizing void spaces and optimizing shipping by fitting more units on every pallet. The four legs also provide a functional benefit, adding extra balance and structural stability to the assembled stand. The diagonal orientation of the legs adds to aesthetic appeal. The assembly ergonomics are also very easy and straightforward with this design as each leg has 3 pegs that are provided with 3 slots on the base plate, allowing for a tool-less, adhesive-less assembly. Overall, Design 1 evaluates as the strongest option for production.

6. Logistic Constraints:

Pallet Packing Analysis:

To minimize overhead shipping costs, we optimized the critical dimensions of our acrylic stand. These critical dimensions refer to the lengths and widths of the base plate and the 4 legs. Optimizing the design dimensions allowed us to further optimize the flat-pack box dimensions to pack efficiently on a standard north american 48" x 40" shipping pallet.

The base plate was designed to be 6" x 6" in order to support the required maximum object load. 1/4" thick acrylic was chosen to ensure our stand maintains structural integrity. Each of the 4 legs maintained dimensions of 2.23" x 1.26" so that they can all stack on top of the base plate adding only one additional 1/4" layer to the final thickness of the part inside the flat-pack box.

Box Footprint Optimization ($n_L \times n_W$):

Using 0.06" E-flute corrugated cardboard wall thickness and 0.13" internal clearance tolerance for easy packing/unpacking, the absolute minimum box side length (defined below as s_{min}) is:

$$s_{min} = 6" + 2(0.06") + 0.13" = 6.25"$$

With the minimum box size now established as 6.25" x 6.25", the maximum number of boxes that can fit along the length (defined as n_L) and along the width (defined as n_W) can be calculated as follows:

$$n_L = \frac{48"}{6.25"} = 7.68 \rightarrow 7 \text{ boxes along the length}$$

$$n_W = \frac{40"}{6.25"} = 6.4 \rightarrow 6 \text{ boxes along the length}$$

To cover 100% of the shipping pallet and eliminate void space, we can calculate the optimized length (defined as L) and width (defined as W) for the flat-pack box.

$$L = \frac{48"}{7 \text{ boxes}} = 6.85"$$

$$W = \frac{48"}{6 \text{ boxes}} = 6.66"$$

The total number of boxes per layer can be calculated using $n_L \times n_W = 42$ boxes per layer.

Vertical Packing and Pallet Capacity:

Standard shipping pallets limit the stacking of the flat-pack boxes to a maximum total height of 60". The pallet itself is 6", leaving 54" of vertical space for stacking. The total thickness of the disassembled acrylic stand is 0.5", as it consists of two layers of 1/4" acrylic. Accounting for the 0.06" corrugated cardboard thickness, and 0.03" of compression tolerance, the total external box height (defined as h_{min}) can be calculated as follows:

$$h_{min} = 0.5'' + 2(0.06'') + 0.03'' = 0.65''$$

Therefore, the total number of vertical layers (defined as n_{layers}) is calculated as:

$$n_{layers} = \frac{54''}{0.65''} = 83.077 \rightarrow 83 \text{ vertical layers}$$

Thus, the maximum capacity of a single pallet (defined as N_{Pallet}) can be calculated as follows:

$$(n_L \times n_w) \times h_{min} = N_{Pallet} = 42 \times 83 = 3,486 \text{ units per pallet}$$

Full-Scale Order Logistics:

To fulfill the total production volume (defined as V_{Total}) of 50,000 units. The total number of pallets required to fit the entire order (defined as P_{Total}) can be calculated as follows:

$$P_{Total} = \frac{V_{Total}}{N_{Pallet}} = \frac{50,000}{3,486} = 14.343 \rightarrow 15 \text{ pallets}$$

7. Finalized Design CAD Screenshots:

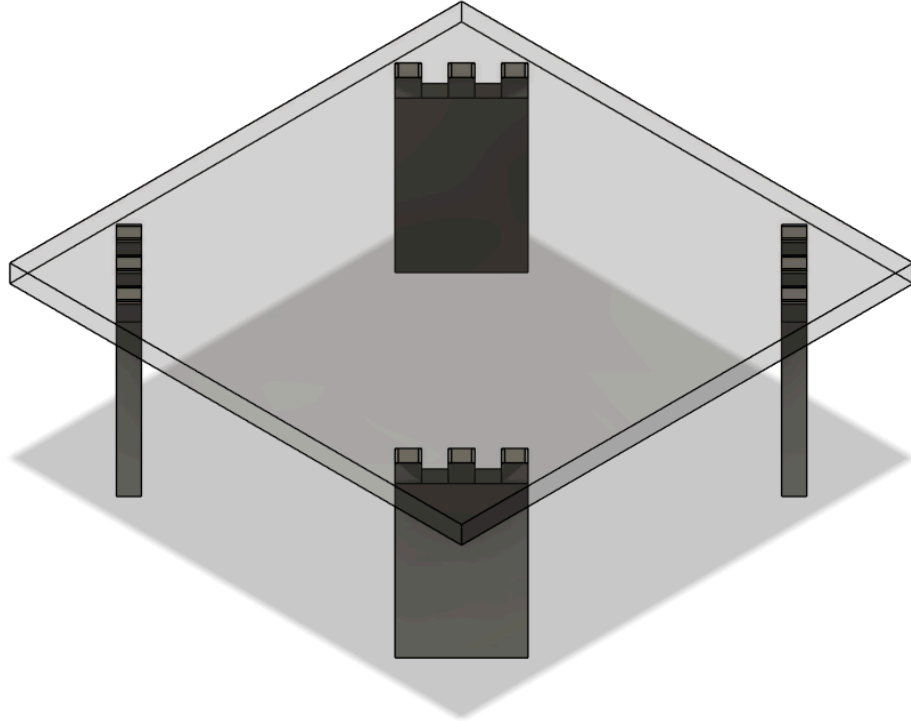


Figure 1.1: Isometric View of Stand

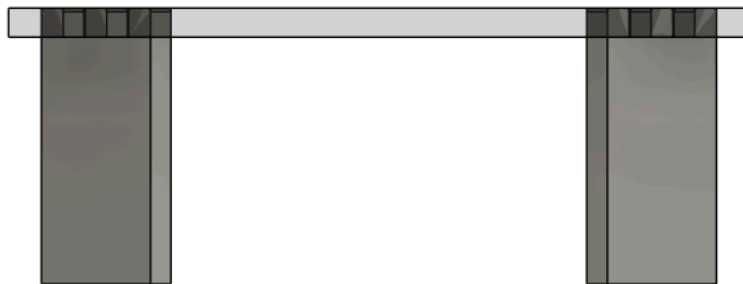


Figure 1.2: Side View of Stand

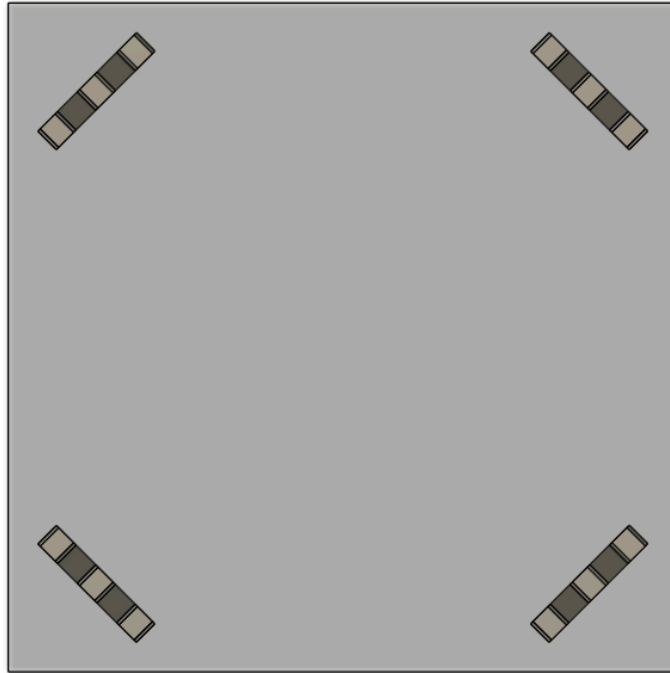


Figure 1.3: Top View of Stand

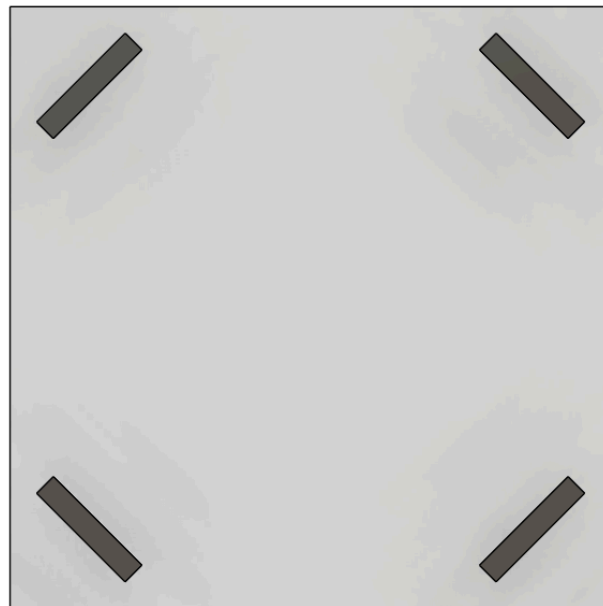


Figure 1.4: Bottom View of Stand

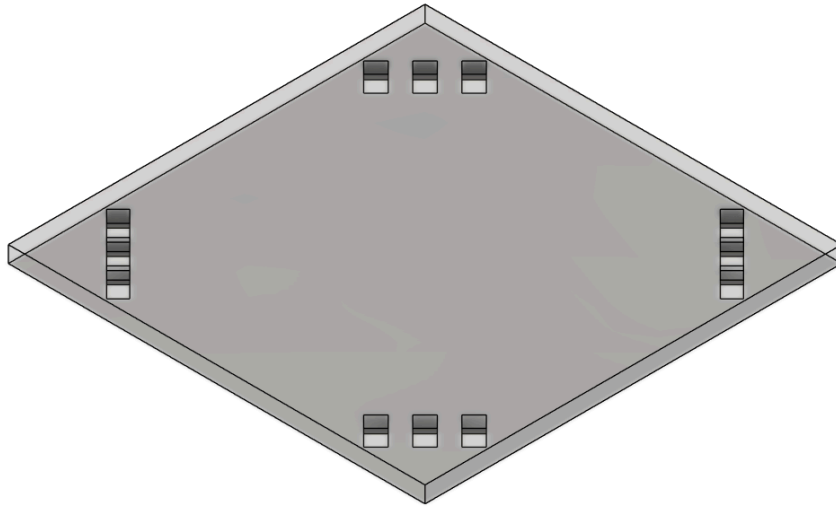


Figure 1.5: Isometric View of Top Plate

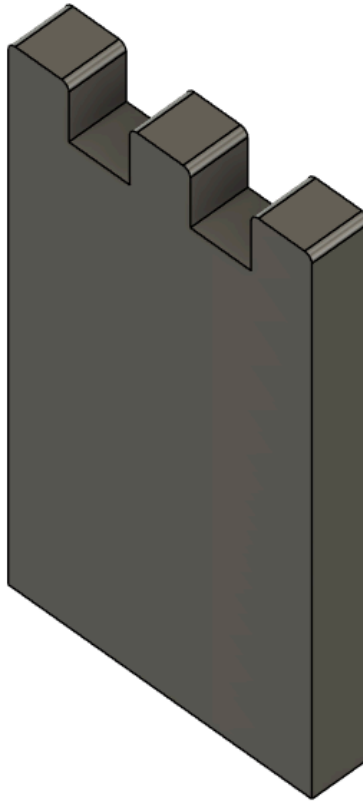


Figure 1.6: Isometric View of One Leg

8. GD&T Drawings:

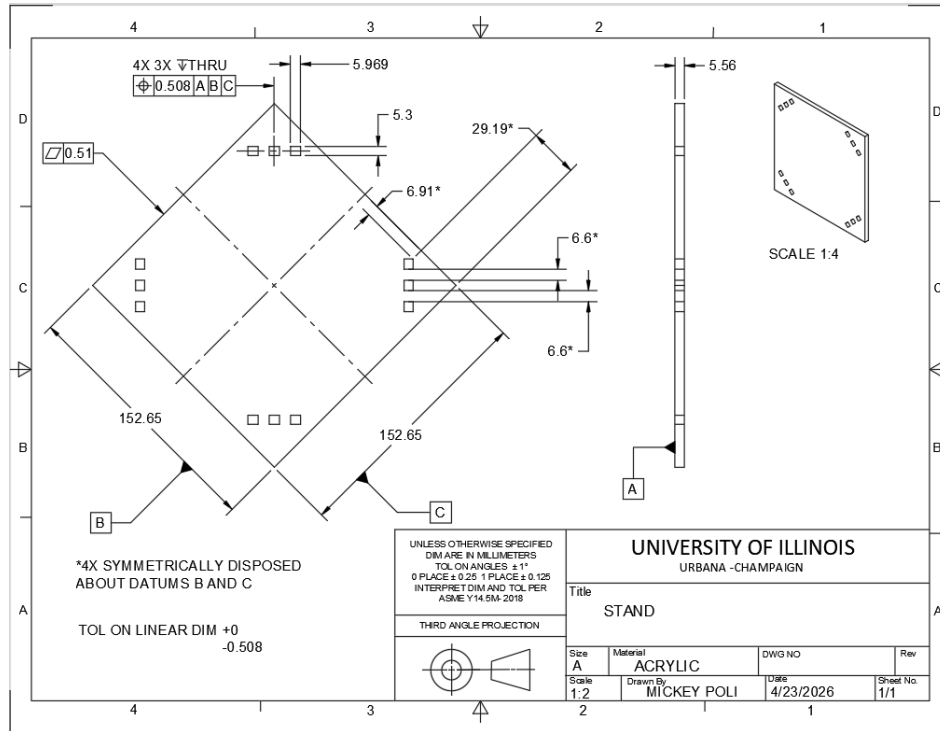


Figure 2.1: Stand Drawing

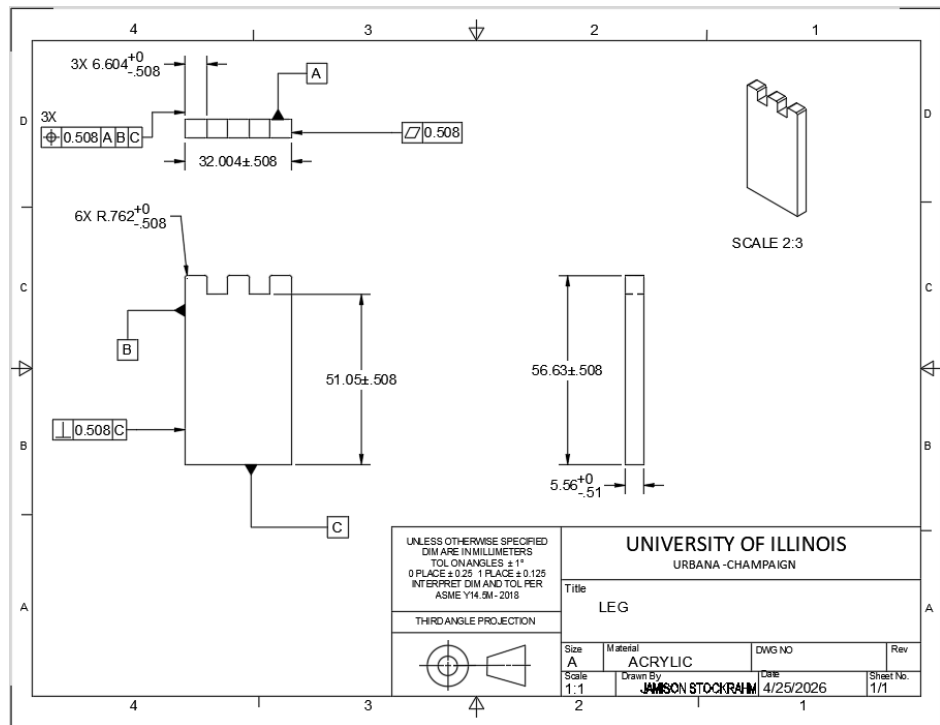


Figure 2.2: Leg Drawing

9. Bill of Materials

¼" Acrylic (12 x 12) sheet from Jackson Innovation Studio = \$10 [1]

Number of Parts Manufactured Per Sheet:

Area of Part 1 (Top Face): 35.523 in^2 (taken from fusion 360)

Area of Part 2 (leg): 2.702 in^2 (taken from fusion 360)

$$\text{Total Part Area: } 2.702 \text{ in}^2 + 35.523 \text{ in}^2 = 38.225 \text{ in}^2$$

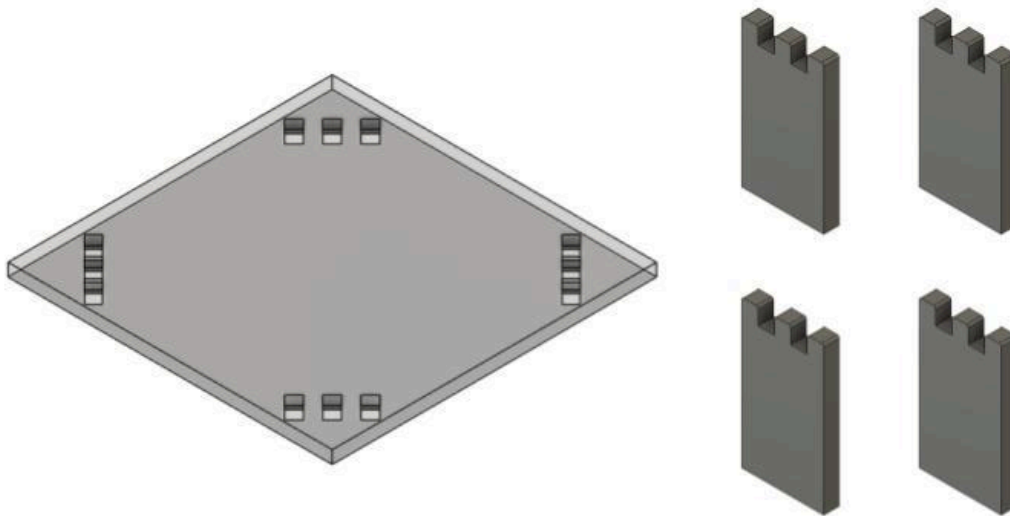
$$\text{Acrylic Sheet Area: } 12\text{in}^2 \times 12\text{in}^2 = 144\text{in}^2$$

Assumption: Space is not fully used efficiently when laser cutting due to part spacing requirements and edge margins; therefore, the total used cutting area is 130in^2

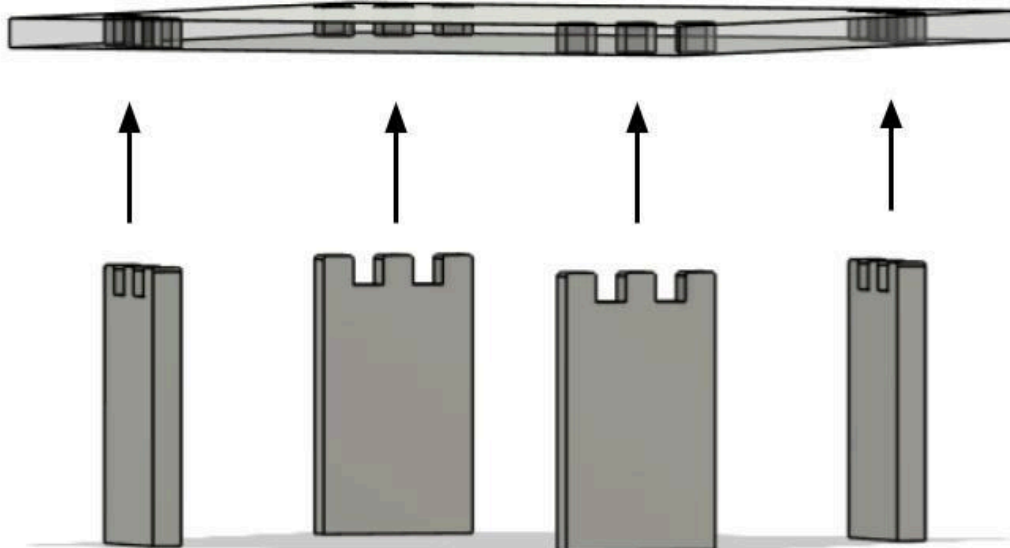
Number of parts produced per sheet:

$$\frac{130}{38.225} = 3 \text{ parts}$$

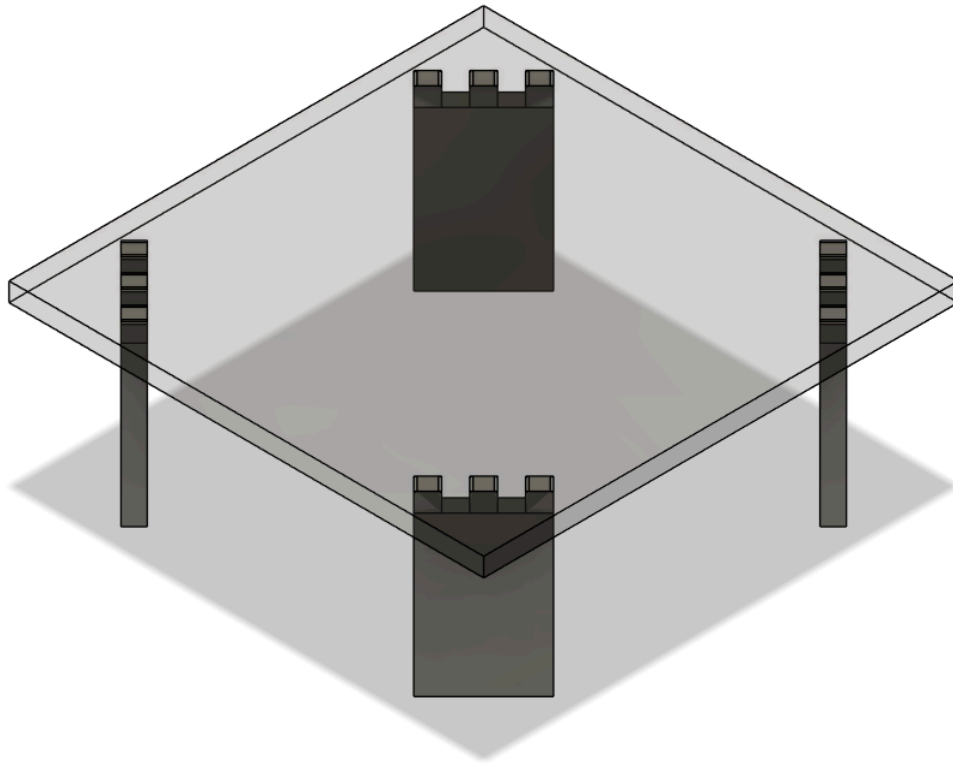
10. Assembly Instructions



1. Acquire Parts 1 (4 units) and 2 (1 unit).



2. Slide the leg pieces into the top face as illustrated above

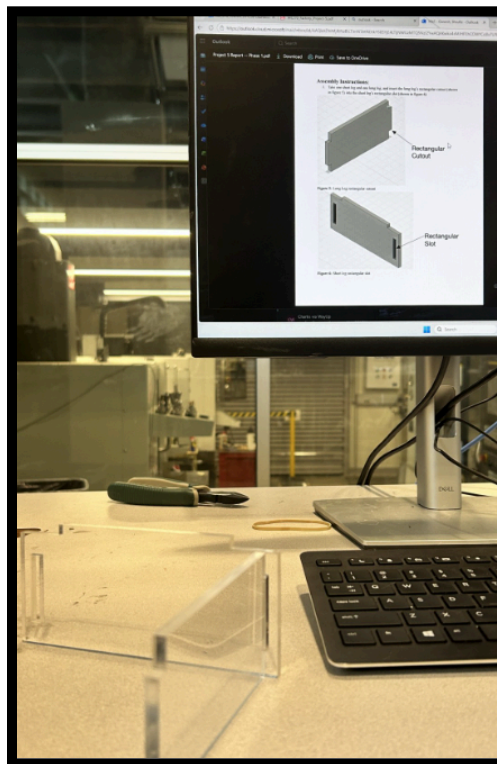


3. The assembled product should look as illustrated above

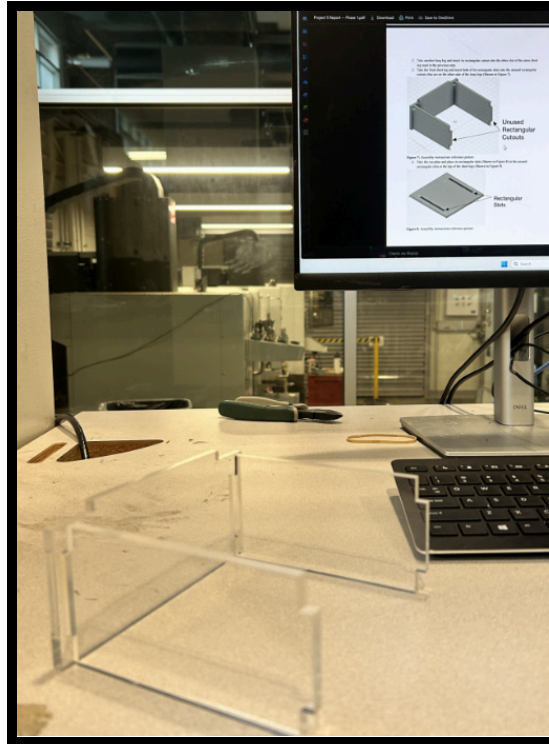
11. Assembly of Team 1's Fabricated Design



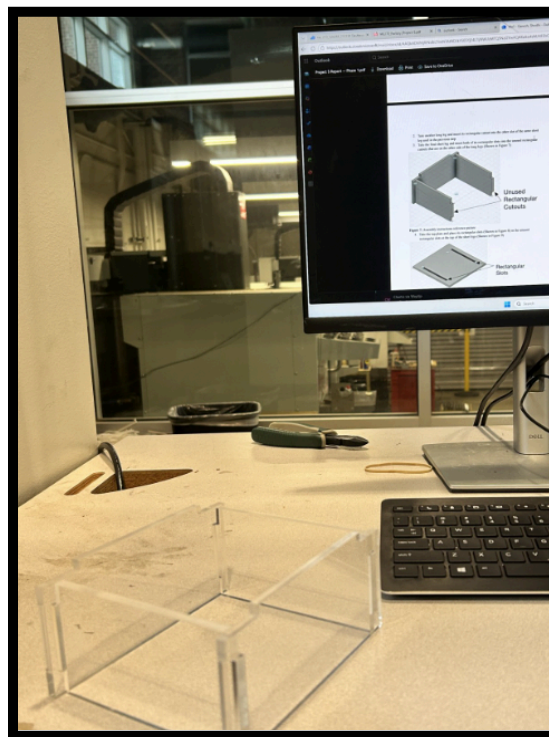
1. We laser cut and removed the plastic wrapping from the acrylic



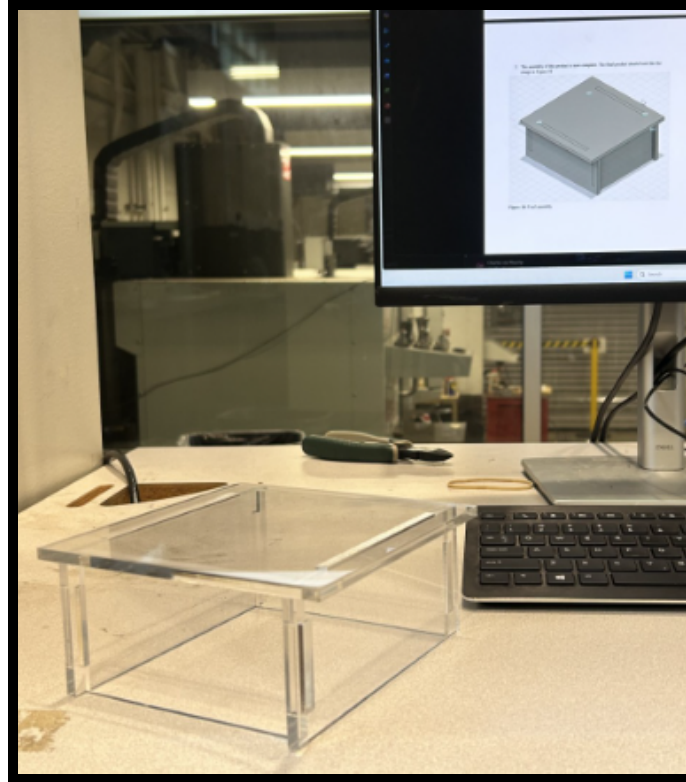
2. Our team then slotted one of the rectangular cutouts into the rectangular slots (following the instructions as directed)



3. We repeated this process with the other side of the stand.



4. Our team attached the final rectangular slot onto the stand.



5. We then attached the top piece onto the stand.

*Assembly Notes: instructions were very easy to follow, and assembly was very easy. However, rectangular slots were slightly too big for rectangular cutouts, and thus all pieces fit together loosely, making the stand wobbly.

12. Initial Observations:

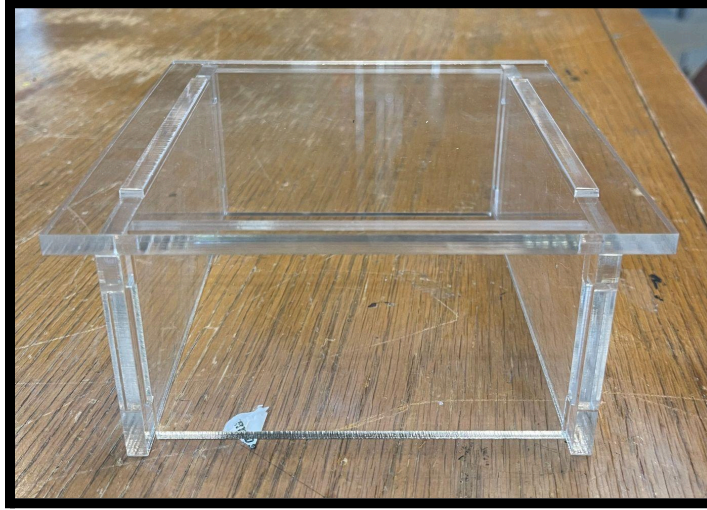


Figure 2.0: Front facing view of stand

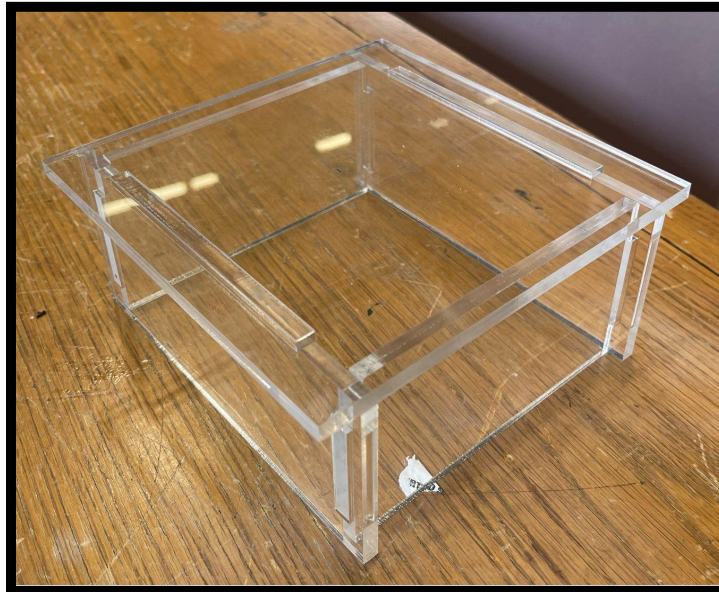


Figure 2.1: Isometric view of stand

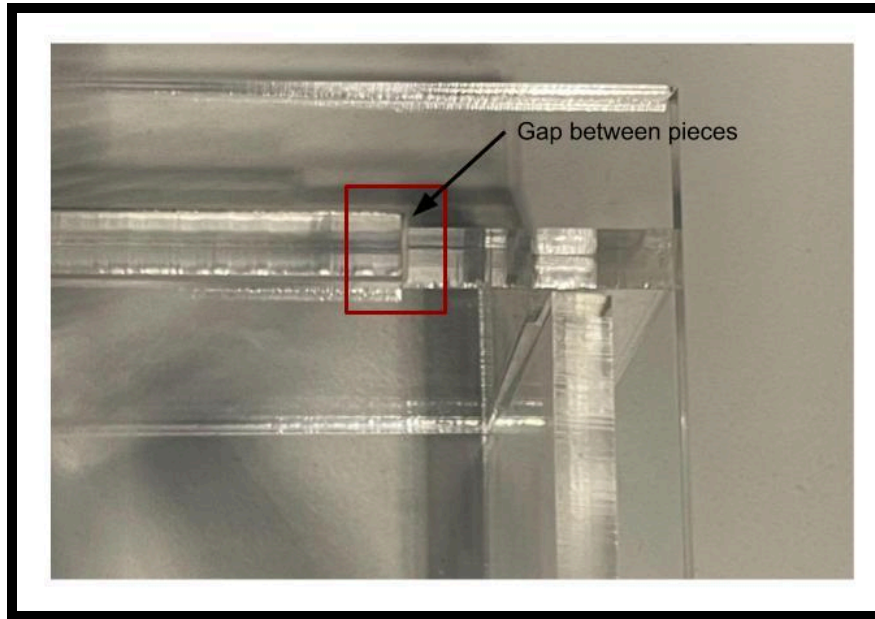


Figure 2.2: Illustration of gaps between pieces on the stand (Top facing)

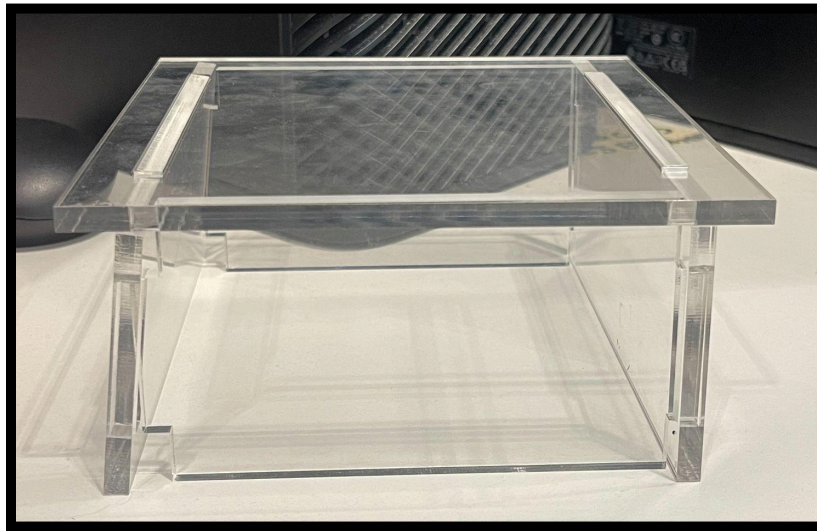


Figure 2.3: Picture illustrating the box's loose slots

Estimated Cutting Time: 5 minutes

Actual Cutting Time: 4 minutes and 55 seconds

Setup Time: 15 min (including file preparation, material setup, machine preparation, and tool prep/part organization before assembly)

Assembly Time: 3 minutes and 48 seconds

13. Redesign Process:

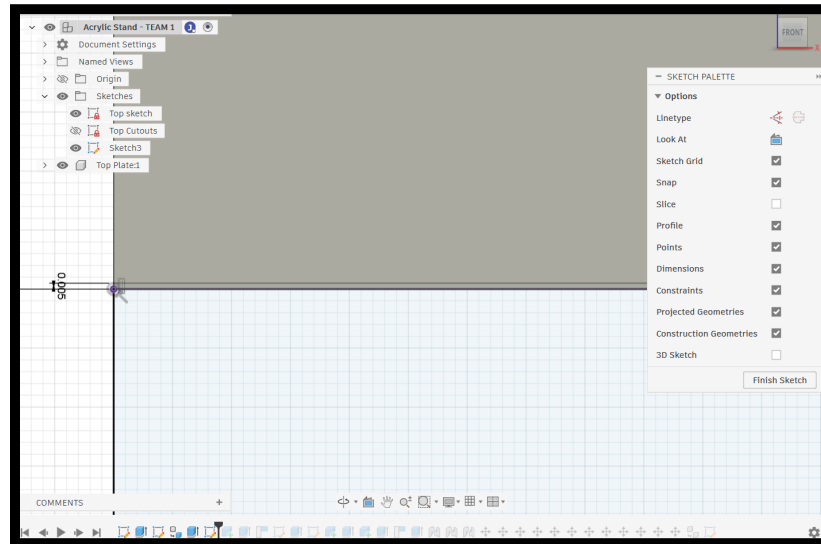


Figure 3.0: Screenshot illustrating the changes made to the parts (0.005 on each side)

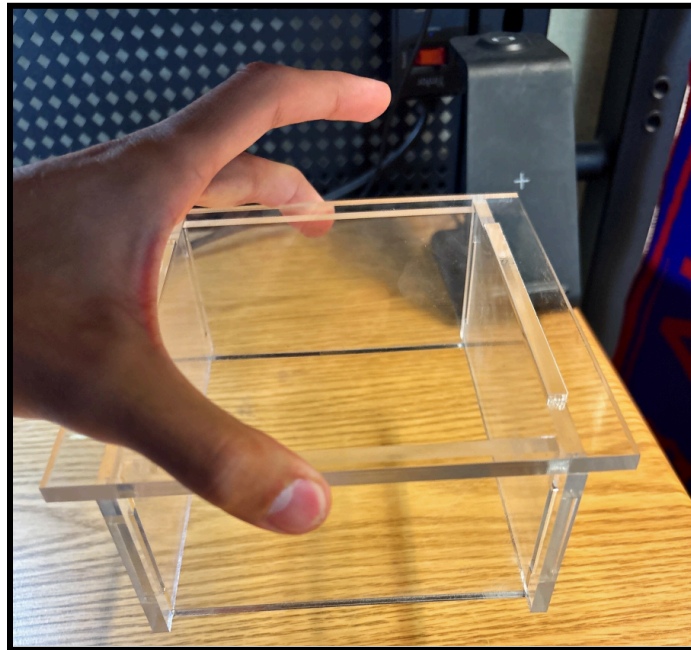


Figure 3.1: Table being held by only the top plate

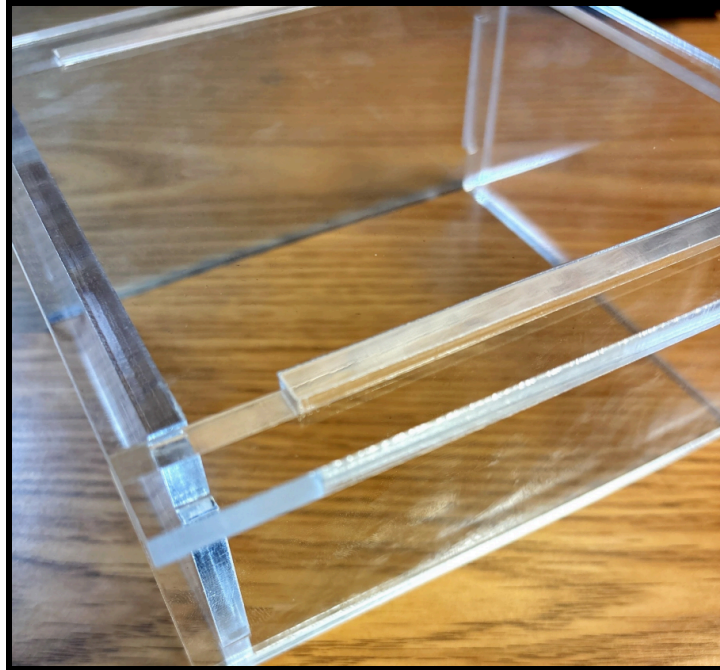


Figure 3.2: Image illustrating no gaps between slots

We found that the slots were loose in the original design because the dimension of the laser kerf was not taken into account, which is 0.005 in. To fix this, we subtracted 0.005 from each edge of the holes for the slots and added 0.005 to each edge of the slots. This made an interference fit, which accounts for the extra material removed from each laser cut. Additionally, we measured the thickness of the acrylic sheet we bought from Jackson Innovation Studio, and found that it was not consistent with the CAD model. The actual thickness was 0.218 in, while the CAD model had it at 0.236 in. This was also most likely a cause for the loose slots. After we made these changes, we cut the parts and found that they had a much better fit, and the part was no longer wobbly. The part was able to be picked up by just the top plate, and could be shaken without the parts becoming loose.

Table 3: Table illustrating design evaluation

Criteria	Description	Score (1-5)	Notes
Completeness of Documentation	All required dimensions, views, and specifications are clearly provided	5	All required dimensions, views, and specifications were provided within their team's CAD files. All sketches were properly dimensioned. Their CAD was very easy to work with.
Clarity of Instructions	Assembly steps and fabrication details are easy to follow	5	The assembly instructions were very clear and easy to follow. They included detailed pictures and annotations to show exactly how parts fit together. No extra force was needed to push parts together.
Manufacturability	Design is feasible with laser cutting and assembly constraints	5	The design was easy to manufacture. Their sketches translated perfectly for laser cutting. We had no trouble laser cutting their design.
Error Rate	Number of missing, incorrect, or conflicting dimensions	5	There were no missing, incorrect, or conflicting dimensions. The stand was manufactured and assembled exactly as their team intended.
Rework / Iteration Required	Number of adjustments required during fabrication due to poor design	5	We needed 2 iterations of fabrications but not because of poor design. The only change we implemented was adjusting slot sizes, making them smaller because the acrylic sheet provided was slightly thinner or the laser width was slightly thicker than the group expected (they used an exact 6mm thickness) so the parts were a bit

			<p>loose. A simple resize of the slots fixed this. The 2nd iteration was fully expected as this is the norm with engineering design. Nothing works perfectly on the first try. This 2nd iteration is once again not due to poor design by their group, their design works perfectly.</p>
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Estimated Cutting Time for 2nd Iteration: 5 minutes 6 seconds

Actual Cutting Time for 2nd Iteration: 5 minutes 6 seconds

Setup Time for 2nd Iteration: 15 min (including file preparation, material setup, machine preparation, and tool prep/part organization before assembly)

Assembly Time for 2nd Iteration: 4 minutes 22 seconds

14. Cost Analysis for Team 1:

Material Cost:

When laser cutting the parts at Jackson Innovation Studio, we had to purchase a full acrylic sheet. Therefore, the material cost is calculated using a full acrylic sheet, as detailed below:

¼" Acrylic (12 x 12) sheet from Jackson Innovation Studio = \$10 [1]

Fabrication Cost:

- a) Setup Cost (for 1 sheet)

Setup time: 15 minutes (900 seconds)

Conversion to hours: $\frac{900}{3600} = 0.25$ hours

Labor price: \$30 per hour [2]

$$\$30 \times 0.25 = \$7.50$$

- b) Laser Cutting Cost (for 1 unit)

Laser Cutting time: 5 minutes 6 seconds (306 seconds)

Conversion to hours: $\frac{306}{3600} = 0.085$ hours

Laser Cutting price: \$40 per hour [2]

$$\$40 \times 0.085 = \$3.40$$

Total Fabrication Cost: \$10.90

Assembly Cost:

Assembly time: 4 minutes 22 seconds (262 seconds)

Conversion to hours: $\frac{262}{3600} = 0.073$ hours

Labor price: \$30 per hour [2]

$$\$30 \times 0.073 = \$2.19$$

Total Cost (for 1 Unit): $\$10 + \$2.19 + \$10.90 = \23.09

Scaling to Production Quantity (50,000 Units):

a) Total Material Cost:

Area of the Top Face: 34.1 in^2

Area of the Side Panel (1): 12.0 in^2

Area of Side Panel (2): 15.2 in^2

$$\text{Total Part Area: } 34.1 + 12.0 + 15.2 = 61.3 \text{ in}^2$$

Acrylic Sheet Area: $12 \text{ in}^2 \times 12 \text{ in}^2 = 144 \text{ in}^2$

Assumption: Space is not fully used efficiently when laser cutting due to part spacing requirements and edge margins; therefore, the total used cutting area is 130 in^2 .

Number of parts produced per sheet:

$$\frac{130 \text{ in}^2}{61 \text{ in}^2} = 2 \text{ parts}$$

$$\frac{50,000}{2} = 25,000 \text{ acrylic sheets}$$

Overall Material Cost: $25,000 \times 10 = \$250,000$

b) Fabrication Cost:

Setup cost is influenced by the number of acrylic sheets used. As the setup cost for 1 acrylic sheet is \$7.50, and a total of 25,000 sheets are required to manufacture 50,000 units, the overall setup cost is calculated below:

$$\$7.50 \times 25,000 = \$187,500$$

Laser Cutting cost is influenced by the number of acrylic stands manufactured. As the laser cutting cost for 1 unit is \$3.40, and a total of 50,000 units are manufactured, the overall Laser Cutting cost is calculated below:

$$\$3.40 \times 50,000 = \$170,000$$

Overall Fabrication Cost: $\$187,500 + \$170,000 = \$357,500$

c) Assembly Cost: $\$2.19 \times 50,000 = \$109,500$

Total Cost (for 50,000 Units): $\$250,000 + \$357,500 + \$109,500 = \$717,000$

Logistic Constraints/Pallet Packing Analysis for Team 1:

Box Footprint Optimization ($n_L \times n_W$):

Team 1's design also utilized a 6" x 6" base plate. Their longer legs were 6" x 2.723" and their shorter legs were 4.974" x 2.505". This still keeps their maximum stand foot print as 6" x 6".

Using 0.06" E-flute corrugated cardboard wall thickness and 0.13" internal clearance tolerance for easy packing/unpacking, the absolute minimum box side length (defined below as s_{min}) is:

$$s_{min} = 6" + 2(0.06") + 0.13" = 6.25"$$

With the minimum box size now established as 6.25" x 6.25", the maximum number of boxes that can fit along the length (defined as n_L) and along the width (defined as n_W) can be calculated as follows:

$$n_L = \frac{48"}{6.25"} = 7.68 \rightarrow 7 \text{ boxes along the length}$$

$$n_W = \frac{40"}{6.25"} = 6.4 \rightarrow 6 \text{ boxes along the length}$$

To cover 100% of the shipping pallet and eliminate void space, we can calculate the optimized length (defined as L) and width (defined as W) for the flat-pack box.

$$L = \frac{48"}{7 \text{ boxes}} = 6.85"$$

$$W = \frac{48"}{6 \text{ boxes}} = 6.66"$$

The total number of boxes per layer can be calculated using $n_L \times n_W = 42$ boxes per layer.

Vertical Packing and Pallet Capacity:

Standard shipping pallets limit the stacking of the flat-pack boxes to a maximum total height of 60". The pallet itself is 6", leaving 54" of vertical space for stacking.

The total thickness of their disassembled acrylic stand is 0.65", as it consists of 3 layers of Jackson Innovation Studio's 1/4" acrylic that actually measures to 0.2167" per layer.

Accounting for the 0.06" corrugated cardboard thickness, and 0.03" of compression tolerance, the total external box height (defined as h_{min}) can be calculated as follows:

$$h_{min} = 0.65'' + 2(0.06'') + 0.03'' = 0.80''$$

Therefore, the total number of vertical layers (defined as n_{layers}) is calculated as:

$$n_{layers} = \frac{54''}{0.80''} = 67.5 \rightarrow 67 \text{ vertical layers}$$

Thus, the maximum capacity of a single pallet (defined as N_{Pallet}) can be calculated as follows:

$$(n_L \times n_w) \times h_{min} = N_{Pallet} = 42 \times 83 = 2814 \text{ units per pallet}$$

Full-Scale Order Logistics:

To fulfill the total production volume (defined as V_{Total}) of 50,000 units. The total number of pallets required to fit the entire order (defined as P_{Total}) can be calculated as follows:

$$P_{Total} = \frac{V_{Total}}{N_{Pallet}} = \frac{50,000}{3,486} = 17.768 \rightarrow 18 \text{ pallets}$$

15. Production Rate for Team 1:

Total Production Time:

a) Setup Time

Setup Time (per sheet): 15 minutes

As we require 25,000 sheets to manufacture 50,000 units, the overall setup time is detailed below:

$$25,000 \times 15 = 375,000 \text{ minutes (6,250 hours)}$$

b) Laser Cutting Time

Laser Cutting Time (per unit): 5.1 minutes

As we are manufacturing 50,000 units, the overall laser cutting time is detailed below:

$$50,000 \times 5.1 = 255,000 \text{ minutes (4,250 hours)}$$

c) Assembly Time:

Assembly Time (per unit): 4.37 minutes

As we are assembling 50,000 units, the overall assembly time is detailed below:

$$50,000 \times 4.37 = 218,000 \text{ minutes (3,642 hours)}$$

Overall Production Time: 6,250hours + 4,250hours + 3,642hours = 14,142 hours

Manufacturing Timeline (50,000 Units):

Length of shift: 8 hours per day [2]

$$\frac{14,142}{8} = 1,768 \text{ days}$$

Assuming that the workers work for 5 days a week, the overall manufacturing timeline can be calculated as follows:

$$\frac{1,768}{5} = 354 \text{ weeks (6.8 years)}$$

16. Inspection Results for Team 3:

The table relies on two critical measurements to be assembled and held together. The critical measurements are the slot length and the length of the thickness of the material. Other measurements, such as display size, must also be inspected to satisfy the 6" x 6" area requirement [2]. The assembly can be seen in Figures 4.1 and 4.2:



Figure 4.1: Front view of the assembled display



Figure 4.2: Side view of the assembled display

The critical measurements were measured with a caliper (see Figure 4.3 and Figure 4.4) and a ruler so they could be recorded and compared to the nominal measurements from the drawings (see Table 4.5)



Figure 4.3: Measuring the thickness of the material



Figure 4.4: Measuring the length of the slot

Table 4.5: Inspection Analysis

Feature	Nominal (in)	Measured (in)	Deviation	Tolerance	Pass / Fail
Slots	0.25	0.25	0.00	± 0.125	Pass
Thickness of Pieces	0.25	0.22	0.30	± 0.125	Fail
Length of Shelf	6.00	5.98	0.02	± 0.25	Pass
Width of Shelf	10.00	9.97	0.03	± 0.25	Pass

NOTE: Although multiple thicknesses and slots could be recorded, all measurements (both thickness of all 4 pieces and length of all 8 slots, and length/width of both shelves) resulted in the same value when measured with the precision of the caliper (two decimals)

Results and Analysis:

The nominal vs. measured dimensions show a fatal flaw in both the design and fabrication process that compromises the quality of the design and the functionality. While the slots, lengths, and widths of the shelves seem to be fairly accurate, it is evident that the kerf of the laser was not accounted for in the design. Some of the measurements are short by 0.02 - 0.03 of an inch, which is likely a result of the thickness of the laser cutting being more than intended on the shelves. Not accounting for kerf may compromise designs relying on press fits, such as this one. This can be fixed by adding 0.05 to the dimensions of the sketches, taking the laser thickness into account beforehand. The more fatal issue, however, is in the fabrication process. The thickness of the material is crucial to the design, since it determines the intended slot size. Since the design called for 0.25" thick material, the slots were designed to perfectly accept 0.25" thick parts. But, since during the fabrication process the material selected was actually 0.22", there is no press fit, and the significant extra clearance fails to lie within the accepted tolerance. Figure 4.6 highlights the gap created by the tolerance failure, and Figures 4.7 and 4.8 show the effects of the gap and how it compromises the stability of the structure.



Figure 4.6: Close-up of gap/misalignment



Figure 4.7: Leaning display (1 shelf)

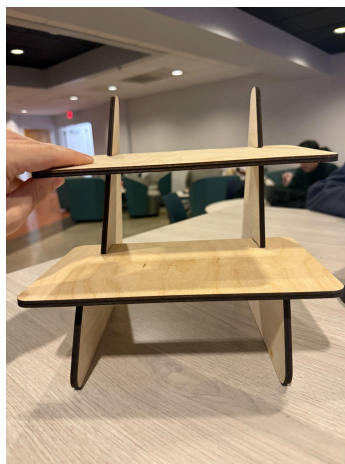


Figure 4.8: Leaning display (Both shelves)

The defect of the assembly could simply be fixed by measuring the thickness of the stock material beforehand and altering the size of the slots to match the material. This would create a tighter press fit, which would minimize leaning or instability, and allow the display to be moved without disassembling or falling apart in the process.

Table 5: Comparison with our design specification

Criteria	Pass/ Fail	Notes
Performance	Pass	The stand was able to easily hold up products (with a multitude of sizes) without collapsing; it was also able to hold itself up without needing external support.
Target Cost	Pass	Laser cutting time and material usage was minimized through the stand's straightforward design; this therefore resulted in a lowered costs for the product.
Packing	Pass	As the design is composed of different individual pieces that come together to form the stand, the product can be packed into a box and shipped with minimal void space.
Manufacturing Process/ Facility	Pass	The design was manufactured (laser cut) at Jackson Innovation Studio.
Size	Fail	As measured and detailed above, the design does violate the 6" x 6" design specification [2] with its measured size of 5.98" x 9.97"
Aesthetics and Finish	Pass	Overall, the manufactured stand has a modern design with clean edges and smooth finishes. It contains a higher and lower level to showcase its products, ensuring that retail products can be easily seen by the passing customer.
Ergonomics	Pass	The product's design is highly straightforward with little-to-no outside help or tools required in its assembly. A user should be able to assemble the stand with minimal time.
Quality & Reliability	Pass	The product contained functional interference fits between its pieces: no extra tools were required in its assembly and disassembly. However, an aspect which could be improved upon is making sure the fits had a higher tolerance and could join together more tightly.

GD&T Compliance:

GD&T	Measurement (in)	Tolerance	Pass/Fail
Parallel top shelf to the ground (Front to back axis)	0.84 in.	0.1 in.	Fail
Parallel walls to the vertical axis	0.43 in.	0.1 in.	Fail
Perpendicularity of walls to the ground	0.43 in.	0.5 in.	Pass
Flatness of the bottom of the base	~0 in.	0.01 in	Pass
Profile of a surface of the bottom shelf from top to bottom	0.21 in.	0.1 in.	Fail

NOTE: The GD&T specifications for parallelism failed to reference datums, so we used what we thought was the most reasonable datum.

Overall, the GD&T was not satisfied. Only 2 out of 5 constraints were met, with the parallelism specifications being far from the required tolerance. This was most likely due to factors such as the laser kerf not being taken into account, and the inaccurate thickness of the wood.

Table 6: Table illustrating Manufacturing Evaluation

Criteria	Description	Score (1-5)	Notes
Dimensional Accuracy	Measured dimensions match design specifications	3	As illustrated in Table 4.5, all except one of the part's features (the thickness of the material) were within tolerance of the GD&T drawings. This resulted in fits which affected the usability of the shelf. GD&T also failed to meet requirements in 3 out of 5 specifications
Assembly Quality	Parts fit properly and assemble without excessive force	4	As the laser kerf was not taken into account when designing the shelf pieces, this resulted in loose fits, causing the display to not function optimally. As shown in figure 4.7, the manufactured display leaned to one side when only 1 shelf was attached to it. However, the parts still fit together comfortably without the need of excessive force.
Surface Quality	Edges, finish, and overall quality meet expectations	5	Overall, the display case was made to a high standard. For example, the edges were all relatively smooth with the corners rounded to ensure user safety. Though the team did use plywood instead of acrylic, they still ensured that the plywood had a high quality finish.
Compliance with Design	Fabricated part matches intended geometry and function	3	Overall, the design was able to hold some products: fulfilling its intended function. However, the size of the product was larger than what was requested within the specification (a maximum 6" x 6" footprint compared to the actual size of 6" x 10"), and therefore points were knocked off because of that.

Overall, this design is given a “pass” during the inspection phase due to its decent dimensional accuracy (as illustrated in Table 4.5), surface quality and aesthetics (detailed in Tables 5 and 6) and functions as intended by the project brief (supporting products and stands independently). However, it could still be improved in areas such as assembly quality; by changing the thickness of the slots to match the thickness of the material and ‘Design compliance’ scaling down the entire design to fit the 6” x 6” maximum size specification [2]. Also, the GD&T requirements could be followed more accurately than they were on this iteration.

Reflection:

We only received feedback from the team that fabricated our original design. They mentioned that all of our dimensions followed our GD&T constraints. Our components fit securely and did not fall out when shaken. One thing that was reported as a slight issue was the difficulty of assembly, as it was challenging to press fit our legs into the top plate, and it was also difficult to disassemble. The team mentioned that they broke one of the legs when trying to disassemble our design. To fix these issues and improve our design in another iteration, we would loosen the tolerances on our holes and pins on our legs so that there is still a tight enough fit to securely hold the legs, while also making it less difficult to assemble and disassemble.

