MMAE 232 Sustainable Foam-Core Chair Technical Report

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***Abstract*—This project design, analyzed and tested a sustainable foam core chair the meet dimensional and weight requirements while supporting a 103kg person without fasteners. Three concept designs were made and evaluated using a Pugh chart, and the winning concept was modeled in Inventor. Analysis was done using lines of force sketches along with FEA to find and remove stress concentration. The final CAD model weighed in at 462g found using the volume and density of the material. A physical prototype was made using a laser cutter and assembled and held together using friction and interlocking parts. The chair was tested incrementally, ending with the professor, where minimal damage occurred. The result indicated a successful chair, made through careful load bearing design, light weighting techniques, and targeted reinforcement, which can be suitable for future use.**

I. Introduction

A. Motivation and Context

Furniture is a very common consumer product, and to benefit economics and the environment, there have been many sustainable approaches in design. Normally, furniture, especially chairs, is made of wood or plastic which is joined by fasteners, all of which increase price, waste, and make it hard to dispose of. This report explores a design of a lightweight chair made of foam core board, without the use of adhesives or fasteners, in order to reduce environmental impact, while still meeting everyday needs of a chair. By eliminating the use of adhesives and fasteners, the design reduces waste and simplifies and of life recycling, making it a relevant case study in sustainable product development.

The design demonstrates light weighting techniques, which are commonly used in mechanical and aerospace industries, demonstrating how the engineering process can be beneficial for product design. This concept chair is a lightweight, recyclable chair that maintains strength and function.

B. Project Objectives and Functional Requirements

The goal of the project was to design, analyze, and fabricate a foam core board chair that can hold the weight of the professor(103kg). Requirements include:

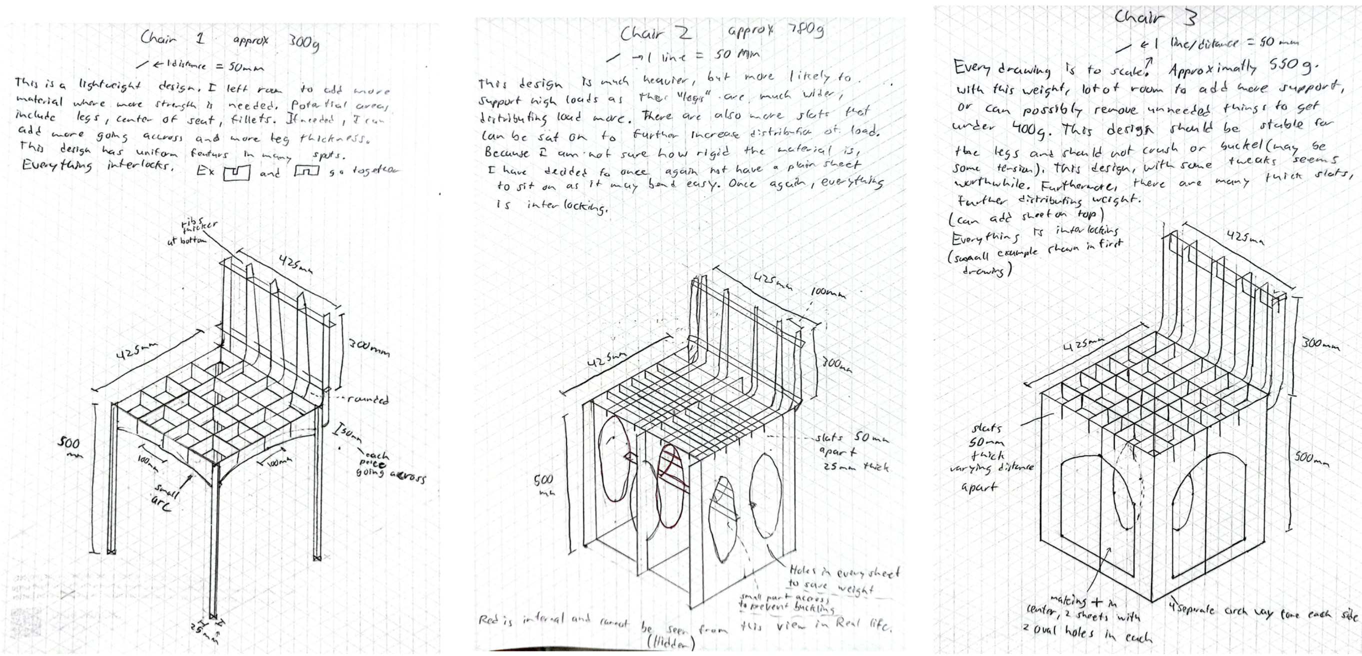
- Support a 103 kg person
- Seat height: 480 mm to 530 mm
- Seat depth: 410 mm to 450 mm
- Seat width: 410 mm to 450 mm
- Back height (from seat): 280 mm to 480 mm
- Material: foam core board sheets (457 mm $\times$ 610 mm $\times$ 5 mm).
- No fasteners, adhesives, or tape.
- Target mass $<$ 800 g, with preference toward $<$ 400 g.

Fig. 1: Final Prototype

II. Concept Generation and Evaluation

A. Sketches and Concept Descriptions

Three design sketches were created to give different ideas and approaches to the chair. Design 1 was a lightweight design, which was made to be under 400g. It included small legs in each corner and chair slats to help distribute load evenly. The



(a) Design 1

(b) Design 2

(c) Design 3

Fig. 2: Hand-sketched concepts

legs were skinny and small arches attached each leg, to help avoid high stress areas. For all of the designs, the back rest starts with the slats, then comes up to act as the back rest, where then all of the ribs for the back rest are connected. Each design also included slats similar to Design 1, however, some had more or less than others. Also, the designs all included interlocking slots and members to hold together. Design 2 had 5 "legs", which were large pieces for foam core which had holes cutout to reduce weight. This design had more slats than the first one, but shorter ones to help distribute weight more while keeping the weight down. Design 3 was similar to Design 2, with slightly different cutouts, and leg layout, and it also had more slats. Design 1, being the lightest, had the highest stress concentration, while design 3 had the lowest.

B. *Pugh Chart and Decision Rationale*

TABLE I: Pugh chart used to evaluate concepts.

Criteria	Weight	Design 1	Design 2	Design 3
Dimensions	4	0	0	0
Chair Weight	4	+	0	0
Looks	1	0	0	0
Comfort	1	-	0	+
Ease of Build	2	+	-	0
Ease of Design	2	+	-	0
Number of Parts	3	0	0	0
Fasteners	4	0	0	0
Chance of Success	6	-	+	+
Weighted Total		1	2	7

To pick the best design, a Pugh chart was used. The analysis using the Pugh chart indicated that Design 3 would be the most promising, as it had the best balance overall, specifically excelling in structural integrity.

Design 3 was selected because it had the highest chance of success while also being the most comfortable, and not being to difficult to design or put together. Though it was not the lightest, due to it probability of success, it was selected over Design 1.

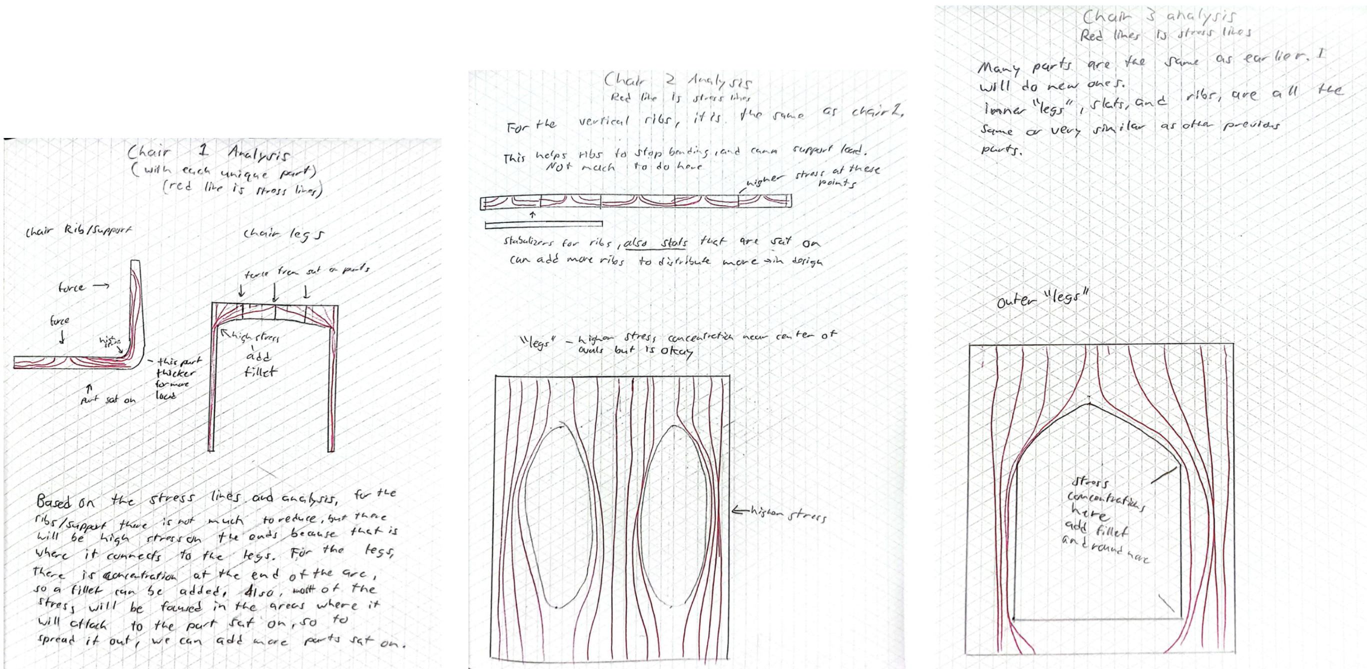
III. Analysis

A. *Lines of Force*

The lines of force sketches for design 1 showed a lot of stress on the corners of the arch. This can be improved by increasing the radius of the arch and include a fillet on the end of the arch. For each design, high stress was found at the intersection of the slats, along with the corner of the ribs. This can be improved by making more slats to distribute load more and increasing the thickness of the corner of the ribs for the back rest. Design 2 had a small amount of stress concentration between and on the edges of cutouts that were used for light-weighting. Design 3 had similar stress concentrations, however due to single large cutouts, it had higher stress concentrations on the sides of the legs. Since the stress concentration was not to high, no design changes were need in account for the stress in Design 2 and 3 legs.

B. *Finite Element Analysis*

FEA was done on Design 3 as it was the sketch that ended up being drawn on Inventor. The analysis was done on the seat of the chair and the backrest. The results indicated high stress where each slat overlapped, along with where the slat connected to the legs. There also seemed to be a good amount



(a) Design 1 (b) Design 2 (c) Design 3

Fig. 3: Lines of Force

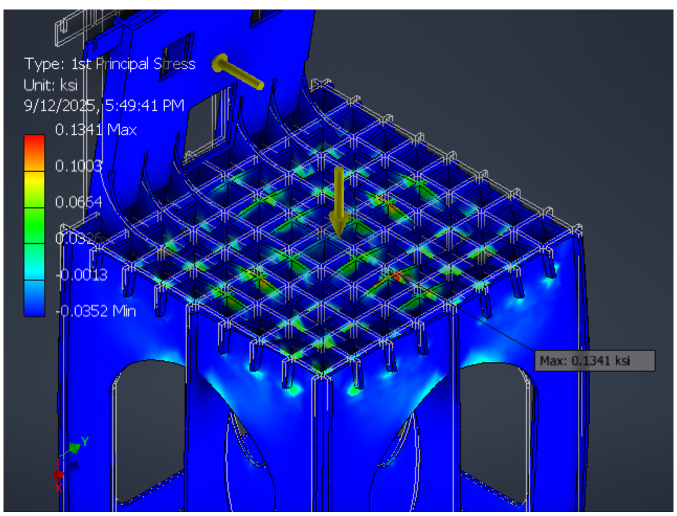


Fig. 4: Stress Analysis of All Weight On Seat of Chair

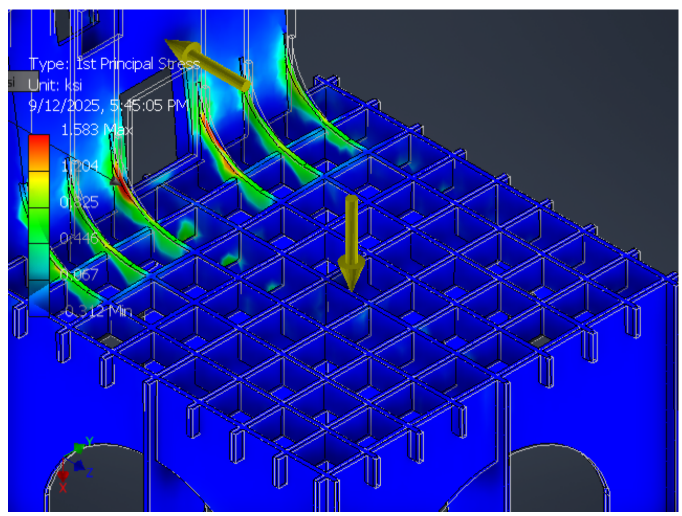


Fig. 5: Stress Analysis of Half Weight On Back of Chair

of stress at the top of the arches. For the backrest, there was a lot of stress on the front corner. These areas of stress concentrations were expected, and very minor adjustments were made in order to reduce it, as not much as needed. The FEA confirmed the lines of force analysis.

IV. Experimental Results

A. Prototype Fabrication and Mass

The prototype was fabricated by laser cutting foam core board sheets, based on DXF files created and provided. The laser cutter, being very precise, made it easy to fabricate and assemble the chair and its interlocking parts. Originally, the assembled chair's mass was estimated to be 788g, however, after getting the new density, it was estimated at 462g, according to Inventor predictions. After one session of laser cutting, I only got a few of my pieces cut out, so I did some small tests with them. From those simple tests and looking at stress analysis results, I made some tweaks to the design. After that, I was able to laser cut my parts and assemble the chair. While assembling the chair, I found out that some parts were to small to provide sufficient support as parts broke during assemble as tolerances were very tight. Due to time constrains, I left those parts as is.

B. Load Testing and Analysis

After assembling the chair, I sat on it. I learned that most of the slats, due to being relatively short and thin, did not provide much support, and many cracked. While this is true, the main structure of the chair remained intact while hold my weight. I then asked a friend who is heavier than me to test the chair, where the same thing happened. Then the professor tested it, and it worked with little deformation to the main structure. The only deformation was slight bend in one of the four outside legs along with more of the slats breaking. Despite partial cracking of slats, the main frame supported a load exceeding 103 kg, validating the design requirements.

V. Discussion

A. Meeting Requirements

My design met all of the functional requirements. It met all of the dimensional constrains which can be seen in the drawing of the assembly. The seat height was 490mm, the seat depth and width were 450mm and 445mm, and the back height was 285mm, all of which meet the retirements. It was also able to hold the professor who is 103kg, while being less than 800g as it was 462g.

B. Light Weighting

To get to the 462g, many light weighting techniques were used. For the back rest, ribs were used to provide the main structural support. For the legs, arches were used along with oval cutouts. These features effectively provided support with making the chair much lighter.

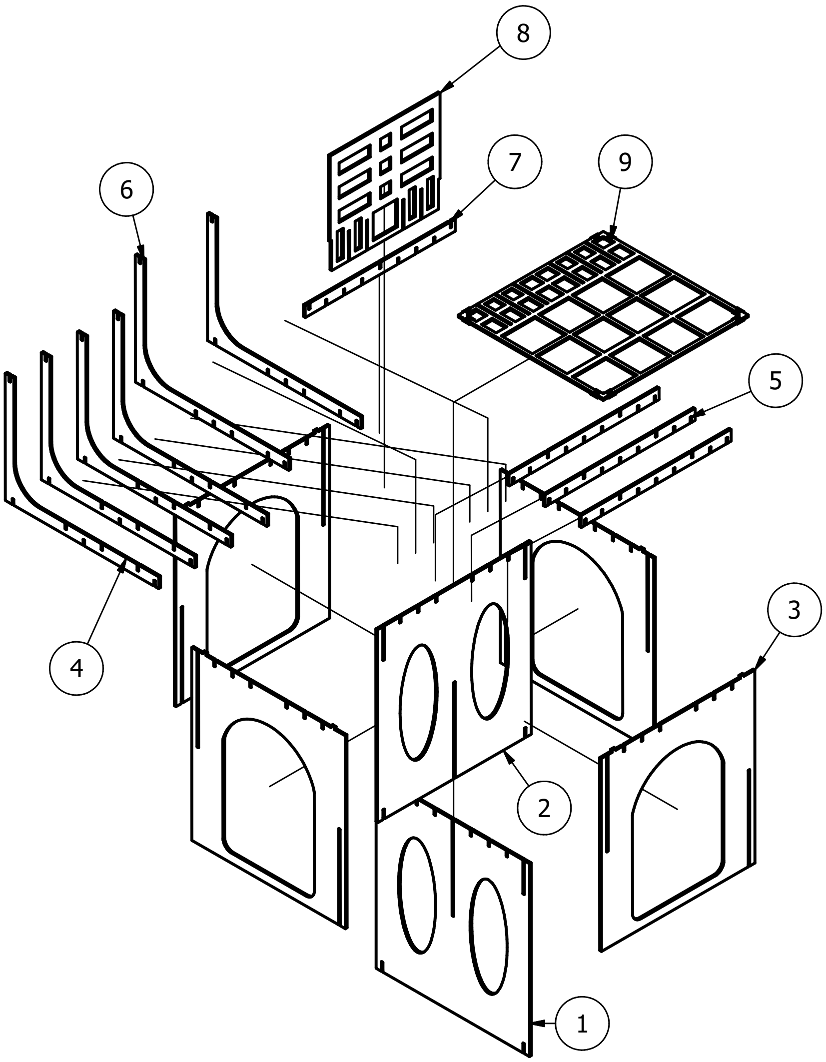
C. Future Improvements

While the chair was successful, there is a lot of room for future improvements. Moving the main legs in would improve the support provided as they were to far apart, causing some of the outside legs to not provide much support. Also, the slats were interlocking, causing weak points where they interlocked as that part was thinner. To fix this, we can make them not interlocking and just put one set underneath the other while still being the same pattern. Also, more support can be added to the back rest by adding more ribs and making them thicker.

VI. Conclusions

This project was a success, as all of the objectives were achieved. A foam core board chair was designed, analyzed, fabricated, and tested to meet all of the requirements (dimensional, load support, weight limit and more). Three concept sketches were made and analyzed using lines of force sketches to find areas of high stress. The concept section shows a Pugh chart which certain weighted criteria used to select the best concept. The chosen concept, Design 3, was modeled on inventor and a FEA was done to further find stress concentration, in order to tweak the design accordingly. Inventor predicted a mass of 462g, which is well in the acceptable range. The chair model, meeting all of the specifications, was then made into DXF files and laser cut, where some issues were found. After minimal tweaks to the design, everything was laser cut and assembled. The interlocking structure and small tolerances led to a tight fit and some assembly issues, but the chair was still overall successful demonstrating high strength to weight ratio. Future work can be done to improve the successful design, though it is not necessary. Overall, the project demonstrated that sustainable, fastener-free furniture can be both lightweight and structurally sound, highlighting the broader potential of engineering methods in product design

Appendix A
Engineering Drawings



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1	1	MMAE 232 Sustainalble Chair Inside Leg2 - Nicholas Skiba
2	1	MMAE 232 Sustainalble Chair Inside Leg - Nicholas Skiba
3	4	MMAE 232 Sustainalble Chair Outside Leg - Nicholas Skiba
4	4	MMAE 232 Sustainalble Chair Slats- Nicholas Skiba
5	3	MMAE 232 Sustainalble Chair Slats - Nicholas Skiba
6	2	MMAE 232 Sustainalble Chair Slats And Back Over - Nicholas Skiba
7	1	MMAE 232 Sustainalble Chair Slats Under - Nicholas Skiba
8	1	MMAE 232 Sustainalble Chair Back Rest - Nicholas Skiba
9	1	MMAE 232 Sustainalble Chair Seat - Nicholas Skiba

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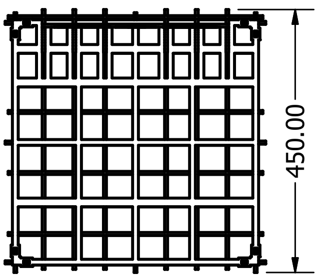

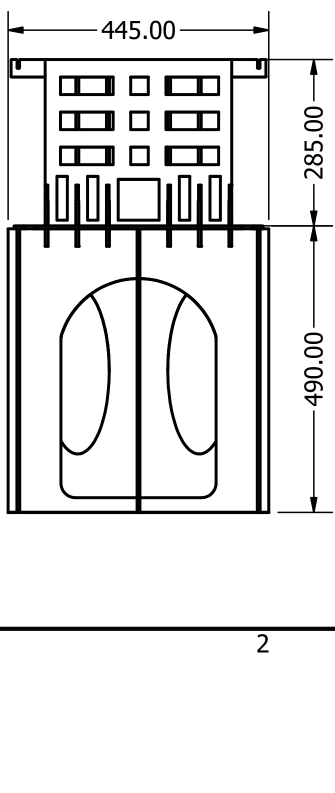

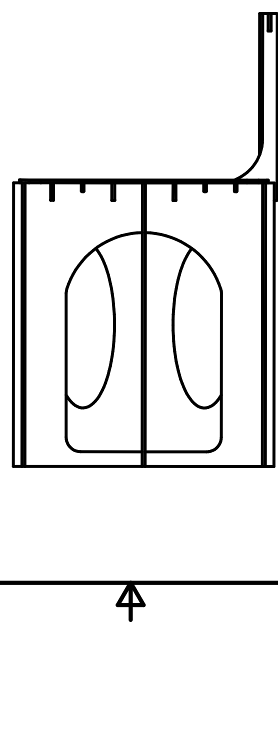

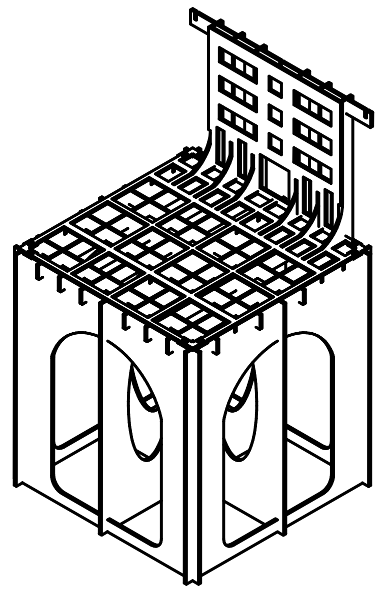

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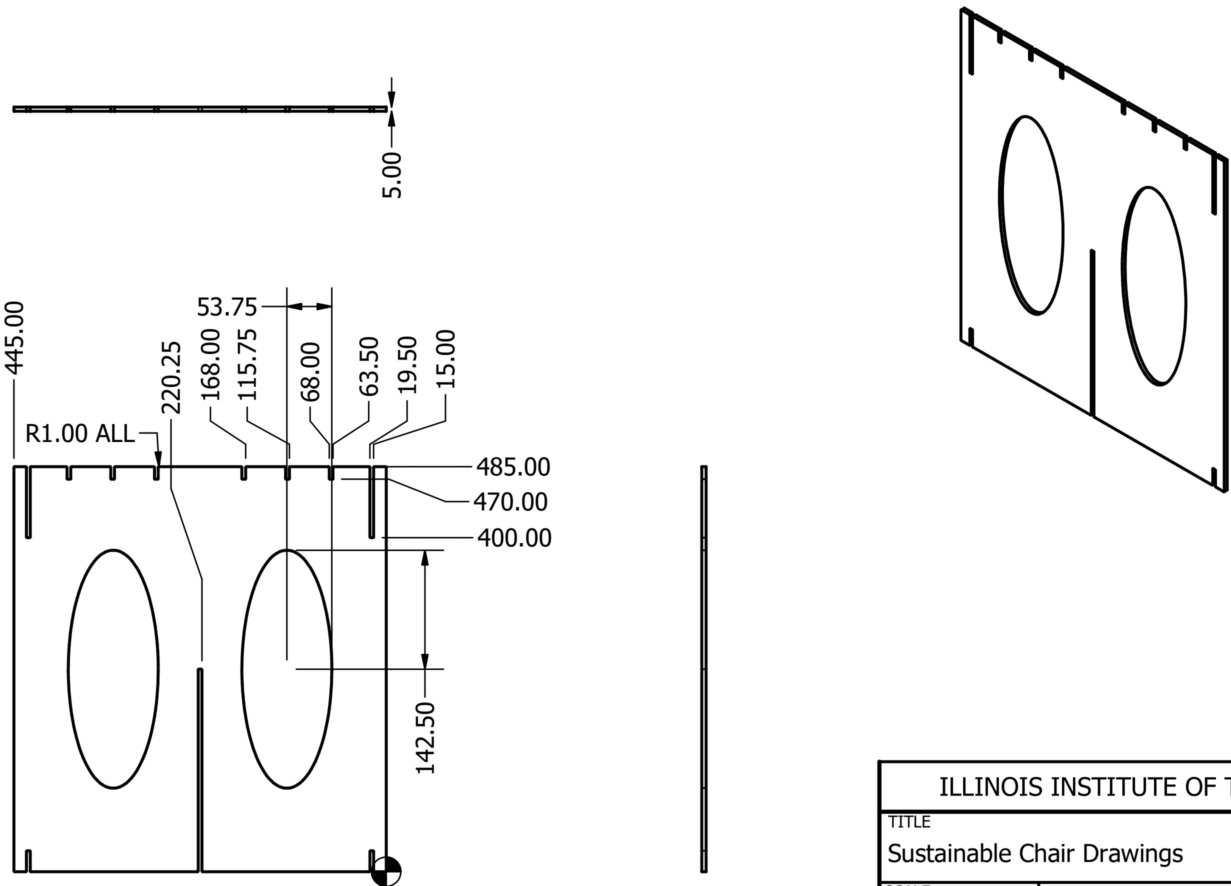

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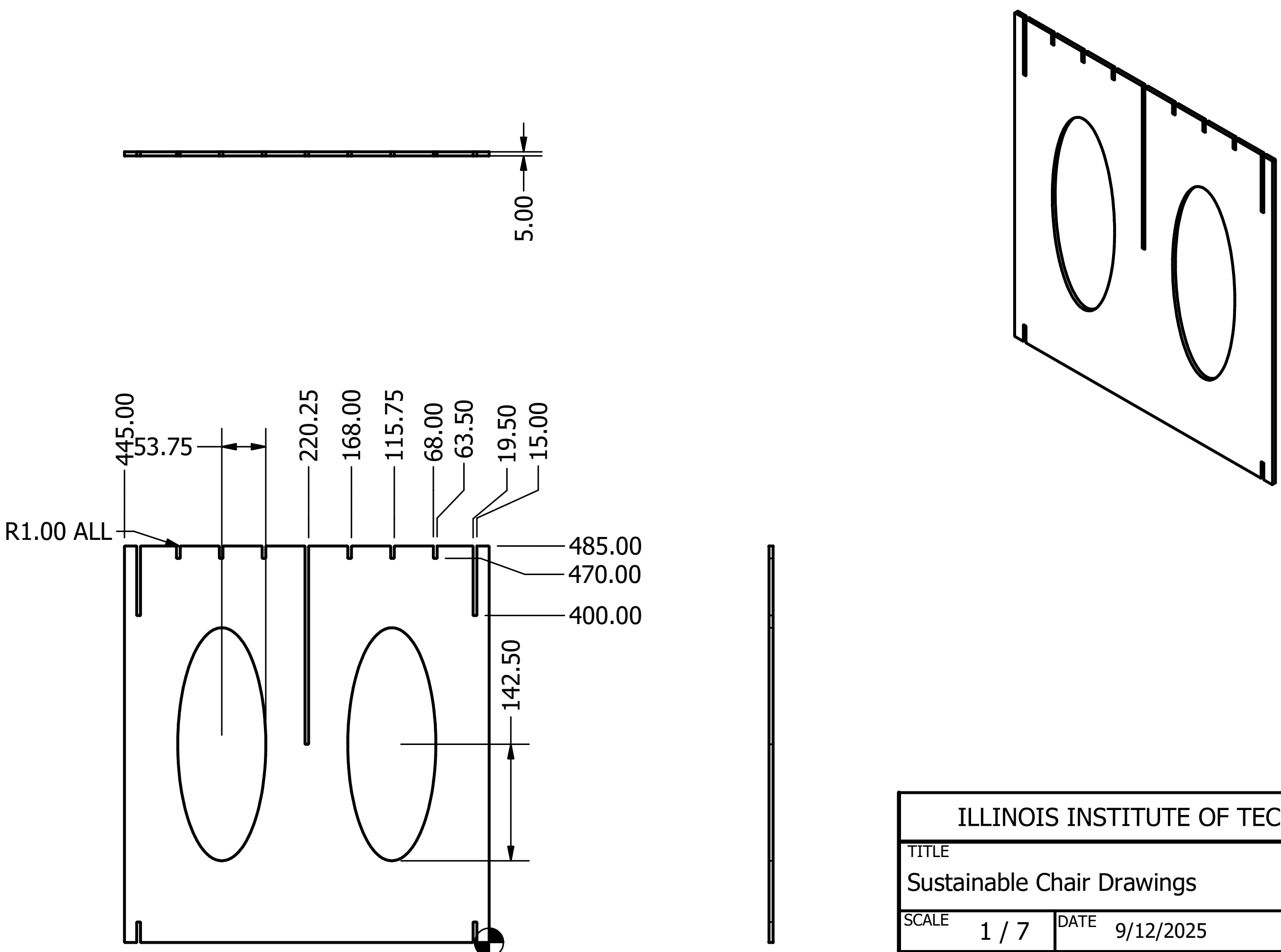

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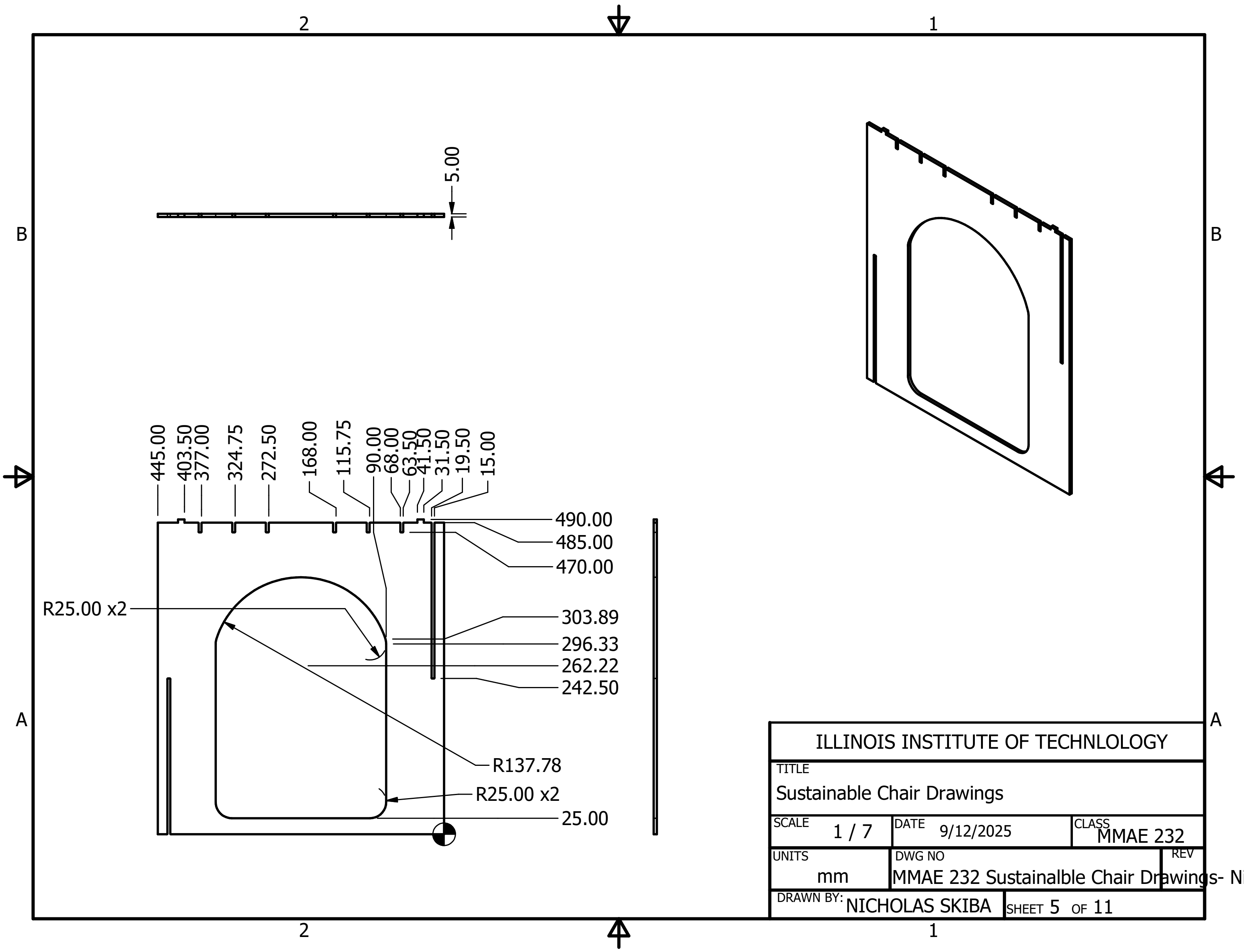

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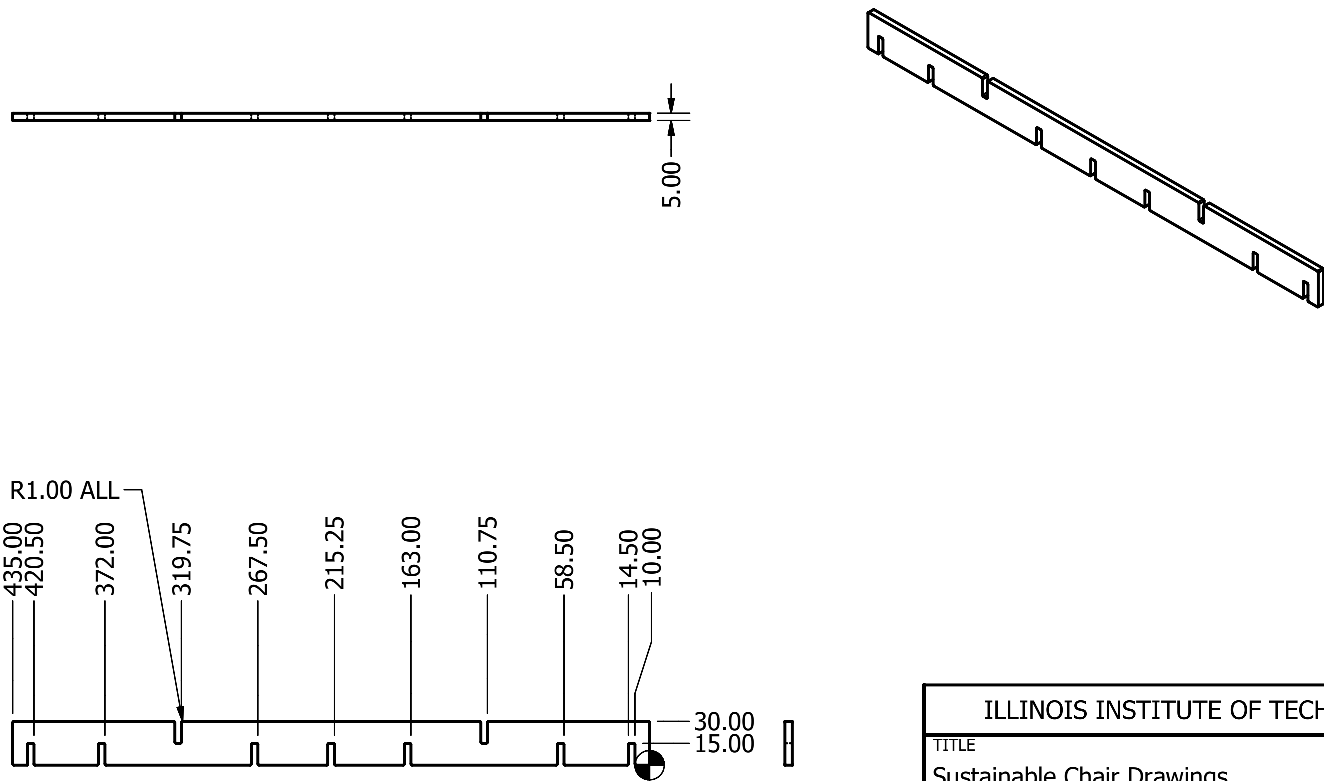

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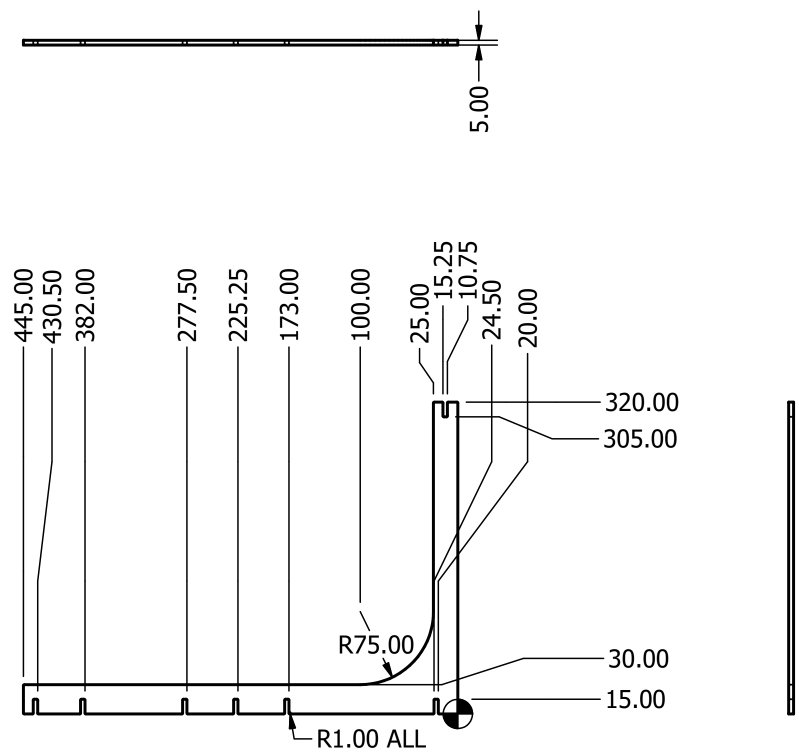

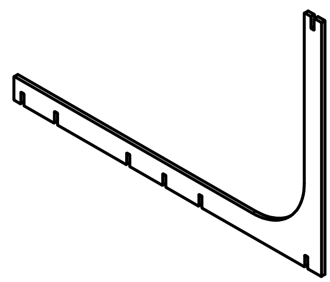

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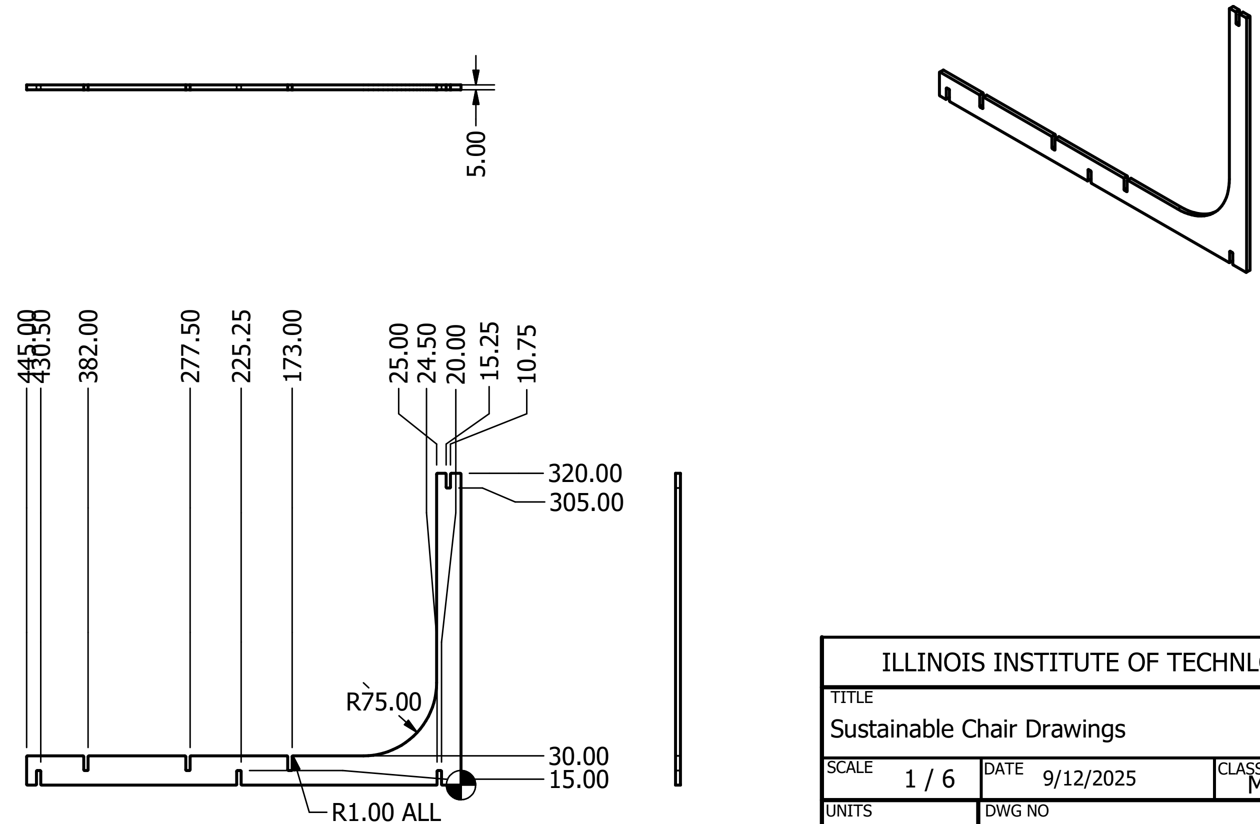

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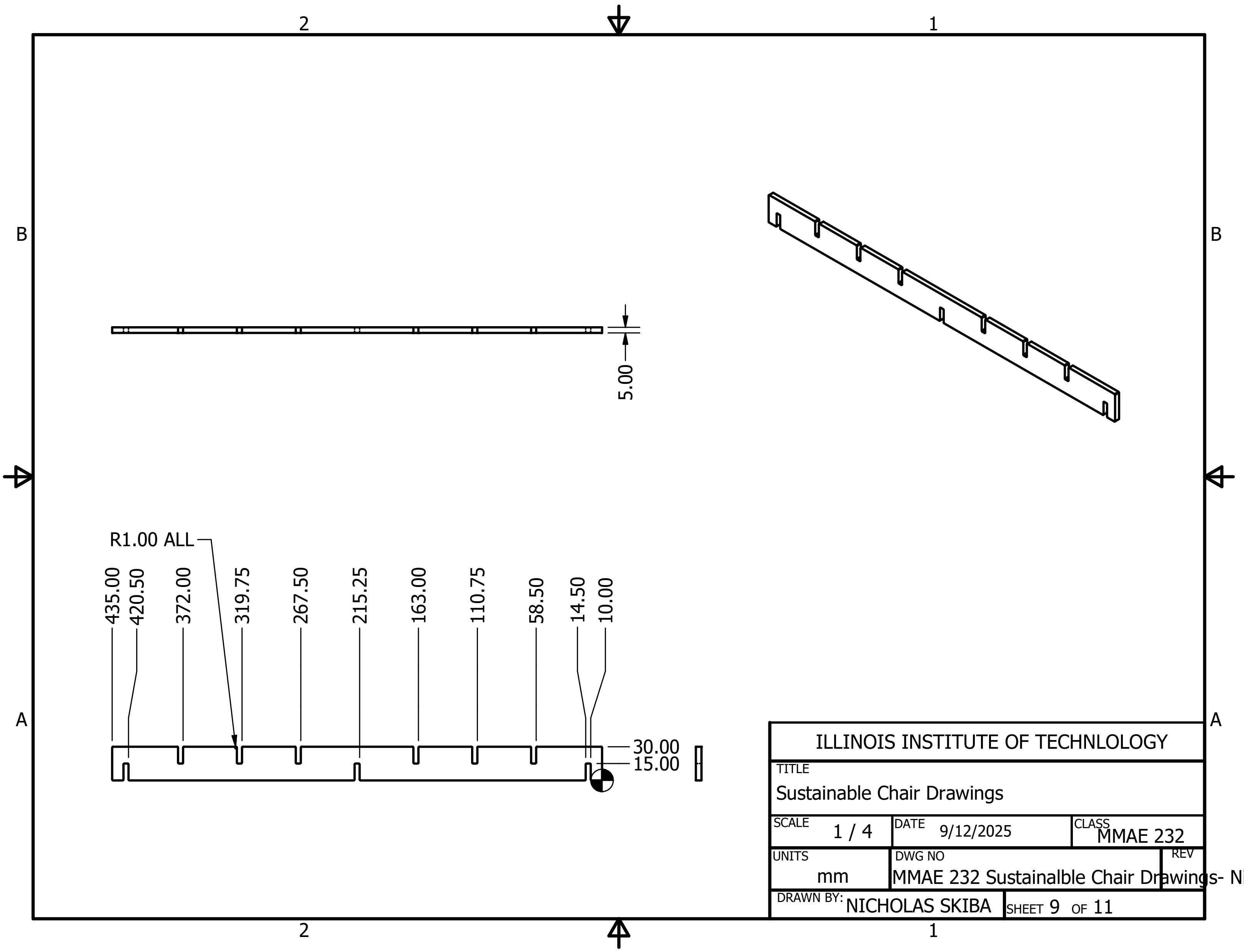

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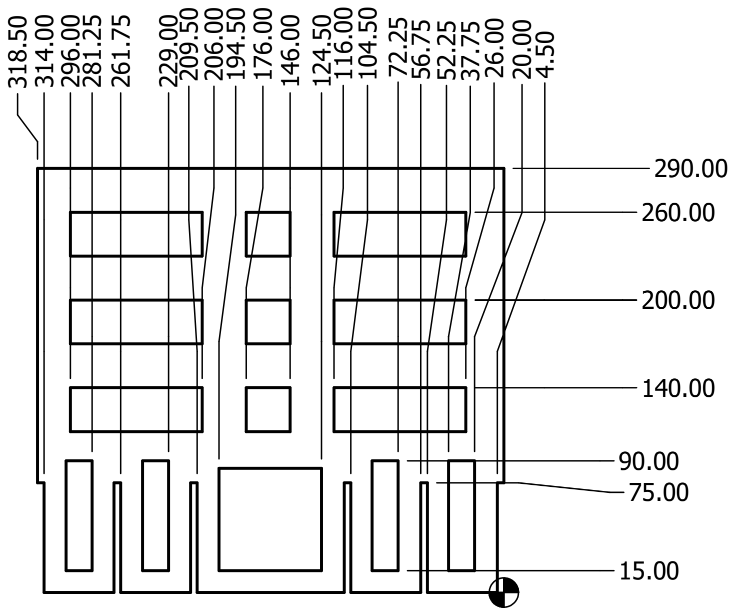

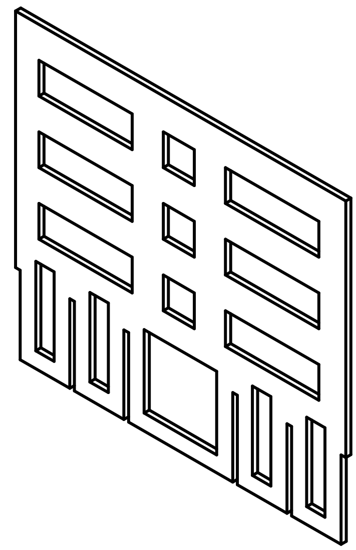

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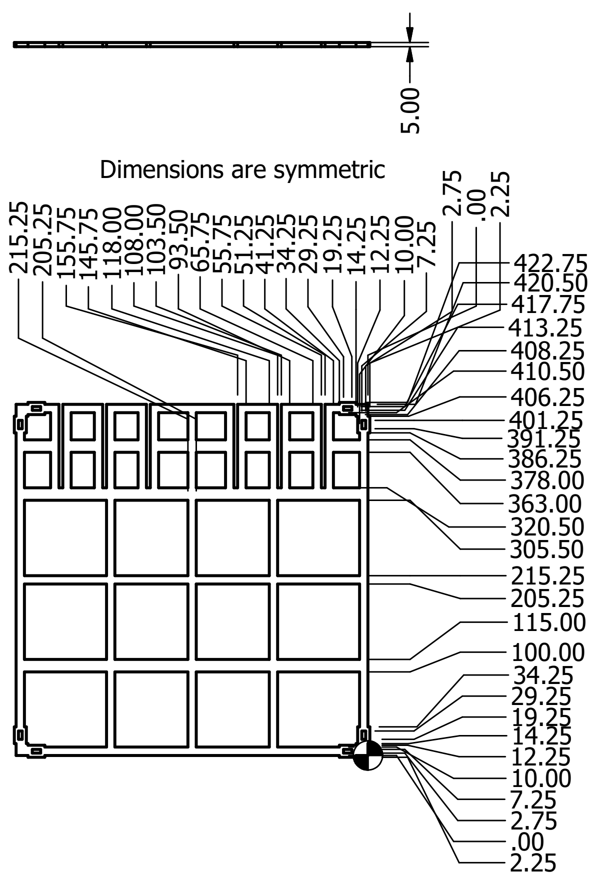

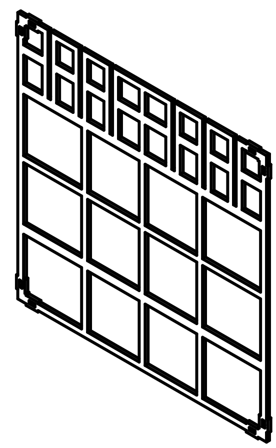

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