ME110 Final Project Report

Team 15: Metamorphic Designs

Sophya Mirza, Antonio Herrera, Aaron Sheyman, Cyrus Xiang, Jack Zilles, Meta Zhou

---

Abstract/Executive Summary

The following report details the product development process for the Metamorphic Design expandable coffee table to dining table concept and final prototype. Our process began with research into the small furniture market as well as the competitive landscape relating to our product concept. Afterwards we gathered insight into our target market of first-time apartment owners and college students in order to develop a structured set of customer needs through individualized interviews compiled by each member. Using the knowledge of our target market and audience, we began to generate product concepts, culminating in the selection of our final product, materialized in the final prototype. With an initial scale 3D-printed model, we made adjustments to mechanical systems integral to having the extended stage withstand substantial load during regular use. We were then able to fully manufacture a full-scale, wooden prototype utilizing a Shopbot CNC mill.

Business Opportunity

Competitive Landscape

Though there were no existing products which matched our concept, we opted to research similar products aiming at the same customer base and trying to resolve the same issue.

cosimates Lift Top Coffee Table [Cost: $219.22 (Amazon.com)]

- Main Issues: Customer reviews indicate the assembly was too confusing and that the expanded table stage was pretty short/uncomfortable to use as a dining table.

VINGLI Lift Top Coffee Table [Cost: $118.99 (Amazon.com)]

- Main Drawbacks: No full functionality as a dining table, meaning only half of the table is used for expanding. Customer reviews indicate materials feel cheap/flimsy

Expand Furniture Box Coffee to Dining Table [Cost: $1995 (expandfurniture.com)]

- Main Drawbacks: Far too expensive for the target market. Seems like there would be little to no functionality as a coffee table (before expanding) because of the lack of leg space and short height.

From researching some of the most popular models in the expanding table, small furniture space on large online retailers such as Amazon, we found three key drawbacks to the products currently available: Lack of functionality as a coffee table, as dining table, or extremely high cost to consumers. Ideally, our product will tackle all these issues and more by using affordable materials and integrating a more practical design for easy use as fully-fletched dining table and coffee table

Customer Needs/Interviews

As a team, our main goal with developing our product was to first understand the needs of the average customer and to implement those needs every step of the way. This first began with gathering first-hand accounts of individuals who had previous experience with folding/expanding furniture and to gather their feedback. We did so by having all team members develop slightly different questions and conduct field interviews with classmates and friends. Some sample questions include…

- *What previous experiences do you have with portable/expanding furniture?*
- *What are the biggest challenges you face when it comes to furniture in small spaces?*
- *What are your thoughts on multi-use furniture available?*

Market Research

Before being confident in pursuing the selected concept of small-space, multi-use furniture, we first wanted a detailed account of the state of the small space furniture market and whether entering this space would result in reasonable success. The following are our findings.

On the issue of reaching a sustainable consumer field. According to FiveThirtyEight.com, the average American will move around 11 times in their lifetime, and more specifically the average American under 40 will move 8 times.This qualifies our previous assumption that there exists a need for furniture that can be readily transported in the case of a change in living situation.

On the issue of average living space. According to RentCafe, the average living space in urban environments is around 290 square feet. This again qualifies another previous assumption that there exists a space in the furniture market for small products which can hold multiple uses to save small spaces from getting cluttered.

On the issue of the sustainability of the small furniture business. From FutureMarketInsights, we found that over the next decade, the small space furniture industry is expected to outperform many other furniture sectors, reaching a market value of $6 billion USD by 2033, growing annually nearly 6.0%. Thus, it is safe to assume that the small furniture market is ripe with market opportunity, and disregarding any outside financial forces such as recessions, we are expecting further growth in the small furniture sector for years to come. This comes from further analysis that the need for urban living spaces has been gradually increasing in recent years, and with unfurnished spaces becoming more and more common for first time buyers, the need for multipurpose and affordable furniture is prevalent.

BMC

Our business proposition and financial model were modeled in the following Business Model Canvas, as was prepared simultaneously by all team members in a scheduled team meeting (see BMC in appendix, table 1.1)

By coming together and fully developing the BMC in a single session, we got a deeper understanding of key main subjects: understanding target audience, effective communication, and adaptability. From identifying all key trade/manufacturing partners necessary to develop our product, we understood that this would require far more communication, planning, and ability to adapt to rapid changes, if for instance a supplier was to opt out from manufacturing. Additionally, by listing all value propositions we reinstated the main factor differentiating our product from the competition, understanding of customer needs. Going back to past research on our customer base, we understood that our product had to prioritize ease of use, durability, and aesthetic value to achieve a healthy relationship with the consumer. Additionally, our business strategy was found to be fairly traditional, with one of two approaches being to focus on direct-to-consumer or retail tie-in such as with IKEA.

Product Value

Our product, the expanding coffee to dining table concept, is fully equipped to handle the necessary competitive, business, and practical restraints due to forces outside simply manufacturing the product itself. For one, our table will focus on transportability, i.e. how easy it is to take apart and move in case of a change in living situation. As we found with most competitive products, no such existing product aims to solve this issue in a world where those in small apartments are often those who move the most frequently. In addition, our product focuses on its full functionality in both stages, as coffee and as dining tables. In both stages, the tables will be able to sustain considerable weight and functional wear/tear. As opposed to the competition, our product will be one of the first to act as a full dining table instead of just a sitting desk and a coffee table in one product. The functionality alone will drive many to purchase our product instead of competition as it would be far more affordable than purchasing two separate products. Finally, our product will continue to prioritize cost to consumers, aiming to outprice the competition in the under $200 range, perfectly suitable for first time apartment owners and college students.

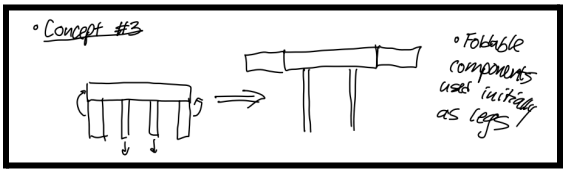
Concept selection

Each team member was tasked with creating 10 designs for our concept. Each member then gave a brief description and pitch for their designs to the rest of the team; explaining the mechanisms and design choices made. Designs that were immediately recognized as improbable or difficult to realize were discarded, and the top 5 designs by each team member were put into a decision matrix (appendix table 1.2). The criteria and weights for our designs were determined to be:

- Manufacturability (0.22): cost and ease of production
- Usability (0.26): ease of use for the customer when expanding and compacting the table
- Space efficiency (0.16): the ratio of the surface area when compacted to the surface area when expanded
- Transportability (0.08): ease of transport from one location to another
- Aesthetic (0.15): visual appeal of the product

- Assembly (0.13): ease of initial assembly for the customer

Designs were given a 1, 0, or -1 in each category, with a score of 1 meaning the concept excels in that category compared to existing products. A score of 0 indicates that the product is on par with current solutions, and a score of -1 means the concept is worse than existing solutions. Designs AH3 and JZ1 scored highest in the decision matrix. As these two concepts were very similar, we decided to pull elements from both designs to create a combined final design.



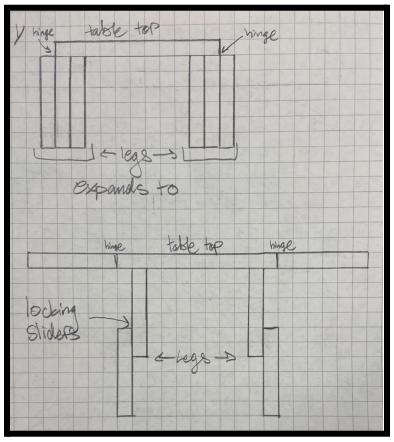


Image 1.1 (left): Design AH3

Image 1.2 (right): Design JZ1

Description of design specification

The target values for our product were as follows:

Metric #	Metrics	Measurement	Units
1	Weight	40-50	lbs
2	Compacted dimensions	15x36x24	inches
3	Fully expanded height	28-30	inches
4	Consumer cost	100-200	$USD
5	Material selection	Wood composite, aluminum fittings	N/A
6	Maximum load	150-200	lbs
7	Time for assembly	<1	hours
8	Time for transitioning	<5	minutes

Table 1: Metrics and Product Specifications

We determined these values based on potential user surveys and standards for currently existing products. The weight and dimensions were based on existing products. The consumer cost was determined from our user surveys, where we asked our potential customers how much money they would be willing to spend on a product like ours. The material was selected to optimize both weight and cost, as wood composite is both cheap and lightweight. Assembly time was determined from our user surveys where we asked what the average amount of time it took customers to assemble furniture. The time for transitioning was determined as it was important to us that the coffee table be easy and quick to transform.

Description of selected concept

Our two selected concepts both focused on a table that could expand both vertically and horizontally, transforming a coffee table into a dining table. The concept also both utilized legs that employed hinges to transform and extend the length of the table. With this information, we began sketching potential ways to make this mechanical movement possible.

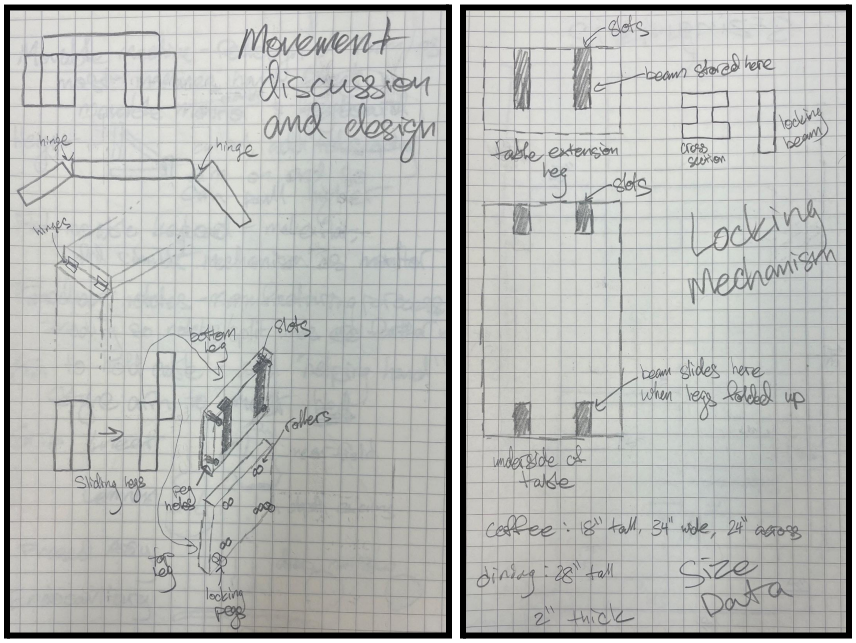


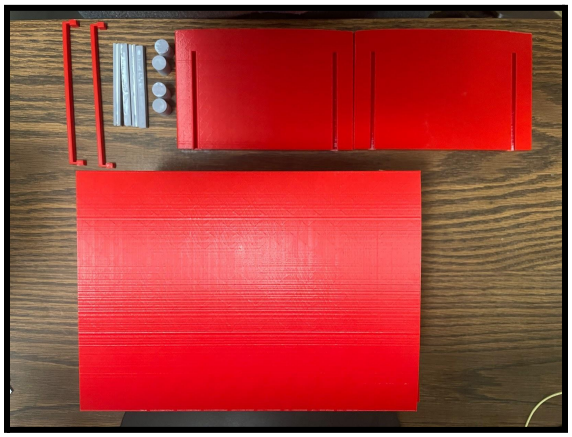
Image 2.1 (left): Height and length adjustment discussion

Image 2.2 (right): Length adjustment locking discussion

Once we had the movement mechanisms down, we began to CAD the design, making adjustments along the way when problems or better techniques presented themselves. After more than 10

iterations, including the adding of a push bar to move all locking bars into place at once and rounded corner pieces to improve aesthetics, the CAD model was finished and ready to be 3D printed for the first tests of a scale prototype (see final CAD models in appendix, images 1.1-1.4).

Images of your prototypes/prototyping process (Jack/Cyrus)



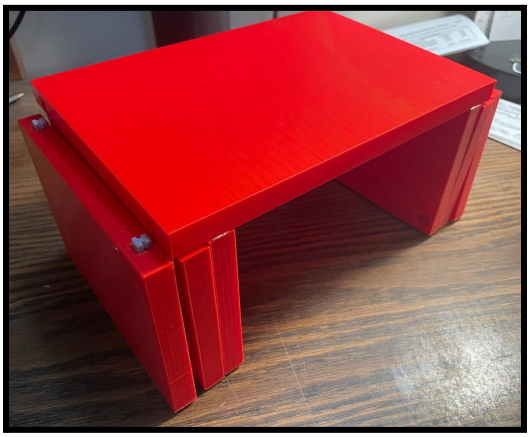


Image 3.1 (left): Individual 3D printed pieces. Image 3.2 (right): Coffee table configuration, 3D printed

Image 3.3: Dining table configuration, 3D printed

Upon the completion and assembly of the first prototype (pictured above), our team agreed that the model looked about how we expected it to. There was a little concern about the sizing of the model due to the fact that the initial prototype was ¼ scale. The look of the model was also affected by the material, which would be wood for the full scale model. The model felt stronger than expected, with any perceived frailty coming primarily from the use of PLA with low infill. We expected the full scale wood

model to be capable of withstanding the forces indicated in our product specs, but we conducted multiple simulations to be sure. The model worked as intended, though there was far more interference from friction than was desired. While this model was not large enough for full user tests, it was excellent at holding small items such as books, keys, and more.

For our next iteration, we decided to add rounded pieces that will fill the edge gaps when all the legs are folded in. When the outside legs are folded up, the rounded pieces will fill the gaps left by the splitting of the bottom two legs. This addition is intended to give the product a more finished look, which will help our need for aesthetics in this project. We also explored different options for the pin connections of the split legs at the bottom; as while it is easy to remove the pins and adjust the legs at a small scale, a full scale model will be much heavier and the process could be too labor intensive for the average user. Overall, this was a strong prototype which did its job and gave us changes to begin implementing changes.

Woodworking differs significantly from 3D printing, posing additional challenges. In 3D printing, software automatically slices and prints the parts. However, in machining, careful consideration is required to determine how the CAD parts will be “sliced” and positioned on the plywood sheet, our chosen stock material. Although we initially planned for 1.5" thick pieces, the stock material is only 0.75" thick, necessitating the slicing of parts and subsequent joining using various methods.

Milling operations have limitations compared to 3D printing, especially when dealing with restricted tool bit variations (e.g., the absence of T-slot bits in Jacobs Hall). Our designs were therefore confined to 2.5D with limited curvatures. To address this, we simplified the geometries of the inner mechanisms of the table, recognizing these limitations prior to manufacturing the full-scale prototype. While we managed to create slots by milling pockets on separate pieces and stapling them together, we made some premature mistakes. For instance, we overlooked the fact that subtractive manufacturing inherently wastes some material for each operation due to the finite diameter of the tool bit. Thus, designing the table's width as 2ft while the stock material's width was 4ft proved unwise, as we could only obtain a single piece from that stock. (This is because the first cut will waste about 0.02ft on the side of

the piece and the stock left is only 1.98ft long, less than 2ft required). Consequently, we ran out of materials and had to borrow additional stock. Attempting to rectify this, we precut using table saw the panels to the correct dimensions before CNC milling. However, this approach presented new challenges, requiring precise alignment of the panels with the mill's bed to avoid offsetting or displacing the desired features (e.g., misalignment of grooves with the panel's outer edge).

After countless hours in Jacobs, multiple mis-machined parts that needed to be rethought, seemingly hundreds of brad nails, and even some blood, we had a functioning wood prototype. It wasn't perfect, but it worked. We learned a lot about DFM for wood and CNC mills through this prototyping process. Our next steps would be redesigning for all of the issues we encountered, then building another table.

Image 3.4 (left): Coffee table configuration. Image 3.5 (right): Transitioning to dining table

Team reflections on the PD process

Overall, the product development process was a success. We were able to create a product that fulfilled our customer needs, key metrics, and the majority of our target values. Throughout the process we conducted thorough research, collaborated effectively as a team, and iteratively refined our design. Several factors that contributed to the success of our product are our key steps in the product development process. We researched our competitors and analyzed the business opportunity, conducted customer interviews, used decision matrix analysis, prototyped, and divided responsibilities accordingly. Each member of our team contributed to the initial stages of research, interviews, and concept generation. One

issue we ran into was effectively weighing the criteria to decide on an initial concept, however, we overcame this through effective and efficient communication. We only set up necessary meetings and messaged over WhatsApp to use our time effectively. We then split up into different roles based on our experiences in manufacturing, testing, developing, and worked together to create initial prototypes and a full-sized product.

During the prototyping phase, we encountered multiple problems. Reiterating our design and perfecting it on Solidworks gave us an opportunity to find critical errors in our design. Through simulations we understood the main structural problems and added supports through redesigning and selecting pins. 3D printing allowed us to view the prototype physically and address additional structural and aesthetic issues. In the machining phase, the thickness of the stock material and limitations in tool bit variability required careful consideration and adaptation in the design process. We adjusted the geometry of the inner mechanisms to accommodate such limitations of the milling operation further discussed in the prototyping section. We also came to a realization that subtractive manufacturing inherently wastes material. Creating a blueprint and layout of the pieces to precisely align them with the mills bed would have helped with this problem. Even though we encountered challenges with machining and material thickness during the manufacturing stage, we could have anticipated such limitations earlier in the design process, which would minimize design iterations. We also realized the importance of aesthetics in user satisfaction and market appeal. Moving forward, we will continue to refine the products design based on our lessons and feedback. We will continue to refine the product's visual appeal and incorporate smooth finishing touches. Additionally, we will develop a more efficient manufacturing process that eliminates excess waste, time, and user input. Through the marketing side, we will continue to develop an effective marketing and distribution strategy to bring our coffee table to the market.

To conclude, our team successfully navigated the product development process through constant iteration, team collaboration, and strategic planning. Our research and prototyping were key aspects in our approach and we look forward to introducing our unique product to the market.

Works Cited

FiveThirtyEight. “How Many Times The Average Person Moves - FiveThirtyEight.” FiveThirtyEight, 20 May 2016, https://fivethirtyeight.com/features/how-many-times-the-average-person-moves/.

RentCafe. “Apartment Space: U.S. Cities Where You Get the Most (& Least) for Your Money.” RentCafe, 22 Apr. 2021, https://www.rentcafe.com/blog/rental-market/market-snapshots/apartment-space/.

Future Market Insights. “Small Space Furniture Market: Global Industry Analysis 2014-2018 and Opportunity Assessment 2019-2029.” Future Market Insights, 2019, https://www.futuremarketinsights.com/reports/small-space-furniture-market.

Amazon.com. “VINGLI Coffee Table with Storage Shelf, Hidden Compartment & Lift Tabletop Dining Table for Living Room, Apartment, Reception Room, Gray.” Amazon.com, https://www.amazon.com/VINGLI-Coffee-Storage-Hidden-Compartment/dp/B09B9YLQ8N/ref=sr_1_30?keywords=coffee+table+converts+to+dining+table&qid=1683075148&sr=8-30&ufe=app_do%3Aamzn1.fos.f5122f16-c3e8-4386-bf32-63e904010ad0.

Amazon.com. “Customer Reviews: VINGLI Coffee Table with Storage Shelf, Hidden Compartment & Lift Tabletop Dining Table for Living Room, Apartment, Reception Room, Gray.” Amazon.com, https://www.amazon.com/product-reviews/B09RWJVHCT/ref=acr_dp_hist_2?ie=UTF8&filterByStar=two_star&reviewerType=all_reviews#reviews-filter-bar.

Expand Furniture. “Box Coffee to Dining Table.” Expand Furniture, https://expandfurniture.com/product/box-coffee-to-dining-table/.

Appendix

Table 1.1

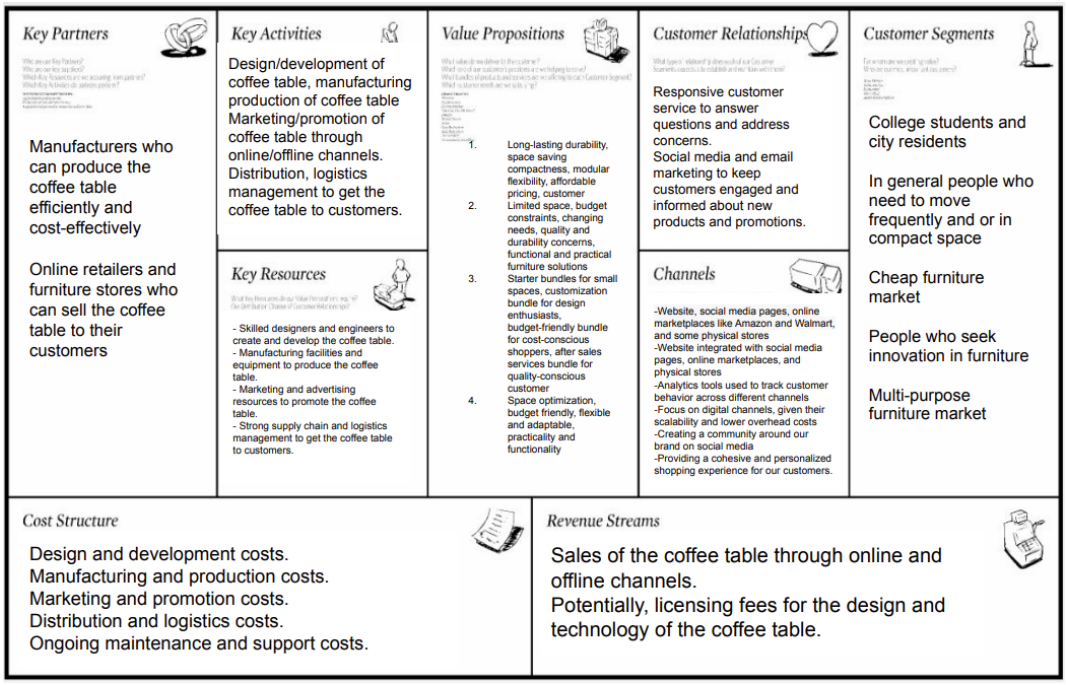


Table 1.2

Ideas	Manufacturability (Aaron, Sophya, Antonio, Jack, Meta, Cyrus)						Usability (Aaron, Sophya, Antonio, Jack, Meta, Cyrus)						Space Efficiency/ Compact (Aaron, Sophya, Antonio, Jack, Meta, Cyrus)						Transportability (Aaron, Sophya, Antonio, Jack, Meta, Cyrus)						Aesthetic (Aaron, Sophya, Antonio, Jack, Meta, Cyrus)						Assembly (Aaron, Sophya, Antonio, Jack, Meta, Cyrus)						TOTAL SCORE
Weight (%)	0.22	0.22	0.22	0.22	0.22	0.22	0.26	0.26	0.26	0.26	0.26	0.26	0.16	0.16	0.16	0.16	0.16	0.16	0.08	0.08	0.08	0.08	0.08	0.08	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13	0.13	0.13	
AS1	1	1	1	1	1	1	1	1	1	1	1	0	0	-1	1	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	1	-1	-1	0	0	1	0	0	1	2.01
AS2	1	0	0	0	0	-1	1	0	1	0	0	1	1	1	1	1	1	1	-1	0	0	-1	-1	-1	0	0	0	0	-1	0	0	-1	1	-1	-1	0	1.01
AS3	1	1	-1	0	-1	0	0	1	0	0	1	1	1	1	1	1	-1	1	-1		0	-1	-1	-1	1	1	1	0	0	1	-1	-1	0	-1	-1	0	1.18
AS4	0	0	0	0	-1	-1	1	-1	1	-1	-1	0	1	1	1	1	-1	1	-1	0	-1	0	-1	0	1	1	1	0	1	1	1	0	-1	0	-1	-1	0.19
AS5	1	1	1	0	1	1	1	1	1	0	-1	0	0	1	1	0	0	-1	1		-1	0	0	-1	0	1	0	0	0	0	1	1	-1	1	0	0	2.11
AH1	-1	1	0	0	1	1	1	0	0	1	1	0	0	0	0	1	1	0	0	1	-1	1	1	-1	1	0	0	1	0	0	1	1	1	1	1	0	**2.57**
AH2	0	0	-1	-1	-1	-1	1	-1	1	0	1	0	0	0	1	1	0	1	0	0	-1	0	-1	0	1	0	1	1	1	1	-1	-1	-1	0	-1	-1	0.06
AH3	1	1	1	1	1	1	1	0	1	1	1	1	1	-1	1	1	1	1	0	-1	-1	0	0	0	1	1	0	1	1	-1	0	1	1	1	1	0	**4.07**
AH4	1	-1	0	-1	1	0	1	0	1	0	1	1	1	-1	1	1	0	1	0	0	-1	0	1	0	0	0	0	0	1	-1	1	-1	0	0	0	0	1.52
AH5	1	0	1	0	1	1	1	1	-1	-1	0	-1	0	-1	1	-1	-1	-1	0	0	0	-1	1	1	1	-1	1	-1	0	-1	1	0	1	1	1	1	0.72
MZ1	-1	-1	0	1	1	1	0	0	1	1	1	1	1	0	1	1	1	0	0	0	-1	-1	1	1	1	0	1	1	1	-1	0	-1	1	0	0	1	2.48
MZ2	-1	0	-1	0	1	0	1	-1	1	1	1	1	1	0	0	1	0	-1	1	0	-1	0	1	1	1	-1	1	1	0	1	1	0	0	0	1	0	1.85
MZ3	0	-1	-1	-1	1	-1	0	-1	-1	-1	0	1	1	-1	1	1	1	0	1	-1	0	1	1	1	1	0	1	0	1	1	1	1	-1	0	0	0	0.27
MZ4	1	1	-1	0	-1	1	0	0	0	0	0	-1	0	-1	1	1	0	0	0	0	-1	0	-1	0	1	1	1	1	1	0	-1	-1	-1	0	-1	0	0.5
MZ5	0	-1	0	0	1	0	1	0	0	0	1	-1	0	-1	0	1	1	1	0	0	0	0	1	1	0	1	1	1	1	0	0	-1	1	1	1	0	1.6
SM1	0	1	1	-1	-1	0	0	1	1	1	0	1	1	1	1	1	0	1	0	1	0	1	0	1	0	1	0	0	-1	-1	0	1	1	0	-1	0	2.06
SM2	0	1	-1	-1	-1	0	0	1	1	-1	-1	-1	0	1	0	0	0	1	0	1	0	1	1	1	1	1	1	0	-1	0	1	1	-1	0	-1	1	0.37
SM3	1	0	1	0	-1	0	1	1	1	0	1	1	0	1	1	-1	1	0	-1	1	-1	0	-1	-1	1	1	1	0	0	0	1	1	1	0	0	1	2.57
SM4	0	1	0	0	0	0	0	0	0	0	-1	0	1	1	0	0	-1	0	0	1	0	0	0	0	0	1	0	0	-1	0	0	1	0	0	-1	0	0.2
SM5	1	1	-1	0	1	0	1	-1	1	0	-1	1	0	-1	1	-1	1	0	-1	-1	-1	-1	-1	-1	1	-1	1	0	0	0	1	1	1	-1	0	0	0.63
JZ1	1	1	1	1	1	1	1	-1	0	1	1	0	1	0	1	1	0	0	0	-1	-1	1	1	-1	1	1	0	1	1	0	0	0	0	1	1	0	**3.1**
JZ2	0	0	1	0	0	0	1	1	1	1	1	1	0	0	0	1	-1	-1	0	0	0	1	1	1	1	1	0	1	0	1	1	-1	1	1	0	0	**2.72**
JZ3	1	1	1	1	1	1	1	-1	-1	0	0	0	1	-1	1	1	1	1	0	1	-1	1	1	1	1	-1	0	0	1	-1	0	0	-1	0	0	1	1.94
JZ4	0	0	0	-1	-1	-1	0	0	0	1	-1	0	0	1	0	0	-1	0	0	1	0	0	-1	0	0	0	0	0	0	1	-1	1	0	0	-1	0	-0.64
JZ5	1	-1	0	0	1	1	1	-1	1	0	1	-1	-1	0	1	0	-1	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0	1	0	1.91
CX1	1	1	1	0	1	1	1	-1	1	0	1	1	0	-1	0	0	0	-1	0	0	-1	0	0	0	0	0	0	0	0	-1	1	0	1	1	0	1	1.85
CX2	0	0	1	0	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	-1	0	1	0	1	-1	1	-1	-1	0	0	0	1	1	0	1	0	**2.79**
CX3	0	1	0	0	1	-1	0	1	1	1	1	1	1	1	1	0	1	1	0	-1	0	0	0	-1	-1	0	0	1	1	-1	-1	1	0	1	0	0	2.29
CX4	0	0	1	-1	0	0	1	0	1	0	0	1	-1	0	0	0	0	0	0	1	-1	0	-1	0	0	-1	0	0	-1	1	0	-1	1	1	-1	1	0.52
CX5	1	1	1	0	0	1	0	-1	0	0	0	0	0	1	0	1	0	1	1	-1	-1	1	1	1	0	-1	0	0	0	-1	1	0	0	0	1	1	1.35

Images 1.1-1.4

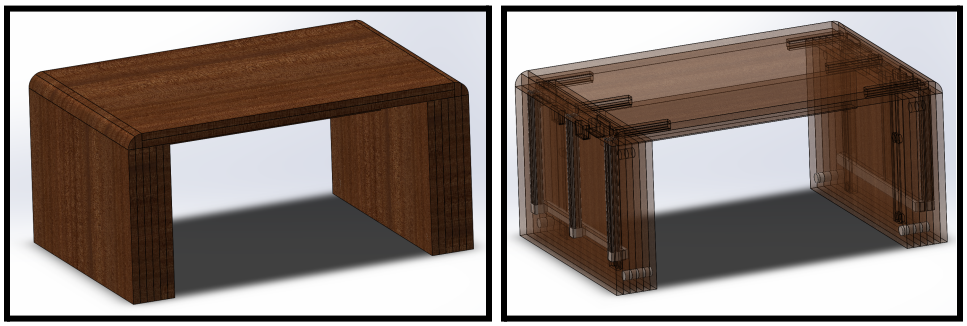


Image 1.1 (left): Coffee table configuration. Image 1.2 (right): Coffee table configuration (interior view)

Image 1.3 (left): Dining table configuration. Image 1.4 (right): Dining table configuration (interior view)

Image 2.1

Image 1.1: The team proving the strength of the prototype