1.6 Concept Selection

3 high fidelity concepts and 5 medium fidelity concepts from the generation process were considered for the concept selection process. These concepts were processed through the House of Quality, Pugh Chart, and Analytical Hierarchy Process tools to select the concept. These tools required selecting the most important customer needs and targets, and consideration was made to the business model being developed alongside the system. The following is the list of concepts considered during this process:

1. *5-Axis Mill With External Linear Actuation, Using Material Selection for Damping, With Polishing Post-Processing, and an Automated Tool Changer*
2. *5-Axis 3D printer With External Linear Actuation, Using Material Selection for Damping, With Polishing Post-Processing, and an Automated Tool Changer*
3. *5-Axis Water Jet using a Robotic Arm, Focused on Material Selection for Damping, with Sand Blasting Post-Processing, and Without a Tool Changer*
4. *3 axis FDM with 4 axis mill belt driven using geometric designed damping utilizing a quick change work space and no tool-changer for milling parts*
5. *3 axis FDM printer with conveyor belt motion during the printing process, with dual extruder head and water chamber for finishing.*
6. *5-axis waterjet with mobile robotic arm, uses geometric damping, water-only, no abrasive applications.*
7. *4 axis laser cutter with variable wattage laser head, externally driven linear actuator, tool changer to change the laser head between etching and cutting.*
8. *4 axis lathe with laser etching module installed in a tool changer.*

1.6.1 Binary Pairwise Comparison.

The most important customer needs were selected for the process and were compared to the eight concepts selected from the high and medium fidelity selections. The interpreted needs of the customers were considered during this process, and it resulted in the following table.

Table 8: Binary Pairwise Comparison

Pairwise Comparison											
	1	2	3	4	5	6	7	8	9	10	Total
Machine can fit on standard desk	-	1	0	1	1	0	1	1	0	0	5
Material Variety	0	-	0	1	1	0	1	0	0	0	3
Runs from standard 120V Outlet	1	1	-	1	1	0	1	1	0	0	6
Simple Operating system	0	0	0	-	1	0	1	0	0	0	2
Fast production of parts	0	0	0	0	-	0	1	0	0	0	1
Machine holds tight tolerances	1	1	1	1	1	-	1	1	1	1	9
Easy installation	0	0	0	0	0	0	-	0	0	0	0
Enclosed work area	0	1	0	1	1	0	1	-	0	0	4
Cost	1	1	1	1	1	0	1	1	-	0	7
Advanced movement	1	1	1	1	1	0	1	1	1	-	8
Total	4	6	3	7	8	0	9	5	2	1	10

In the table, each row compared to a column. Scoring a 1 represents that the row is more important than a column, while a 0 represents that the column is more important than the row. This showed allowed for the weights in the house of quality to be developed, as well as showing what the important features would be. The most important feature for the machine was that it needs to hold tight tolerances, followed by it having advanced motion and cost. The least important features were found to be ease of installation, then speed to manufacture parts and an easy-to-use operating system.

1.6.2 House of Quality.

Considering the weight factors and of each customer's needs, the House of Quality was implemented during this process. Using the tool, the most important engineering characteristics were isolated from the concept selection process.

Table 9: House of Quality

House of Quality

		Engineering Characteristics												
Improvement Direction		►	►	►	►	▼	▲	▼	▼	►	►	►	►	▼
Units		Hz	Hz/m	N	N	m	m/s^2	m	m/s^2	s	m^2	m	rpm	C
Customer Requirements	Importance Weight Factor	Controls Vibration	Maintains axial stability/rigidity	Holds all Machine components	Holds workpiece securely	Provides Accuracy	Accelerates to position	Stops at position	Decelerates to stop	Access to emergency stop	Encloses machine	Reconizes position	Controls cutting feed/force	Controls internal temperature
Machine can fit on standard desk	5	▽		●							○			
Material Variety	3	▽	○		▽								●	○
Runs from standard 120V Outlet	6						▽		▽				○	
Simple Operating system	2									○		●		
Fast production of parts	1	○	○	○	○	○	▽	○	▽			▽	○	
Machine holds tight tolerances	9	●	●		●	●	○	●	○			▽	○	
Easy Installation	0			○						▽				
Enclosed work area	4			○							●			▽
Cost	7	▽		▽										
Advanced movement	8	●	○		○	●	●	●	●			●	●	
Raw Score		33	27	30	24	24	21	24	21	9	15	24	36	9
Relative Weight		11.11%	9.09%	10.10%	8.08%	8.08%	7.07%	8.08%	7.07%	3.03%	5.05%	8.08%	12.12%	3.03%
Rank Order		2	4	3	5	5	9	5	9	12	11	5	1	12

Relationship		
Strong	●	9
Medium	○	6
Weak	▽	3

Direction of Improvement	
Maximize	▲
Target	►
Minimize	▼

Using the results from this table, we can determine what is needed to be considered successful, while identifying what we want to include to improve the system overall. This table utilized the direction of improvement for each function and the strength of the relationship between the metrics and our targets. From this, we found that the most important functions to optimize are its ability to control the cutting feed and force, the system's ability to control vibration or offer stability, and the ability to contain all machine components within the system. We found similar importance in its ability to maintain axial stability and the movement system, pointing to those aspects as ways of increasing the quality and capability of the system.

1.6.3 Pugh Charts.

After determining the importance of different features through a bitwise comparison and the house of quality, all of the concepts were then compared to each other through a pugh chart. This gives a better understanding of the different options that could be selected in reference to a machine currently on the market, and then in reference to one of the concepts. Doing this will help give a rough standpoint on which ideas seem more viable than others, without going in to as full of detail as an analytical hierarchy process that will be done later.

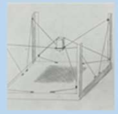
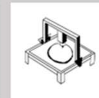
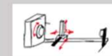
Table 10: Initial Pugh Chart

PUGH vs Datum

Selection Criteria	Datum (Tormach 770MX CNC Mill)	Concepts 1	2	3	4	5	6	7	8
Machine can fit on standard desk		+	+	+	+	+	S	+	+
Material Variety		S	-	-	-	-	S	+	S
Runs from standard 120V Outlet		S	S	S	S	S	S	-	S
Simple Operating system		+	-	-	+	S	S	-	S
Fast production of parts		S	-	+	-	S	S	-	S
Machine holds tight tolerances		S	-	S	-	-	+	+	S
Easy installation		S	-	-	+	+	-	+	+
Enclosed work area		S	S	S	S	S	-	S	S
Cost		+	+	-	+	+	-	S	+
Advanced movement		+	-	S	S	S	+	-	S
Number of pluses		4	2	2	4	3	2	4	3
Number of minuses		0	6	4	3	2	3	4	0

After comparing all eight concepts to a datum that is currently sold on the market, there certain aspects stood out as more noticeable. There were a few machines that were better performing than the datum with three or four pluses and no negatives, and a few machines with a high number of negatives, performing worse than the datum. From this, the most viable options that were found were options one and eight, with a lower quality option in concept number five. This process was then repeated where the concepts would all be compared to a concept that score.

Table 11: Concept Only Pugh Chart

PUGH vs Concept								
		Concepts						
								
Selection Criteria	3	1	2	4	5	6	7	8
Machine can fit on standard desk	Concept 3	S	S	S	S	S	S	S
Material Variety		+	-	-	-	S	+	S
Runs from standard 120V Outlet		S	S	S	S	S	-	S
Simple Operating system		S	S	S	S	S	-	-
Fast production of parts		S	-	-	-	S	-	S
Machine holds tight tolerances		+	-	-	-	S	S	+
Easy installation		S	-	+	+	+	-	-
Enclosed work area		S	S	S	S	S	S	S
Cost		+	+	+	+	S	S	S
Advanced movement		+	-	-	-	+	-	S
Number of pluses		4	1	2	2	2	1	0
Number of minuses		0	5	4	4	0	5	2

The middle ground concept was concept three, which performed similarly or worse than the datum in most categories. From this, all the concepts were compared again in respect to concept three. This yielded interesting results where concept one still maintained the highest score, but concept eight was performing poorly in comparison. However, concept six was rated higher than before. Now, moving forwards we will look more specifically at concept one, eight, five, and six when making our selection.

1.6.4 Analytical Hierarchy Process.

After going through the house of quality, the next step is the analytical hierarchy process. This process allows for all the different function's importance to be determined, and then the different concepts to be compared similarly. Below is a chart highlighting the comparison of the different functions, but the comparison of concepts for each function can be found in Appendix G.

Table 12: Analytical Hierarchy process

Analytical Heirarchy Proccess

Criteria Comparison Matrix [C]										
	Machine can fit on standard desk	Material Variety	Runs from standard 120V Outlet	Simple Operating system	Fast production of parts	Machine holds tight tolerances	Easy installation	Enclosed work area	Cost	Advanced Movement
Machine can fit on standard desk	1.00	0.14	1.00	0.11	0.20	5.00	0.11	0.33	3.00	7.00
Material Variety	7.00	1.00	9.00	1.00	1.00	9.00	0.20	5.00	3.00	9.00
Runs from standard 120V Outlet	1.00	0.11	1.00	0.20	0.20	3.00	0.11	0.11	3.00	3.00
Simple Operating system	9.00	1.00	5.00	1.00	3.00	9.00	1.00	5.00	9.00	9.00
Fast production of parts	5.00	1.00	5.00	0.33	1.00	7.00	0.33	7.00	7.00	7.00
Machine holds tight tolerances	0.20	0.11	0.33	0.11	0.14	1.00	0.11	0.11	0.20	1.00
Easy installation	9.00	5.00	9.00	1.00	3.00	9.00	1.00	7.00	9.00	7.00
Enclosed work area	3.00	0.20	9.00	0.20	0.14	9.00	0.14	1.00	7.00	7.00
Cost	0.33	0.33	0.33	0.11	0.14	5.00	0.11	0.14	1.00	1.00
Advanced Movement	0.14	0.11	0.33	0.11	0.14	1.00	0.14	0.14	1.00	1.00
Sum	35.68	9.01	40.00	4.18	8.97	58.00	3.26	25.84	43.20	52.00

By comparing all the functions in a similar way to the pairwise table and introducing weights, it allows for this to be a more accurate system than the Pairwise, House of Quality, and Pugh charts. It allows for the full range of concepts to be compared in every single way we would like, which is big in determining the final concept. From this analytical hierarchy process, the most important functions were found to be the tolerances, advanced movement systems, and power source. While the least important were ease of installation, a simple operating system, and the material variety. These were very similar to the function weights in the house of quality, except these are more specific and will allow for a better analysis. This was taken as strong justification moving forward into the final decision matrix.

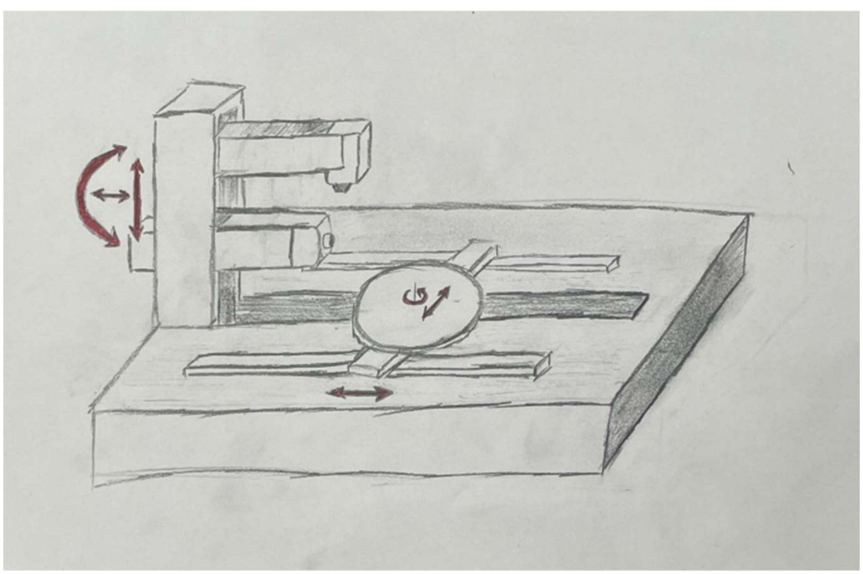
1.6.5 Selected Concept and Validation.

The final step in the concept selection process after the analytical hierarchy process is the Final Decision Matrix. The final decision matrix compares the importance weight factor of each function to each concept so that a final concept can be selected. The chart below represents the final decision matrix.

Table 13: Final Decision Matrix

Final Decision Matrix								
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Conept 8
Fits on a desk	1.33	0.67	2.67	0.67	8.44	2.00	1.56	4.89
Tight Tolerances	2.00	23.33	6.67	5.33	17.33	4.67	6.00	2.00
Material variety	0.13	1.75	0.65	0.97	1.69	0.58	0.52	0.13
Installation	0.82	0.15	0.45	0.26	0.11	0.97	0.30	0.63
120V Outlet	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71
Enclosure	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Operating System	0.62	0.10	0.90	1.62	0.10	0.71	0.33	0.38
Cost	4.07	1.85	7.41	3.33	1.11	3.70	3.70	4.81
Speed to Produce	0.15	1.99	0.81	1.25	1.99	0.29	0.59	0.22
Advanced Motion	1.67	1.67	4.44	10.00	22.22	1.67	8.89	4.44
sum	15.90	36.61	29.11	28.55	58.10	19.71	27.00	22.63
rank	1	7	6	5	8	2	4	3

By adding each column down and comparing the rank across the sum row, a concept is selected that best suits the functions on the left of the matrix. The numbers in the 'sum' row represent the rank that each concept falls in compared to the others, the lower the rank the better the concept fits the functions. This allows for the best concept to be selected without bias from our personal views.



From this process, concept 1 was selected as the best contender for the functions that we plan to implement. This concept is a 5-axis mill with external linear actuation, using material selection for damping, with post-processing polishing, and an automated tool changer. Due to its high performance in the material variety, tolerances, and advanced motion, the option is justified as the selection through this matrix. In addition, this justification is supported by the sponsor of the project, and the group will be pursuing this as an entrepreneurial pursuit supported by funding from the TechGrant competition winnings, which is contingent on the selection of concept 1. Between the weighted decision and the business factors, the five-axis CNC milling system compacted to a tabletop size is the best option for development for our task of creating a tabletop rapid prototyping system.