Concept Selection:

The final design of the project was selected using analytical tools such as House of Quality, Pugh Chart, and Analytical Hierarchy Process (AHP). The five medium-fidelity and three high-fidelity concepts developed during concept generation were initially considered and assessed using concept selection tools.

The House of Quality translates requirements obtained from the customer needs into engineering characteristics. These quantifiable design variables are used in both the Pugh Chart and the AHP to assist in the assessment and selection of design concepts. The House of Quality considers weighted factors for each function, which were developed using a Pairwise Comparison chart. The most important engineering characteristics, each achieving over 20% of the overall weight, were sample stability for sensor readings (both rotationally and translationally) and position precision of the samples. Sample rotation range and accepting various sample sizes were also deemed important with overall weights above 10%. Mass of the system and storage volume were chosen to be significant engineering characteristics despite an unimpressive ranking in the House of Quality. This allows for additional subsystems of the project, such as storage, to be represented within the selection process. The House of Quality generated to form the rankings of each engineering characteristic can be seen in Figure 12.

Figure 12

		Engineering Characteristics											
Column:		1	2	3	4	5	6	7	8	9	10	11	12
:Direction of Improvement		↑	↑	↑	↓	↑	↓	↓	↑	↓	↓	↓	↑
Units:		cm	kg	cm	mm	cm	mm/s	rad/s	rad	cm^2	kg	m^3	# of Samples
Customer Requirements	Importance Weight Factor	Sample Loca	Hold Sample	Collection R	Position Precision	Accept Sample Size (diameter)	Sample Stability for Sensor Readings (Translation)	Sample Stability for Sensor Readings (Rotation)	Sample Rota	Sample Exp	Mass of Syst	Volume of S	Storage Volume
Light Weight	1		1								9	7	5
Precise Motion	4		1	3	9		7	7					
Sample Size Range Accomodation	1		5	3	1	9	1	1		3	1		5
Allows Sensors to See All Sides of Sample	3				3	3	7	7	9				
Secures Samples in Storage	1					7				5		3	3
Raw Score		0	10	15	46	25	50	50	27	8	10	10	13
% Relative Weight		0.00	4.48	6.73	20.63	11.21	22.42	22.42	12.11	3.59	4.48	4.48	4.92
Rank Order		12	8	6	3	5	1	1	4	11	8	8	7

Using a Pugh Chart, the eight medium and high-fidelity concepts were narrowed down to four design concepts for final consideration. The clamp arm was chosen to be the datum for the first Pugh Chart since it is similar to designs being used in current applications. After the completion of the first Pugh Chart, two concepts (Bucket Collector and Vacuum) were eliminated from the selection process while Spin Fingers was set as the new datum. The first Pugh Chart used in the selection process can be seen in Figure 13.

Figure 13

Selection Criteria	Clamp Arm	The Rock Picker	Claw Machine	Microspine Gripper	Track Hands	Bucket Collector	Vacuum	Spin Fingers
Mass of System	Datum	-	-	-	-	-	-	+
Position Precision		-	+	-		-	-	
Accept Sample Size (diameter)		+		+	+	+	-	
Sample Stability for Sensor Readings					-	-	-	
Storage Volume		-	-	-	-	-	-	-
Sample Rotation Range		-				-	-	
Number of Pluses:		1	1	1	1	1	0	1
Number of Minuses:		4	2	3	3	5	6	1

The Pugh Chart was completed once more with the new set datum. This Pugh Chart resulted in two more concepts being eliminated for consideration (Claw Machine and Track Hands). This narrowed potential designs for selection to four concepts: Clamp Arm, Rock Picker, Spin Fingers, and Microspine Gripper. The second Pugh Chart used in the selection process can be seen in Figure 14.

Figure 14

Selection Criteria	Spin Fingers	The Rock Picker	Claw Machine	Microspine Gripper	Track Hands	Clamp Arm
Mass of System	Datum	-	-	-	-	-
Position Precision		-	-		-	
Accept Sample Size (diameter)		+		+	+	
Sample Stability for Sensor Readings					-	
Storage Volume		+	-	+		+
Sample Rotation Range		-			-	
Number of Pluses		2	1	2	1	1
Number of Minuses		3	2	1	4	1

An Analytical Hierarchy Process (AHP) is used once the final designs have been dictated by the Pugh Charts. In an AHP, the selection criteria are compared with an exaggerated pairwise comparison where more important criteria are rated with a 3 – slightly more important, 5 – more important, 7 – significantly more important, or 9 – critically more important. The corresponding criteria (the criteria ranked less important) is then rated with the inverse (1/rating). If a criterion is deemed to have the same importance, then a rating of 1 is given. A unique feature of the AHP is that it also produces a consistency ranking which must be below a threshold, dependent on the number of criteria, to be considered a consistent ranking. If criterion A is ranking higher than criterion B, and C is rated higher than A, but B is ranked higher than C, then there is some bias in the rankings. The consistency check ensures that these issues can be easily discovered and resolved. The outcome is a weight for each criterion that will be used in a final weighted comparison of the concepts. The criteria weights for our project can be seen in Table 2 below.

Table 2

Criteria Results	Weights
Mass	0.072
Precision	0.159
Sample Size	0.028
Stability	0.401
Storage	0.031
Rotation Range	0.308

From Table 2, Stability and Rotation Range are our most important criteria. Mass has a lower weight than we had initially expected, but the device mass is less important if it cannot complete its objective.

Once the criteria weights have been established, an AHP is created using the concepts with respect to each of the weighted engineering criteria. While the process is the same, the ranking changes from importance to the predicted quality of the design with 3 – slightly better, 5 – better, 7 – much better, and 9 – critically better. This results in a number of AHP charts equal to the number of engineering criteria. The results are shown below in Table 3.

Table 3

Concept	Mass	Precision	Sample Size	Stability	Storage	Rotation Range
Spin Fingers	0.549	0.430	0.069	0.172	0.057	0.313
Rock Picker	0.071	0.089	0.575	0.099	0.263	0.063
Microspine	0.080	0.051	0.287	0.365	0.122	0.313
Clamp Arm	0.300	0.430	0.069	0.365	0.558	0.313

Now that all the weights have been found, the cross product of the concept row from Table 3 and the criterial column from Table 2 can be used to find an alternative value for the concept.

Table 4

Concept	Alternative Value
Spin Fingers	0.277
Rock Picker	0.103
Microspine	0.268
Clamp Arm	0.352

The AHP and the other concept selection tools concluded that Clamp Arm was the most suitable concept for the project. The group agrees with this decision; however, declined to move forward with the entirety of this design. This is due to Clamp Arm lacking innovation and the project being composed of multiple subcomponents that are interchangeable. The modularity of this project allows for designs to be further improved upon using more appropriate subsystems (Onboarding, Orienting, and Storage) from other designs.

Spin Fingers scored comparably to Clamp Arm in all aspects except for storage and stability. The inferior storage system of Spin Fingers hindered the overall alternative value score resulting in Clamp Arm to succeed in selection. The Spin Fingers design utilized a simple bucket to contain collected samples while the Clamp Arm used a honeycomb structure. The honeycomb structure is superior due to its high packing factor and ability to secure samples individually.

The stability was rated due to the inherent stability of a separate module, not relying on the stability of the joints of a robotic arm. The Spin Fingers concept can be designed in such a way that the needed stability to ensure proper sensor readings can be achieved.

The group collectively decided that the amalgamation of the Clamp Arm with the Spin Fingers design would result in the most suitable concept that promotes innovation. This combination of the two designs resulted in the bucket used in Spin Fingers to be replaced by the honeycomb structure present in Clamp Arm. The final design consists of a spin fingers end effector attached to a robotic arm that both onboards and orients samples while storing them within a honeycomb storage area. The final design for the project is depicted in Figure 15.

Figure 15