Concept Selection

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Introduction

The Psyche Rover team was tasked with developing a robotic explorer to traverse potential terrains encountered on the 16 Psyche Asteroid. Up to this point, the team has gathered and interpreted customer needs, devised targets and metrics, and attempted to generate successful concepts, with the concept selection process relying on the preceding steps. The customer requirements, Appendix A, functional decomposition, Appendix B, and concept generation, Appendix C, provide the necessary tools to perform concept selection.

The concept selection process can be broken down into three steps. The first step in the concept selection process is the use of an analytical hierarchy process. This can be done with a pairwise comparison that uses weight factors or with the more complicated pairwise matrix. The next step is to establish the House of Quality (HoQ), which translates the customer requirements into quantitative engineering characteristics and helps rank their importance. The ranking of engineering characteristics helps with the final step of conducting Pugh chart analysis. The Pugh chart uses a datum to examine the concepts against each other. The comparison criteria comes from the high-ranking engineering characteristics developed in the HoQ, with a final concept then being selected.

Using this combination of analytical processes helps with making the appropriate choice and ensures customer requirements are included in every step of the decision-making process.

Quality Functional Deployment (QFD)

Quality functional deployment (QFD) is a planning and collaborative problem-solving design methodology that focuses on the integration of customer needs and requirements at every stage of the design process (Dunlap, 2019). QFD helps identify and rank the necessity of a set of technical requirements in satisfying customer needs.

The House of Quality (HoQ) is a QFD construct used to translate customer needs into quantitative and qualitative engineering requirements. A streamlined HoQ consists of the customer requirements and their importance rating, the engineering characteristics, the relationship matrix, absolute and relative importance, as well as the rank ordering (Dunlap, 2019). A pairwise comparison and HoQ were constructed as outlined by the QFD process.

Explanation of Criteria

Before the concept selection process, the customer need statements were organized and categorized into eight different criteria: mobility, detection, cost, durability, size, stability, longevity, and operation. The re-organization allowed the design team to more efficiently implement customer needs into the chosen concept selection tools.

The customer needs that were categorized with mobility include the robotic explorer's *ability to maneuver through various changes in surface topography, depression, and curvature*, *ability to operate on varying material compositions, ability to travel on surfaces with variable hardness and roughness*, and *ability to traverse both metal and rock surfaces*. The customer needs that were categorized with detection include the robotic explorer's *ability to detect obstacles* and *detect sudden changes in surface elevation*.

The cost category includes the customer need of *the prototype for the robotic explorer is designed and implemented for $2,000 or less*. Durability correlates to the *robotic explorer withstands low temperatures*, and customer needs categorized with size include *the robotic explorer is sized to fit its deployment apparatus*, as well as *be housed on the Psyche spacecraft*.

For stability, customer needs of *the robotic explorer capably carries mission essential equipment* and *remains on the planetary body after landing* were grouped. Operation customer needs include *the robotic explorer functions independent of the planetary body's magnetic characteristics, operates on an airless body, has controlled and autonomous functionality,* and *is capable of being operated by human personnel*. Customer need categorized under longevity are *the robotic explorer functions for the duration needed to gather data samples* and *withstands two asteroid orbits*.

Pairwise Comparison

As previously stated, an HoQ requires customer requirements and their respective ranking. A pairwise comparison matrix was used to develop the importance weight factor of the customer requirements in relation to one another, Figure 1.

To devise the matrix, the translated customer requirements, Appendix A, generated in earlier stages of the design process were grouped into similar classes, providing comprehensive categories and avoiding requirement overlap. Developed customer requirement categories were placed in matching order in the pairwise matrix.

Customer requirement column entries were compared to each respective row entry, with the analyses assessing the importance of a column entry relative to the row entries. A “1” was awarded for the column entries that were deemed more important than the row entry, and a “0” was assigned for the opposite scenario. Dashes were allocated when duplicate customer requirement categories were compared.

Row and column totals were then calculated. The shared total entry indicated the maximum possible total for a particular row entry. The total sum of the row rankings was used for the importance weight factor in the HoQ.

AHP - Pairwise Comparison											
Customer Requirements		1	2	3	4	5	6	7	8	Total	Rank
1	Mobility	-	1	0	1	1	0	1	0	4	4
2	Detection	0	-	0	1	1	0	1	0	3	5
3	Cost	1	1	-	1	1	1	1	1	7	1
4	Durability	0	0	0	-	1	0	1	0	2	6
5	Size	0	0	0	0	-	0	0	0	0	8
6	Stability	1	1	0	1	1	-	1	1	6	2
7	Longevity	0	0	0	0	1	0	-	0	1	7
8	Operation	1	1	0	1	1	0	1	-	5	3
Total		3	4	0	5	7	1	6	2	n-1 = 7	

Figure 1 - Pairwise Comparison

After comparison, the design team determined that “size” was not a crucial comparison criteria, being assigned a weight of “0”. As such, it was neglected in subsequent concept evaluation.

House of Quality

The House of Quality was constructed to determine the rank order of the engineering characteristics, Figure 2. Engineering characteristics relevant to newly developed customer requirement categories were selected from previously generated targets and metrics, Appendix D. Units were assigned for quantitative characteristics, with “n/a” being applied to qualitative descriptions. Improvement direction was allocated based on group discretion, with upward arrows indicating a desirable increase and downward arrows indicating a desirable decrease. Customer requirements and their corequisite importance weight factors, established in the pairwise comparison, were listed in the HoQ.

The relationship matrix was completed using collaborative decision-making and the contribution of engineering characteristics to each respective customer requirement category was assessed. A “9” was used to indicate strong correlation between a customer requirement and an engineering characteristic. A “3” was assigned for moderate correlations. Entries with slight correlation were assigned a “1” and non-existent relationships were attributed a “-“.

Column raw scores were calculated by multiplying customer requirement importance weight factors to their corequisite column entries in the relationship matrix and summing the total. The total raw score was calculated as the sum of all raw scores. The relative weight was calculated through percentage computations relative to a column's raw score to the total raw score. The relative weights determined the rank order of the engineering characteristics, with 1st ranking being assigned to the most important category with the greatest relative weight.

House of Quality																								
		Engineering Characteristics																						
Improvement Direction		↑	↑	↓	-	↓	↑	↑	↑	↑	↑	↑	↑	↓	↓	↓	↑	↓	↑	↑	↓	-	-	-
Units		%	Day	%	n/a	s	°	in	°	in	MP	kbps	in	%	in/s	s	ft/s	ft	ft^3	in^2	in	n/a	n/a	n/a
Customer Requirements	Importance Weight Factor	Percentage Converted to Useful Work	Operational Longevity	Driving Duty Cycle	Wi-Fi Connection	Input and Output Lag	Detect Terrain Slope	Detect Obstacle Size	Navigate Terrain Slope	Navigate Obstacle Size	Pixel Quantity	Video Quality	Detection Radius	Sudden Acceleration or Deceleration	Sudden Descent	Reporting Time	Velocity	Turn Radius	Enclosure Volume	Charging Surface Area	Center of Gravity	Withstands Enviornmental Conditions	Budget Adherence	Locomotion Style
Mobility	4	9	-	9	9	3	3	3	9	9	-	-	3	3	3	1	9	9	1	3	9	9	-	9
Detection	3	1	-	-	3	9	9	9	-	-	9	9	9	9	9	3	-	3	-	-	-	9	-	-
Cost	7	3	9	-	3	-	-	-	-	-	3	3	1	-	-	-	1	-	9	9	-	9	9	3
Durability	2	1	3	-	-	1	1	1	3	3	-	-	3	-	-	1	1	-	-	-	-	9	-	3
Stability	6	3	3	-	-	3	3	3	9	9	-	-	3	9	9	3	3	1	3	1	9	-	-	9
Longevity	1	9	9	9	1	1	-	-	-	-	-	-	1	-	-	1	3	-	-	9	-	9	-	-
Operation	5	9	9	9	9	9	3	3	3	3	1	3	3	3	3	9	9	9	3	9	3	9	-	3
Raw Score:	**2379**	134	141	90	112	105	74	74	111	111	53	63	86	108	108	79	101	96	100	135	105	198	63	132
Relative Weight (%)		5.6%	5.9%	3.8%	4.7%	4.4%	3.1%	3.1%	4.7%	4.7%	2.2%	2.6%	3.6%	4.5%	4.5%	3.3%	4.2%	4.0%	4.2%	5.7%	4.4%	8.3%	2.6%	5.5%
Rank Order		4	2	16	6	11	19	19	6	6	23	21	17	9	9	18	13	15	13	3	11	1	21	5

Figure 2 - House of Quality

Pugh Chart

The higher-ranking engineering characteristics from the HoQ are used in the Pugh chart; however, since the weight distribution is relatively equivalent among the engineering characteristics, the design team chose to differentiate the concepts using the high level customer requirements. The Pugh chart compares each concept relative to a datum concept for each selection criteria category. The pluses indicate the compared concept is better than the datum for a respective category. The minuses indicate that the concept is worse than the datum, and an "S" shows that the concept and the datum are the same for a particular comparison. The first developed Pugh chart, Table 1, uses Concept 1 as the datum.

Pugh Chart 1					
Selection Criteria	**Datum**	**Concepts**			
		2	**3**	**4**	**5**
Mobility	Concept 1	S	+	+	-
Detection		-	-	S	+
Cost		S	S	S	S
Durability		+	-	+	-
Stability		+	+	+	+
Longevity		S	-	-	+
Operation		+	+	+	-
Pluses (+)		3	3	4	3
Minuses (-)		1	3	1	3
Satisfactory (S)		3	1	2	1

Table 1 - Pugh Chart 1

After analysis, Concepts 3 and 5 had the greatest number of minuses for the first iteration and were eliminated. Concepts 2 and 4 graded well against the datum, with only one minus being attributed to each concept. For the second Pugh chart iteration, Table 2, the design team chose to compare Concepts 2 and 4, with Concept 4 being selected as the new datum.

Pugh Chart 2		
Selection Criteria	**Datum**	**Concepts**
		2
Mobility	Concept 4	-
Detection		-
Cost		S
Durability		+
Stability		-
Longevity		+
Operation		S
Pluses (+)		2
Minuses (-)		3
Satisfactory (S)		2

Table 2 - Pugh Chart 2

Using the second Pugh chart, the design team determined that Concept 2 had several disadvantages in the stability, detection, and mobility selection criteria; however, it did outperform the datum in longevity and durability. Using pairwise comparison, the HoQ, and Pugh chart determination methods, Concept 4 was chosen as the selected concept, though the design team sought additional verification.

Decision Matrix

The decision matrix is a tool used to objectively select the most appropriate concept based on the assigned criteria and their corresponding weights. The concepts created during concept generation were ranked based on mobility, detection, cost, durability, stability, longevity, and operation. Cost, stability, and operation were determined to be the most critical from the pairwise comparison, with weights of 7, 6, and 5, respectively. The concepts were scored for each criteria on a scale of 1-10 and then ranked based on their respective weights. Assessing scores calculated using the decision matrix, Figure 3, the design team determined that Concept 4 would be the most suitable choice, providing independent validation for previously used selection methods.

Decision Matrix						
Criteria	**Weight**	**Concepts**				
		1	**2**	**3**	**4**	**5**
Mobility	4	6	6	8	8	6
Detection	3	6	6	8	8	6
Cost	7	6	3	6	6	6
Durability	2	8	8	4	8	4
Stability	6	6	6	8	8	8
Longevity	1	3	8	8	8	8
Operation	5	10	10	10	10	10
Total:		**189**	**173**	**212**	**220**	**198**

Figure 3 - Decision Matrix

Final Concept Selection Choice

The design team used several methods in determining the appropriate selection to meet and exceed customer needs, with Concept 4 being chosen as the most suitable prospect. It was recognized that several alterations should be made to improve the design, as the sole use of photovoltaic cells could limit the robotic explorer's longevity and durability. The use of standalone batteries is a potential supplement the design team will consider. Additionally, Dr. Dunlap, the design team's faculty advisor, suggested the investigation of various suspension systems and cautioned against the potential detriments of omnidirectional wheels on rigid terrain. The employment of additional wheels will also be considered to achieve a static gait. A final rendering that implements various changes will be available in the team's next design review.

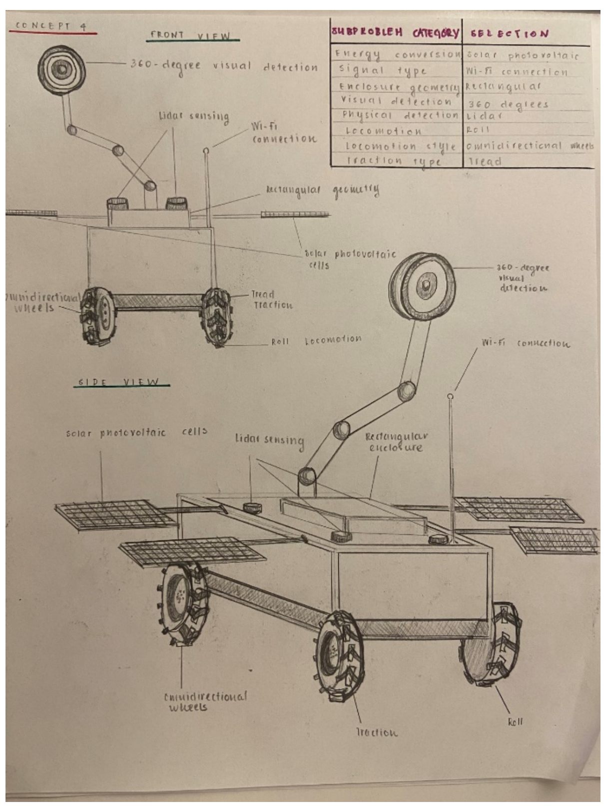


Figure 4 - Concept 4

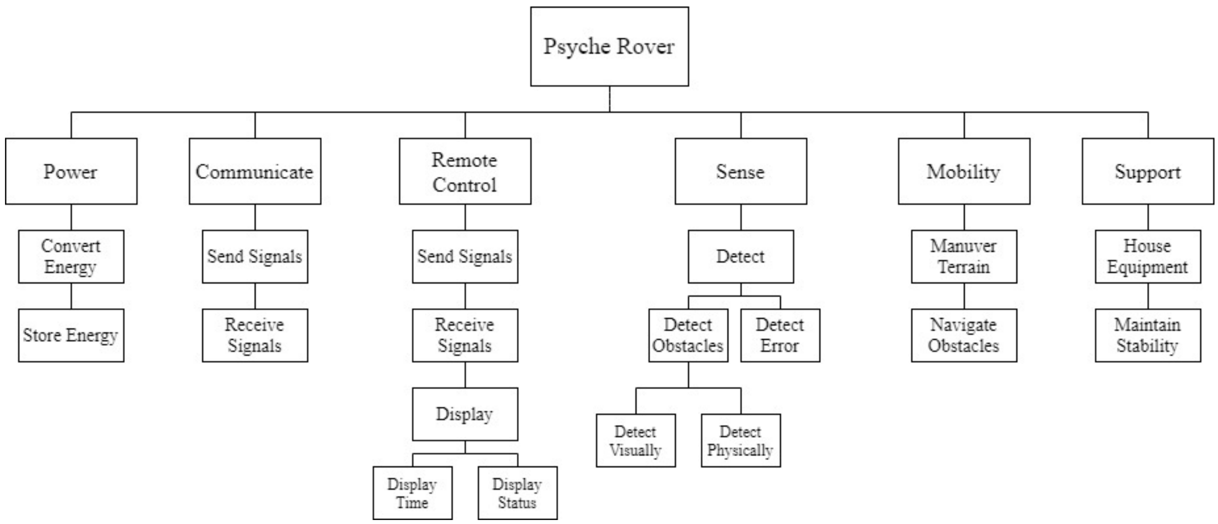
References

Dunlap, D. (2019, October 2). *Quality Function Deployment.* [PowerPoint slides].

Appendix A – Customer Needs

Question	Customer Statement	Interpreted Need
What types of terrains have been encountered on previous missions?	Asteroids have been shown to be covered in craters.	The robotic explorer manuevers through various changes in surface topography, depression, and curvature.
	Boulder rocks and big stones have been seen on asteroid surfaces.	The robotic explorer detects obstacles.
	Different rock types with varying characteristics have been detected.	The robotic explorer works on varying material compositions.
	Basaltic materials were expected, but surfaces similar to hard snow were encountered.	The robotic explorer can travel on surfaces with variable hardness and roughness.
	Comet terrains were mostly flat with some steep cliffs.	The robotic explorer detects and avoids sudden changes in surface elevation.
	The surfaces were non-magnetic, contrary to what was expected.	The robotic explorer functions independent of a planetary body's magnetic characteristics.
What is the budget for this project?	The school has allowed for a $2,000 budget for Senior Design projects.	The prototype for the robotic explorer is designed and implemented for $2,000 or less.
What type of environment is expected on Psyche?	Psyche is expected to have a low gravity, approximately $0.144 m/s^2$.	The robotic explorer remains on the planetary body after landing.
	Psyche has no atmosphere.	The robotic explorer operates on an airless body.
	The temperatures on Psyche are expected to be extremely cold.	The robotic explorer withstands low temperatures.
What types of terrain are expected to be encountered on Psyche?	Fractures and porous space, possibly hidden under regolith.	The robotic explorer traverses both metal and rock surfaces.
	Metal tektites and blocks, but possibly no persistent or deep metal regolith.	
How long will the robotic explorer need to operate at a time?	Spirit and Opportunity robotic explorers were designed to operate for 90 days.	The robotic explorer functions for the duration needed to gather data samples.
	MASCOT was designed to last two asteroid rotations.	The robotic explorer withstands two asteroid orbits.
How will the robotic explorer be deployed?	The robotic explorer will be deployed from the Psyche spacecraft.	The robotic explorer can be housed on the Psyche spacecraft.
Should the robotic explorer be autonomous or remote operated?	Explorers on previous missions have been hybrids.	The robotic explorer has controlled and autonomous functionality.
Who is going to operate the robotic explorer?	The robotic explorer will be operated by NASA personnel.	The robotic explorer is capable of being operated by human personnel.
Are there sizing requirements (i.e. dimensions, weight)?	The Curiosity rover was as large an as SUV.	The robotic explorer is sized to fit its deployment apparatus.
	Previous robotic explorers were sized based on the equipment needed for the mission.	The robotic explorer capably carries mission-essential equipment.

Appendix B –Functional Decomposition



Appendix C – Concept Generation

C-1 Morphological Chart

Morphological Chart

Energy Conversion	Signal Type	Enclosure Geometry	Visual Detection	Physical Detection	Locomotion	Locomotion Style	Traction Type
Electrical to Mechanical	Radio Frequency	Rectangular	Go-Pro	Lidar	Hover	Plain Wheels	Tread
Solar Thermal to Mechanical	Wi-Fi Connection	Domical	Cell Phone	Radar	Roll	Omnidirectional Wheels	Spoke
Solar Photovoltaic to Mechanical	Bluetooth	Hexagonal	Point-and-Shoot Camera	Bumper	Jump	Diaphragm	Magnetic
Mechanical to Electrical	USB 2.0	Polygonal	Disposable Camera		Walk	Retractable Legs	
	USB 3.0	Square	DSLR Camera			Tracks	
	Satellite		360-Degree Camera			Stationary Legs	
	Infrared					Thrusters	
	RFID						
	GSM						
	GPS						

C-2 Concept Drawings

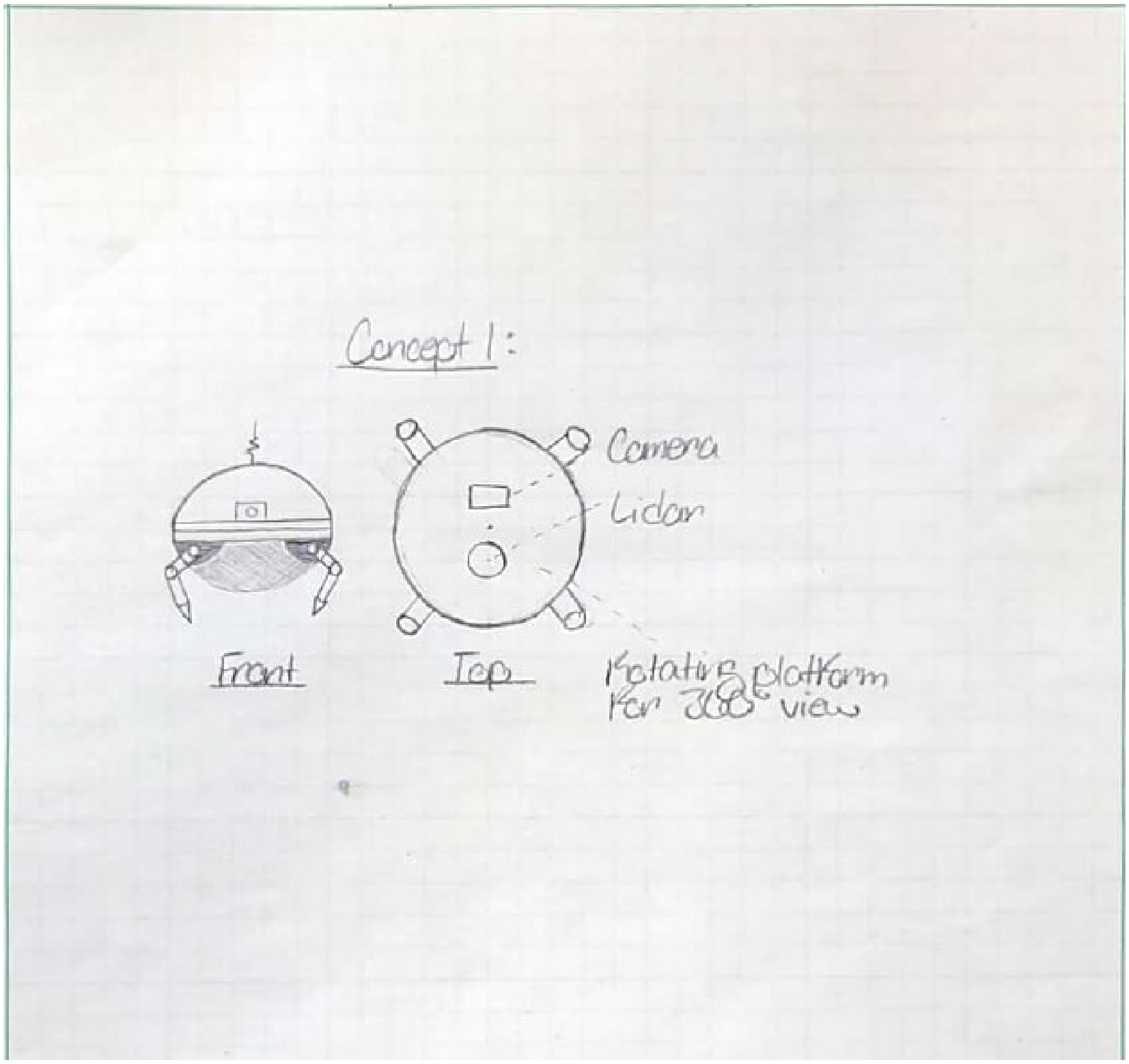


Figure 5 - Concept 1

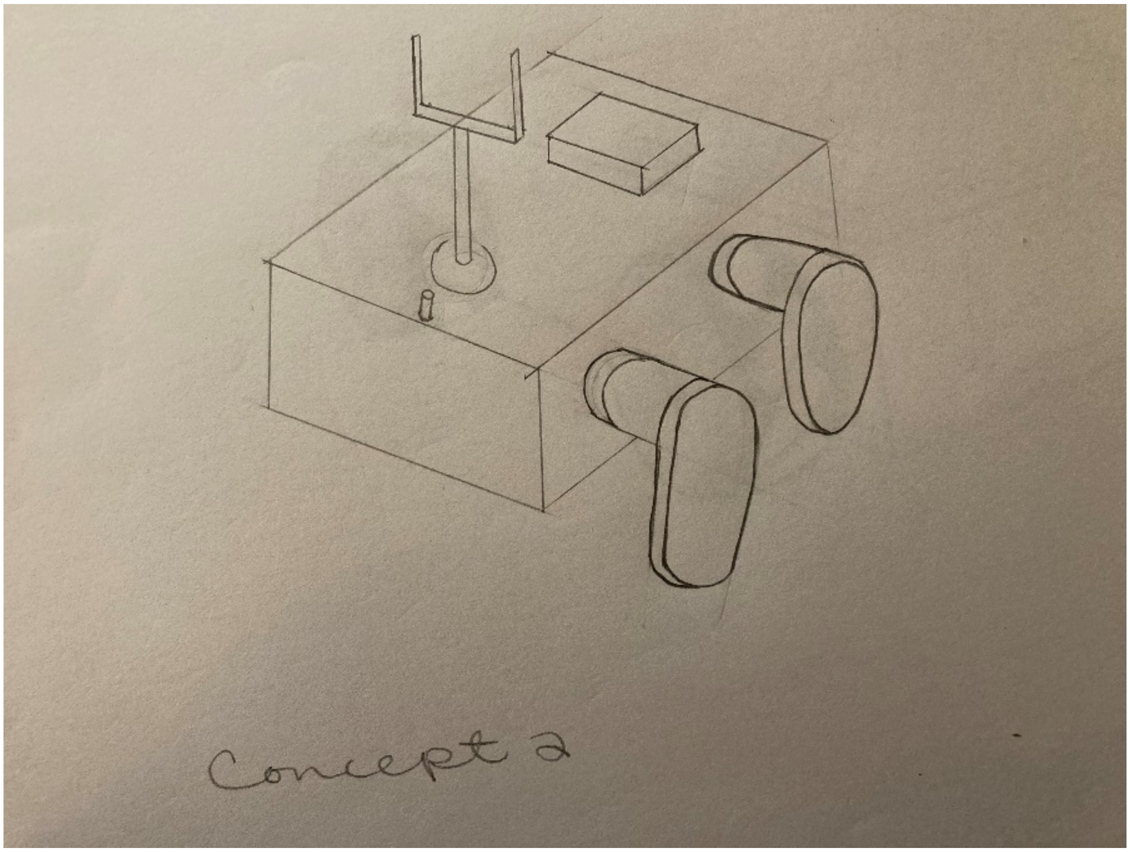


Figure 6 - Concept 2

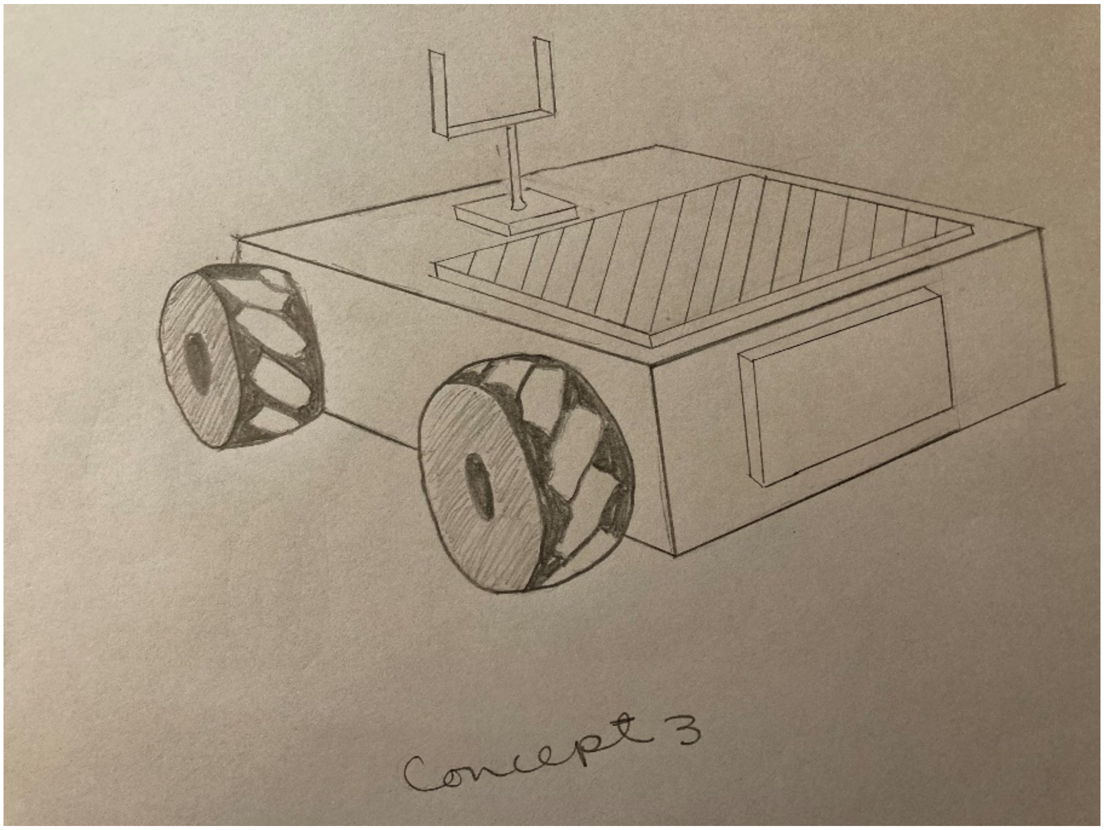


Figure 7 - Concept 3

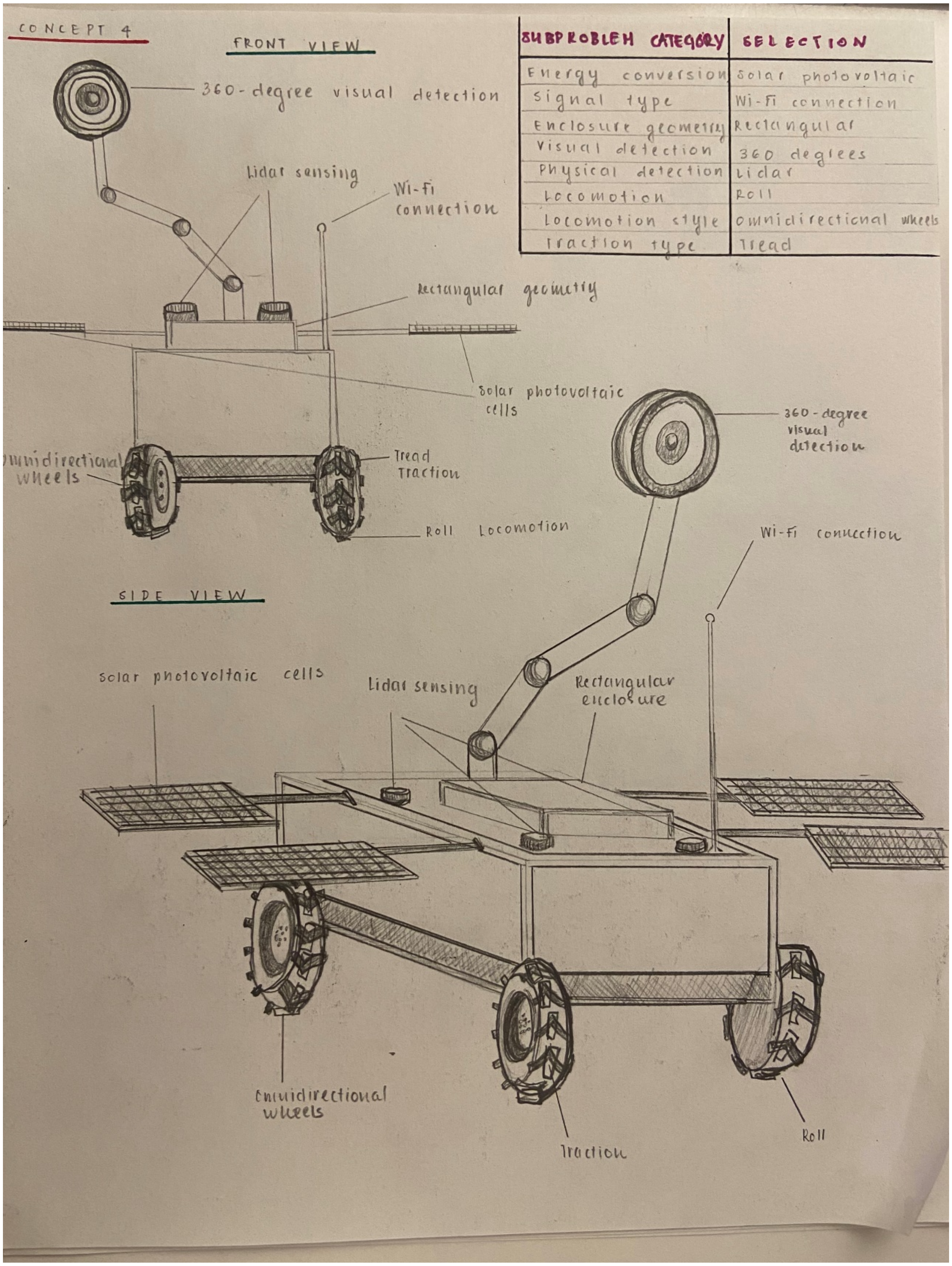


Figure 8 - Concept 4

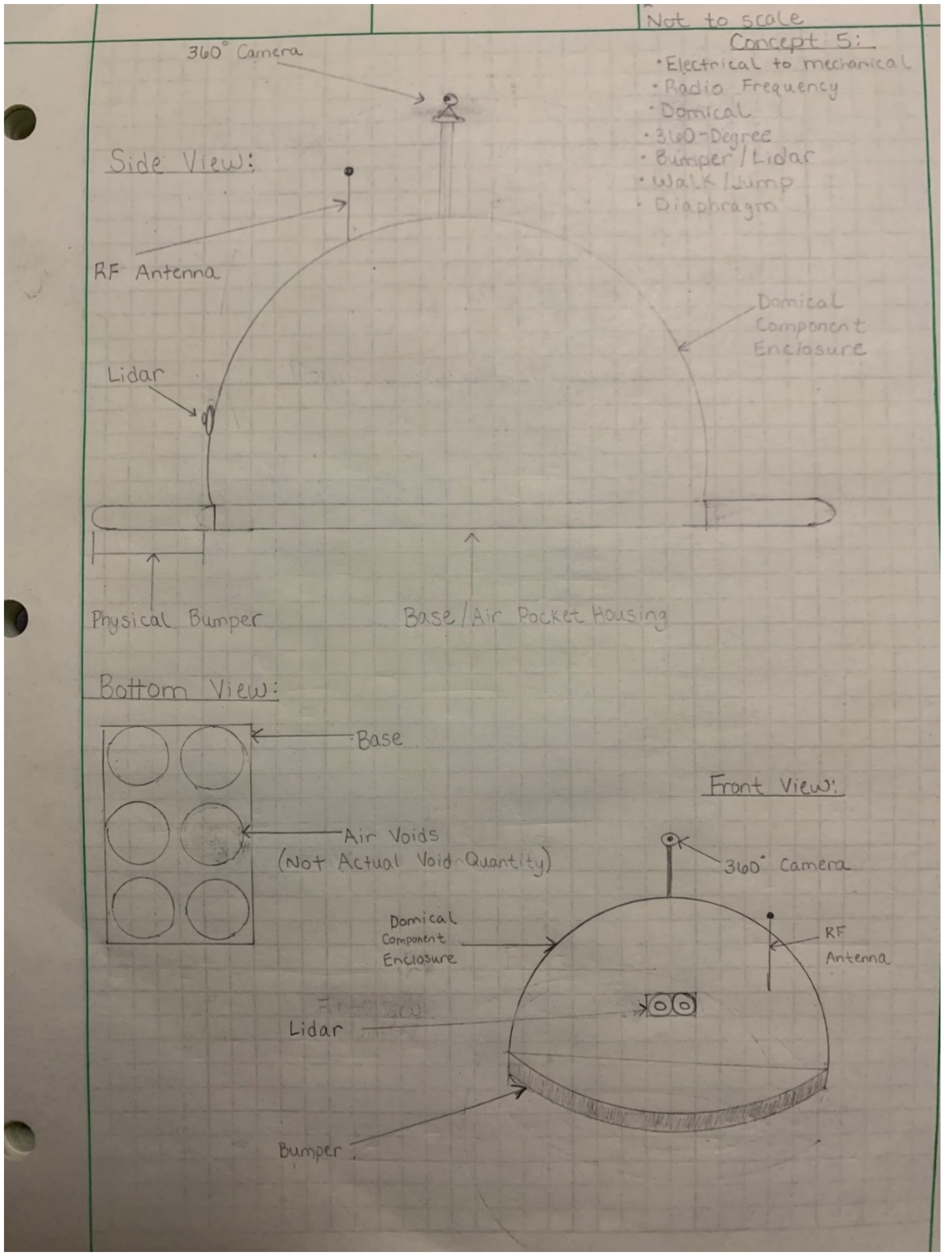


Figure 9 - Concept 5

Appendix D – Targets & Metrics

Psyche Rover - Targets & Metrics Catalog				
Function	**Metric**	**Target**	**Critical**	**Notes**
Power				
Convert Energy	Percentage Converted to Useful Work	80+%	Yes	Thermal to Mechanical Electrical to Mechanical
Store Energy	Operational Longevity	60-90 days	Yes	
	Driving Duty Cycle	20%	Yes	Expected driving capacity
Communicate				
Send Signals	Wi-fi Connection	802.11 2.4 GHz or 5 GHz	Yes	
Receive Signals	Wi-fi Connection	802.11 2.4 GHz or 5 GHz	Yes	
Remote Control				
Send Signals	Output Lag	0.5 seconds	Yes	
Receive Signals	Input Lag	0.5 seconds	Yes	
Display				
Display Time	Seconds	Accurate within 2.5%	No	
Display Status	Text	Successfully display text	No	
Sense				
Detect				
Detect Obstacles	Terrain Slope	20^{o} + incline 20^{o} + decline	Yes	
	Obstacle Size	Diameter: 8 in Length/Width/Height: 6 in	Yes	
Detect Visually	Pixel Quantity	8 megapixels	No	
	Video Quality	2,500 to 4,000 kbps	No	HD Quality
Detect Physically	Detection Radius	12 in	No	
Detect Error	Sudden Acceleration or Deceleration	20% increase/s 20% decrease/s	No	
	Sudden Descent	1 in/s	No	
	Reporting Time	1 s >	No	
Mobility				
Maneuver Terrain	Velocity	0.10 ft/s	Yes	Curiosity Rover achieved 0.127 ft/s
	Turn Radius	1 ft	No	
Navigate Obstacles	Terrain Slope	20^{o} > incline 20^{o} > decline	Yes	
	Obstacle Size	Diameter: 8 in > Length/Width/Height: 6 in >	Yes	
Support				
House Equipment	Enclosure Volume	$0.5ft^{3}$ (8"x10"x12")	Yes	Size estimated through similar rover designs
	Charging Surface Area	$10in^{2}$	No	Amazon AMX3d
Maintain Stability	Center of Gravity	Low (CG < H/2)	Yes	
***Additional Non-Function Needs**				
Durable	Withstands Environmental Conditions	Yes	Yes	Gravity = 0.144 m/s^{2}
Economic	Budget Adherence	≤ $2,000.00	No	
Original	Locomotion Style	Distinct from Standard Rovers	No	Wheels commonly used